

Dual Nature of Radiation and Matter

- A certain minimum amount of energy is required to be given to an electron to pull it out from the surface of the metal. This minimum energy required by an electron to escape from the metal surface is called the work function of the metal. The minimum energy required for the electron emission from the metal surface can be supplied to the free electrons by any one of the following physical processes:
 - Thermionic emission: By suitably heating, sufficient thermal energy can be imparted to the free electrons to enable them to come out of the metal.
 - Field emission: By applying a very strong electric field (of the order of 10^8 V m^{-1}) to a metal, electrons can be pulled out of the metal, as in a spark plug.
 - Photo-electric emission: When light of suitable frequency illuminates a metal surface, electrons are emitted from the metal surface. These photo(light)-generated electrons are called photoelectrons.

- Photoelectric effect is the phenomenon of emission of electrons by metals when illuminated by light of suitable frequency. Certain metals respond to ultraviolet light while others are sensitive even to the visible light. Photoelectric effect involves conversion of light energy into electrical energy. It follows the law of conservation of energy. The photoelectric emission is an instantaneous process and possesses certain special features.
- Photoelectric current depends on
 - (i) the intensity of incident light, the number of photoelectrons emitted per second is directly proportional to the intensity of incident radiation.
 - (ii) the potential difference applied between the two electrodes, for a given frequency of the incident radiation, the stopping potential is independent of its intensity.
 - (i) the nature of the emitter material.
- The stopping potential (V_0) depends on (i) the frequency of incident light, and (ii) the nature of the emitter material. For a given frequency of incident light, it is independent of its intensity. The stopping potential is directly related to the maximum kinetic energy of electrons emitted:

$$eV_0 = (1/2) m v_{\max}^2 = K_{\max}$$

- Below a certain frequency (threshold frequency) ν_0 , characteristic of the metal, no photoelectric emission takes place, no matter how large the intensity may be.
- The classical wave theory could not explain the main features of photoelectric effect. Its picture of continuous absorption of energy from radiation could not explain the independence of K_{\max} on intensity, the existence of ν_0 and the instantaneous nature of the process. Einstein explained these features on the basis of photon picture of light. According to this, light is composed of discrete packets of energy called quanta or photons. Each photon carries an energy $E (= h \nu)$ and momentum $p (= h/\lambda)$, which depend on the frequency (ν) of incident light and not on its intensity. Photoelectric emission from the metal surface occurs due to absorption of a photon by an electron.
- Einstein's photoelectric equation is in accordance with the energy conservation law as applied to the photon absorption by an electron in the metal. The maximum kinetic energy $(1/2)m v^2$ is equal to the photon energy ($h\nu$) minus the work function $\phi_0 (= h\nu_0)$ of the target metal:

$$V_0 e = h\nu - \phi_0 = h(\nu - \nu_0)$$

This photoelectric equation explains all the features of the photoelectric effect. Millikan's first precise measurements confirmed the Einstein's photoelectric equation and obtained an accurate value of Planck's constant h . This led to the acceptance of particle or photon description (nature) of electromagnetic radiation, introduced by Einstein.

- Radiation has dual nature: wave and particle. The nature of experiment determines whether a wave or particle description is best suited for understanding the experimental result. Reasoning that radiation and matter should be symmetrical in nature, Louis Victor de Broglie attributed a wave-like character to matter (material particles). The waves associated with the moving material particles are called matter waves or de Broglie waves.
- **PARTICLE NATURE OF LIGHT: THE PHOTON**
 - In interaction of radiation with matter, radiation behaves as if it is made up of particles called photons.
 - Each photon has energy $E (=h\nu)$ and momentum $p (= h\nu/c)$, and speed c , the speed of light.
 - All photons of light of a particular frequency ν , or wavelength λ , have the same energy $E (=h\nu = hc/\lambda)$ and momentum $p (= h\nu/c = h/\lambda)$, whatever the intensity of radiation may be. By increasing the intensity of light of given wavelength, there is only an increase in the number of photons per second crossing a given area, with

each photon having the same energy. Thus, photon energy is independent of intensity of radiation.

- Photons are electrically neutral and are not deflected by electric and magnetic fields.
- In a photon-particle collision (such as photon-electron collision), the total energy and total momentum are conserved. However, the number of photons may not be conserved in a collision. The photon may be absorbed or a new photon may be created.

- **WAVE NATURE OF MATTER**

The de Broglie wavelength (λ) associated with a moving particle is related to its momentum p as: $\lambda = h/p$. The dualism of matter is inherent in the de Broglie relation which contains a wave concept (λ) and a particle concept (p). The de Broglie wavelength is independent of the charge and nature of the material particle. It is significant

measurable (of the order of the atomic-planes spacing in crystals) only in case of sub-atomic particles like electrons, protons, etc. (due to smallness of their masses and hence, momenta). However, it is indeed very small, quite beyond measurement, in case of macroscopic objects, commonly encountered in everyday life.

The matter-wave picture elegantly incorporated the **Heisenberg's uncertainty principle**. According to the principle, it is not possible to measure both the position and momentum of an electron (or any other particle) at the same time exactly. There is always some uncertainty (Δx) in the specification of position and some uncertainty (Δp) in the specification of momentum.

- Electron diffraction experiments by Davisson and Germer, and by G. P. Thomson, as well as many later experiments, have verified and confirmed the wave-nature of electrons. The de Broglie hypothesis of matter waves supports the Bohr's concept of stationary orbits.