Note

This course is cross-listed as Physics 262 and Applied Physics 284. Both course numbers refer to the same course, and you may sign up for either one.

Teaching staff

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Course aims and objectives

Since this is a graduate class, the main focus is to prepare you for research. I hope that by the end of the course, you are able to read and understand journal articles involving statistical mechanics, ask questions at research seminars and colloquia, and use the tools of statistical mechanics in your own research.

In contrast to an undergraduate course, where the focus would be primarily on problem solving, this course aims at also developing higher-level skills that are important for research. To use statistical mechanics in research, a student must be able to

1. **Understand**: Follow the steps of what is being presented in the readings and lectures.
2. **Apply**: Solve problems using your understanding of material.
3. **Explain**: Explain to others the concepts and their relevance to the problem.
4. **Interpret**: Draw connections and analogies between different problems/questions.
5. **Critique**: Make judgements about which interpretations, explanations, and results are valid and useful.
6. **Create**: Synthesize or develop new research ideas and directions.

Whereas an undergraduate course might focus on the first two levels (understanding and applying), this course will focus on building all of these skills. The assignments and assessments therefore include not only problems, but also open-ended questions and discussion.

What to expect

Statistical mechanics has applications in almost every field of physics: condensed matter, astrophysics, atomic and molecular physics, biophysics, and more. Our goal will be to develop the fundamentals in just enough detail to do some interesting physics with them. I won't spend a lot of time on formal derivations or subtle points; instead, I'll emphasize physical understanding and breadth.

I want this course to be engaging and useful to you. Too often, statistical mechanics courses emphasize tedious calculations on made-up systems. I will endeavor not to be tedious. Also, some courses try to engage students by constructing "mysteries" (such as Gibbs' Paradox or the origin of the $N!$ term in the partition function) that are only mysterious because of the way they are presented. I will endeavor not to build excitement by intentionally confusing you.

We will cover

- Probability distributions, random walks

- Classical statistical mechanics
- Statistical thermodynamics
- The meaning of entropy
- Quantum statistical mechanics
- Statistical mechanical models
- Phase transitions
- Critical phenomena and the renormalization group

Because each topic in the course builds on the previous, it's important not to get behind. All of this means that you might not want to take this course if you are taking 3 (or even 2) other courses. It's going to require a lot of your attention.

Lectures

Lectures will include presentation of the material along with some discussion and in-class exercises. Attendance is expected and makes up a portion of your grade.

I encourage questions and discussion during class time. A part of your grade will be based on participation.

Readings

I will post my lecture notes before each class, along with some instructions for which parts you should read before lecture. I will try to keep the pre-class reading brief, so that you can do it in a reasonable amount of time (15 minutes), but you are of course welcome to read the entire notes before class.

There is no required textbook, but there are two that I recommend:

1. *Statistical Mechanics: Entropy, Order Parameters and Complexity*, 2nd edition (2021) by James P. Sethna. The author has also made a pdf version available on his website.
2. Yeomans, J. M., *Statistical mechanics of phase transitions*.

Both texts should be available at the COOP.

Several other texts are on reserve at the library. Ones that you may find useful include

- Cardy, John L., *Scaling and renormalization in statistical physics*. My lectures on phase transitions at the end of the course will draw on the approaches of Cardy (this book) and Yeomans.
- Chandler, David, *Introduction to modern statistical mechanics*. A clear and concise graduate-level text, though not as pedagogical as Sethna.
- Schroeder, Daniel V., *An introduction to thermal physics*. Probably the best undergraduate-level text. Useful as background reading or as a refresher on thermodynamics.

Sections

I will usually lecture on Mondays and Wednesdays. Fridays are reserved for section, with a couple of exceptions (these will be announced). The goals of sections are to

1. review the concepts introduced in the lectures on Monday and Wednesday
2. show how to apply those concepts to solve problems
3. discuss the broader relevance of the concepts in current research

The TF will lead the section. In the problem-solving part of the section, you will be asked to work with your classmates on problems. The TF will then explain how they would approach solving these problems. Sections are the bridge between skill 1 (understanding) and higher-level skills (applying, explaining, and interpreting).

Homeworks

Homeworks will be assigned weekly on Wednesday and will be due the following Wednesday at 11:59 PM. We have a policy that encourages you to try your own ways of answering the questions and then reflecting on your answers. See below for details of the policy.

Most of each homework assignment will consist of problems. It's through doing the problems that you will learn how to apply statistical mechanics to different systems. You'll need to work together with your peers to understand the questions and the physical consequences of the results you derive.

Homeworks also include literature assignments, which involve reading a research article and answering questions about it. Make sure to set aside time to read the articles. The assignments will expose you to the course material in a research context and will encourage you to explain and interpret the material.

Assessments

There will be a midterm and final assessment. The assessments are projects that will consist of engaging with recent research involving statistical mechanics. You will read and understand papers, explain the research in terms of course concepts, and interpret and critique the results, and suggest further directions for research. Details of the assessments will follow, but you should expect them to include presentations and question/answer sessions. These assessments are meant to build and test the higher-level skills listed above (primarily explanation, interpretation, and critique).

