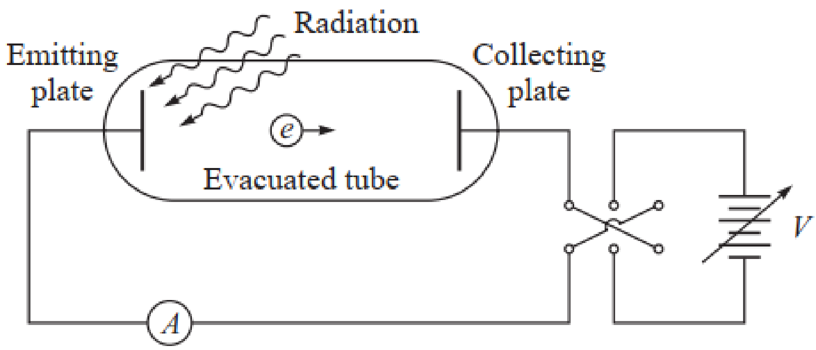
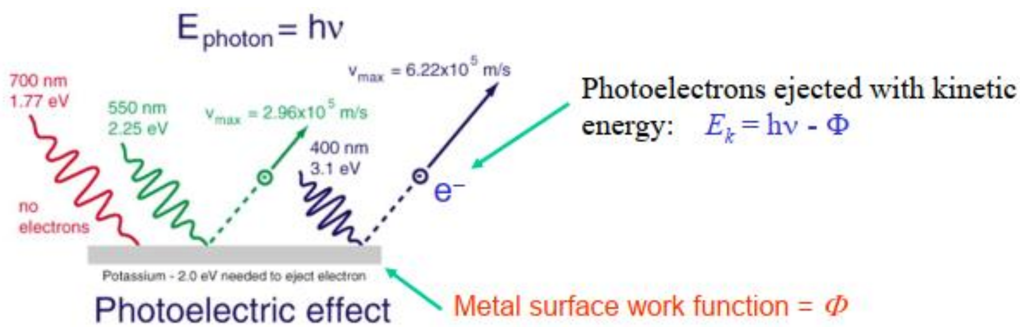
1.2 Photoelectric Effect (Einstein 1905)

When electromagnetic radiation of high enough frequency is incident on a metal surface, electrons are emitted from the surface. This phenomenon is called photoelectric effect. The emitted electrons are generally called photoelectrons. This effect was discovered by Heinrich Hertz in 1887.





The following interesting results were obtained in the study:

(1) No electrons are emitted if the incident radiation has a frequency less than a threshold value ν_o. The value of ν_o varies from metal to metal.

(2) The kinetic energy of the emitted electrons varies from zero to a maximum value. The maximum value of energy depends on the frequency and not on the intensity of radiation. It varies linearly with the frequency.

(3) The number of photoelectrons emitted per second, or the photoelectric current, is proportional to the intensity of radiation but is independent of the frequency.

(4) The photoelectric emission is an instantaneous process, i.e., there is negligible time lag between the incidence of radiation and the emission of electrons, regardless of how low the intensity of radiation is.

Light consists of discrete packets (quanta) of energy = photons.

…(1.5)

$$E = h\nu = E_k + \Phi$$

$$\nu = \frac{\lambda}{c} \qquad \Phi = h\nu_o \qquad E_k = \frac{1}{2}mv^2$$

Photoelectrons ejected with kinetic energy:

$$E_k = h\nu - \Phi = h\nu - h\nu_o \qquad \ldots(1.6)$$

Each photon has: Energy = Planks constant × Frequency

Energy in Joules: $E = h\nu = 6.626 \times 10^{-34}(J.s) \times \nu(s^{-1})$

Or, $E = \frac{hc}{\lambda} = \frac{1.99\times10^{-25}(J.m)}{\lambda(m)}$

Energy in (eV): $E = h\nu = 4.14 \times 10^{-15}(eV.s) \times \nu(s^{-1})$

Or, $E = \frac{hc}{\lambda} = \frac{1.99\times10^{-25}(J.m)}{\lambda(m)} = \frac{1240(eV.nm)}{\lambda(nm)}$

