Physics PHY 4523-001, spring semester 2017, 3 credit hours

STATISTICAL MECHANICS AND THERMODYNAMICS

Reductionist dogma asserts that once one understands the fundamental laws governing particles (*e.g.*, $\mathbf{F} = m\mathbf{a}$ or Schrödinger's equation), one can simply integrate those laws to predict the behavior of any system to which they apply. This is a big lie. Consider a gas of molecules confined to a box; to make the example even simpler, imagine that the gas molecules do not interact among themselves, so that the only force encountered is at the walls, where we can assume specular reflection. Thus the motion of any given molecule is trivial: given the initial position and velocity of a molecule, it is easy to calculate its position and velocity at any future time. The difficulty is that there are 10^{23} such molecules in the box; the logbook of initial positions and velocities (which one could never hope to measure) would not fit on all the hard drives of all the computer disks in the world. Even if one could do the calculations, the results would be another set of 6×10^{23} numbers, and it is hard to imagine how one could use them in that form.

Statistical mechanics and thermodynamics are concerned with how to extract *useful* information out of systems with large numbers of degrees of freedom. Of course, everyone is already familiar with the example of the ideal classical gas; the "solution" to the problem of how to deal with 6×10^{23} degrees of freedom reduces these to just three "state" variables: volume, pressure, and temperature. The somewhat awkward title of the course reflects two differing historical approaches. Traditional thermodynamics is a beautiful, self-contained gem based on a small number of axioms governing the state variables; its development in the nineteenth century preceded the modern atomistic understanding of matter. In contrast, statistical mechanics begins with the quantum picture of nature and derives the axioms of thermodynamics, although its application is actually broader.

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LECTURES: Tuesdays and Thursdays, 3:30–4:45 P.M., ISA 2023

RECITATIONS AND MIDTERM: Fridays, 1:00–1:50 P.M., ISA 2023

OFFICE HOURS: Thursdays 8:30–9:30 A.M., ISA 2022-D and (usually) after each class, 5:00–5:30 Tuesdays and Thursdays. I am also available by appointment and when you can find me not in another meeting.

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TA OFFICE HOURS: Mondays 10:00–10:30 A.M., Bohr Tutorial Room, ISA 4019 A; Fridays 2:00–2:45 P.M., Bohr Tutorial Room, ISA 4019 A.

PREREQUISITES

Some knowledge of quantum mechanics, at least what's covered in Modern Physics, is assumed: you need to know about the energy levels of the square well and of the hydrogen atom and to know the Schrödinger equation and the difference between Fermions and Bosons. Problem-solving experience at the level of the intermediate physics courses—any one of Electricity and Magnetism I, Classical Mechanics, or Quantum I will suffice—is essential. This class is a prerequisite for entry to physics graduate school and for specific courses in materials science, physical chemistry, solid-state physics, plasma physics, lasers, electrical or chemical engineering, and quantum computer science, among other subjects.

REQUIRED TEXTBOOKS

Prices are estimated. "Required" means that I expect students to read these two books and will assign problems from them; of course, the books will be available on reserve at the library or available electronically from the Library's Web site.

- C. Kittel and H. Kroemer, *Thermal Physics* (2nd ed. with corrections as of 1994), Freeman, ISBN 0-7167-1088-9. Retail price $138. Kittel is a sold-state theorist, best known as the first "K" in the RKKY effect. Kroemer was awarded the Nobel Prize in Physics in 2000, in part for his work in the invention of the integrated circuit. A quick survey of other universities suggests it is the most popular book for this course.
- Enrico Fermi, *Thermodynamics*, Dover, ISBN 0-486-60361-X. Retail price $9. One of the giants of experimental and theoretical physics, Fermi was awarded the Nobel Prize in Physics in 1938. This book presents some of the elementary results of the course from a traditional thermodynamic point of view as opposed to the statistical viewpoint of Kittel and Kroemer.

SUPPLEMENT RECOMMENDED FOR PURCHASE

A copy of this book should be available on reserve at the library.

- F. Mandl, *Statistical Physics* (second edition, 1988), Wiley, ISBN 0-471-91533-5. Retail price $55. I recommend this book for its clear explanations and worked problems, but it doesn't go through as many applications as Kittel and Kroemer. For magnetism, note that this text uses MKS instead of the customary Gaussian units.

