

Syllabus and Topics

33-765 Statistical Mechanics

Spring 2010

Robert F. Sekerka
6416 Wean Hall, Phone 412-268-2362
rs07@andrew.cmu.edu
<http://sekerkaweb.phys.cmu.edu>

January 10, 2010

Course and Credit:

33-765 Statistical Mechanics is a graduate course and carries a credit of 12.0 units.

Class Schedule:

This class is scheduled to meet MWF 9:30 - 10:20 in WEH 7316. There are a total of 43 classes scheduled for the semester. The last class is on Friday, April 30. The current enrollment is 17. Class attendance is important and correlates strongly with grades.

University Holidays:

Mid-semester break: Friday March 5

Spring break: Monday March 8 - Friday March 12

Spring Carnival: Friday April 16

Exams and Grades:

There will be a mid-semester exam (35%) and a three hour final exam (45%). Homework will count 20%. **Late homework will not be accepted!**

Exam Dates:

Mid-semester exam: Monday, March 1, time and place TBD.

Final exam: To be scheduled by the registrar on one of the following dates: May 3-4, 6-7, 10-11.

Attention: DO NOT MAKE AIRLINE RESERVATIONS THAT CONFLICT WITH THESE DATES! Make your travel plans accordingly.

Text:

The textbook for this course is Robert F. Sekerka, “Thermostatistical Physics,” (work in progress available on the course web site as a pdf for your personal use).

Other Recommended Text:

RKP R. K. Pathria, Statistical Mechanics (Butterworth, New York, 1996) second edition, ISBN 0 7506 2469 8 (paperback) Available at CMU bookstore.

HC Herbert B. Callen, Thermodynamics and an Introduction to Thermostatistics (John Wiley & Sons, New York, 1985) ISBN 0-471-86256-8

KW Kerson Huang, Introduction to Statistical Mechanics, Second Edition (Taylor & Francis, New York, 2001) ISBN 0-7484-0942-4 (paperback)

FR Fredrick Rief, Fundamentals of Statistical and Thermal Physics, (John Wiley, New York, 2008) ISBN-10: 1577666127 ISBN-13: 978-1577666127

MQ Donald A. McQuarrie, Statistical Mechanics (University Science Books, Sausalito, California, 2000) ISBN 1-891389-15-7

Other Books:

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

GNS Walter Greiner, Ludwig Neise and Horst Stöcker, Thermodynamics and Statistical Mechanics, English edition, translated from the German by Dirk Rischke (Springer, New York, 2000) ISBN 0 387 94299 8 (paperback)

LL L. D. Landau and E. M. Lifshitz, Statistical Physics, Part I, Landau and Lifshitz Course of Theoretical Physics, Volume 5 (Butterworth-Heinemann, Oxford, 1980) 3rd edition ISBN 0 7506 3372 7 (paperback). See also Part II, E.M. Lifshitz and L.P. Pitaevskii, ISBN 0 7506 2636 4

MQ Donald A. McQuarrie, Statistical Mechanics (University Science Books, Sausalito, California, 2000) ISBN 1-891389-15-7

MS M.D. Sturge, Statistical and Thermal Physics, Fundamentals and Applications (A.K. Peters, Natick, Massachusetts, 2003) ISBN 1-56881-196-9

HC Herbert B. Callen, Thermodynamics and an Introduction to Thermostatistics (John Wiley & Sons, New York, 1985) ISBN 0-471-86256-8

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

EF Enrico Fermi, Thermodynamics (Dover edition, New York, 1956) ISBN 0486-60361-X

Reserve: The above books and a few others are on reserve in the E&S Library.

Course Objective:

The objective of this course is to develop a working knowledge of statistical mechanics at the graduate level 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:

This course develops the methods of statistical mechanics and uses them to calculate observable properties of systems in thermodynamic equilibrium. Topics treated include the principles of classical thermodynamics, canonical and grand canonical ensembles for classical and quantum mechanical systems, partition functions and statistical thermodynamics, fluctuations, ideal gases of quanta, atoms and polyatomic molecules, degeneracy of Fermi and Bose gases, chemical equilibrium, ideal paramagnetism and introduction to simple interacting systems. 3 hrs. lecture, 1 hr. recitation. Typical Texts: Reif, Statistical and Thermal Physics; Pathria, Statistical Mechanics.

Prerequisites:

Graduate status or permission of the instructor.

Course Website:

There will be a course website for 33-765. To access it, go first to my homepage

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

Go to the section Course Information for Enrolled Students (password protected) and click on 33-765 Statistical Mechanics, Spring 2010. A dialog box will pop up. Your username is authorizeduser and I will give you the password in class.

