Question 29. Consider a 20 W bulb emitting light of wavelength 5000 Å and shining on a metal surface kept at a distance 2 m. Assume that the metal surface has work function of 2 eV and that each atom on the metal surface can be treated as a circular disk of radius 1.5 Å.

(i) Estimate number of photons emitted by the bulb per second. [Assume no other losses]

(ii) Will there be photoelectric emission?

(iii) How much time would be required by the atomic disk to receive energy equal to work function (2 eV)?

(iv) How many photons would atomic disk receive within time duration calculated in (iii) above?

(v) Can you explain how photoelectric effect was observed instantaneously?

Solution:

According to the problem, $P = 20$ W, $\lambda = 5000$ Å $= 5000 \times 10^{-10}$ m, distance (d) = 2 m, work function $\phi_0 = 2$ eV, radius $r = 1.5$ A $= 1.5 \times 10^{-10}$ m

Now, Number of photon emitted by bulb per second, $n' = \frac{dN}{dt}$

(i) Number of photon emitted by bulb per second is $n' = \frac{p}{hc/\lambda} = \frac{p\lambda}{hc}$

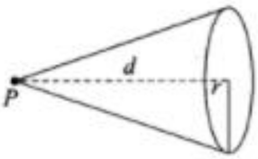
$$= \frac{20 \times (5000 \times 10^{-10})}{(6.62 \times 10^{-34}) \times (3 \times 10^8)}$$

$$\Rightarrow \quad n' = 5 \times 10^{19}/\text{sec}$$

(ii) Energy of the incident photon

$$= \frac{hc}{\lambda} = \frac{(6.62 \times 10^{-34})(3 \times 10^8)}{5000 \times 10^{-10} \times 1.6 \times 10^{-19}} = 2.48 \text{ eV}$$

As this energy is greater than 2 eV (i.e., work function of metal surface), hence photoelectric emission takes place.



(iii) Let Δt be the time spent in getting the energy ϕ = (work function of metal).
Consider the figure, if P is the power of source then energy recieved by atomic disc

$$\frac{P}{4\pi d^2} \times \pi r^2 \Delta t = \phi_0$$

$$\Rightarrow \quad \Delta t = \frac{4\phi_0 d^2}{Pr^2}$$

$$= \frac{4 \times (2 \times 1.6 \times 10^{-19}) \times 2^2}{20 \times (1.5 \times 10^{-10})^2} \approx 28.4\text{s}$$

(iv) Number of photons received by atomic disc in time Δt is

$$N = \frac{n' \times \pi r^2}{4\pi d^2} \times \Delta t$$

$$= \frac{n' r^2 \Delta t}{4d^2}$$

$$= \frac{(5 \times 10^{19}) \times (1.5 \times 10^{-10})^2 \times 28.4}{4 \times (2)^2} \approx 2$$

Now let us discuss the last part in detail. As time of emission of electrons is 11.04 s.

Hence, in this-problem, the photoelectric emission is not instantaneous.

(v) In photoelectric emission, there is an collision between incident photon and free electron of the metal surface, which lasts for very very short interval of time ($\approx 10^{-9}$ s), hence we say photoelectric emission is instantaneous.