PHYS 3350: Thermal Physics (every second winter)

Calendar description: This course gives a comprehensive overview of thermodynamics and statistical mechanics. Topics in thermodynamics include equations of state, the three laws of thermodynamics, the Maxwell relations, and the kinetic theory of gases. Topics in statistical mechanics include the idea of particle ensembles and the partition function, classical and quantum statistics, thermodynamics of magnetism, Bose-Einstein and Fermi-Dirac gases, and information theory.

Contents

Overview

This course is cycled with PHYS 3400 (Electrodynamics), and thus will have both third and fourth year students enrolled. This course is taught in the second semester so that all students will have had PHYS 3200 (Mathematical Methods in Physics I) and PHYS 3500 (Quantum Mechanics I).

Prerequisites

PHYS 1101 University Physics II (indirect)

This course is the only place where students will see any thermodynamics before PHYS 3350. Concepts in statistical mechanics are seen no where else, and are totally new to students entering this course.

PHYS 3200 Mathematical Methods in Physics I

This course provides the only mathematical background most students will have in second order ODEs, and complex numbers and analysis.

PHYS 3500 Quantum Mechanics I

Traditionally, though not necessarily, PHYS 3350 has approached statistical mechanics from a quantum physics point of view, and PHYS 3500 provides the background in Quantum Mechanics to support this approach. Students will have covered the first half of Griffith's text on Quantum Mechanics, or equivalent, and thus should be familiar with the Heisenberg Uncertainly Principle, the Pauli Exclusion Principle, probability functions, expectation values, angular momentum states, and will have seen the Schrödinger equation used to describe one-electron atoms. Ideas in perturbation theory, WKB methods, multi-electron atoms, fine and hyperfine splitting, *etc.*, are not encountered until PHYS 4500 (Quantum Mechanics II) which the fourth year students will have had, but the third year students not.

Dependent courses

Student Outcomes

Students completing PHYS 3350 should begin to master the following skills:

1. Obtain a fluidity with partial derivatives while managing interdependent variables;
2. Interpret and use a phase diagram;
3. Establish an intuitive connection between the thermodynamical and statistical pictures of nature.

Curriculum

The following curriculum is based on the Table of Contents in Carter's text, *Classical and Statistical Thermodynamics*, one of the suggested texts below.

1. equations of state
   - ideal and van der Waal's gases
   - expansivity and compressibility
2. first law of thermodynamics
   - heat, work, internal energy, enthalpy
   - Gay-Lussac-Joule and Joule-Thompson experiments
3. second law of thermodynamics
   - entropy and irreversible processes

- combined first and second laws (the Tds equations)
- free expansion
- entropy changes in solids and liquids

4. third law of thermodynamics
5. thermodynamic potentials
   - Maxwell relations
   - Helmholtz and Gibb's functions
   - chemical potentials and reactions
6. kinetic theory of gases
   - pressure, temperature, and mean molecular motion
   - specific heat capacity
   - effusion
7. statistical thermodynamics
   - distinguishable particles
   - thermodynamical probability and entropy
   - quantum states, energy levels, and density of states
8. classical and quantum statistics
   - Boltzmann statistics
   - Fermi-Dirac, Bose-Einstein, and Maxwell-Boltzmann distributions
   - the partition function; equipartition of energy
   - entropy change of mixing
9. thermodynamics of magnetism
   - paramagnetism, ferromagnetism
   - adiabatic demagnetisation
10. Bose-Einstein gas
    - blackbody radiation
    - Bose-Einstein condensation (*e.g.*, liquid helium)
11. Fermi-Dirac gas
    - the Fermi energy

- free electrons in a metal (*e.g.*, white dwarf)

12. information theory (optional)
    - uncertainty and information
    - maximum entropy
    - connection to the laws of thermodynamics

Suggested texts

Classical and Statistical Thermodynamics by Ashley Carter (ISBN)

- 3.5/5 stars on amazon.com
- has been used frequently at SMU

Thermodynamics and an Introduction to Thermostatistics by Herbert Callen (ISBN)

- 4.5/5 stars on amazon.com
- similar coverage to Carter, though in a different order

Introduction to Statistical Mechanics and Thermodynamics by Keith Stowe (ISBN)

- 4.5/5 stars on amazon.com

Notes to the instructor

1. This course is cycled with PHYS 3400 (Electrodynamics) and always offered in the winter term. Thus students will be a mix of third and fourth year students in their second semester. The fourth year students will have had both courses in Mathematical Methods in Physics (PHYS 3200 and PHYS 3201) while the third year students will have had the former, and be taking the latter concurrently.

   The curriculum has been designed so that the mathematics needed in Thermal Physics, namely partial derivatives, line integration, second order ODEs, complex numbers and analysis, is covered in MATH 2303, MATH 2311 and PHYS 3200 . However, if the instructor feels math from the second math methods course (PHYS 3201) is also needed, he or she should coordinate the timing of topics with the instructor of that course.

2. This is a "terminal course" in that no other courses in the curriculum depend upon it. Thus there is some latitude in which subjects are emphasised and covered by the instructor. However, it is the intent and desire of the curriculum committee and department that students finishing this course will gain a good idea of how traditional thermodynamics follows from the ideas of statistical mechanics.

3. Other than three weeks on thermodynamics in first year (PHYS 1101), this is the only place where students will see thermodynamics in the programme. It is therefore meant as a comprehensive course in thermal physics.