

Syllabus and Topics

33-341 Thermal Physics I

Fall 2007

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Class Schedule:

This class is scheduled to meet MTWF 1:30 - 2:20 and carries a credit of 10.0 units. MWF meetings are in PH A18A. T classes (usually recitations) are in HH B131. There are a total of 56 classes scheduled for the semester. The last class is on Friday, December 7. The current enrollment is 33 students. Class attendance is important and correlates strongly with grades.

University Holidays:

Labor Day Monday September 3

Mid Semester Break Friday October 19

Thanksgiving Break Wednesday November 21 - Friday November 23

Exams and Grades:

There will be three in-class exams (15% each) and a three hour final exam (35%). Homework will count 20%. Each homework problem will be graded on a deliberately coarse scale, 0,1,2 or 3. Homework answers will be posted on the course web site after each due date. **Late homework will not be accepted!**

Tentative Exam Dates:

First Exam Monday September 24 (16th class)

Second Exam Wednesday October 17 (30th class)

Third Exam Monday November 19 (47th class)

Final Exam The final exam will be scheduled by the registrar on one of the following dates: December 10-11, 13-14, 17-18

Venue The first three exams will be held in the evenings from 6-8 PM in rooms to be announced.

Texts:

The main text for this course is my draft book *Thermostatistical Physics*, available as a pdf on the course web site. This is a work in progress and will change as the semester progresses. Other textbooks (available at the bookstore) are:

C Recommended text: Herbert B. Callen, *Thermodynamics and an Introduction to Thermostatistics*, (Second edition, John Wiley & Sons, New York, 1985) ISBN 0-471-86256-8

F Recommended text: Enrico Fermi, *Thermodynamics* (Dover edition, New York, 1956) ISBN 0486-60361-X

Other Books:

Textbooks used in previous years:

KK Charles Kittel and Herbert Kroemer, *Thermal Physics* (W.H. Freeman, New York 1980) ISBN 0-7167-1088-9 (second edition)

DC David Chandler, *Introduction to Modern Statistical Mechanics* (Oxford University Press, New York 1987) ISBN 0-19-504277-8 (pbk.)

Reserve The above books and other recommended books are on reserve in the E&S Library.

Course Objective

The objective of this course is to develop a working knowledge of the laws and methods of thermodynamics and elementary statistical mechanics and to use this knowledge to explore various applications. Many of these applications will relate to topics in materials science and the physics of condensed matter.

Catalog Description

The three laws of classical thermodynamics, which deal with the existence of state functions for energy and entropy, and the value of entropy at the absolute zero of temperature, are developed along phenomenological lines. These laws are applied to deduce relationships among heat capacities and other thermodynamic quantities by means of Maxwell

relations. The thermodynamic laws are generalized to open systems and various auxiliary thermodynamic potentials, such as enthalpy, Helmholtz free energy and Gibbs free energy are introduced via Legendre transformations. The foundations of modern statistical mechanics are presented in the context of the microcanonical ensemble and used to understand the interpretation of entropy in terms of probability. Then the canonical ensemble is introduced and used and to calculate some thermodynamic quantities from simple models. Criteria for equilibrium of multicomponent systems are developed and applied to phase transformations and chemical reactions. Models of solutions are obtained by using statistical mechanics and applied to deduce simple phase diagrams for ideal and regular solutions. The concept of thermodynamic stability is introduced and illustrated in the context of phase transformations.

Prerequisites:

33-111 Physics for Science Students or 33-106 Physics for Engineering Students I, 21-115 Differential Calculus, 21-116 Integral Calculus, and 33-234 Quantum Physics, or permission of the instructor

Course Website

There will be a course website for 33-341. To access it, go first to my homepage

<http://sekerkaweb.phys.cmu.edu>

and then click on 33341 Thermal Physics I, Fall 2007 (under Course Information for Enrolled Students). A dialog box will pop up. Your username is **authorizeduser** and I will give you the password in class.

Teaching Assistant

The teaching assistant assigned to this course is Chien-Yi CHEN, chienyic@andrew.cmu.edu, extension 8-6205). He will be grading the homework and helping to proctor some of the exams.

Tentative Topics¹

S-1, S-2 etc. indicate chapters in Sekerka's draft book, *Thermostatistical Physics*; C-1, C-2 etc. indicate chapters in Callen; F-1, F-2 etc. indicate chapters in Fermi (recommended texts used in previous years).

