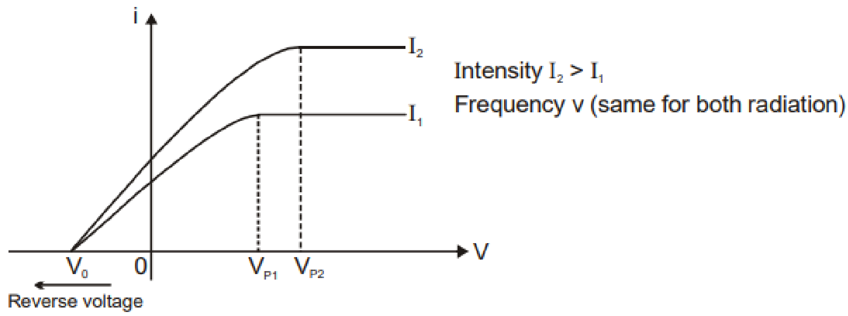
DUAL NATURE OF RADIATION

PHOTOELECTRIC EFFECT AND WAVE THEORY OF LIGHT

CUT OFF POTENTIAL OR STOPPING POTENTIAL

When the polarity is reversed, electrons experience retardation in the discharge tube. As the potential difference is increased with reverse polarity, the number of electrons reaching the anode decreases, resulting in a reduction in the photoelectric current in the circuit. This is illustrated in the accompanying figure, depicting the variation of current with an increase in voltage across the discharge tube in the opposite direction.

It is observed that at a specific reverse voltage, denoted as V_0, the current in the circuit becomes zero. This voltage represents the point at which the faster electrons emitted from the cathode are retarded and stopped just before reaching the anode.



The voltage V_0 can be calculated using equation (1) by substituting vf = 0, where the equation is derived from the relationship between stopping potential and the kinetic energy of electrons.

$$\frac{1}{2}mv_{\max}^2 - eV_0 = 0$$

$$eV_0 = \frac{1}{2}mV_{\max}^2$$

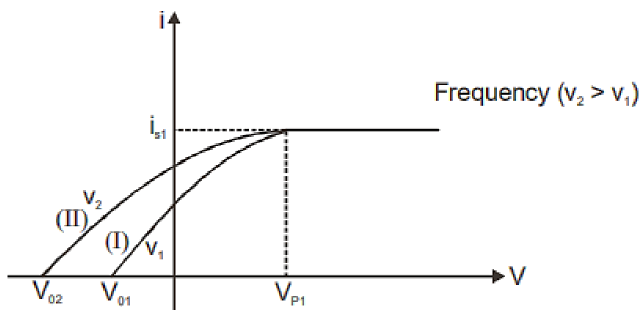
$$V_0 = \frac{\frac{1}{2}mv_{\max}^2}{e} \qquad \text{... (2)}$$

$$V_0 = \frac{hv - \phi}{e} \qquad \text{... (3)}$$

In the graph shown, it is observed that the curves plotted for two different intensities, I_1 and I_2, have the same V_0. The current in both cases is cut off at the same reverse potential V_0. This can be explained by equations (2) and (3), indicating that V0 depends solely on the maximum kinetic energy of ejected electrons, which, in turn, is determined by the frequency of light and remains unaffected by the intensity of light. Therefore, in the aforementioned graphs where the frequency of incident light is the same, the value of V_0 is consistent. This reverse potential difference V_0, where the fastest photoelectron is stopped, and the current in the circuit becomes zero, is referred to as the cutoff potential or stopping potential.

EFFECT OF CHANGE IN FREQUENCY OF LIGHT ON STOPPING POTENTIAL:

If the experiment is repeated, keeping the number of incident photons constant and increasing the frequency of incident light, the resulting variation graph of current with voltage can be illustrated, as depicted in the accompanying figure.



The graph is generated for two incident light beams, denoted by different frequencies v_1 and v_2, while maintaining the same photon flux. Since the number of ejected photoelectrons remains constant for the two instances of incident light, it is observed that the pinch-off voltage (V_{01}) and saturation current is 1 are identical. However, due to the varying kinetic energy of the fastest electron in the two cases resulting from different frequencies, the stopping potential differs. In graph II, where the frequency of incident light is higher, the maximum kinetic energy of photoelectrons is also elevated, requiring a higher stopping potential. Therefore, V_{01} and V_{02} can be expressed as follows:

$$V_{01} = \frac{hv_1 - \phi}{e} \quad \dots (4)$$

$$V_{02} = \frac{hv_2 - \phi}{e} \quad \dots (5)$$

Generally, for a specific metal characterized by a work function denoted as ϕ, if V_0 represents the stopping potential for an incident light with frequency v, the relationship is expressed as follows:

$$eV_0 = hv - \phi$$

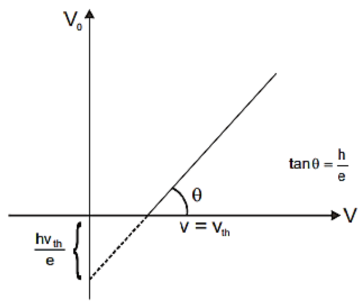
$$eV_0 = hv - hv_{th} \quad \dots (6)$$

$$V_0 = \left(\frac{h}{e}\right)v - \frac{hv_{the}}{e} \qquad \text{... (7)}$$

Equation (7) illustrates that the stopping potential V_0 exhibits a linear proportionality to the frequency v of the incident light. This relationship between the stopping potential and frequency is depicted in the accompanying figure. The equation (6) can be expressed as:

$$\frac{1}{2}mv_{\max}^2 = eV_0 = h\left(V - V_{th}\right) \qquad \text{... (8)}$$

Equation (8) is recognized as Einstein's Photoelectric Effect equation, offering a direct correlation between the maximum kinetic energy, stopping potential, frequency of incident light, and the threshold frequency. This equation serves as a fundamental expression to describe the intricate interplay of these parameters in the context of the photoelectric effect.



Example.

Determine the frequency of light causing the complete cessation of electrons ejected from a metal surface when subjected to a retarding potential of 3 V. The onset of the photoelectric effect in this metal occurs at a frequency of $6 \times 10^{14}\text{sec}_{-1}$. Calculate the work function for this particular metal.

Solution.

The critical frequency for the specified metal surface is

$$V_{th} = 6\times10^{14}\,Hz$$

Hence, the work function for the metal surface is

$$\phi = hv_{th} = 6.63\times10^{-34}\times6\times10^{-14} = 3.978\times10^{-19}\,J$$

As stopping potential for the ejected electrons is 3V, the maximum kinetic energy of ejected electrons will be

$$KE_{\max} = 3eV = 3\times1.6\times10^{-19}\,J = 4.8\times10^{-19}\,J$$

According to photo electric effect equation, we have

$$hv = hv_{th} = KE_{\max}$$

$$V = \frac{\phi + KE_{\max}}{h} = \frac{3.978\times10^{-19} + 4.8\times10^{-19}}{6.63\times10^{-34}} = 1.32\times10^{15}\,Hz$$