chapter - 11

Radiation & Dual nature of matter

IMP.
Q. 1 Define ~~Dual~~ work function?
Q. 2 Define electron volt?
Q. 3 why metals have large no. of free electrons?
Q. 4 give the proper condition, which is best ~~des gives~~ suitable for electron emission by photon.

Q. 5 Define therm ionic emission.
Q. 6 Define photoelectric emission.

Ans. # Free electron in metals :-

i) In metals the electron in the outer shells of the atoms are loosely bound. They move freely through out the lattice of positive ions, such loosely bound electrons are called free electrons.

ii) The free electrons however remain confined to the conductor and can not leave it's surface at ordinary temperature and under moderate electric field.

iii) There is a potential ~~force~~ barrier at the metal surface by which the free electron have to overcome in order to just escape from the metal surface.

Ans. 1) # Work function :-

i) The minimum amount of energy required by an electron to escape from the metal surface is called work function, denoted by " ϕ_0 " or " W_0 ".

Work function depends upon :-

i) The nature of the metal
ii) ~~So~~ The condition of it's surface

Ans. 2)
Electron volt :-

i) The unit of work function electron volt
ii) one electron volt is the kinetic energy gained by an electron when it is accelerated through a potential diff. of 1 volt.

iii) Energy gained by electron = work done by electric field

$$\text{Energy gained by electron} = qV$$
$$= eV$$
$$= (1.6 \times 10^{-19})(1V)$$
$$= 1.6 \times 10^{-19} \text{ Joule}$$

$$\boxed{\therefore 1 \text{ electron volt} = 1.6 \times 10^{-19} \text{ J}}$$

→ Work functions of some photon sensitivity metals.

Work function of some photo sensitive metals:-

	Metal	Work Function
1)	Cs	2.14 eV
2	K	2.30 eV
3	Na	2.75 eV
4.	Ca	3.20 eV
5.	Mo	4.17 eV
6.	Pb	4.75 eV
7.	Al	4.28 eV
8.	Hg	4.65 eV
9.	Ag	4.70 eV
10.	Ni	5.15 eV
11.	Pt	5.65 eV

also Ans. 4.

→ The metal having less work function, is best suitable for electron emission by photon.

Electron Emission :-

→ The phenomena of emission of electron from a metal surface is called electron emission.

→ For the emission of electron from the metal surface the energy of e^- must be higher than the work function of metal.

→ There are following methods for electron emission –

i) Therm ionic Emission or Thermo ionic Emission
ii) Field Emission
** iii) photoElectric Emission
iv) secondary Emission

also Ans.5

i) Thermo ionic Emission :-

when a metal is heated its free e- get sufficient thermal energy and they can overcome the surface barrier. This type of method for removal of e- is called Thermo ionic Emission and Emitted e^- is called Thermo Electrons.

ii) Field Emission :-

when a metal surface is subjected to very high Electric field of the order of 10^3 to ~~10 volt~~ 10^8 Volt, Electrons are emitted from it. this type of Emission known as field emission.

also Ans.6

iii) Photo Electric Emission :-

It is the process in which electrons are emitted from a metal surface when Electromagnetic radiations of high frequency are incident on it. The emitted electrons are known as Photo Electrons but the rate of emission is very slow.

iv) Secondary Emission :-

When a fast moving electron strike a metal surface, they transfer some of their energy to the free electron, therefore energy of free electron becomes more and they get ejected from metal surface.

The photon picture of Electromagnetic radiation:-

i) The light of sufficiently high frequency falls on a metal surface electron are emitted this phenomena is known as Photo Electric Effect.

ii) In year 1890 Max plank proposed his quantum theory the energy of an electromagnetic wave is not continously distributed over the wave form, Instead an electromagnetic wave travels in the form of discrete packets or bundles of energy called "quantum". One quantum of light radiation is called photon which travels with the speed of light.