Example: The threshold (cutoff) frequency is 1.2 x 10^{15}Hz. What is the threshold wavelength? What is the work function of tin?

$$\nu_o = 1.2 \times 10^{15} Hz$$

$$\lambda_o = \frac{c}{\nu_o} = \frac{3 \times 10^8}{1.2 \times 10^{15}} = 2.5 \times 10^{-7} m = 250\ nm$$

$$\Phi = h\nu_o = 6.625 \times 10^{-34} \times 1.2 \times 10^{15} = 7.95 \times 10^{-19} J$$

$$\Phi = \frac{7.95 \times 10^{-19}}{1.6 \times 10^{-19}} = 4.97\ eV$$

Einstein's Theory—Photons

- **Einstein** explained the photoelectric effect using Planck's quantum hypothesis. In order to explain the spectral distribution of **blackbody radiation**,

- **Planck** had assumed that the exchange of energy between the walls of a cavity and the radiation of frequency ν takes place in quanta of magnitude $h\nu$, where h is called Planck's constant. ***Einstein*** *suggested that the incident radiation itself acts like quanta of energy* $(h\nu)$. These quanta later came to be known as photons.
- When a photon collides with an electron in the metal surface, it can be absorbed, imparting all its energy to the electron immediately.
- If the work function of the metal is Φ, then this much energy is expanded to remove the electron from the surface.

Therefore, the maximum kinetic energy E_{max}, and the corresponding velocity v_{max}, of the emitted electron are given by;

$$E_{max} = \frac{1}{2}mv_{max}^2 = h\nu - \Phi \qquad \ldots(1.7)$$

This is called Einstein's photoelectric equation. It shows that E_{max} varies linearly with the frequency ν of the incident radiation.

ν_o is the threshold (cutoff) frequency Thus; $\Phi = h\nu_o$ then

$$E_{max} = h\nu - \Phi = h(\nu - \nu_o) \qquad \ldots(1.8)$$

Clearly, no emission is possible if $\nu \leq \nu_o$.

Stopping or cut-off Potential; For a certain value V_o of this negative potential, the most energetic electrons are just turned back and therefore the photoelectric current becomes zero.

$$eV_0 = E_{\max}$$

$$eV_0 = h(\nu - \nu_0)$$

$$\boxed{V_0 = \frac{h}{e}(\nu - \nu_0)} \qquad \ldots(1.9)$$

Conclusion:

An increase in the intensity of radiation results in an increase in the number of photons striking the metal per second but not in the energy of single photons.

Therefore, the number of photoelectrons emitted per second, and hence the photoelectric current, increases, but not the energy of photoelectrons.

Since the electron emission is the result of a direct collision between an electron and a photon, there is no time delay before emission starts.

PROBLEM: Find the number of photons emitted per second by a 40 W source of monochromatic light of wavelength 6000 Å.

Solution: Let the number of photons be *n*. Then

$$nh\nu = E$$

$$n = \frac{E}{h\nu} = \frac{E\lambda}{hc}$$

$$= \frac{40 \times 6000 \times 10^{-10}}{6.63 \times 10^{-34} \times 3 \times 10^{8}}$$

$$= \boxed{12.06 \times 10^{19}}$$

H.W

1- The work function of a metal is 3.45 eV. What is the maximum wavelength of a photon that can eject an electron from the metal?

2- A metal of work function 3.0 eV is illuminated by light of wavelength 3000 Å. Calculate (a) the threshold frequency, (b) the maximum energy of photoelectrons, and (c) the stopping potential.

3- (a) A stopping potential of 0.82 V is required to stop the emission of photoelectrons from the surface of a metal by light of wavelength 4000 Å. For light of wavelength 3000 Å, the stopping potential is 1.85 V. Find the value of Planck's constant.

(b) At stopping potential, if the wavelength of the incident light is kept fixed at 4000 Å but the intensity of light is increased two times, will photoelectric current be obtained? Give reasons for your answer.

4- Light of wavelength 4560 Å and power $1mW$ is incident on a Caesium surface. Calculate the photoelectric current, assuming a quantum efficiency of 0.5%. Work function of Caesium =1.93 eV.