Grader:

The grader for this course is Guowei He, WeH 6332A, guoweih@andrew.cmu.edu, phone 8-4382. We will check off which homework problems are done and grade a few from each set at random. Answers will be posted on the course web site after the due date for each set.

Tentative Topics¹

Review of Thermodynamics

- Three laws (Chapters 2-4)
- Thermodynamic potentials (Chapters 5-6)
- Maxwell relations; Jacobians (Chapter 5, Appendix B)
- Equilibrium and stability criteria (Chapters 6-7)

Statistical Measure of Disorder

- Information Theory: Shannon's measure of disorder (CA Chapter 17)
- Unique result; relationship to quantum states and entropy

Microcanonical Ensemble, Chapter 14

- Microcanonical ensemble, fundamental assumptions (Chapter 11)
- Enumerating microstates; distinguishable versus indistinguishable particles
- Stirling's approximation (Appendix A)
- Examples: Two-state quantum system; quantum harmonic oscillator
- Three-state quantum system, microcanonical ensemble (numerical)
- Ideal gas; Gibbs correction
- Multicomponent ideal gas; entropy of mixing

Classical Microcanonical Ensemble, Chapter 15

- Phase space
- Liouville theorem and consequences

¹Some items will be covered only if time permits, depending on the pace of the class. This is especially true for items near the end of the list. I have given the probable order of presentation but might fine tune the order later to make the flow of information more logical.

- Relationship of quantum states to phase space
- Example: Classical Ideal gas

Canonical Ensemble (Chapter 17)

- Derivation from microcanonical ensemble
- Derivation from most probable distribution
- Most probable values versus mean values (Pathria 3.2)
- Factorization theorem
- Examples for weakly interacting distinguishable particles: (Chapter 13)
 - Two state quantum system
 - Quantum harmonic oscillator
 - Rigid linear rotator
 - Heat capacity of a solid; Blackbody radiation
- Indistinguishable particles; ideal gas
- Maxwell-Boltzmann distribution
- Energy dispersion
- Paramagnetism
- Relationship of partition function to density of states

Classical Canonical Ensemble (Chapter 18)

- Classical partition function versus quantum partition function
- Use of canonical transformations (Appendix D)
- Classical ideal gas
- Law of Dulong and Petit
- Averaging theorem and equipartition
- Virial theorem
- Examples: Rotation of diatomic and polyatomic molecules (Appendix E)
- Classical thermodynamic perturbation theory (Appendix F)

Grand Canonical Ensemble (Chapter 19)

- Relationship to particle reservoirs and chemical potential
- Derivation from microcanonical ensemble
- Gibbs sum; Kramers function; Kramers potential
- Dispersion of particle number and energy
- Ideal systems, orbitals and factorization
- Fermi and Bose distribution functions
- Fermi, Bose and classical ideal gases
- Classical ideal gas with internal structure
- Role of nuclear spins: para- and ortho-hydrogen
- Generalized ensembles and fluctuations

Unified Treatment of Ideal Fermi and Bose systems (Chapter 20)

- Integral representation of thermodynamic functions
- High temperature expansions
- Virial expansion of the equation of state

Bose Condensation (Chapter 21)

- Bose-Einstein condensation
- Entropy and heat capacity at constant volume
- He_4 lambda anomaly and its measurement in microgravity
- Phase diagram of helium, a quantum fluid
- Heat capacity at constant pressure
- Isentropes and isotherms

Degenerate Fermi Gas (Chapter 22)

- Fermi gas; free electron model of a metal; Fermi sphere
- Sommerfeld expansion; thermal properties of free electron gas
- Pauli paramagnetism; Landau diamagnetism

- Thermionic emission
- Semiconductors

Ising Model (Chapter 24)

- Introduction to cooperative phenomena
- Mean field treatment
- Pair statistics
- Exact solution of Ising model in one dimension, zero field
- Transfer matrix; exact solution of Ising model in one dimension
- Discussion of the Onsager exact solution in two dimensions
- Survey of numerical results in three dimensions
- Criticality, universality, scaling

Quantum Statistics (Chapter 23)

- Pure and mixed states
- Density operator; density matrix
- Quantum mechanical analog to Liouville theorem
- Density operator in various ensembles
- Examples (Pathria 5.3)
 - Electron in a magnetic field
 - Free particle in a box
 - Harmonic oscillator
- Indistinguishable particle statistics; “Boltzsons”, Fermions and Bosons

Approximation Methods

- Quantum thermodynamic perturbation theory (Appendix F)
- Bogoliubov variational theorem (Callen 20-1)