COIN TOSSING EXPERIMENT – 1

1. **What is a system?**
   ANS: A system is defined by the collection of a large number of particles.

2. **What is ensemble?**
   ANS: A collection of a number of macroscopically identical but essentially independent systems.
   Microscopically identical – each of the system constituting an ensemble satisfies the same macroscopic conditions like volume, energy, pressure and temperature and the total number of particles etc.
   Essentially Independent – the system (in the ensemble) is mutually non-interacting to others i.e., the system differs in microscopic conditions like parity, symmetry, quantum states etc.

3. **What is a microstate?**
   ANS: Each possible combinations of positions and velocities, momentum of all molecules refers to a microstate of the system.

4. **What is Macrostate?**
   ANS: The macrostate of a system refers to its macroscopic properties such as its temperature, pressure, volume and density.

DISTRIBUTION FUNCTIONS EXPERIMENT – 2

1. **Write the Distribution Functions for Maxwell-Boltzmann, Fermi-Dirac and Bose-Einstein.**
   ANS:

Maxwell-Boltzmann Distribution Function

The average number of particles in a state of energy ε is a system of particles at absolute temperature T is

$$f_{MB}(\varepsilon) = Ae^{-\frac{\varepsilon}{kT}} \qquad (2)$$

A= Constant
=Depends on number of particle in the system
=It has the same role as that of normalization constant in case of wave function
k=Boltzmann's constant
=1.381×10^{-23} J/K=8.617×10^{-3} eV/K

Combining Eq. (1.a) and (2), we get $n(\varepsilon) = g(\varepsilon) f_{MB}(\varepsilon)$

$$\boxed{n(\varepsilon) = Ag(\varepsilon)e^{-\frac{\varepsilon}{kT}}} \qquad (3)$$

Let's apply MB statistics to find the distribution of energies among the molecules of an ideal gas

18.3 Bose–Einstein Condensation

- A gas of non-interacting particles (atoms & molecules) of relatively large mass.
- The particles are assumed to comprise an ideal B-E gas.
- Bose – Einstein Condensation: phase transition
- B – E distribution: $f(\varepsilon) = \frac{N(\varepsilon)}{g(\varepsilon)} = \frac{1}{e^{\frac{(\varepsilon-\mu)}{kT}} - 1}$

Fermi-Dirac distribution and the Fermi-level

Density of states tells us how many states exist at a given energy E. The Fermi function $f(E)$ specifies how many of the existing states at the energy E will be filled with electrons. The function $f(E)$ specifies, under equilibrium conditions, the probability that an available state at an energy E will be occupied by an electron. It is a probability distribution function.

$$\boxed{f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}}$$

(2.7)

E_F = Fermi energy or Fermi level

k = Boltzmann constant = 1.38×10^{-23} J/K = 8.6×10^{-5} eV/K

T = absolute temperature in K

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Boltzmann	Bose Einstein	Fermi Dirac
$\overline{n}_k = \frac{1}{\exp\left(\frac{\varepsilon-\mu}{k_B T}\right)}$	$\overline{n}_k = \frac{1}{\exp\left(\frac{\varepsilon-\mu}{k_B T}\right)-1}$	$\overline{n}_k = \frac{1}{\exp\left(\frac{\varepsilon-\mu}{k_B T}\right)+1}$
indistinguishable $Z=(Z_1)^N/$**N!** n_K<<1	indistinguishable integer spin 0,1,2 …	indistinguishable half-integer spin 1/2,3/2,5/2 …
spin doesn't matter	bosons	fermions
localized particles Ψ don't overlap	wavefunctions overlap total Ψ symmetric	wavefunctions overlap total Ψ anti-symmetric
gas molecules at low densities	photons ^{4}He atoms	free electrons in metals electrons in white dwarfs
"unlimited" number of particles per state n_K<<1	unlimited number of particles per state	never more than 1 particle per state

2. **Explain Fermi energy and chemical potential and their importance/significance.**

Fermi energy and chemical potential are two related concepts in the field of condensed matter physics that are crucial for understanding the behaviour of electrons in materials.

Fermi energy, also known as the Fermi level, is the highest energy level occupied by electrons in a material at absolute zero temperature. It is named after Enrico Fermi, the Italian physicist who first proposed the concept. The Fermi energy is a fundamental parameter that determines many electronic properties of materials, such as their electrical conductivity, thermal conductivity, and optical properties.

Chemical potential, on the other hand, is a thermodynamic quantity that describes the energy required to add or remove a particle from a system. It is defined as the partial derivative of the internal energy of a system with respect to the number of particles in the system, at constant temperature and volume. In condensed matter physics, the chemical potential is often used to describe the energy required to add or remove an electron from a material.

The importance of Fermi energy and chemical potential lies in their ability to describe the behaviour of electrons in materials. In particular, the Fermi energy determines whether a material is a metal, an insulator, or a semiconductor. Metals have a Fermi energy that lies within the conduction band, which allows electrons to move freely throughout the material and conduct electricity. Insulators have a large energy gap between the valence and conduction bands, which prevents electrons from moving freely and thus they do not conduct electricity.

Chemical potential also plays a crucial role in determining the behaviours of electrons in materials. For example, the chemical potential of a material can affects its response to an external electric field or magnetic field. It can also determine the direction of electron flow in a circuit, and can be used to predict the behaviours of electron transport in a wide range of materials, from metals to semiconductors and beyond.