DUAL NATURE OF MATTER & RADIATION

I) PHOTOELECTRIC EFFECT

1. **Photons** :
   a) Photons are packets of energy which are emitted by source of radiations.
   b) Photons travel in straight line with speed of light (3×10^8 m/s).
   c) Photons are electrically neutral.
   d) Photons are not deflected by electric and magnetic fields.
   e) If the frequency of radiation is ν then energy of photon (E) = $h\nu = \frac{hc}{\lambda}$

   Where c = velocity of light

   λ = wavelength of radiation

   h = Planck's constant = 6.6×10^{-34} J.s.

   f) The number of photons of wavelength λ emitted in t sec. from a lamp of power p is given by $n = \frac{Pt\lambda}{hc} = \frac{Pt}{h\nu}$

2. a) The emission of electrons from the surface of a metal when exposed to electromagnetic radiation of a suitable frequency is called photoelectric effect.
   b) This phenomenon was discovered by Hertz and experimentally verified by Hallwachs, Lenard, J.J.Thomson, R.A.Millikan and others.
   c) The current due to photoelectrons is called photoelectric current. It is independent of frequency of light and energy of incident light. The photoelectric current does not follow the ohm's law.
   d) The photoelectric effect is based on law of conservation of energy
   e) Alkali metals like lithium, sodium, potassium, cesium etc emit electrons with visible light only.

3. **Lenard laws of photoelectric emission**

   i. Photoelectric emission is an instantaneous phenomenon. i.e., there is no time lag between the falling of light and emission of photoelectrons. (time lag is 10^{-9} second).
   ii. For every metal surface, there is a limiting frequency below which no photoelectrons are produced. This frequency is called **threshold frequency** (ν_0). Different metals have different threshold frequencies. The corresponding wavelengths are called **threshold wavelengths** (λ_0) or **cut-off wavelengths.**
   iii. The rate of emission of photoelectrons from the surface of a metal is directly proportional to the intensity of the light falling on it.
   iv. The maximum kinetic energy of the emitted photoelectrons does not depend upon the intensity of the incident radiation.
   v. The maximum kinetic energy of the emitted photoelectrons is directly proportional to the frequency of the incident radiation and depends on the nature of metals.
   vi. The photoelectric emission is independent of temperature of the cathode.

4. The velocity of electrons ejected from near the surface will be greater than those coming from the interior of the substance.

5. **Work function:** The minimum energy required to remove an electron from the surface of a metal without giving kinetic energy to the electron is called *work function* (W). Its unit is eV

6. Among the alkali metals (sodium, potassium, rubidium, cesium) cesium is the best metal for photoelectric emission as its work function is the least.
7. As the atomic number of elements increases, the work function will decrease.
8. When the temperature of a metal increases, the work function will decrease.
9. **Threshold frequency (ν_0) :**
   i) It is the minimum frequency of the incident radiation below which photo-electrons are not emitted from a metal surface.
   ii) The work function, $W = h\nu_0$, where h is Planck's constant.
   iii) The threshold frequency of sodium is 5.6×10^{14} Hz., that for potassium 5.26×10^{14} Hz and for Caesium 4.55×10^{14} Hz.

10. **Threshold Wavelength (λ_0):**
   i) It is the maximum wavelength of the incident radiation above which there is no photo electric emission from the surface of a metal.
   ii) The threshold wavelength for sodium is 5400A°, that for potassium 5700 A° and for Caesium 6590 A°.
   iii) The work function, $W = h\nu_0 = \frac{hc}{\lambda_0}$
   iv) If W is in ev and λ_0 in A°, the above equation can be written as $W = \frac{12400}{\lambda_0} eV$.

11. **Stopping potential (V_s):**
   i) The stopping potential is that value of the retarding potential difference to be applied between the surface of a photosensitive plate and the electrode of the collector, which is just sufficient to stop the most energetic photo electrons emitted.
   ii) The stopping potential or cut off potential V_s is measure of the maximum K.E. of the emitted photo electrons.
   iii) $qV_s = K = \frac{1}{2}mv^2$ Joules

   Where q is the charge of the electron in C and V_s is the stopping potential in Volts.
   iv) If the maximum K.E. of electron is x eV then the stopping potential is given by $V_s = -x$ volt.
   v) Stopping potential (V_s) ∝ frequency of incident radiation and $V_s \propto \frac{1}{\text{Work function}}$.
   vi) Stopping potential is independent of intensity of incident radiation, power of the source of light and distance between sources of light and photo metal.
   vii) If atomic number of photo metal increases then stopping potential also increases because work function decreases.

12. If stopping potentials corresponding to wavelengths λ_1 and λ_2 ($>\lambda_1$) are V_1 and V_2 then work function of metal, $W = \frac{\lambda_1 V_1 - \lambda_2 V_2}{\lambda_2 - \lambda_1}$.

13. If wavelength of incident light is changed from λ_1 to λ_2 ($< \lambda_1$) then the charge in stopping potential,

$$V_2 - V_1 = \frac{hc}{e}\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)$$

Where e = charge of electron.

