

Part I: Introduction

Class schedule: Jan 15, 20, 22;

Reading assignments: S1, S6; R2.1-2.3, R2.5

Examples marked with * are important and should be studied carefully and thoroughly.

I.1 Translation between macroscopic and microscopic behavior

Statistical physics studies, through the statistical approach, systems of many particles, which covers a wide scope of physics subjects. The purpose of the course is to understand the physics of macroscopic behavior of a system by relating it to the microscopic properties of the particles of the system.

Example 1: a gas/solid/liquid system, a magnet, a conductor, plasmas in a star and stellar atmosphere, the radiation field, the Galaxy, and the universe, are all many-particle systems and can be studied in statistical physics.

Example 2: an ideal monatomic gas with N gas particles can be described with $6N$ variables specifying each particle's position and momentum. In macroscopic view, only a few parameters, like T , V , P , N , are relevant in classical thermodynamics.

I.2 Measurement of macroscopic properties

Macroscopic properties of particle systems are time and space smoothed; measurements can be done when the system is in *equilibrium*.

Example 3: macroscopic (measurement) and microscopic (atomic) time and spatial scales.

I.3 State of the system

Macroscopic properties are related to microscopic properties. Given external constraints, the system can stay in *accessible states*.

*Example 4 (class notes, R2.2, S1.B.6-7): the state of a system of spin particles: the microscopic states refer to combinations of spins, and the macroscopic state refers to the total magnetic moment or total magnetic energy in an external magnetic field. Usually, each of the allowed magnetic energy (macro-state) can have numerous micro-states.

Remarks: (a) with increasing number (N) of spin particles in the system, the total number of accessible micro-states, i.e., the number of spin configurations, will increase. (b) with N increasing, the total number of macro-states, or the number of allowed total magnetic energy, will increase. (c) Given a specific energy range, with increasing N , the number of accessible micro-states will increase. E.g., given $E_B = \mu_B B$, for $N = 3$, there are 3 accessible micro-states; for $N = 5$, there are 10 accessible micro-states.

When N is a large number, we can define $\Omega(E, \delta E) = \psi(E + \delta E) - \psi(E) = g(E)\delta E$ as the *number*

of accessible (micro-)states in the energy range of E and $E + \delta E$, and $g(E)$ as the *density of states*.

*Example 5 (class notes, S.1.B.4-5, S.6.D.3-4, R2.1, R2.5): the state of a system of ideal monatomic gas; applying uncertainty principle to draw *phase space* diagram and make estimate of *number of accessible states*: $\Omega(E, \delta E) \sim E^{\frac{3}{2}N-1} V^N \delta E$, E being the total kinetic energy.

Remarks: the number of accessible (micro-)states increases rapidly with the system macro-state parameters E , V , and N . Here E is the internal energy of the gas.

The energy of a system is also quantized. But usually even a very small change of energy in the macroscopic scale is still a lot larger than the energy difference between adjacent microscopic states thus includes numerous microscopic states. Therefore we often treat $\psi(E)$ as a continuous function of E .

Example 6: estimate the energy gap between adjacent microscopic states in (a) a spin particle system; (b) a gas system, in comparison with macroscopic energy.

The number of accessible microscopic states corresponding to a certain, or a certain range of, macroscopic state, as a fraction of the total number of accessible microscopic states of the system, is the probability of the system staying in that macroscopic state. Note that this applies to the system in *equilibrium*.

A definition of *equilibrium*: a system in *equilibrium* is such that the probability of the system staying in the accessible states does not vary with time.

Example 7: calculate the probability of gas particles staying within a certain part of the box.

Some tricks to help with order-of-magnitude estimate: $e^N = 10^{N \log(e)}$, $y^N = 10^{N \log(y)}$, $\log(e) = 0.4343$, $\log(2) = 0.3010$, $\log(3) = 0.4771$, $\log(4) = 2\log(2)$, $\log(5) = 1 - \log(2)$, $\log(6) = \log(2) + \log(3)$