# PHYS 8310 – Statistical Mechanics

Instructor: Cass Sackett
Office: PLSB 104
email: sackett@virginia.edu
Phone: 924-6795

Meeting time: TR 11:00-12:15
Room: Physics TBD
Course website: www.virginia.edu/tbd
Office hours: Thursday 8-9 PM, Physics 219

On September 12, 2012, *The Economist* magazine ran an article about the conflict in Syria under the headline: "Rebel forces: Entropy increasing." Suppose your grandmother saw this and called you up to ask what entropy meant. (Assume this is your artistic grandmother, not your other grandmother with the PhD in engineering.) Could you give her an answer that would satisfy her? If your research advisor happened to be eavesdropping, would it satisfy her as well?

Obviously *The Economist* is using a metaphor here, and it is a common one. But the metaphor only works because entropy really means something, and explaining this meaning in a way that is both simple and correct requires more than just a cursory understanding. In fact, entropy is one of the central concepts in the theory of statistical mechanics, and a solid grasp of that theory is useful for much more than satisfying your grandmother's curiosity. The tools of statistical mechanics are widely used in *every* branch of physics research, and they underpin a vast amount of science outside of physics as well. The fact that the subject is covered on the department's PhD qualifier exam reflects this importance. In this course you will master the tools of statistical mechanics by developing a clear conceptual framework for the subject and applying it in practical problem-solving techniques.

However, the PhD degree is not only an affirmation of your abilities as a researcher, but also a certification of your competence to teach physics (to your grandmother or anyone else). This course will help prepare you for teaching by modeling a variety of learner-centered teaching methods and providing opportunities to reflect on their effectiveness. You will find that this reflection is not only useful for your development as a teacher, but that it will significantly improve your own understanding of the subject.

**Prerequisites**

You are expected to have completed an upper-division undergraduate class in statistical mechanics or thermal physics. (An advanced course in physical chemistry would likely suffice as well.) You are not necessarily expected to have mastered all of the material covered in that course, but if you feel your preparation was particularly weak, you should consult with the instructor about your concerns.

You should also be very comfortable with quantum mechanics at the level of a good upper-division undergraduate course. The mathematics required is technically only multivariable calculus, but a very high level of proficiency at calculus will be needed.

**Course objectives**

Both research and teaching involving statistical mechanics requires a thorough mastery of the subject. This is a challenging goal, but it can be broken down into a set of concrete objectives. By the end of this course, you will be able to:

- Define, explain, and relate the key concepts of statistical mechanics
- Use the tools of statistical mechanics to solve challenging and unfamiliar problems
- Consciously apply effective problem-solving and test-taking skills
- Relate statistical mechanics to practical applications in physics and beyond
- Recognize and appreciate active-learning and group-learning techniques in teaching

**Meeting the objectives**

We will use a range of techniques to assess your progress toward these goals. Feedback will be derived from variety of sources, including the instructor, your peers, and yourself.

*Problem assignments* (30%):

You will have weekly assignments of challenging problems to solve. These assignments will reinforce your conceptual understanding of statistical mechanics and hone your problem solving skills. Some assignments will require using a computer for numerical tasks. You will work on problem assignments in collaboration with a study group, and in many cases a structured approach will be provided for you to use and assess. Further information on the problem assignments can be found below.

*Journal* (15%):

Each week, you will prepare a short journal entry either reflecting on your learning process or exploring how the topics covered in class relate to broader science or society. A set of prompts will be provided to which you can respond, or you may choose a subject of your own. These assignments will allow you to step back and engage in the course material as a scientist, as a teacher, and as a self-directed learner. Further information on the journal can be found below.

*Course Engagement* (25%):

Education research shows conclusively that you can learn effectively only when you are actively engaged in the learning process. One aim of the course is to model a class format encouraging engagement, so many opportunities will be provided including pre-class preparation, in-class activities, and post-class reflections. Your engagement with your study group will also contribute, as evidenced by your group's overall performance on the assignments and exams. Further details can be found below.

*Examinations* (30%):

The course will feature two midterms and a final exam. The exams will use a format similar to the PhD qualifier exam.

**Grading Scale**

The course will use a fixed grading scale:

| | |
|---|---|
| 90-100 | A |
| 85-90 | A- |
| 80-85 | B+ |
| 75-80 | B |
| 70-75 | B- |
| <70 | C |

In corner cases, your total score will be rounded up to the nearest 0.1%.