Property of photons :-

i) All photons emitted by any source travels through free space with speed of light that is 3×10^8 m/s.

ii) Energy of photon,

$$E = hF = h\nu$$

where, $h \to$ plank constant

$$h = 6.626 \times 10^{-34} \text{ Js}$$

$$F = \nu = \frac{c}{\lambda}, \quad c \to \text{velocity of light}$$

$\lambda \to$ wave length

iii)

$$E = hF$$

$$E = \frac{hc}{\lambda}$$

$$E = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{\lambda}$$

$$\boxed{E = \frac{1240}{\lambda} \text{ eV}}$$ eV $\to$ Electron volt.

iv) The moving mass of a photon can be determine by Enstein Mass Energy relationship.

$$\boxed{E = mc^2}$$

$$\boxed{E = h\nu}$$

Equating Both eq^n.

$$mc^2 = h\nu$$

$$\boxed{m = \frac{h\nu}{c^2}}$$

v) Linear momentum of photon is ~~can be determine from~~

$$\boxed{P = mc}$$

vi) photons are electrically neutral and not deflected by Electric field and magnetic field.

vii) If the Intensity of the light of given wave length is increased, there is an increase in no. of photons incident on a given area in a given time but the energy of each photon remains same.

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viii) From theory of relativity mass of moving particle is given by

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$m = \frac{m_0 c}{\sqrt{c^2 - v^2}}$$

where, $m_0 \rightarrow$ rest mass of particle

Since photon moves with speed of light

then

$$\Rightarrow \quad m = \frac{m_0 c}{\sqrt{c^2 - c^2}}$$

$$\Rightarrow \quad m = \frac{m_0 c}{\sqrt{0}}$$

$$\Rightarrow \quad \frac{m(0)}{c} = m_0$$

$$\Rightarrow \quad \boxed{m_0 = 0}$$

It means that at any time we can not analyse that photon is in rest that is photon moves with the speed of light (3×10^8).

Numerical

1. what is the frequency of photon whose energy is 66.3 eV.

Sol.

Given
66.3 eV
$66.3 \times 1.6 \times 10^{-19}$

$$\Rightarrow \quad E = hF$$

$$\Rightarrow \quad \frac{66.3}{h} = F$$

$$\Rightarrow \quad F = \frac{66.3 \times 1.6 \times 10^{-19}}{6.626 \times 10^{-34}}$$

$$\Rightarrow \quad F = \frac{66.3 \times 1.6}{6.626} \times 10^{15}$$

$$\Rightarrow \quad F = \frac{663}{66.3} \times 1.6 \times 10^{15}$$

$$\Rightarrow \quad F = 16 \times 10^{15} \text{ Hz}.$$

(2) Calculate the no. of photons in 6.62 J of radiation Energy of frequency 10^{12} Hz. Given that $h = 6.62 \times 10^{-34}$ Js.

Sol. Given, $h = 6.62 \times 10^{-34}$ JS

$E_\gamma = 6.62$

$\Rightarrow E = hF$

$\Rightarrow 6.62 = 6.62 \times 10^{-34} \times F$

$\Rightarrow 10^{34} = F$

$\Rightarrow 10^{34} = \frac{1}{T}$

$\Rightarrow T = 10^{-34}$

$\Rightarrow E_\gamma =$ (no. of photons) (Energy)

$\Rightarrow 6.62 = n(hF)$

$\Rightarrow 6.62 = n(6.62 \times 10^{-34} \times F)$

$\Rightarrow 6.62 = n(6.62 \times 10^{-34} \times 10^{12})$

$\Rightarrow \cancel{6.62 = n}$

$\Rightarrow 1 = n \times 10^{-22}$

$\Rightarrow 10^{+22} = n$

$\Rightarrow \boxed{n = 10^{22}}$

Hence no. of photons is 10^{22}.

