

# PHYS 324 – Thermodynamics of Materials

Dr. Christopher Moore

## 1 Course Description

In this course we will study the thermal properties of matter, phenomena involved in the flow of heat, and physical manifestations of work. These topics will be covered empirically and via the kinetic theory and statistical mechanics. Emphasis will be placed on applications with materials, specifically crystal structures.

### 1.1 Contact Information

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### 1.2 Texts

Enrico Fermi, *Thermodynamics*

Kenneth Denbigh, *The Principles of Chemical Equilibrium*, 4th edition

Thom Espinola, *Introduction to Thermophysics*, out-of-print (will be provided to students)

## 2 Course Objectives

Upon successful completion of this course, you will:

1. Understand how to define a thermodynamic system and its state;
2. apply the fundamental laws of thermodynamics to these systems;
3. understand thermodynamic potentials and their uses;
4. have a working knowledge of statistical methods, specifically partition functions; and
5. be able to apply these statistical methods to gas and solid crystal systems.

## 3 About Thermodynamics

Thermodynamics is about developing a rigorous understanding of natural processes, which may seem tedious. The useful applications don't begin until a solid foundation is developed. Most of you would probably rather learn about quantum teleportation, or cosmology, or whatever you kids are into these days. However, you will find that in order to speak intelligently about any area of physical existence, a solid understanding of how systems interact is necessary. That is what we will learn in this course: how systems interact.

Much of what you will learn as a scientist or engineer will rely on your comprehension of thermodynamics. Unfortunately, most of you do not yet know about all the wonderful things you are going to learn and how they depend on this course. So, there will be times when you will be struggling to learn something without knowing why you should bother to learn it. It will become clear later in your career. I was where you sit once and I was honest not much of a thermo-fan when I took this course as an undergraduate. However, I now truly like thermodynamics. I can appreciate its elegance and beauty because I have seen exactly how useful it is. It takes many years to master this subject, so I do not expect you to do so in one semester. However, I do expect you to be able to intelligently speak about the subject and fulfill the objective outlined above.

A thorough understanding of thermodynamics—especially the second law—separates qualified scientists from amateurs and pretenders. (You know who I'm talking about when I say pretenders: just about everyone that writes anything on the internet.)

*“The law that entropy always increases—the second law of thermodynamics—holds I think, the supreme position among the laws of Nature. If someone points out to you that your pet theory of the universe is in disagreement with Maxwell's equations, then so much worse for Maxwell's equations. If it is found to be contradicted by observation, well these experimentalists do bungle things sometimes. But if your theory is found to be against the second law of Thermodynamics, I*

*can give you no hope; there is nothing for it but to collapse in deepest humiliation."*

- Sir A.S. Eddington.

*"Lisa, get in here. In this house we obey the laws of thermodynamics!"*

- Homer Simpson.

## 4 Grading

Grades will be assigned according to the following scale:

- A 90 – 100 exceptional work, significantly above the expectations of the course
- B 80 – 89 excellent work, solid understanding of all concepts
- C 70 – 79 good work, solid understanding of main concepts
- D 60 – 69 poor work, weak understanding of main concepts

Assessments are weighted as follows:

- Class participation 10%
- Homework 20%
- Exams 40%
- Final Exam 30%

### 4.1 Class Participation

A quantitative measure of class participation will be assigned as follows:

We meet 52 days this semester. You will receive 2 points per day for each day you completely satisfy the participation requirement, 1 point for each day you partially satisfy the requirement, and 0 points for each day you do not satisfy any requirements for participation. Points will be assigned as follows:

Full credit (2 points): attend, attentive, at least one question or one insightful comment. Partial credit (1 point): attend, attentive. No credit (0 points): did not attend or attended but remained asleep or otherwise non-attentive.

You will lose 1 point for each day that you are late to class subtracted after earned points. This means if you are late and contribute nothing during class, you will receive 0 points for the day. If you are late and sleep during class

then you will receive -1 points for the day. DO NOT be late!

You will accumulate points throughout the year. Your final participation grade (10% of the entire course grade) will be calculated by taking your total number of points and dividing by 100. There is a maximum available 104 points. Therefore, you may skip or sleep during class two days without a direct penalty, or you may sit back and merely listen for four days without direct penalty.

### 4.2 Homework

Homework assignments will be posted almost every Friday and will be due the Monday of the following week at 5 pm (i.e., you will have about 10 days to complete each homework, although on three of those days you will have two different assignments.)

You are encouraged to work in groups and turn in a single homework for the entire group. Group homework will receive a 5% bonus score. In other words, if the homework score is 62, then everyone in the group will receive a 65.  $[(62 \cdot 0.05) + 62 = 65]$ . I hope that you will use the group homework as a vehicle for cooperative teaching and learning as well as a time-saving device. Regarding the group homework, some students fall into a trap of letting other members of their group do the hard intellectual work and think that they can catch up in time to take the exams. Of course, this is not only a mistake and not an effective way to learn, it is also bad manners. If you try this strategy, I assure you that it (and you) will fail.

If you choose to work in a group, it is each group member's responsibility that the group's homework is turned in on time.

You will be allowed one and only one late homework. No exceptions.

After your homework is graded, you will have the opportunity to re-do homework problems where you lost points for half the credit. This is my little incentive to get you to not only look at the solutions posted online, but work through them.

### 4.3 Exams

Four exams will be given, three during the semester and a final during the scheduled time for this course. The final will be cumulative.

## 5 Honor Code

The Honor Code has four basic provisions that strictly prohibit lying, cheating, stealing and plagiarism. These provisions are standards of integrity and are moral obligations that you are expected to keep in this course. There will be a lot of group work during this course; however, the exams are to be completed independently. Working together on all other assignments is encouraged.

## 6 Schedule

Thermodynamic variables

State variables and functions

Thermodynamic systems and processes

Energy and work

Properties of materials

Stored energy in solids, 1st Law for fluids

Quasi-static processes

Heat capacities and gaseous behavior

Internal energy and enthalpy for fluids

Thermo functions for general systems

EXAM 1

The second law

Heat stored during phase changes

Using Maxima to plot curves

Gibbs free energy

Entropy content in materials

Stable Phases of H<sub>2</sub>O w/ Maxima

Equilibrium thermodynamics

Potential to add chemical species

Chemical potential and equilibrium

Equilibrium reactions and constant

Maxwell's relations

EXAM 2

Stat. mech. and phase space

Equilibrium

Equilibrium and a magnetic material

Flipping coins and rolling dice

Microcanonical ensemble and DOS

Entropy, temperature and pressure

An ideal monatomic gas

Canonical ensemble and partition function

Canonical ensemble, heat and work

Thermodynamics of the partition function

The ideal gas, again!

Grand canonical ensemble

Thermo of the grand canonical ensemble

The ideal gas, yet again!

EXAM 3

Fermions, bosons, and classical particles

Maxwell-Boltzmann statistics

Fermi-Dirac statistics

Example: electrons in metals

Bose-Einstein condensates (fun)

Applications: gases

Applications: solids