Policies

There are a couple of principles that guide the course policies:

1. I assume you want to learn the material. So even though there are many ways to potentially save yourself time on the assignments (like using AI tools to solve the problems), you realize that such approaches won't help you learn the material and achieve the skills listed above.
2. Optimal learning requires a mix of individual and group work. Thinking about and occasionally even struggling with concepts and problems on your own is part of the learning process. The homework policy is designed to encourage you to try things on your own, without penalties for making mistakes. It's important to remember, though, that a lot of learning takes place in discussions with others. That's why we do group exercises in lectures and section, and why I encourage you to discuss the problems in the homework with your peers (and to find a study group as soon as you can!).

Grading

Homeworks will count toward approximately 40% of your grade, the midterm assessment 20%, final assessment 35%, and participation 5%.

Homework policy

Homeworks must be submitted electronically as PDF files. If you need to scan, please remember that all of the SEAS and Physics department printers have scanning functionality and document feeders. Please make sure the text is legible, both before and after you scan.

Our method of grading homeworks does not penalize you for making mistakes or having misconceptions, which are a natural part of the learning process. We will give you the opportunity to correct and resubmit your homework (for full credit) after solutions have been distributed.

To take advantage of this opportunity you must turn in a complete assignment *before solutions are distributed.* "Complete" means that you have made a reasonable attempt *on all of the problems:* for each problem you have stated all assumptions, shown all your steps, and made your reasoning clear in both words and equations. Your answer might turn out to be incorrect, but by making a complete attempt you will be in a good position to figure out where you went wrong. Make sure to take advantage of office hours so that you can turn in a complete attempt.

After you turn in your homework, we will look at it, and if you have turned in a complete attempt at all the problems, we will let you know that your assignment is eligible for you to correct and resubmit. We will distribute solution sets, which you are encouraged to look at and study before you resubmit.

You may then, using a different color, correct your own assignment, explaining clearly where you went wrong (if anywhere) and what your misconception or mistake was, then showing how to get the correct result. We will grade this corrected, resubmitted assignment.

You may of course choose not to resubmit, in which case we will grade your original submission.

Collaboration and academic integrity policy

You are encouraged to discuss the homework problems with your classmates, but your initial and final submissions must be your own work. On each homework you must state the names of the people you worked with and list all the sources you used. For the midsemester and final assessments, you will be working in teams. For these assessments, your submissions must be the work of your team only. Each student in the team takes responsibility for the submitted work. Therefore it is important to work together at each stage of the assessment. Note that any violations of academic integrity (such as plagiarism) will reflect on the entire team.

Please review the GSAS Handbook (https://gsas.harvard.edu/policy/academic-integrity) for general information on academic integrity. Harvard takes academic integrity seriously, and any violations will be referred to GSAS (for graduate students) or the Harvard College Honor Council (for undergraduates).

Policy on generative artificial intelligence

The most common generative AI tools, such as ChatGPT, can complete steps of assignments youâ€™ll be doing in this course, though likely with mistakes. The policy for using those tools is as follows:

Homework assignments: While you may use ChatGPT or other generative artificial intelligence (AI) tools to help you understand concepts presented in the lectures and sections, you *may not* use ChatGPT or any other generative AI tools to solve problems in the homeworks. The homeworks are structured so that you learn by trying problems yourself, making mistakes, and correcting them. The use of generative AI short-circuits this learning process.

Midterm and final assessments: While you may use generative AI tools to help you understand the concepts presented in the articles and texts you will review in the assessments, you *may not* use generative AI to prepare presentations, papers, or any other submitted work. The midterm and final assessments are designed to test your ability to relate course concepts to research. This is a core learning objective of the course, and the use of generative AI will hinder your progress toward this objective (and will likely also give you incorrect results).

Any use of generative AI tools must be appropriately acknowledged and cited. Violations of this policy will be considered academic misconduct. Note that different courses at Harvard may have different AI policies, and it is your responsibility to conform to expectations for each course.

Asking for help: Office hours and Slack

The teaching staff is here to help! We have office hours, and we monitor the Slack workspace for questions. Please post questions about lecture material or homework problems in one of the public Slack channels (we will set up a separate channel for each homework) rather than direct messaging, since other students may have the same question.

Accommodations for students with disabilities

Students needing academic adjustments or accommodations because of a documented disability must present their Faculty Letter from the Disability Access Office (DAO) and speak with the professor by the end of the second week of the term. Failure to do so may result in the Course Head's inability to respond in a timely manner. All discussions will remain confidential, although faculty are invited to contact DAO to discuss appropriate implementation.

Use of course materials

Unless otherwise marked, all materials in this course are protected by U.S. copyright law [17 U.S.C. Â§ 102]. Materials presented in an educational context are for personal use and study and should not be shared, distributed, or sold digitally or in print outside the course without written permission.

In plain language: you are not allowed to upload course materials such as lecture notes, solution sets, or assignments to public websites such as Course Hero or Chegg unless the material explicitly grants you permission to do so.