TENTATIVE COURSE OUTLINE

My plan is mostly to follow the treatment in Kittel and Kroemer, using lectures to add context as well as to clarify some of the calculations. The following is subject to change.

week of 1/9	What is temperature? Review Physics I. Counting microstates.
1/16	Ensemble averages; statistical definitions of entropy, temperature; laws of thermodynamics; Canonical ensemble, partition function, Boltzmann factor.
1/23	The fundamental thermodynamic identity; Helmholtz free energy; classical ideal gas.
1/30	Some applications: blackbody radiation, electrical noise, Debye theory of phonons in solids.
2/6	Gibbs (grand canonical) ensemble and the chemical potential.
2/13	Fermi-Dirac, Bose-Einstein, and Maxwell-Boltzmann distributions; more on the ideal gas.
2/20	The degenerate Fermi gas and metals; Bose-Einstein condensation.
2/27	Heat and work; thermodynamic definition of entropy; heat engines; the Carnot cycle.
3/6	Review and catchup; **MIDTERM EXAMINATION FRIDAY 10 MARCH**.
3/13	March meeting of the American Physical Society in New Orleans: **no classes**.
3/20	Gibbs free energy and chemistry.
3/27	Phase transitions; the van-der-Waals gas; mean-field treatment of ferromagnetism.
4/3	Binary mixtures and phase equilibrium.
4/10	Cryogenics, or how to make things really impressively cold.
4/17	Viscosity; transport (Boltzmann equation).
4/24	The modern theory of critical phenomena and the Renormalization Group; catch-up and review; reading period (4/27 and 4/28)
—	**FINAL EXAMINATION THURSDAY 4 MAY 12:30–2:30 P.M. (12:30–14:30)**

We are not planning to cover chapter 13 of Kittel and Kroemer on semiconductors, as this topic is treated in detail in the course on solid-state physics, nor much of chapter 15. If we run short on time, we may leave off the last few topics in the outline. If we have extra time, and if the class is so inclined, I have a list of more modern topics not covered in the textbooks, including density matrices, computational methods (*e.g.*, Metropolis Monte Carlo), Onsager's solution of the two-dimensional Ising model, transfer matrices, Einstein's treatment of Brownian motion, and Shannon entropy and Fisher information.

HOMEWORK

Homework will be assigned and collected every one or two weeks. *Doing* the homework is the best way to learn and the most important activity you will undertake in the course; do not skip it! Each week's assignment will also suggest relevant readings in the textbooks. Homework will be worth 20% of the grade. Student learning outcomes: at the end of the course, you will be able to solve realistic problems, synthesizing the ideas outlined in this syllabus. **You are not to consult solutions from other students, the Web, or a solutions manual. I am just as good with Google as you are and have no trouble recognizing copied solutions. You must list any sources (other than Kittel and Kroemer or Fermi) you used in preparing your homework. By turning in any assignment, you certify that it represents your own effort. See policy below on cooperation, collaboration, and cheating.**

RECITATIONS AND PARTICIPATION

I expect students to participate in and out of the classroom. Attendance will be taken at Friday recitations and will count for 2% of your grade; you need to be present for the whole period to be counted. The rest of your participation grade will come from postings to the course list-server. Each student will be expected to make at least two substantive posts each month (January, February, March, and April). Examples of substantive posts include questions on the material, answering another student's question, or a request for something to be covered in class. The posts will be worth 3% of the grade.

You should subscribe right away to the list server by sending a one-line message to

`listserver@ewald.cas.usf.edu.`

The one line (in the body, not the subject) should read "`subscribe 4523`." Once you have subscribed, you may post questions and comments to the whole class by sending e-mail to `4523@ewald.cas.usf.edu`. **The address for subscribing is different from the address for posting.** *Note that you must use a* `.usf.edu` *return address: mail sent from all other addresses will bounce.* There is a link to the archive of posts on the course Web site.

EXAMINATIONS

The midterm examination is scheduled for 10 March and the final exam for 4 May. Whichever exam on which you do better will count for 50% of your grade, while the other exam will count for 25%. If you know you cannot make one of the examinations, you must tell me as soon as possible in advance. Plan to arrive on campus early on examination days.

COOPERATION, COLLABORATION, AND CHEATING

Students are encouraged to discuss problem-solving methods *after* each has attempted the problems. Research and my own experience have shown that the most common reason for a student dropping out of physics is the belief that he or she needs to do all the work alone. On the other hand, you should first try each problem. Then when you get together with your colleagues, you will find each stuck at a different place, and together you will get unstuck. While the instructor will always try to help, you will find the most valuable resource in other students.

Getting unstuck is very different from copying a solution. For example, it is reasonable for a student who has set up the problem but is having trouble evaluating an integral to ask a colleague how she evaluated the integral or for two students whose answers differ by a factor of two to compare notes to figure out where one of them might have gone wrong. It is quite another matter for Bill to copy Mary's solution (or mine from a previous year).

Please read the policy on integrity of scholarship in the general catalogue. Unfortunately, I have seen violations of this policy in my past classes. It is really very easy for me to detect cheating, and any confirmed case **will result in a grade of FF** in the course and could result in expulsion from the university.

Many of the homework exercises will come out of Kittel and Kroemer, and a note in the preface indicates that a solutions manual exists. You are not to consult this or any other solutions manual, any previous year's homework, or any other source of solutions, but you may consult other textbooks, which you should list on your homework solutions (see above). In case of any question on the policy, please e-mail me.

ADDITIONAL BOOKS (roughly in order of difficulty)

Most of these books aim at a level comparable to this course's, while the introductory chapters of the ones toward the end may be useful for review. Some of these books are on reserve in the library. In case you're interested in purchasing reference books, note that Dover books are inexpensive.