**Class activities**

The course will use a mixture of different class activities, including lectures, discussion, short quizzes, conceptual exercises, and group problem solving. In some cases, preparatory work will be assigned to do before class, and/or reflective work after class. Attending class each day is essential for benefitting from these activities.

**Study Groups**

A central component of this class will be your study group, which is a team of four to five students who will work together to teach and learn from one another. Study groups will be assigned, and you will rotate through three different groups over the semester. Research confirms what you have likely experienced, that peer instruction can be a very effective learning strategy. You also learn more by helping your peers than you do by working individually. You and your team will work together on homework assignments and in-class activities, and your group's overall performance is part of how your course engagement will be evaluated. Study groups will be assigned, and you will rotate through three different groups over the semester.

**Office Hours**

Rather than using the conventional office-hours format, I will hold an optional weekly problem session on Thursday evenings from 8 to 9 PM. I will not prepare material for this session, but I will bring some interesting-looking problems for us to work through together. You are welcome to bring problems as well. As I won't know the solutions ahead of time, we will approach these problems as peers, which is usually educational for everyone involved.

If you want help with the homework or the regular class material, email me and schedule an appointment at a convenient time. You are also welcome to set up an individual weekly appointment time that fits your schedule.

**Time Management**

The course is structured to require no more than eight hours per week of effort outside of class. Techniques for managing your time will be discussed, but if you find yourself continually exceeding this level of effort, you should consult with your instructor.

**Academic Integrity**

Effective learning requires a balance between individual and collaborative efforts. On any given homework assignment, clear guidance will be provided about which tasks you need to do on your own and which should be done in collaboration with your study group. Similarly, assignments will indicate what type of outside resources you may use. Violating these guidelines would be doing yourself a disservice, and result in no credit being awarded on the assignment. Failure to follow stated guidelines on an exam would be grounds for referral to the Honor Council.

## Problem Assignments

Typically, a problem assignment will involve three phases of effort:

- In the first phase, you will attempt to solve the problem on your own, often using a structured approach defined in the assignment.
- In the second phase, your study group will meet, compare individual efforts, and come to agreement on a collaborative solution.
- In the third phase, you will individually revise your work to reflect the group's input. If you realize that you remain confused about an issue, you are welcome to consult again with your group members, but the explicit point here is to avoid simply copying a group member's solution; if you are unable to reconstruct the solution for yourself, then you have not learned how to solve the problem.

For each phase, a time limit will be suggested and you will document the actual amount of time you spend. You will also document your impression of the relative contribution each member (including yourself) made to the group solution, as a percentile score. These scores are used to help evaluate your course engagement.

All assignments will be graded. If you are not satisfied with your result, you may revise the assignment for half credit. For example, if you initially score a 2 and revise it to a 5, your final score will be 2 plus half of (5-2), or 3.5. The instructor's solutions will not be posted until after revised problems are due, but you are welcome to consult with your group or other class members during revision.

*Deadlines*: Assignments are due at the start of class each Tuesday. Late assignments will be accepted up to one week past the due date, but with a one-point penalty per problem regardless of the reason the assignment is late. Revised assignments must be received within one week of the graded assignment's return.

*Grading rubric*: Homework and exam problems will typically be evaluated with the following rubric. Exceptions will be noted when they occur.

| Score | Description |
|---|---|
| 0 | No attempt to solve problem |
| 1 | Recognition of the topic, but no clear description of the correct principles required |
| 2 | Identification of the principles required, but little or no execution |
| 3 | Proper application of principles, but substantial errors in execution;<br>Plausible misidentification of principles, executed with consistency |
| 4 | Proper principles and execution, but errors leading to implausible result |
| 5 | Proper principles and execution, no significant errors<br>Proper principles and execution, minor errors in execution leading to plausible result |

Here the *principles required* are the key concepts and equations that are needed for a correct solution. A plausible misidentification of principles occurs when you fail to identify the correct principles, but take an approach that could seem, on its face, to lead to the correct solution. *Execution* encompasses the mathematical manipulations required to achieve the desired results, both straightforward computations (*ie*, evaluating an integral) and less straightforward tricks (*ie*, using integration by parts to convert an integral to a more useful form). An *implausible result* is one with the wrong units, wrong limiting behavior, or clearly unrealistic numerical value.

## Journal

Each week, you will write and electronically submit a journal entry in response to a prompt. A set of prompts is listed below, and further prompts may be added during the semester. Occasionally I may require a particular prompt for a given week, but otherwise you may select a prompt of your choice. Over the course of the semester (16 weeks), you must address at least 10 different prompts from the list; the remaining entries may duplicate prompts or use a prompt of your own devising. (If I like your prompt and add it to the list, then your entry will count as one of the 10 required responses!)