Introduction (S-1; F-1; C-1)

- Scope of Thermal Physics; Temperature; Macroscopic *vs* Microscopic

¹Some items will be covered only if time permits, depending on the pace of the class.

- Extensive *vs* Intensive State Variables (C-2)
- Energy in Mechanics
- Elementary Kinetic Theory; Pressure of an ideal gas

The First Law of Thermodynamics (S-2; F-2; C-1)

- Statement of the First Law; Energy as a Function of State
- Discussion of Heat and Work
- Quasistatic Work; Reversible *vs* Irreversible; Path Dependence; Heat Capacities
- Example Calculations of Work and Heat; Isothermal, Isobaric; Isochoric; Reversible Adiabatic; Irreversible Adiabatic
- Enthalpy

The Second Law of Thermodynamics (S-3; F-3,4; C-1,2)

- Statement of the Second Law; Entropy as a Function of State; Thermodynamic Temperature; Basic Inequality; Equilibrium
- Discussion of Second Law; Extension to Non-Isolated Systems
- Historical Basis: Carnot cycle (C-4)
- Combined First and Second Laws; Maxwell Relations; Irreversibility; Equations of State; Fundamental Equation (C-1)
- Examples: Entropy for Expansion of an Ideal Gas
- Latent Heat; Example: Melting of Ice
- Statistical Interpretation of Entropy

The Third Law of Thermodynamics (S-4; C-1,11; F-8)

- Statement of the Third Law; The Entropy Constant at Absolute Zero
- Discussion: Statistical Mechanics Interpretation
- Implications of the Third Law: Heat Capacities, Thermal Expansion, Compressibility, Phase Transformation

Open systems (S-5; C-3)

- Single Component; Chemical Potential
- Multicomponent Open Systems; Degrees of Freedom; Maxwell Relations (C-7)
- Euler Theorem; Application to Extensive and Intensive Functions

- Euler Equation; Gibbs-Duhem Equation
- Composition; Partial Molar Quantities; Method of Intercepts
- Legendre Transforms; Examples

Equilibrium and Thermodynamic Potentials (S-6; F-5; C-5)

- Entropy *vs* Internal Energy Criterion
- Equilibrium Conditions; Phase Rule (F-5, C-9)
- Helmholtz Free Energy Criterion; Maximum Work (Isothermal)
- Gibbs Free Energy Criterion; Maximum Excess Work; (Isothermal and Isobaric)
- Enthalpy Criterion; Maximum Excess Work; (Isobaric)
- Kramers Potention and Criterion

Monocomponent Phase Equilibrium (S-9)

- Coexistence Curves in T - p plane; Phase Diagram
- Clapeyron Equation (F-4)
- Approximate Coexistence Curves; Calusius–Clapeyron Equation
- Sketches of the Thermodynamic Functions

Thermodynamic Stability (S-7; C-8)

- Brief Discussion of Methodology
- Summary of Results

van der Waals Fluid (S-8; F-4)

- Equation of State; Liquid–Gas Phase Transition; Spinodal Curve
- Thermodynamic Functions
- Phase Equilibrium, Miscibility Gap, Common Tangent Construction
- Chord Costruction; Stability, Instability, Metastability
- Explicit Results; Maxwell Construction

Part II, Statistical Mechanics

Microcanonical Ensemble (parts of S-11,12; C-15)

- Ensemble Approach
- Fundamental Hypothesis for Isolated Systems; Equal Probability of Microstates
- Two-State System; Entropy; Temperature and State Probability
- Harmonic Oscillator; Calculation of the Multiplicity Function
- Comments on Classical Statistical Mechanics; Phase Space (S-12)

Weakly Interacting Distinguishable Particles (S-13)

- Derivation of the Boltzmann Distribution (Isothermal, Most Probable Distribution)
- Partition Function; Formulae for Thermodynamic Functions
- Two-State System (Paramagnetic)
- Harmonic Oscillator
- Heat Capacity of a Solid
- Blackbody Radiation; Planck Distribution Function
- Rigid Linear Rotator

Introduction to Canonical Ensemble (parts of S-14, C-16)

- Derivation I for Entire System of Interacting Particles
- Partition Function; Formulae for Thermodynamic Functions
- Factorization Theorem for Weakly Interacting Distinguishable Subsystems
- Ideal Gas
- Remarks about Classical Canonical Ensemble (parts of S-15)

Introduction to Grand Canonical Ensemble (parts of S-16, C-17)

- Basis and Conditions for Applicability; Result of Derivation
- Fermi-Dirac Distribution Function
- Bose-Einstein Distribution Function