PHYS2002 - Many Particle Systems
Lecture Outline - Semester 2, 2023

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Text: There is no text for this course. The lecture notes (consisting of a mixture of typed notes and handwritten notes) will be complete and can be treated as a text. If you wish to read more widely, the following books are recommended:

- *Thermodynamics and an Introduction to Thermostatistics*, 2nd Edition, by H. B. Callen
- *Statistical Physics: An Introductory Course* by D. J. Amit and Y. Verbin.

Proposed Lecture Content

Lecture 1. Macroscopic versus microscopic descriptions; averaging over microstates in macroscopic measurements; equilibrium states; equations of state for ideal gases and Van der Waals gases.

Lecture 2. Quasistatic processes; energy conservation and the first law of thermodynamics; quasistatic work done on a gas.

Lecture 3. Exact and inexact differentials; path dependence of integrals of inexact differentials; volume independence of internal energy of ideal gases; specific heats at constant volume and pressure for ideal gases; extensive and intensive parameters.

Lecture 4. Entropy of an ideal gas, entropy as another thermodynamic parameter, change in etropy for an infinitesimal quasistatic process, entropy postulates, entropy maximum principle for closed thermodynamic systems.

Lecture 5. Systems with variable particle number, expressions for intensive variables in terms of partial derivatives of energy and entropy, Euler relation. Gibbs-Duhem relation and its significance, entropy change during the isothermal expansion of an ideal gas, reversible and irreversible processes.

Lecture 6. Conditions for equilibrium of a composite closed system upon removal of constraints, the thermodynamic potentials F, H, and G. Equilibrium for open systems expressed as extremum principles for the thermodynamic potentials.

Lecture 7. Difference between statistical mechanics and thermodynamics, distribution function over microstates, averaging involved in macroscopic measurements, fundamental postulate of statistical mechanics and generalized entropy.

Lecture 8. Probability distribution for a closed system, minimizing the generalized entropy subject to constraints, method of Lagrange multipliers.

Lecture 9: Equilibrium probability distribution for system in contact with a heat reservoir, canonical partition function, relation to free energy and thermodynamics.

Lecture 10: Ideal gases: discreteness of momenta, approximation of sum over momenta by an integral, number of accessible states as a function of energy. Accounting for indistinguishability, entropy, equations of state.

Lecture 11: Paramagnetism; magnetic moments in external fields, canonical partition function for system of magnetic moments, temperature dependence of mean magnetisation, Curie law.

Lecture 12: Canonical partition function for a system of distinguishable particles in terms of single particle partition function, modified Boltzmann statistics to account for indistinguishability, limitations of modified Boltzmann statistics.

Lecture 13: Entropy revisited, irreversibility and change in number of accessible states, canonical partition function for a single harmonic oscillator. Einstein's solid; model in terms of harmonic oscillators, canonical partition function, average energy, specific heat and comparison with experiment, reasons for limitations of the model.

Lecture 14: Statistical mechanics of identical particles; Bose-Einstein, Fermi-Dirac and Maxwell-Boltzmann statistics, enumeration of states in terms of occupation number for indistinguishable particles. Grand canonical partition function, evaluation for BE and FD statistics.

Lecture 15: Thermodynamic significance of the grand canonical partition function, mean particle numbers for FD and BE statistics, BE and FD distributions. Fermi gases: examples, mean occupation numbers, $T = 0$ limit, Fermi energy and its relation to chemical potential, Fermi momentum, Fermi sphere.

Lecture 16: Free electron gas: enumeration of momentum states, mean particle number, expression for Fermi energy, modifications to distribution at nonzero temperature, real metals.

Lecture 17: Thermodynamics from derivatives of the logarithm of the grand canonical partition function. Pressure of an electron gas in the small T limit. Chemical potential of an ideal gas, behaviour of Bose gases at low temperatures, importance of quantum effects at low temperatures, behaviour of chemical potential at low temperatures.

Lecture 18: Bose Einstein condensatation: macroscopic occupation of groundstate, calculation of T_B, behaviour of real systems. Free photon gas - vanishing of chemical potential, relativistic energy momentum relation, pressure as function of temperature and as a function of energy density.