**Prompts**:

- Describe a connection between the course material and a colloquium or seminar you saw this week
- Describe a connection between the course material and a research topic in the Physics department
- Describe a connection between the course material and a research topic in a UVa department other than Physics.
- Describe a connection between the course material and a popular news report
- Describe something new you learned from a homework assignment
- Describe a course topic you understand now that was previously confusing
- Describe something you did not understand in a homework assignment
- Describe something you did not understand in a lecture
- Describe something that someone in your study group explained to you
- Describe something that you explained to someone in your study group
- Describe an in-class activity that you found effective
- Describe an in-class activity that you found ineffective
- Propose a problem for a test and explain why it is a good one
- Assess your own performance on a homework problem
- How would you explain entropy and its importance to your grandmother?

Your journal entry should clearly identify the prompt you are responding to.

*Format*: Each entry should be at least 200 words long (not including the prompt), and use proper grammar and spelling.

*Deadlines*: Journal entries are due every Monday at 6:00 AM. Late entries will be instead applied to the following week.

*Evaluation*: For each entry, points are awarded as follows:

3 points: entry addresses a suitable prompt
1 point: entry has sufficient length
1 point: entry uses correct spelling and grammar

Beyond this, the content of the entry is up to you, but plainly frivolous entries will not receive credit.

## Course Engagement

Your engagement in the course counts for 25% of your final grade. This will be evaluated in four areas:

*Pre-class and post-class assignments* (5%): On some days, you will be given short assignments to complete before or after a class. These will typically be designed to assess and let you reflect on your conceptual understanding. Where needed, evaluation rubrics will be provided with the assignment. As this material will be closely tied to a particular class, late assignments will not be accepted.

*In-class activities* (5%): When you participate in class activities, you will receive credit for course engagement. In most cases, this will be based simply on whether you were present and participating, but some activities may involve more detailed evaluation.

*Study group performance* (10%): You should be engaged and invested in the learning performance of your fellow group members. To reflect this, you will receive engagement credit proportional to the average scores for your group on each homework assignment and exam. Half of this credit (5%) will be based on homework assignments, and half (5%) on exams.

*Group contributions* (5%): Your study group contributions will be peer and self-assessed on each homework assignment. For each problem, contribution score will be rated out of five points. Two points are awarded for completing your assessment, and the remaining three points are scored based on the average of your peers' report of your contribution:

- 1 point – contribution below 10%
- 2 points – contribution between 10% and 20%
- 3 points – contribution 20% or more

## Examinations

The midterm and final examinations will be held in class

| | |
|---|---|
| Midterm 1: | Tuesday, February X |
| Midterm 2: | Tuesday, March Y |
| Final: | May Z, 9 AM to noon |

Like the PhD qualifier, these exams will consist of complex problems similar to those in the qualifier study guide. You will have about 45 minutes per problem. The exams will be closed-book, but you may refer to an approved table of mathematical formulas. Unlike the qualifier, you will have the opportunity to revisit the problems on your midterm exams as those weeks' homework assignment.

The exams will be graded using the same rubric used for homework assignments.

**Activity Ideas**

*Lectures*: Some prerecorded lecture bites for students to watch online. Pre-class test focusing on concepts introduced in lecture.

*Discussion*: Discuss lectures and pre-class quiz. Revisit issues students were confused by, and discuss further questions. Bring out connections to research topics and general science.

*TAPPS*: Pairs or triplets of students, one works through a relatively straightforward problem, speaking out loud. Other student listens and comments (but doesn't actually provide solutions). Alternate roles. Give listener correct final answer, so they know when they are right. Review problems at end of class.

*Identify the principle*: Give group a set of questions, have them identify the principles likely to be involved in their solution. Need a list of principles for this to work? These problems could be narrow or broad, and draw from physics and other disciplines.

*Structured problem solving*: Give group a more challenging problem with a set of prompting questions to guide them to a solution.

*Derive a structure*: Give group a challenging problem and my solution. Have them work out a set of prompts that would guide a student to a solution.

*Send a problem*: Groups rotate through a set of problems. The final group synthesizes everyone's solutions, gives the best answer, and discusses common pitfalls. Have some bonus problems for groups to work on if they finish early.

*Concept map*: prepare a concept map for a unit. Start with individual efforts, have group discuss and put together a collaborative map. Do this towards end of each unit.