33-765 Statistical Physics, Spring 2019 Syllabus

Course

Lecture	MWF	9:30am – 10:20am	DH A301D
Recitation	M	1:30pm – 2:20pm	DH A200

Lecturer

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https://www.facebook.com/groups/460797093978324/

Textbook

Robert H. Swendsen, "An Introduction to Statistical Mechanics and Thermodynamics," Oxford University Press, 2012.

Other useful textbooks

Mehran Kardar, "Statistical Physics of Particles,"
Cambridge University Press, 2007.

Donald A. McQuarrie, "Statistical Mechanics,"
University Science Books, 2000.

Terrell L. Hill, "An Introduction to Statistical Thermodynamics,"
Dover, 1987.

Hermann Schulz, "Statistische Physik,"
Harry Deutsch GmbH, 2005

Content of this course

Arena

Statistical Physics attempts to explain macroscopic phenomena in terms of underlying microscopic laws. The large-scale behavior of systems, which we characterize by means of a small number of variables, emerges after eliminating the many microscopic degrees of freedom of their fundamental constituents. These generally unobservable degrees of freedom are far too numerous to follow, but precisely for this reason they can be treated *statistically*, making use of the law of large numbers and the central limit theorem: averages of a large number of random variables tend to converge to well defined distribution functions, and their relative fluctuations become smaller than other experimental errors. For instance, the pressure of a gas, the electric conductivity of a wire, or the Young modulus of rubber result from a proper statistical treatment of gas molecules, electrons in a solid, and entangled polymer chains, respectively. For this reason, Statistical Physics is the microscopic foundation of Thermodynamics.

Topics

The key topics to be covered in every "Introduction to Statistical Physics" course only vary in small degrees. Central to all discussions is an understanding of some essential probability theory, statistical ensembles, the connection to thermodynamics, various illuminating model systems (such as the ideal gas or the harmonic crystal), and some good approximation schemes to deal with all those problems that can't be solved exactly. In this course, we will begin with the (classical) ideal gas, introduce the notion of entropy, then move on to an overview of thermodynamics, and return to visit statistical mechanical ensembles (microcanonical, canonical, grand canonical). The necessary probability theory will be filled in as we go. We then extend the treatment to quantum statistical physics, visiting some of the famous example problems like black body radiation and Bose-Einstein condensation. Time permitting, we will also deal with phase transitions.

I will try to follow Swendsen's text sequentially, but will bring in extra material from other sources, for instance to illuminate or expand on some aspects in a different way.

In case of doubt, I will rather spend more time on the elementary but absolutely crucial basics, than to rush through and strive to cover some beautiful but advanced material. I know that many students eager to study this (or in fact any) material yearn to go to the more advanced stuff—the fancy, the modern, the challenging. But alas, I have seen far too many times that if people approach advanced material without truly owning the foundation, they are incapable of working creatively on the advanced level. But once you have really thoroughly understood the basics, the advanced topics will always come naturally and could even be read up on your own. Conversely, if you miss the basics, the door to all the beautiful stuff will invariably remain shut.

Goals

After having taken this course, you should be able to do the following:

- Understand, how macroscopic behavior emerges from suitable averages over a huge number of microscopic degrees of freedom, and give examples illustrating this process.
- Master those concepts of probability theory that lie at the heart of our physical discussion, such as probabilities and probability densities, Bayes theorem, transformation of probability distributions, moments, correlation and dependence, characteristic functions, central limit theorem, Jensen's inequality.
- Be familiar with standard statistical ensembles and use them suitably to solve problems (e.g., do partition functions of simple model systems and calculate their thermal properties from the resulting thermodynamic potentials).
- Be familiar with the basics of thermodynamics, and how it links to statistical physics.
- Grab a book on statistical physics and feel comfortable diving into topics beyond what we have discussed, aspects which look beyond the simple model systems—for instance: non-ideal gases, theory of liquids, phase transitions, mean field theories, renormalization, statistical field theory.

Organization

Homework

Homework will be assigned and graded on a weekly basis. Late homework will *not* be accepted (unless it is the result of an officially excused absence).

I will not hand out sample solutions, but I will *extensively* discuss the solution in the recitation session.

I expect that your solutions are written up *carefully* and *legibly*. If you are a graduate student in this class, then recall that *you have a degree in physics*, and hence I expect you to be able to communicate your physical reasoning in a *professional* way. If you are an undergraduate—here's your chance to learn this. Practice makes the master, and I will give you ample opportunity to practice.

I spend *a lot* of time thinking about good homework problems. You should take them as opportunities to solidify your knowledge, apply it in new circumstances, and find the limits of your own understanding (that you then need to specifically work on!). If you rely too much on external help (*e.g.* Google or your friends) in solving your homework problems, you deprive yourself of a valuable opportunity to learn the material and identify your own limits. Same if you do the homework in the last minute. Hence: don't do the homework in the last minute. *Just don't*. Since the exam problems will be quite similar to homework problems, I can *guarantee* from experience that such an approach *will* come and haunt you in the exams.

Homework has multiple purposes in my grand scheme of things. Of course, one of them is to practice the material we have learned. But I also frequently use homework to introduce concepts and topics beyond what either the book or my classes cover. Interesting novel applications, new aspects to an old theme, outlook for things to come, alternative techniques, fun and useful theorems—*etc*. This is especially true since I wish to complement the book (which primarily aims for a 2-semester undergraduate course) with a few graduate level topics. Hence, if you feel that at times the homework is not perfectly aligned with classroom material, well then—guilty as charged. It's a feature, not a bug.