14. Einstein's explanation of photoelectric effect:

a) Einstein treated photoelectric effect as a collision between a photon and the atom of photo metal.

b) When a photon strikes a metal surface, the entire energy of the photon is transferred to a single electron in the emitter. The energy supplied to the electron is used in two ways

i) Part of the energy is used in ejecting the electron from the metal (work function)

ii) The remaining energy is used to provide K.E. to the ejected electrons.

c) Einstein's photoelectric equation is given by

$h\nu = W + \frac{1}{2}mv^2$ or $h\nu = W + K.E_{max}$

$h\nu = h\nu_0 + \frac{1}{2}mv^2$

Here ν is frequency of incident radiation and ν_0 is threshold frequency, $\frac{1}{2}mv^2$ is maximum KE of electrons.

K. E_{max} or $\frac{1}{2}mv^2 = h(\nu - \nu_0)$

$\Rightarrow \frac{1}{2}mv^2 = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$

As $K.E_{max} = V_s e$, we can write

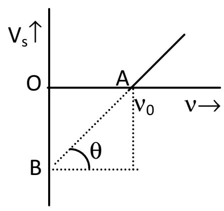
$V_s e = h(\nu - \nu_0)$

$\Rightarrow V_s e = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$

15. Millikan experiment:

a) R.A. Millikan verified Einstein's equation experimentally. Millikan measured stopping potential for different frequencies of incident radiation for a given emitter.

b) Einstein photoelectric equations verified by Millikan's for low frequencies of radiations.



c) Millikan plotted a graph between V_s and ỹThe graph shape is a straight line as shown in the figure. The slop of the graph =h/e.

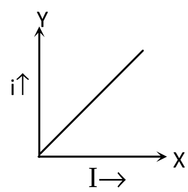
d) Determination of h:

1) $h = \frac{K_2 - K_1}{\nu_2 - \nu_1} = \frac{e(V_{S_2} - V_{S1})}{\nu_2 - \nu_1}$

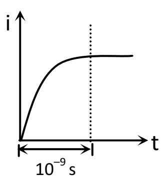
2) $h = \frac{(K_2 - K_1)\lambda_1\lambda_2}{c(\lambda_1 - \lambda_2)}$

16. Graphs on photoelectric effect:

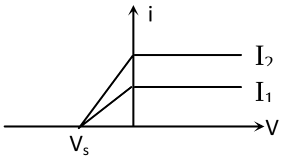
a) Variation of photocurrent with intensity of incident light on the photo metal is represented by this graph. I–photocurrent and I– intensity of light.

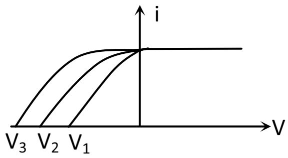


b) Time dependence of photocurrent is represented by this graph. It takes about a nano second for the photocurrent to attain the saturation value.

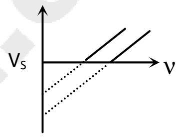


c) Variation of photocurrent with the accelerating potential difference or anode potential for different frequencies is as shown in this graph. Here intensity of each light is same. V_1, V_2 and V_3 are different stopping potentials for different incident frequencies $\nu_1 \nu_2$ and ν_3 respectively. ($\nu_3 > \nu_2 > \nu_1$ and $V_3 > V_2 > V_1$) From this graph it is observed that stopping potential or maximum K.E. of photoelectron depends on incident frequency but independent of intensity.



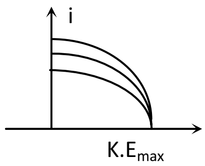


d) Variation of photocurrent with intensity of incident radiation for the same frequency is as shown. As the positive potential increases, the photocurrent reaches a saturation value. If the intensity is increased by keeping the frequency same photocurrent and saturation current increase. Hence V_s is the negative potential which is stopping potential. V_s is independent of intensity.

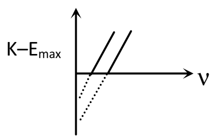


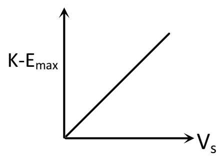
e) For the same frequency, maximum K.E. for different photocurrents or incident intensities varies as shown in this graph.

f) The variation of stopping potential with frequency of incident radiation will be as shown in this graph. It is a straight line with slope *h/e*. Intercept on frequency axis gives the threshold frequency of the photo metal. Intercept on Y –axis (V_s axis) gives $h\nu_0/e$ when the graphs are drawn for different metals they are parallel straight lines with the same slope *h/e*. Different intercepts on X – axis denote different threshold frequencies for different photo metals.

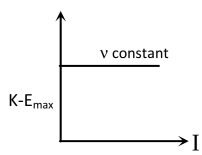


g) The variation of maximum K.E. of photoelectrons with frequency of incident radiation will be as shown in the graph. It is a straight line with slope *h*. Intercept on X-axis gives threshold frequency. Intercept on Y-axis gives work function when the graphs are drawn for different metals, they are parallel straight lines with same slope different intercepts on X-axis denote different threshold frequencies of different photo metals.





h) If a graph is drawn by plotting maximum kinetic energy on Y-axis and stopping potential on X-axis it will be a straight line passing through the origin. Slope of the line gives electronic charge 'e'.



i) If a graph is drawn by plotting $K.E_{max}$ or Y-axis and intensity on X-axis, it will be a straight live parallel to X – axis.