

Physics 211

Statistical Mechanics

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OUTLINE:

- Random Walks
- Microcanonical Ensemble
- Entropy
- Canonical Ensemble
- Grand Canonical Ensemble
- Quantum Statistical Mechanics
- Degenerate Quantum Gases
- Magnetism
- Landau's Theory of Phase Transitions
- Landau Theory with Continuous Symmetry
- Superfluids
- Fluctuations
- The Liquid-Gas Phase Transition
- Multi-Critical Points
- Scale Invariance and Critical Phenomena

1 Introduction

In this course, we will study the basics of *statistical mechanics*, the physics of systems with a very large number of degrees of freedom. You would think that, as the number of degrees of freedom of a mechanical system increase, its behavior becomes more and more complex. However, even though this is true, certain aspects of this behavior take on a new simplicity. This simplicity appears in three distinct ways:

- *Coarse graining*: By averaging over the small-scale motions of the system, we derive a simple behavior of the collective degrees of freedom visible at large scales.
- *Emergence*: New laws of physics apply at the level of the collective phenomena that have no counterpart at the microscopic level.
- *Universality*: System that are apparently unrelated at the microscopic level show the same behavior when considered at very large scales.

In this course, we will study systems that illustrate all of these concepts.

To begin, I will consider a problem that properly belong to statistics and not statistical mechanics, the theory of random walks. This will, however, illustrate the idea of coarse graining and the use of very large numbers to simplify the description of a system with many degrees of freedom.

We will then discuss statistical mechanics proper. I will present the various ensembles of systems used in statistical-mechanical calculation and give a brief justification for the validity of their use. I will discuss the equivalence of the ensembles. I will present a derivation of classical thermodynamics based on these ideas. This is all very standard material, but one purpose of this course is to be foundational, and every student of physics should see this material presented in a unified way and as clearly as possible. To conclude this segment of the course, I will derive the properties of classical and quantum idea gases.

From here, the course will deal exclusively with the theory of phase transitions. Thermodynamic phases are states of matter with distinct macroscopic properties that arise from a common set of microscopic particles and interactions. The canonical example of thermodynamic phases are the disordered and magnetized phases of a magnet. The latter phase has global ordering and lower symmetry than the equations of motion. How is this possible? What happens when the disordered material becomes ordered? What types of ordering transitions are possible. What special properties can be found in ordered phases? These fascinating questions will occupy us in the second half of the course.

In this presentation, I will lean heavily on the well-constructed textbook

- Sethna, *Statistical Mechanics: Entropy Order Parameters, and Complexity*

I will also draw on the other excellent textbooks that exist for this subject, especially

- Landau and Lifshitz, *Statistical Mechanics*

Additional literature is linked at the bottom of the course Web page:

<http://www.slac.stanford.edu/~mpeskin/Physics212/>