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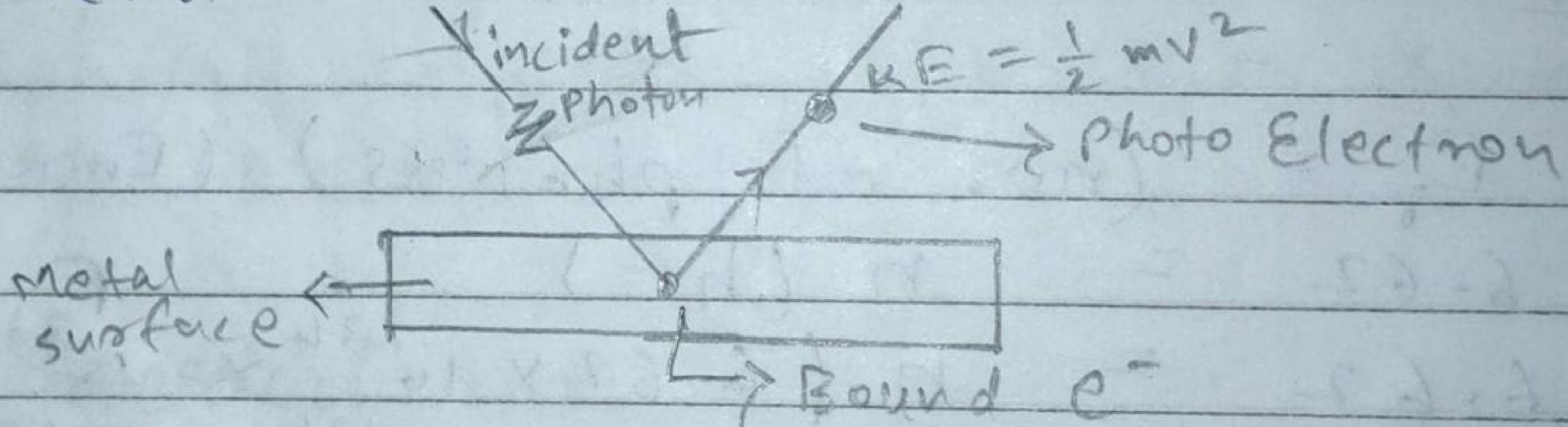
Einstein's Photo Electric Effect :-

i) In year 1905, Einstein Explain photo electric effect on the basis of planck quantum theory.

ii) The main points of Einstein theory of photo electric effect are :-

a) photo electric effect is the result of interaction of two particles, one a photon and other an electron of the metal.



b) The minimum energy required to liberate an electron from the metal surface is called work function (ϕ_0) of the metal

c) Each photon interacts with one electron. The energy $h\nu$ of incident photon is used up in two parts :-

1) a part of energy is used in work function (ϕ_o) for liberating the e^- from metal surface.

2) The remaining energy of the photon is used in imparting kinetic energy to the ejected e^-.

Therefore

d) By the conservation of energy ⟹

Energy of incident photon = (max. Kinetic energy of photo electron) + (work function)

$$\boxed{E = h\nu = \frac{1}{2} m v_{max}^2 + \phi_o}$$

$$\Rightarrow \boxed{\frac{1}{2} m v_{max}^2 = h\nu - \phi_o}$$

$$\Rightarrow \boxed{K.E._{max} = h\nu - \phi_o} \longrightarrow (i).$$

e) If the incident photon is of Threshold frequency ν_o then

$E = h\nu_o$ is just sufficient to free the electron from metal surface and does not give ~~the~~ it kinetic energy.

from (i),

$$0 = h\nu_o - \phi_o$$

$$\boxed{\phi_0 = h\nu_0}$$

So,

$$K.E_{max} = h\nu - h\nu_0$$

$$\boxed{K.E_{max} = h(\nu - \nu_0)} \longrightarrow (2)$$

Eqⁿ (1) and (2) is called Einstein photo electric emmison.

~~Experimental study of Photo Electric Effect:-~~

Threshold frequency :-

i) Threshold frequency is the minimum frequency from which low frequency light can not emit electrons from a metal surface, no matter how ~~high~~ the intensity of light is.

