PHYS 449 - Statistical Mechanics I
Course Outline

There is no official textbook for this course.

Suggested References:

- ‘An Introduction to Thermal Physics,’ by Daniel V. Schroeder: this was the textbook a couple of years ago, and the course notes are loosely based on this. You should be able to find copies around. It is also only $61.84 at amazon.ca.

- ‘Introductory Statistical Mechanics’ by Roger Bowley and Marianna Sanchez: this was the textbook longer ago, so you might be able to find copies of this around also.

- ‘Statistical Mechanics: A Survival Guide,’ by Mike Glazer and Justin Wark: This is a bare-bones textbook, only the essentials! It’s cheap (fifty bucks or so) and less than a hundred pages in large type.

- ‘Fundamentals of Statistical and Thermal Physics,’ by F. Reif: this is the ‘moldery oldie,’ the book that many departments use because nothing really good has been written since it was published in 1965. So this is a good general reference. Regular thermodynamics and statistical mechanics don’t really go out of date, though somehow it manages. It is listed at $100.93 on amazon.ca. Unless you can read german - the german version is only $58.74.

- ‘Entropy, Order Parameters, and Complexity,’ by James P. Sethna. This is totally based on computer simulations, and isn’t really a textbook in the traditional sense. It is very cool, but ever so slightly advanced for undergrads. Grab this if you become bored with the regular material!

The main point of this course is to bridge the gap between the physics of the olden days (thermodynamics, the study of very large things) and that of these days (quantum mechanics, the study of very small things). The topic might seem a bit out of place at first glance, because it doesn’t seem to follow naturally from many of the courses you’ve been studying so far, like classical mechanics, electricity & magnetism, optics, electronics, quantum mechanics, etc. In fact this is a subject that includes and spans all of these disciplines, and many of the things you’ll learn are the first things you actually apply as a working physicist in the ‘real world.’ So it’s practical. But it’s also a different way of thinking about the natural world that cuts to the very heart of how we interpret nature. In the process, we’ll uncover a few bizarre theories widely accepted today that I think will surprise you.

This Statistical Mechanics course includes the material in the Thermodynamics course that used to be offered separately. In fact, there are many common points of overlap between these two topics, and a few years ago the department decided to merge them. Thermodynamics is much older (starting mid-17th century or so, coinciding with the industrial revolution), and was originally developed to explain the macroscopic properties of classical gases and liquids, and how engines work. It is primarily a mathematical description of extensive experimental observations. But it doesn’t explain why things are the way they are. For this one needs statistical mechanics, which was developed much later (late 19th century onward). It generalizes the behaviour of a single particle to the many many particles that exist in real systems. In fact, statistical mechanics was developed even before
its foundations were justified, particularly the idea of particles and quantum mechanics. For this reason it was given a pretty rough ride at the time. These days, physicists don’t really make any distinction between the two disciplines, using insights and applying ‘tricks’ from one or the other whenever suitable.

So instead of giving you a blow-by-blow historical treatment of both areas, I will start with some thermodynamics for the purposes of motivation, then talk about statistical mechanics a while, then return to thermodynamics, etc. So the flow will be more about uncovering the ideas and facts related to these disciplines, from the modern point of view. I’ll need to introduce some basics from quantum mechanics to do things properly, but I will make sure to keep things simple. The purpose of this first course in Statistical Mechanics is to introduce you to the main ideas and formalism, and to discuss both the foundations of the discipline as well as their practical implementations. By the end of this course, you will have learned a bit about some deep concepts like entanglement & the arrow of time, and also will have a better understanding of how engines work! In PHYS 451 we explore more realistic systems and also consider how quantum mechanics enters our classical world. But that’s another course....

We’ll be roughly following the textbook by Schroeder, Chapters 1-6, and doing something like one chapter every two weeks. But I am covering lots of other material as well, so I have written up some pretty extensive class notes. These are on the course website http://people.ucalgary.ca/~dfeder. It is these that I’ll be following closely. I encourage you to print these out and to bring them to class, to be annotated with things that I say or maybe change. For this purpose you might consider printing them out one-sided and putting them in a binder, so that you can add comments on the blank page just to the left. Whenever I supplement this material with stuff from other sources, I’ll be sure to hand out any additional reading. Most likely, I’ll post the material to the course website.

Speaking of the website, I will post all new assignments on the website as soon as I hand them out. Likewise for the solutions to the assignments. I will hand out an assignment approximately once every week and a half, so you can expect something like eight assignments for the term, four in the first half and four in the second.
Here’s the breakdown of the material. This table of contents is pulled directly from the course notes.