- Ambegaokar, *Reasoning about luck: probability and its uses in physics*, Cambridge, 1996. This intelligently and eloquently written slim book is aimed at liberal-arts majors with no mathematical or scientific background beyond high-school algebra and covers elements of statistics, mechanics, thermodynamics, and quantum mechanics.
- Feynman, *Lectures on Physics vol. I*, Addison-Wesley. Chapters 39-46 are most relevant to this course. Any time I think I understand something in elementary physics, I come back to Feynman for new insight. Feynman was awarded the 1965 Nobel Prize in Physics for his work in quantum electrodynamics; he also contributed to the statistical mechanics of superfluid helium.
- Baierlein, *Thermal Physics*, Cambridge, 1999. Slightly more modern than Kittel and Kroemer (includes an elementary development of critical phenomena). (MKS units)
- Schroeder, *An Introduction to Thermal Physics*, Addison-Wesley, 2000. This recent text begins with the thermodynamic definition of entropy, introducing the statistical interpretation a little later. (MKS units)

- Pippard, *The Elements of Classical Thermodynamics*, Cambridge, 1963. Similar to Fermi's book, somewhat more sophisticated, this book takes the completely traditional thermodynamic approach without so much as a mention of statistical mechanics.
- Reif, *Fundamentals of Statistical and Thermal Physics*, McGraw Hill, 1965. Reif writes more elegantly, and he takes more care with subtle mathematical points than Kittel and Kroemer, for example, in the enumeration of microstates. Finally, I think the arguments become perhaps too careful for an introductory text, as the reader encountering ideas for the first time may not see clearly which are the ideas and which the subtleties.
- Chandler, *Introduction to Modern Statistical Mechanics*, Oxford, 1987. Concise textbook with a mixture of elementary and difficult topics and problems, aimed at theoretical physical chemists. This was one of two texts in graduate Statistical Mechanics, PHY 6536, in fall 2007.
- Yeomans, *Statistical Mechanics of Phase Transitions*, Oxford, 1992. This will be a useful reference when we discuss critical phenomena. Yeomans was my postdoctoral supervisor. If we had two semesters for the undergraduate course, I would use this as the primary text for part of the year.
- Goodstein, *States of Matter*, Dover, 1975, 1985. This is a graduate text, but the first chapter contains thorough discussions of thermodynamics and statistical mechanics. It will make good sense as a review once you have seen the concepts a first time.
- Thompson, *Classical Equilibrium Statistical Mechanics*, Oxford, 1988. Good advanced text. As with Goodstein, you will appreciate the first two chapters after you've spent a couple of months with the more elementary books. Includes many worked problems.
- Pathria, *Statistical Mechanics*, Pergamon, 1972. Similar to Landau and Lifshitz.
- Landau and Lifshitz, *Statistical Physics*, 3rd. ed., Part 1 (transl. Sykes and Kearsley), Pergamon, 1980. This is the classic graduate textbook. Most graduate students in theoretical physics will own the whole set by Landau and Lifshitz. Landau was awarded the Nobel Prize in Physics in 1962 for his work in solid-state physics (*e.g.*, his theory of Fermi liquids) and the physics of superfluid helium.

ATTRIBUTES OF A SUCCESSFUL PHYSICS MAJOR

I've asked former students to offer their observations on what it takes to be successful. Here are some of their responses, along with my own:

- Attend office hours;
- Be dedicated: it takes time and effort;
- Work steadily: don't wait until the day before a test to study;
- "No way" should you have an outside job if you're taking a full course load;
- Successful students check their work and use the full time allotted for tests;
- They solve homework problems by thinking, not by Googling;
- They stop by professors' offices to pick up final exams once they're graded or early in the next term;
- Many of them belong to SPS;
- They attend (nearly) every class;
- They work 6–12 hours a week outside of class *per class* reading, studying, and completing assignments.

AGREEMENT

I ask students to agree to the following statement as part of first-day attendance: "I understand that to pass this course I shall need to commit at least six to twelve hours a week outside class to reading and homework and to attend at least 75% of the lectures. Presenting someone else's work as my own, copying without attribution, and consulting homework solutions are examples of cheating. I understand that, under university and department policy, any student who cheats or participates in cheating will receive a grade of FF in the course and that further sanction (such as expulsion from the university) is possible. I am responsible for reading the syllabus."

OFFICIAL NOTICES IN ACCORDANCE WITH COLLEGE AND DEPARTMENT POLICY

You may give away notes for free but may not sell them or tapes. Students who will miss a class meeting due to a planned religious observance are requested to inform the instructor, in writing, by the second class meeting. Please let me know if you require any accommodation due to physical disability or injury. Letter grades may include + and −. Any presentation as one's own work of material copied from elsewhere constitutes plagiarism and could result in expulsion from the university. Standard university policies listed at `http://usf.edu/undergrad/standard-policies.aspx` are incorporated by reference.