DUAL NATURE OF MATTER AND RADIATION

Dual nature of matter

Since radiation has dual nature i.e., it possesses properties of both; wave and particles and universe is composed of radiation and matter, therefore de–Broglie concluded that the matter must also possess dual nature, since nature loves symmetry.

De–Broglie Hypothesis

According to de–Broglie, a moving material particle sometimes acts as a wave and sometimes as a particle or a wave is associated with a moving material particle which controls the particle in every respect. The wave associated with moving material particle is called matter wave or de–Broglie wave, whose wavelength is given by, $\lambda = \frac{h}{mv}$ where m is the mass of the particle moving with velocity v and h is Planck's constant.

De–Broglie wavelength associated with electron accelerated under a potential difference V volt is given by,

$$\lambda = \frac{12.27 A^\circ}{\sqrt{V}}$$

The wave nature of electron i.e., de–Broglie hypothesis was established experimentally by Davisson and Germer in 1937 for slow electrons and by G.P. Thomson for fast electrons.

Electric Charge

The passage of electric current through air is called electric discharge through the air. A potential difference of 20,000 V is required to produce sparking across a gap of 1 cm in air at normal pressure. The voltage required for the discharge through air or gas depends upon (i) the nature of the gas (ii) the pressure of the gas, (iii) the nature of electrodes and (iv) distance between the electrodes.

Discharge Tube

A glass tube provided with an arrangement to be used to study the passage of electric discharge through gases at low pressure is called discharge tube.

Cathode Rays

These are the stream of high speed electrons moving from cathode to anode in a discharge tube at a pressure of 0.01mm of mercury.

Properties of Cathode Rays

i) Cathode rays travel in straight line

ii) Cathode rays shoot out normally from the surface of cathode irrespective of the position of anode

iii) They possess a lot of kinetic energy and can exert mechanical pressure.

iv) They produce heat in metals when they fall on them

v) Cathode rays are deflected by electric field

vi) Cathode rays are deflected by magnetic fields

vii) They can affect a photographic plate

viii) They produce fluorescence, when they fall on certain substances.

ix) They ionize the gas through which they pass.

x) They travel with high speed ranging from $\frac{1}{30}^{th}$ to $\frac{1}{10}^{th}$ of velocity of light.

xi) When fast moving cathode rays are stopped by the metal of high atomic number, X–rays are produced.

xii) Cathode rays can pass through thin aluminium or gold foils without puncturing them.

xiii) They exhibit interference and diffraction phenomena under suitable arrangements, hence they behave as waves.

Nature of Cathode Rays

Cathode rays are stream of fast moving electrons and cathode rays are not electromagnetic rays.

Specific Charge of Cathode Rays means charge/mass of cathode rays. It was determined by J.J. Thomson, using electric and magnetic fields applied on a fine beam of electrons, at the same place but perpendicular to each other.

Formula used is, $\frac{e}{m} = \frac{E^2}{2VB^2}$

Where, E is the electric field applied, B is the magnetic field applied and V is the potential difference between anode and cathode, under which the electron is accelerated before entering the electric and magnetic fields. The value of specific charge of cathode rays (or electron) is 1.7589×10^{11} C kg^{-1}.

Electronic Charge was determined by Millikan, which was found to be 1.602×10^{-19}C.

Free electrons in metals

These are loosely bound electrons of the atoms, which can move freely within the metal surface but cannot leave the metal surface at room temperature.

Work function of metal

It is the minimum energy required by an electron to just escape from the metal surface as to overcome the restraining forces at the surface of metal. Work function of a metal is generally denoted by W_0 and it is usually expressed in electron volt (eV).

Electron emission

Electron emission is the process when an **electron** escapes from a metal surface.

The electron emission can be obtained from the following processes:

(i) Thermionic emission

(ii) Photoelectric emission

(iii) Secondary emission

(iv) Field emission

Photon

These are the packets of energy (or energy particles) which are emitted by a source of radiation. They travel in a straight line. The energy of a photon, $E = h\nu = \frac{hc}{\lambda}$. The photons emitted from a source, travel through space with the same speed (equal to the speed of light). The frequency of a photon does not change when it travels through different media but its wavelength changes in different media as the velocity of a photon in different media is different.

The rest mass of photon is zero. Its momentum is $\frac{h\nu}{c}$ or $\frac{h}{\lambda}$.

Photoelectric effect

It is the phenomenon of emission of electrons from the surface of metals, when light radiations of suitable frequency fall on them. The emitted electrons are called photoelectrons and the current so produced is called photoelectric current. Alkali metals; like lithium, sodium, potassium, cesium etc. show photoelectric effect with visible light, whereas metals like zinc, cadmium, magnesium etc. are sensitive only to ultra–violet light for photoelectric effect.

Laws of photoelectric emission

1) For a given metal and frequency of radiation, the number of photoelectrons ejected is directly proportional to the intensity of the incident light.

2) For a given metal, there exists a certain minimum frequency of the incident radiation below which no emission of

photoelectrons takes place. This frequency is called threshold frequency.

3) Above the threshold frequency, the maximum K.E. of the emitted photoelectrons is independent of the intensity of the incident light but depends upon the frequency (or wavelength) of the incident light.

4) The photoelectric emission is an instantaneous process.

Einstein's photoelectric equation is

$$\frac{1}{2}mv^2 = h\nu - W_0 = h\nu - h\nu_0 = h(\nu - \nu_0)$$

Where, ν is the frequency of the incident photons, ν_0 is the threshold frequency of metal, v is the velocity of ejected photo–electron from the metal surface and m is the mass of photo–electron.

Cut off potential or stopping potential

It is that minimum negative potential given to anode in a photo–cell for which the photo–electric current becomes zero. It is denoted by ν_0.

The value of stopping potential is different for different metals but is independent of the intensity of the incident light.

Photoelectric cell

It is a device which converts light energy into electrical energy.

Photoelectric cells are of three types

i) Photo emissive cell

ii) Photo voltaic cell

iii) Photo conductive cell