Physics 551

Statistical Mechanics

Tuesday and Thursday, 2:50 to 4:05PM, Room P306.

Prof. Cristian D. Batista

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Course Description: Many systems in nature are far too complex to analyze directly. Solving for the behavior of all the atoms in a block of ice, or the boulders in an earthquake fault, or the nodes on the Internet, is simply not feasible. Despite this fact, such systems often exhibit emergent simple and striking behaviors. Statistical mechanics explains these emergent behaviors of complex systems. The concepts and methods of statistical mechanics have penetrated many fields of science, engineering, and mathematics; Ensembles, entropy, Monte Carlo, phase transitions, fluctuations and correlations, nucleation, and critical phenomena are central to physics and chemistry, but also play key roles in the study of dynamical systems, communications, bioinformatics, and complexity. This course will cover the basic concepts and methods of statistical mechanics, which can be readily applicable to not only traditional physics but also to interdisciplinary sciences. Note that Statistical Mechanics is by nature a very mathematical subject and sometimes requires mathematical sophistication and rigor that goes beyond the level of a typical Physics course. For this reason, it is very important to be familiarized with the mathematical concepts that are described in second chapter of the book by Mehran Kardar. While we will devote three lectures to this chapter, this course assumes that the students are already familiarized the basic mathematical tools that are employed in that chapter. The same is true for the review of thermodynamics that is presented in the first chapter of the same book.

1. *Probability.* Binomial, Poisson, and Gaussian distributions. Central limit theorem. Rules for large numbers. Information, entropy and estimation.

2. *Thermodynamics.* The zeroth law, the first law, the second law. Entropy and thermodynamic potentials. Stability conditions and third law.

3. *Kinetic theory of gases.* Liouvilles theorem. BBGKY hierarchy. Boltzmann equation. H-theorem. Equilibrium properties. Conservation laws.

4. *Classical statistical mechanics.* Microcanonical ensemble. Ideal gas. Gibbs paradox. Canonical and grand canonical ensembles.

5. *Quantum Statistical Mechanics.* Dilute polyatomic gases. Vibrations of a sold. Black-body radiation. Quantum macrostates and microstates.

6. *Ideal quantum gases.* Hilbert space. Grand canonical formulation. Degenerate ideal Fermi and Bose gases. Bose Einstein condensation.

7. *Interacting particles.* Cluster expansion. Second virial coefficient and Van der Waals equation. Critical point behavior. Landau Mean field theory; order parameter, mesoscopic equation, scaling laws, critical phenomena, phase transitions.

Credit Hours: 3

Main text: Mehran Kardar, Statistical Physics of Particles (Cambridge, 2007) is the main textbook for this course and its presentation style is mathematical and concise.

Additional texts:

- Jim Sethna, Statistical Mechanics: entropy, order parameters and complexity (Oxford, 2011) explains the similar topics in an easier yet less rigorous manner. It contains many good exercise problems on modern statistical physics topics. The electronic book can be found at http://pages.physics.cornell.edu/ sethna/StatMech/EntropyOrderParametersComplexity.pdf.

- R. K. Pathria, Statistical Mechanics (Butterworth-Heinemann, second edition) is the student-friendly and pedagogical textbook.

Grade Distribution:

Homework	30%
Midterm Exam	30%
Final Exam	40%

Course Policies:

- **General**
  - Computers are not to be used unless instructed to do so.
  - Quizzes and exams are closed book, closed notes.
  - **No makeup quizzes or exams will be given.**
- **Grades**
  - Grades in the **C** range represent performance that **does not meet expectations**; Grades in the **B** range represent performance that **meets** the expectations; Grades in the **A** range represent work that is **excellent**.
  - Students are responsible for tracking their progress by referring to the online gradebook.

- **Assignments**
  - Students are expected to work independently. **Offering** and **accepting** solutions from others is an act of **plagiarism**, which is a serious offense and **all involved parties will be penalized according to the Academic Honesty Policy**. Discussion among students is encouraged, but when in doubt, direct your questions to the professor.
  - **No late assignments will be accepted**.