CHAPTER

11 Dual Nature of Radiation and Matter

Planck's Quantum Theory

- According to Planck's quantum theory, light is considered to be made up of small packets (or particles) of energy known as quanta of energy or radiation.

  Energy, $E = h\nu = \frac{hc}{\lambda} = \frac{12400}{\lambda(\text{Å})}$ eV

Photons

- Momentum of one photon is $\frac{h}{\lambda}$.
- When radiation interacts with matter, the radiation behaves as if it is made of particles like photons.
- Einstein proposed that electromagnetic radiation (or simply light) is quantized and exists in elementary amounts (quanta) that we now call photons.
- Photons are not deflected by electric and magnetic fields which shows that they are neutral and do not carry any charge.
- The energy of photon depends upon the frequency of radiation but is independent of the intensity of radiation.

Photoelectric Effect

- When light of suitable frequency illuminates a metal surface, electrons are emitted. This process of ejection of electrons using light is known as photoelectric emission. Photoelectrons ejected from metal have kinetic energies ranging from 0 to K_{max}.
- A certain minimum amount of energy is required for an electron to be pulled out from the surface of a metal. This minimum energy is called the work function (ϕ) of that metal. Work function is minimum for cesium (1.9 eV).
- Einstein equation for photoelectric effect is,

  $hv = \phi + KE_{max} \quad \Rightarrow \frac{hc}{\lambda} = \frac{hc}{\lambda_0} + eV_s$
- The minimum frequency of the incident light below which photoelectrons are not ejected from the metal surface is known as threshold frequency (ν_0).

  Work function, $\phi = hv_0 = \frac{hc}{\lambda_0}$

  λ_0 = threshold wavelength
- The minimum negative potential given to the metal plate with respect to the collector at which the photoelectric current becomes zero is known as stopping potential or cut-off potential. Here $KE_{max} = eV_s, V_s =$ stopping potential

  Stopping potential is independent of intensity of light used.
- The number of photoelectrons emitted per second is directly proportional to the intensity of the incident radiation.
- The maximum kinetic energy of the ejected electrons is independent of the intensity of incident radiation but depends upon the frequency of the incident radiation.

Radiation Pressure

Radiation pressure, $P = \frac{I}{c}(1+r)$. Here I is the intensity of incident radiation, c is the speed of light and r is the reflectivity of the surface.

For 100% reflection, $r = 1$ and for 100% absorption $r = 0$.

De-Broglie Hypothesis

- It says that a wave is associated with a moving material particle. The wavelength associated with a moving particle is given by $\lambda = \frac{h}{mv}$, where m is the mass of the particle moving with v velocity and h is Planck's constant. This wave is called de-Broglie wave.
- Matter waves cannot be electromagnetic in nature because electromagnetic waves are produced by motion of charged particles.

Heisenberg's Uncertainty Principle

According to Heisenberg's Uncertainty Principle, it is not possible to measure exactly both the position and momentum of a microscopic particle (say electron) at the same time. That is,

$\Delta x \Delta p \geq \frac{\hbar}{2}$, where $\hbar = \frac{h}{2\pi}$,

Key Tips

- Einstein's photoelectric equation, $\frac{1}{2}mv_{max}^2 = h\nu - h\nu_0$
- Work function and threshold frequency or threshold wavelength related as, $\phi_0 = hv_0 = \frac{hc}{\lambda_0}$
- Energy of photon, $E = h\nu = \frac{hc}{\lambda}$

- Momentum of photon, $p = \frac{E}{c} = \frac{h}{\lambda}$
- de-Broglie wavelength of a material particle, $\lambda = \frac{h}{mv}$
- de-Broglie wavelength in terms of energy of a particle (E), $\lambda = \frac{h}{\sqrt{2mE}}$
- de-Broglie wavelength of an electron accelerated through a potential V volt, $\lambda = \sqrt{\frac{150}{V}}$ Å $= \frac{12.27}{\sqrt{V}}$ Å
- de-Broglie wavelength of a particle in terms of temperature (T), $\lambda = \frac{h}{\sqrt{3mkT}}$