

STATISTICAL MECHANICS

There are branches of physics that do not use classical mechanics and others that do not use quantum mechanics. Electricity and magnetism may be important for many areas of research, but not for all. Most of physics can safely ignore string theory. However, there is no area of physics, from cosmology to materials science and biophysics, that does not depend crucially on statistical mechanics.

Fundamentally, this is because the direct application of microscopic principles to more than a few degrees of freedom is, in practice, impossible. For example, undergraduates learn to solve Schrödinger's equation for a single particle in a box. Add a second interacting particle, and one has to resort to numerical solution. What of 10^{23} particles?

Statistical mechanics consists of distilling large numbers of degrees of freedom, $\sim 10^3$ – 10^{23} , down to a small number of physical observables. In essence, it reduces the vast amount of information to which we have no access to a single number, the entropy, while making testable predictions about the observables we care about. For this reason, it is central not only to physics but also to other fields that deal with information, such as computer science, quantitative biology, and mathematical finance.

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MEETING TIMES: Mondays, Wednesdays, and Fridays, 9:40–10:30 in room 130, Mathematics-Physics building (PHY). Official **OFFICE HOURS** will be announced; I am also usually available during the day, evenings, and weekends. You may give away notes for free but may not sell them or tapes.

Prerequisite. A good undergraduate course in statistical mechanics and thermodynamics (or physical chemistry) is advisable. If you don't know what it means to construct the partition functions of non-interacting classical, Fermi, and Bose gases, you might consider taking the undergraduate class, PHY 4523, first. Nonetheless, I intend to review the main undergraduate results in the first few weeks.

Textbooks

Material for most lectures and homework will be drawn from two textbooks:

1. *R.K. Pathria, *Statistical Mechanics*, 2nd. ed., Butterworth-Heinemann, 1996, ISBN 0-7506-2469-8, and
2. J.P. Sethna, *Statistical Mechanics: Entropy, Order Parameters, and Complexity*, Oxford, 2006, ISBN 978-0-19856677-9.

Jim Sethna has also made his book available in PDF at his Web site:

<http://www.lassp.cornell.edu/sethna> .

The two main books follow complementary approaches. While Pathria concentrates on the state of the subject as of 1979 (and mostly as of 1949), Sethna is primarily interested in the problems people are studying currently. On the other hand, Sethna downplays the inescapably quantum nature of classical statistical mechanics, which Pathria recognizes.

There are many good supplementary textbooks; I'm asking the bookstore to stock the following, but don't feel obliged to purchase it:

* Marked books should be on reserve at the library.

3. *D. Chandler, *Introduction to Modern Statistical Mechanics*, Oxford, 1987, ISBN 0-19-504277-8. Chandler's was one of two textbooks we used two years ago in this course, and while the students liked the book for part of the course, they found its coverage sketchy or non-existent on others.

If you feel like spending more money on books, these two really ought to sit on the shelf of every statistical mechanician:

- Richard Feynman, *Statistical Mechanics: A Set of Lectures*, 2nd ed., Perseus, 1998, ISBN 0201360764.
- *L.D. Landau and E.M. Lifshitz, *Statistical Physics Part I*, 3rd ed., Elsevier/Butterworth-Heinemann, 1984, ISBN 0-7506-3372-7. The classic of the field.

More books:

- *C. Kittel and H. Kroemer, *Thermal Physics*, 2nd ed., Freeman, 1980, ISBN 0716710889. This is the textbook I've used in the undergraduate course. It is full of applications as disparate as the cosmic microwave background and the cytoplasm of algae. If you need a reference for undergraduate stat mech, this would be a good choice. I've put it on reserve (*) at the library.
- *M. Plischke and B. Bergersen, *Equilibrium Statistical Physics*, 3rd ed., World Scientific, 2006, ISBN 981-256-155-2. This was one of two primary textbooks, the other being Chandler's, when the course was offered in 2007.
- *D.A. McQuarrie, *Statistical Mechanics*, 2nd ed., University Science Books, 2000, ISBN 1891389157. The chemistry department usually uses McQuarrie as the primary text in their version of this course. It is similar to Pathria but with less emphasis on topics like magnetism and more on molecular vibrations.
- N.G. van Kampen, *Stochastic Processes in Physics and Chemistry*, 3rd ed., North-Holland, 2007, ISBN 0444529659. This contains the best treatment I've seen of Ito's Lemma, the stochastic calculus, and the relation between the Fokker-Planck and Langevin equations.
- M. Toda, R. Kubo, and N. Saito, *Statistical Physics I: Equilibrium Statistical Mechanics*, 2nd ed., Springer, 2006, ISBN 3540536620; R. Kubo, M. Toda, N. Hashitsume, *Statistical Physics II: Nonequilibrium Statistical Mechanics*, Springer, 2006, ISBN 354053833X. This is the Kubo of the Kubo formalism, and the second volume even has a section answering van Kampen's objection to his microscopic linear-response theory. I might switch to these two books in a future year.
- *David Goodstein, *States of Matter*, Dover, 1975, ISBN 048649506X. Besides offering a cogent review of undergraduate thermodynamics and statistical mechanics in the first two chapters, this book has the best opening paragraph of any physics textbook ever written.
- Julia Yeomans, *Statistical Mechanics of Phase Transitions*, Oxford, 1992, ISBN 0198517300. Good introduction to universality and the renormalization group; intended for undergraduates.
- Nigel Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group*, Perseus, 1992, ISBN 0201554097. More advanced than Yeomans's treatment but still accessible.
- T. Hill, *An Introduction to Statistical Thermodynamics*, Dover, 1960, ISBN 0-486-65242-4. This is intended as an advanced undergraduate textbook.
- T. Hill, *Statistical Mechanics: Principles and Selected Applications*, Dover, 1956, ISBN 0-486-65390-0. This presents a more formal treatment of the fundamental results in the undergraduate book above.
- A.I. Khinchin, *Mathematical Foundations of Statistical Mechanics*, George Gamow, transl., Dover 1960 (from 1949 edition), ISBN 0486601471. As the title suggests, Khinchin tries to be mathematically rigorous, but unlike most mathematics books, he explains everything as he goes along.
- C.J. Thompson, *Mathematical Statistical Mechanics*, Macmillan, 1972. Another mathematical approach, this time starting with neither ensemble theory nor thermodynamics (although both are covered later) but rather with kinetic theory.
- C.J. Thompson, *Classical Equilibrium Statistical Mechanics*, Oxford, 1988, ISBN 0198519842. Same author, different emphasis and approach; good treatments of some exactly-solved models.

