Chapter 0

Abstract and sources

This is a set of lecture notes prepared for PHYS 526: Statistical Physics (Emory, Spring 2020). There are undoubtedly typos and errors in this document: please email any corrections corrections to:

daniel.m.sussman@emory.edu

0.0.1 Pre-course thoughts/philosophy/strategy

The text for this course as taught by the professor before me was Pathria, which I think forms a good core for a graduate stat phys class (plus, it has the great benefit of being freely available online to Emory students, a feature we should not ignore). At the same time, the undergraduate course here at Emory uses Schroeder's "Thermal physics" textbook, and in my view there is a substantial jump from the way material is covered there to how Pathria begins. Graduate school should be a step up, of course, but in my view it would be helpful to provide students with a slightly easier "on-ramp" to the subject (particularly given the diversity of background in undergrad stat mech). Thus, my view for this course is to begin with a "lightning review" of both thermodynamics and probability theory, drawing inspiration from the first part of Kardar's *Statistical Physics of Particles*. From there we will continue on to the core of the course.

I agree with Kadanoff[1] that part of the beauty of statistical mechanics is in its deeply interconnected structure, and that "[o]nce we get into any aspect of the subject, we can travel outward to reach the entire, rich structure." This course will touch on several of the different "entry ports" outlined in his book (albeit in a very different order): the operational definition of quantum stat mech via the Gibbs average, the classical statistical mechanical definition via phase space integrals and the Hamiltonian, the Landau-favored free energy formulation starting with the partition function, and the Langevin and Fokker-Planck formulations.

In more detail (as also illustrated by the course syllabus), I think of the structure of this course in roughly thirds. The first third encompasses the reviews of thermodynamics and probability theory mentioned above: this includes the "begin by treating thermodynamics as black box, phenomenological theory that one builds a consistent mathematical structure for (based on empirical observations" perspective, along with a information-theoretic view

[1] *Statistical Physics: Statics, Dynamics, and Renormalization*, World Scientific Publishing Co, 2000

of (Shannon) entropy in the lectures on probability. The first third also includes kinetic theory, with the aim of introducing Liouville's theorem, the BBGKY hierarchy, and ultimately concluding the Boltzmann H-theorem. Much of this portion of the course has no direct correspondence with the Pathria text, although there are numerous resonances (and some direct overlap) with the appendices and the first three chapters.

The second third of the course will get into a much more traditional core stat mech coverage, looking at first the classical and then quantum statistical mechanical formulations alluded to above. Much of the lecture notes in these sections (cover aspects of ensemble theory, partition functions, the density matrix formulation of quantum stat mech, Bose and Fermi gases) will closely mirror the material in the heart of a standard first semester of a Pathria-based graduate course, and will benefit from existing lecture notes on this material.

The final third of the course has three aims: to introduce students to various methods of treating interacting systems, to discuss phase transitions and critical phenomena, and to touch on various aspects of near- and out-of-equilibrium statistical mechanics. It is my hope that we will have time to devote some time to the Langevin formulation mentioned above, the fluctuation-dissipation theorem, and other topics mentioned at the end of the syllabus.

0.0.2 Sources used

These notes are far from original. They represent a combination of many of the sources that I learned stat mech from, as well as resources from professors both local to Emory and non-local. As I said on the syllabus for the class, "Graduate-level statistical physics is a subject with many available textbooks and wide disagreements about which one(s) to use." For these notes I have particularly drawn from:

1. Pathria & Beale (Statistical Mechanics, 3rd edition; Primary source),
2. Kardar (lectures & Statistical Physics of particles; Primary source),
3. Preskill (Chapter 10 of his Quantum Information notes for discussion on information entropy and mutual information.)
4. David Tong (Chapter 2 of his lecture notes on Kinetic Theory for parts of Chapter 3 of this document, Chapter 1 of his notes on Statistical Physics for parts of Chapter 4 of this document)
5. Huang (Chapter 5 for some parts of hydrodynamics, Section 3.6 of this document. Also, the structure of this book (which is, not surprisingly, echoed in Kardar) has inspired the progression of topics covered here)
6. Boettcher (lecture notes; general secondary source),
7. Goldenfeld (lecture notes; general secondary source),
8. Kadanoff (book; general secondary source),

0.0.3 Basic notation in the text

Triple lines, like so:

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refer to estimated lecture breaks.

Text that appears in blue in these documents are things that I probably won't write on the board, but will likely be discussed, or provide (hopefully) useful additional context, etc. Text that appears in red in these documents are things that I intend to *not* go over in lectures, and which are perhaps not related to the core ideas of the course but are necessary to complete particular derivations. A first example are some elements of classical scattering theory that appears in Chapter 3: Calculating the differential cross sections that appear there are not particularly in the scope of the class, but the definitions help us get to the Boltzmann equation.

0.0.4 Course feedback

It is my intention to regularly solicit feedback on my teaching both from my faculty observer and from the students themselves (for instance, via google-forms surveys, etc.). As this is my first teaching assignment for graduate students, and in addition to fundamental feedback on how I can be a better teacher, I am particularly curious about (a) the overall pacing and difficulty of the lecture/problem sets/exams relative to other courses and relative to student expectations, and (b) how accurate my assumptions are about the need for the mini "on-ramp" of thermodynamics and probability to help bring everyone to a similar baseline.