Physics III: Introduction to Statistical Physics

Course syllabus

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Schedule:

- **Lectures:** Monday, Wednesday, and Friday from 1:15PM – 2:45 PM in RM. 5-233.
  Attending lectures is mandatory.
- **Recitations:** Thursdays from 2:30PM – 3:30PM in RM. 5-233. Attending recitation is mandatory
- **Office Hours (Tentative):** Mobolaji: MWF 12:30 – 1:15 PM in RM. 5-233;
  Jason: MF 6:00 - 7:30 PM in 6th floor lounge Simmons.

Course Description

This course will introduce the concepts and formalism at the foundations of statistical physics. Statistical physics concerns the physics of systems with many degrees of freedom. In terms of content, by the end of the course, students should understand qualitative and quantitative definitions of entropy, the implications of the laws of thermodynamics, and why the Boltzmann distribution is important in modeling systems at finite temperature. In terms of skills, students should have increased their familiarity with mathematical methods in the physical science, learned how to write short programs to simulate random events, and become more adept at articulating their understanding of physics.

Math and Physics Prerequisites: Students should be proficient in algebra, trigonometry, and basic differentiation and integration. Students should also have had prior exposure to and practice with Newton's laws of motion, 1D kinematics, and conservation of energy.

Online Resources

The course will not have a formal textbook. However, many useful references can be found online.

- Stanford Statistical Physics by Susskind: A series of seven lectures on statistical physics. This is a more advanced course which concludes by discussing quantum systems.
- Entropy, Order Parameters, and Complexity by Sethna: Online version of a modern textbook on statistical physics. Covers many unique applications of statistical physics in the problems. This course overlaps with chapters 1, 3, 5, and 6.
- MIT 8.044 OCW Course site: OpenCourseWare collection of materials for MIT's 8.044, the first statistical physics course in the undergraduate physics sequence.

Assignments:

Most of the knowledge and skills you gain from this course will come from the problems you solve in assignments. Consequently, how much you learn will grow in direct proportion to how much effort you put into these assignments.

But you should see these well-defined problems of the assignments as bare-minimum requirements for your learning: If you want to obtain any actionable familiarity with the material, you will certainly have to work through these problems (or others like them), but in order to develop a deeper proficiency you will have to look beyond the assigned work and develop your own ways to interpret the world through the material you're learning.

In completing these assignments, you can use online resources and your peers for help, but plagiarism (passing off someone else's work or explanation as your own) is not acceptable and will result in a zero for the assignment.

> **Noting Collaboration:** To prevent any mistakes in this direction, at the end of your assignment, list the people you collaborated with and the online resources you referenced. This list does not mean you can copy derivations from your friends as long as you cite them. Any work you submit must follow from your own reasoning.

Finally, in writing up your work, it is important to not only write out derivations but to include an explanation of your mathematical derivations. In short, **you need both words and equations** in your solution. The lecture supplement ("Sup 01" on the course website) will review the proper format for writing up your solutions.

> **Due Dates:** Except for the last assignment, problem sets will be due on Wednesday the morning before the start of class (under the TA's door). The last assignment will be due on the Monday (July 31st) before the final exam.

Exams:
There will be a midterm on Friday July 13th and a final exam on Tuesday July 31st.

Evaluation:
There are no formal grades in MITES, but you will receive numerical grades on your assignments and exams so that you can track your proficiency with the material. Overall, don't stress too much about the absolute value of these grades over the course of the program. What is more important is consistently showing up in class, recitation, and office hours, and working to complete all assignments.

Topic Outline:

- **Calculus, Probability, and Combinatorics:** integration and differentiation; normalization, means, and variances; permutations and combinations
- **Entropy:** game of twenty questions; $S = \log_2 \Omega$ definition; more general $S = -\sum_i p_i \log_2 p_i$ definition; connection to physical systems
- **Laws of Thermodynamics** equilibrium temperature; you cannot win, but you can break even; you can only break even at absolute zero; you cannot reach absolute zero
- **Free Energy and Phases:** definition of microstate and macrostate; free energy and 2nd law under constant temperature; order parameter and phase transition
- **Boltzmann distribution:** derivation of Boltzmann distribution; definition of partition function; relationship between partition function and free energy
- **Ideal Gases:** partition function; average energy; ideal gas law; entropy
- **Laplace's method:** evaluating exponential integrals; mean field model
- **DNA dimerization:** model of interacting single-stranded DNA
- **Simulating systems:** Markov Chain Monte Carlo simulation
- **Non-equilibrium statistical physics:** master equation and diffusion equation