1. **Energy in Thermal Physics (First Law of Thermodynamics)**
   
   (a) Thermal Equilibrium
   (b) The Ideal Gas
   (c) Thermodynamic Derivation
   (d) Mechanical Derivation
   (e) Equipartition of Energy
   (f) Heat and Work
   (g) Compression Work: the Adiabat
   (h) Heat Capacity

   
   (a) Two-State Systems (aka Flipping Coins)
      
      i. Lots and lots of trial
      ii. Digression: Statistics
   (b) Flow toward equilibrium
   (c) Large Systems
      
      i. Discrete Random Walks
      ii. Continuous Random Walks
      iii. Quantum Walks and Quantum Computation
   (d) Entropy
      
      i. Boltzmann
      ii. Shannon Entropy
      iii. von Neumann Entropy

3. **Equilibrium**
   
   (a) Temperature
   (b) Entropy, Heat, and Work
      
      i. Thermodynamic Approach
      ii. Statistical Approach
   (c) Paramagnetism
   (d) Mechanical Equilibrium and Pressure
   (e) Diffusive Equilibrium and Chemical Potential

**Midterm Examination**
4. **Engines and Refrigerators**
   (a) Heat Engines
   (b) Refrigerators
   (c) Real Heat Engines
      i. Stirling Engine
      ii. Steam Engine
      iii. Internal Combustion Engine
   (d) Real Refrigerators
      i. Home Fridges
      ii. Liquefaction of Gases and Going to Absolute Zero

5. **Free Energy and Chemical Thermodynamics**
   (a) Free Energy as Work
      i. Independent variables $S$ and $V$
      ii. Independent variables $S$ and $P$
      iii. Independent variables $T$ and $V$
      iv. Independent variables $T$ and $P$
      v. Connection to Work
      vi. Varying particle number
   (b) Free Energy as Force toward Equilibrium

6. **Boltzmann Statistics (aka The Canonical Ensemble)**
   (a) The Boltzmann Factor
   (b) $Z$ and the Calculation of Anything
      i. Example: Pauli Paramagnet Again!
      ii. Example: Particle in a Box (1D)
      iii. Example: Particle in a Box (3D)
      iv. Example: Harmonic Oscillator (1D)
      v. Example: Harmonic Oscillator (3D)
      vi. Example: The rotor
   (c) The Equipartition Theorem (reprise)
      i. Density of States
   (d) The Maxwell Speed Distribution
      i. Interlude on Averages
      ii. Molecular Beams
   (e) Gibbs’ Paradox

7. **Grand Canonical Ensemble (time permitting)**
   (a) Chemical Potential Again
   (b) Grand Partition Function
   (c) Grand Potential

**Final Examination**
Grading Philosophy and Scheme

Because I try to encourage participation as much as possible, I have put a heavier accent on assignments and previews than is maybe customary. Each week, students will be expected to write a preview of at most one page each. These will summarize the main conceptual points to be covered in the next week. The emphasis is on understanding rather than on the formalism, so mathematics should be avoided unless absolutely required. **Marks will be deducted for unnecessary use of mathematics!** The reviews are to be submitted at the beginning of the first lecture of each week, and no late reviews will be accepted. These don’t have to be long, often a paragraph or two does the trick. I have never liked exams much so if people would like to have a take-home exam for the midterm instead, that’s fine with me – let’s work it out together.

The final exam will only explicitly test material from the second-half of the course (i.e. the material not explicitly covered in the midterm). That said, you can’t forget what you learned in the first half, because the second-half material builds on it. For this reason I have chosen to weight the midterm and final equally. But I have a long-standing policy of wiggling here: for your final grade I will take the best result of a 20-30, 25-25, or 30-20 split between the midterm and final grades. Other than this, I **do no further manipulations of the grades.**

To help figure out where you stand during the course of the semester, here is the grading scheme I use for all my courses. It might look tough, but I tend to mark easy! Keep this in mind as you progress through the course so that you always know what your current letter grade is.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>94+</td>
<td>A+</td>
</tr>
<tr>
<td>90+</td>
<td>A</td>
</tr>
<tr>
<td>86+</td>
<td>A-</td>
</tr>
<tr>
<td>82+</td>
<td>B+</td>
</tr>
<tr>
<td>78+</td>
<td>B</td>
</tr>
<tr>
<td>74+</td>
<td>B-</td>
</tr>
<tr>
<td>70+</td>
<td>C+</td>
</tr>
<tr>
<td>66+</td>
<td>C</td>
</tr>
<tr>
<td>62+</td>
<td>C-</td>
</tr>
<tr>
<td>58+</td>
<td>D+</td>
</tr>
<tr>
<td>54+</td>
<td>D</td>
</tr>
<tr>
<td>54-</td>
<td>F</td>
</tr>
</tbody>
</table>