Dual Nature of radiation :-

Q. What do you mean by dual nature of radiation?

Ans. The phenomena light interference, diffraction and polarization etc. can be explain only on the basis of wave nature of light.

on the other hand phenomena light photoelectric effect, compton effect etc. can be explain only in terms of quantum theory of light. This indicates that light radiation has dual nature that is, it is sometimes behaves like a wave and sometimes as a particle.

Dual Nature of Matter:-

→ De-Broglie waves:-

According to louis Victo De-broglie (in year 1924) - "material particles in motion should display wave light properties".

This reasoning was based on the following consideration

a) The whole energy in the universe in the form of electromagnetic radiation and matter.

b) ~~Measure~~ Nature loves symmetry:-

since radiation has dual nature, from symmetrical consideration de-broglie predicted that matter must have dual nature.

Thus the particle like electrons, protons, Neutrons etc. should not only behave like mass point but they should also ~~execute~~ exibits wave nature when in motion.

Q. Define De-Broglie wave.

Ans. The wave associated with material particles in motion are called matter or De-Broglie waves.

and their wave length is called De-Broglie wave length.

Q. Derive the expression for De-Broglie wave ~~length~~ equation.

Ans. According to plank quantum theory,

$$E = hF \longrightarrow (1)$$

where, $h \rightarrow$ Plank constant
$F \rightarrow$ frequency of proton

Consider photon mass is m
So energy associated with it by,

$$E = mc^2 \longrightarrow (2)$$ {Einstein Energy-mass relationship}

from (1) & (2),

$$\Rightarrow hF = mc^2$$

$$\Rightarrow h\frac{c}{\lambda} = mc^2$$

$$\Rightarrow \frac{h}{\lambda} = mc$$

$$\Rightarrow \lambda = \frac{h}{mc}$$

$$\lambda = \frac{h}{P} \quad \left\{ \begin{array}{l} \text{where, } P \rightarrow \text{momentum of photon} \\ P = mc \end{array} \right\}$$

According to De-Broglie Hypothesis, it must be true for material particle like electron, proton, neutron etc.

$$\boxed{\lambda = \frac{h}{P}}$$

where, $m \rightarrow$ mass of particle
$P \rightarrow$ momentum of particle.

Therefore,

$$\boxed{\lambda \propto \frac{1}{P}}$$

Therefore the wave length (λ) of moving particle is inversaly proportional to particle momentum.

If $v = 0$ then λ will be infinite.
This implies that waves are associated with material particles only when they are in motion.

Debroglies wavelength

i) Consider an electron of mass "m" and charge "e". let "v" be the final velocity obtained by the electron when it is accelerated from rest through potential diff. of "V"

ii) The kinetic Energy gained by the electron is equal to work done on the electron by the electric field.

Therefor K.E. of e^- will be,

$$K \cancel{K.E.} = \frac{1}{2} mv^2$$

$$2K \cancel{2K.E.} = mv^2$$

$$2K \cancel{2K.E.} = \frac{m^2 v^2}{m}$$

$$2Km = (mv)^2$$

$$2Km = p^2$$

or

$$K = \frac{1}{2} \frac{p^2}{m}$$

⇒ Kinetic energy = Work done

$$\frac{1}{2} \frac{p^2}{m} = eV$$

$$\boxed{p = \sqrt{2meV}}$$

we know that from Debroglie wave equation,

$$\boxed{\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}} = \frac{h}{\sqrt{2mK}}}$$

This eqn shows the debroglies wave length of e^-.

$$\because \quad \lambda = \frac{h}{\sqrt{2meV}}$$

and $h = 6.626 \times 10^{-34}$ J.s.
$e = 1.6 \times 10^{-19}$ C
$m_e = 9.1 \times 10^{-31}$ kg

$$\lambda = \frac{6.626 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times V}}$$

$$\lambda = \frac{12.3 \times 10^{-10}}{\sqrt{V}}$$

$$\boxed{\lambda = \frac{12.3}{\sqrt{V}} A^{\circ}}$$ or $$\lambda = \frac{1.23}{\sqrt{V}} \text{ nano meter}$$