Course Syllabus
PY410, Spring 2020
Statistical Physics

Instructor: Professor Shyamsunder Erramilli
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Office hours: Tu :11:00 AM − 12:20 PM, PHO 824
Wed: 11:00 AM – 12:20 PM PHO 824

Learning Assistant: Thomas Tenzin
Grader: TBN
Lecture: TuTh 9:30 AM – 10:45 AM, **PSY B51**
Discussion: Wed 12:20 PM − 1:10 PM, **PSY B39**
Course Website: On backboard at learn.bu.edu
Lecture Material: Selected class notes will be available on blackboard.

Goals for the course: Learn the probabilistic description of a system with a large number of degrees of freedom in equilibrium. Appreciate the relation between Information and Entropy. Understand the fundamental concept of emergent phenomena in Physics.

Required Textbook: Gould and Tobochnik, *Statistical and Thermal Physics with computer applications,* Princeton University Press, 2010. Additional notes will be supplied as needed.

Supplemental Texts: No other textbook is required. Additional notes will be supplied as Lecture Notes. There are several classic textbooks on Statistical and Thermal Physics that you should be aware of. The classic textbooks do not integrate computational methods that are fundamental to statistical physics.

Classic textbooks:

- Kittel and Kromer, Thermal Physics, 2nd Ed W. H. Freeman (1980). Comprehensive text that we grew up on.
- F. Mandl, Statistical Physics, 2nd Ed John Wiley & Sons (1988). Mostly just the canonical ensemble
- H. B. Callen, Thermodynamics and an Introduction to Thermostatistics, John Wiley & Sons (1985). Takes a postulatory approach.

Some Graduate level texts:

• R. K. Pathria and P. D. Beale, *Statistical Mechanics*, 3rd Ed, Elsevier (2011).
• M. Kardar, *Statistical Physics of Particles*, Cambridge University Press (2007).
• M. Kardar, *Statistical Physics of Fields*, Cambridge University Press (2007).
• D. Chandler, *Introduction to Modern Statistical Mechanics*, Oxford University Press (1987).

Numerical methods:

• For numerical methods in Physics with MATLAB, Alejandro Garcia, *Numerical Methods for Physics,* 2nd edition Prentice Hall (2000). A revised Python version has also been released.

Homework: Homework problems will be assigned every week. The list of problems in the homeworks serve as a 'Question Bank', and examination questions will be based closely on the homework problems. During weekly discussion sections, student "volunteer teams" will be called upon by the Instructor to lead the presentation of selected homework problems. Class participation and Discussion section participation, Pre-test and Post-Test will count for 5% of the course grade. Late homework will not be accepted.

3D Printing Project: You will be following Maxwell's footsteps in rendering an interesting multi-dimensional function surface plot. Instead of using plaster casts, you will work in small teams that use a 3D Printer to generate the surface plot. Each team will prepare a short 10-minute team presentation that explains your project that you will exhibit at the end of the semester.

Exams: There will be one mid-term exam and a final exam. No books or notes will be allowed during exams. *PLEASE NOTE*: At least 50% of the questions on the midterm and final examination will be either identical to, or based closely on, assigned homework problems that together form a 'Question Bank'. This is to encourage you to work on solving ALL the homework problems during the semester.

Grading: The course grade will be based on the following weights:
Discussion section participation - 4%
Pre-Test and Post-Test – 1% (*Full credit just for attempting*)
Homework and Quizzes - 20%
Computational Assignments (Python) – 15%
Midterm Exam - 20% (February/March)
3D Printing Team Project – 10%
Final Exam – 30%

Integrity and Honesty

All students are required to adhere to the Boston University rules and regulations regarding cheating. These rules will be strictly enforced in this class and violators will be brought before the appropriate University Committees. In particular all exams are to be the sole work of individual students. Students may discuss with other students the various homework assignments, but each student must write up the solutions in their own words and equations. During the discussion sections, we will review the solutions of homework problems due the next week.

Course Content

PY410 courses cover Statistical Mechanics and Thermodynamics. The goal of this course is to teach you to a probabilistic description of complex systems with a large number of degrees of freedom. Students will explore the relation between Information and Entropy, and how this leads to Emergent Phenomena. It is expected that students will have had undergraduate math courses involving vector calculus and partial differential equations, at the level of the pre-requisite course PY 355, Methods of Theoretical Physics; and Modern Physics at the level of PY351 (or PY 313), or equivalent courses in Engineering or Chemistry.

Computational exercises

You are required to learn to perform computational exercises and simulations on elementary Quantum and Classical systems with a large number of degree of freedom. The Physics department is transitioning to a Python-based approach in all undergraduate courses. You are encouraged to submit computational assignments in the form of Python Jupyter notebooks. There are a large number of excellent computational platforms. To keep things manageable for the course grader: For those wishing to use MATLAB, Mathematica or other platforms, although your solutions may be accepted and graded, the grader and instructors cannot provide any help and assistance.

TOPICS: Chapter numbers refer to Gould and Tobochnik

1. A New Paradigm in Physics for the 21st century: *Entropy, Information and Emergent phenomena.*

2. Fundamentals of Thermodynamics, Chapter 2
    a. Postulatory Approach to Thermodynamics
    b. Laws of Thermodynamics
    c. Free Energy, Specific Heat
    d. The Maxwell relations
3. Introduction to Probability, Chapter 3
    a. Randomness
    b. Probability distribution and moments
    c. Information and Entropy
    d. Bayesian Statistics
4. Methodology of Statistical mechanics, Chapter 4
    a. The Boltzmann factor
    b. The Canonical ensemble and Partition function
    c. Examples: Two level System and Particle in a Box
    d. The Grand Canonical ensemble
5. Magnetism and Spin Systems, Chapter 5
    a. Paramagnetism and Ferromagnetism
    b. The Ising Model
    c. The 2D Ising model, computational approach
    d. Phase transitions and the emergence of ferromagnetism
6. Many-particle systems Chapter 6
    a. Ideal Gas in the Semiclassical Limit
    b. Bose and Fermi Statistics
    c. Quantum ideal gas systems
    d. Blackbody radiation
    e. Einstein theory of specific heat
7. Special Topics: (Class Notes)
    a. Biological Physics: Entropy and Life
    b. Free energy and equilibrium in biomolecular interactions
    c. *Sum, ergo cogito*. Consciousness as an emergent phenomenon.
    d. Black Hole Thermodynamics
    e. The relationship between Black Holes and Life in our Universe