Exams

There will be one midterm exam and one final. The date of the midterm will be announced early in the course; it will take place during usual class hours. I will let you know about the date for the final as soon as it becomes available (this is decided by the registrar, not me). Don't make any travel plans before you know this date as you *have* to take it to pass the class.

Grading

The weighting of the homework, midterm, and final is as follows:

Homework: 30%
Midterm: 30%
Final: 40%

Working together

It is OK to work together on homework. However, when the time comes to write up the solutions, I expect you to do this on your own, and it would be best for your own understanding if you put aside your notes from the discussions with your classmates and wrote up the solutions entirely from scratch. Remember that the problems in the exams will not be all that different from the homework problems, and if you are unable to reconstruct by yourself a solution you have figured out in a group effort, you will not be able to do this in an exam either. Trust me, I have seen this happen many times. Homework isn't just a way to get points. It is your most direct feedback on whether you understand what I expect you to understand. If you begin to struggle, work on it and talk to me.
Of course, working together on exams is *expressly forbidden*.

Attendance

I will not take attendance. You are old enough to know how to budget your time. That being said, I *strongly* believe it is in your best interest to *attend class on a regular basis*. If you fail to do so, then don't count on catching up by meeting with me during office hour, since my time is valuable too, and I will not spend it on repeating a lecture that you decided to miss. If you could not attend for very good reasons, this is different; but in this case, please come prepared by (a) having read the pertinent chapter of the book and (b) obtained and studied the lecture notes from your classmates, so that we can directly focus on the part that might still be unclear.

Also: this should go without saying, but unpleasant experiences suggest that it doesn't: you don't have to come to class, but if you do come, then *I expect you to be on time*. People shuffling in late are invariably a source of distraction. Plus: I'm old school enough to hold the view that it is impolite (towards other student as well as towards me) to be late, especially if it's chronic behavior.

Important: If you are not able to turn in a homework assignment or take an exam because of an unexcused absence, *you will not be able to turn the homework in late or take the exam*. This does not apply if extraordinary circumstances prevented you from showing up, but they indeed have to be severe. The list of *non*-extraordinary circumstances contains, but is not limited to: forgetting, too busy, visit of friends or family, missed bus, printer failure, anything for which you could have gotten an excused absence ahead of time.

What I expect from you

For the physics graduate students in the class: remember that Statistical Physics is one of the classes you have to pass in order to be moved on to candidacy, and often in one way or the other its content features as a conceptual background to research you are doing, and so it might crop up in the oral exam. It is therefore in your own best interest to do as well as possible, given that you've already decided to go to grad school in physics and at some point want to be passed on to candidacy. The situation for graduate students from other departments is different, but please remember that—unlike the physics grads—you decided on your own to take this course, so make the best of it and don't waste your precious time. For the undergraduate students taking this course: this is your chance to get ahead of the game when/if you go on to grad school. If you go in physics, this is a course you'll run into, so you might be able to place out or at least go in already with the scars!

If you have questions about the material, please feel free to ask them in class, if at all possible. This will give me a fighting chance to see whether I'm keeping everyone on board. If you are uncomfortable with this, please come to office hours and/or send me an email with your question. Well, and then there's the course's facebook page, on which I'd *love* to see a vibrant discussions of all things statistical.

Statistical Physics is the foundation for an incredible amount of material, since the concept of systematically removing unimportant detail of a usually messy situation and thus arriving at accurate quantitative predictions is almost at the heart of what it means to do physics. Physicists never describe reality; they always describe a cleverly simplified model of it, one that can be quantitatively analyzed and from which useful predictions can be gleaned. The art of creating a good model is to throw everything away that doesn't matter, and only keep the pieces that are important, which requires experience and good judgment. Also, you absolutely must know how the stuff you threw away indirectly affects the remaining content of your model. Statistical Physics is the conceptual framework for all of this. You therefore should strive to understand it as deeply as possible. Your best bet to do this is to read the text, consult other textbooks if you are still confused, work hard at solving the homework problems, and then find some other problems in StatPhys to solve. It's *that* important!

I will have class information, occasional extra notes, homework sets, and all kinds of other useful material posted on the following website for this course:

`http://www.andrew.cmu.edu/course/33-765`

Be sure to check this site on a regular basis.

And finally…

Please take care of yourself! *Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep, and taking some time to relax. This will help you achieve your goals and cope with stress.*
All of us benefit from support during times of struggle. You are not alone. There are many helpful resources available on campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful.

If you or anyone you know experiences academic stress, difficult life events, or feelings like anxiety or depression, I strongly encourage you to seek support. Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit their website at http://www.cmu.edu/counseling/. Consider reaching out to a friend, faculty or family member you trust for help getting connected to the support that can help.

If you or someone you know is feeling suicidal or in danger of self-harm, call someone immediately, day or night:

CaPS: 412-268-2922
Re:solve Crisis Network: 888-796-8226
If the situation is life threatening, call the police:
    On campus: CMU Police: 412-268-2323
    Off campus: 911

If you have questions about this or your coursework, please let me know.