Course structure and evaluation

Tests. In-class tests are scheduled for the last Mondays in September and October, but be aware that these could be postponed because of storms. There will be a written final examination on Wednesday, 9 December at 10:00 AM (note time). If you have to miss an examination (for example, to present results at a conference), you are responsible for letting me know as far in advance as practical or, in case of unforeseen circumstances, as soon as possible afterward.

Homework, Oral Presentations, and Participation. Homework will be assigned weekly or biweekly. Working out homework problems is the most valuable part of a graduate class. I am aware that solutions to problems from popular textbooks can often be found on the Web. You are not to consult such Web sites (*e.g.*, Cramster, Rapidshare) or solutions manuals on any homework you submit. It's a waste of your time to copy someone else's solution and a waste of my time to correct it. I am just as good at using Google as you are, so don't think you can get away with it. As always, you warrant that any work you submit is your own, except as you provide references. If you do consult other books or published articles, you must cite them. You may discuss assigned problems with classmates, if you cite their help, but it is unacceptable to copy each other's solutions. Again, solutions manuals, books of solved problems, and anything posted on the Web are all off-limits.

As part of some assignments, I will ask a volunteer to give a 15-minute presentation on a set topic, which may be a section from one of the books or may involve additional reading, and to lead a discussion of that topic. The presenter will receive a grade for the presentation, and the other people in the class will receive grades for their participation in the discussion. It is therefore important for everyone, not just the week's presenter, to do the reading in advance.

Tentative course outline (topics and order may change)

week topic

- 1 overview, including connection between thermodynamics and statistical mechanics; review of probability
- 2 thermodynamics, phase equilibrium, random walks
- 3 **Labor Day 9/7**; classical phase space and ensembles
- 4 ensemble theory and quantum gases
- 5 ensemble theory and quantum gases
- 6 **test 9/28**; dense gases and liquids; correlation functions
- 7 mean-field theory and phase transitions
- 8 critical phenomena and the renormalization group
- 9 critical phenomena and the renormalization group
- 10 **test 10/26**; Ising and Kosterlitz-Thouless in two dimensions
- 11 stochastic processes, Markov chains, Brownian motion, Fokker-Planck, Langevin
- 12 stochastic processes, Markov chains, Brownian motion, Fokker-Planck, Langevin; **Armistice Day 11/11**
- 13 linear-response theory
- 14 linear-response theory, fluctuation-dissipation theorem; **Thanksgiving holiday 11/27**
- 15 reserve for review/hurricane make-up
- 16 **final examination, 10:00–12:00, Wednesday, 9 December**

Standards for written solutions. Since good communication is essential to science and to your professional development, grammar, organization, and style count. Students are encouraged to discuss homework, but cooperation must not include copying or plagiarism. You may look things up in books and journals in the library, but looking at previous years' solutions, solutions on the Web, or a solutions manual *is cheating* and **will result in expulsion from the university** under a policy of the USF Graduate Council. You need to cite any outside sources (*i.e.*, other than the required textbooks) you consulted on the homework: as examples, before a derivation (which you may follow but not copy verbatim) you might write "this derivation fills in the missing details in section 10.9 of Jackson, third edition," or before a difficult integral, "Mary showed me this integral in Gradsteyn and Ryzhik, (3.456)."

When turning in any assignment, including homework and papers in this class, a student implicitly certifies that the work, the ideas, and the wording are his or her own except as other works have been cited clearly. Briefly, not citing a work from which one has borrowed ideas is a form of dishonesty; copying phrases verbatim without setting them off typographically and citing the source is plagiarism.