Syllabus and Topics
33-765 Statistical Mechanics
33-342 Thermal Physics II
Spring 2009

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Dual Registration:

33-765 Statistical Mechanics is a graduate course and carries a credit of 12.0 units. It can also be taken as an advanced undergraduate course, 33-342 Thermal Physics II, for a credit of 10.0 units. The course material is the same but graduate students and undergraduate students will be graded separately.

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, May 1. The current enrollment is 14 (12 graduate students and 2 undergraduates). Class attendance is important and correlates strongly with grades.

University Holidays:

Mid-semester break: Friday March 6

Spring break: Monday March 9 - Friday March 13

Spring Carnival: Friday April 17

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 2, time and place TBD.

Final exam: To be scheduled by the registrar on one of the following dates: May 4-5, 7-8, 11-12.

Attention: 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)

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 33-765/33-342. 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 2009. A dialog box will pop up. Your username is authorizeduser and I will give you the password in class.

Teaching Assistant:

There is no teaching assistant for this course. Consequently I will check off whether homework problems are done and grade one or two from each set at random.

Tentative Topics[1]

Review of Thermodynamics

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

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
- 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

[1] Some 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.

- 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 B)
- Classical thermodynamic perturbation theory

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
- 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 E)
- Bogoliubov variational theorem (Callen 20-1)