ATOMIC PHYSICS

2.PHOTOELECTRIC EFFECT

POINTS TO REMEMBER

1. **PHOTOELECTRIC EFFECT:**
   a. Photoelectric effect was discovered by Hertz, demonstrated by Hallwacks and theoretically explained by Einstein.
   b. When electromagnetic radiations like UV rays, x-rays, visible light is incident on alkali metals like lithium, sodium etc., then electrons are emitted from those metals.
   c. These electrons are called photoelectrons and this effect is called photoelectric effect and the current developed is called photocurrent.
   d. Photocurrent is of order of 10^{-6}amp
2. **Laws of Photoelectric Effect:**
   a. The frequency of incident radiation below which no photoelectron is emitted from the photo surface is called threshold frequency (γ_0).
   b. The maximum velocity or kinetic energy of the ejected electron depends upon the frequency of incident light. It is independent of the intensity incident radiation.
   c. The photoelectric (saturation) current depends upon the intensity of the incident radiation. It is independent of frequency of incident light.
   d. Photoelectric effect is an instantaneous process. The time lag between incidence and emission of electrons is about 10^{-9}sec. (Photoelectric current I $\alpha \frac{1}{d^2}$).
3. **Work Function:**
   a. It is the minimum energy of incident radiation required to just take out an electron from the photo surface. It is expressed in eV. $W_0 = h\,\gamma_0$ Where γ_0 is the threshold frequency.It depends upon the nature of the photo surface.
   b. It is the minimum frequency of the incident radiation below which photo-electrons are not emitted from a metal surface.
   c. In alkali group, as the atomic number increases, work function decreases.
   d. Among alkali metals, work function is minimum for cesium (1.9eV) and maximum for lithium (2.5eV).
   e. For a given frequency of incident photons, smaller the work function, greater the KE of the ejected electrons.
   f. When the temperature of a metal increases, the work function will decrease.
   g. If W is in ev and λ_0 in A°, the above equation can be written as $W = \frac{12400}{\lambda_0}$ eV .

4. Stopping potential (V_s) :
   a. 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.

b. The stopping potential or cut off potential V_s is measure of the maximum K.E. of the emitted photo electrons. $eV_s = K = \frac{1}{2}mv^2$ Where q is the charge of the electron and V_s is the stopping potential in Volts.

5. Einstein's Equation:

a. This obeys the law of conservation of energy.

a. 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.

Einstein's photoelectric equation is given by

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

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

Here γ is frequency of incident radiation and γ_0 is threshold frequency Greater the kinetic energy of electrons greater the stopping potential.

6. Photo electric cell or Photo Cell :

a) Photocells are the most important devices which are based on application of the photoelectric effect. It is called magic eye.

c) There are three kinds of photocells namely photo emissive cell, photovoltaic cell and photoconductive cell.

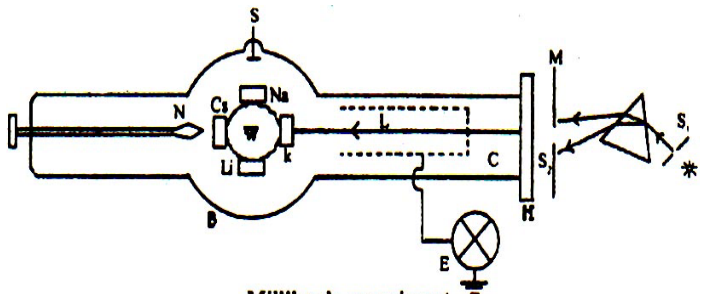
1. Define Photo electric effect? Write the laws of photoelectric effect. (May2009)

Describe Millikan's experiment to verify Einstein's equation.

A: **Photo electric effect:** Photoelectric effect was discovered by Hertz, demonstrated by Hallwacks and theoretically explained by Einstein. When electromagnetic radiations like UV rays, x-rays, visible light is incident on alkali metals like lithium, sodium etc., then electrons are emitted from those metals. These electrons are called photoelectrons and this effect is called photoelectric effect and the current developed is called photoelectric current. Photocurrent is of order of 10^{-6}amp.

<u>Laws of Photoelectric Effect</u>:

- The frequency of incident radiation below which no photoelectron is emitted from the photo surface is called threshold frequency (γ_0).
- The maximum velocity or kinetic energy of the ejected electron depends upon the frequency of incident light. It is independent of the intensity incident radiation.
- The photoelectric (saturation) current depends upon the intensity of the incident radiation. It is independent of frequency of incident light.
- Photoelectric effect is an instantaneous process. The time lag between incidence and emission of electrons is about 10^{-9}sec. (Photoelectric current I $\alpha \frac{1}{d^2}$)



Millikan's experiment

Millikan's experiment:

The apparatus consists of an evacuated bulb B with a rotating wheel W on which different alkali metals can be fixed. By rotating the wheel , light coming from the window is made to incident on the required photo surface.

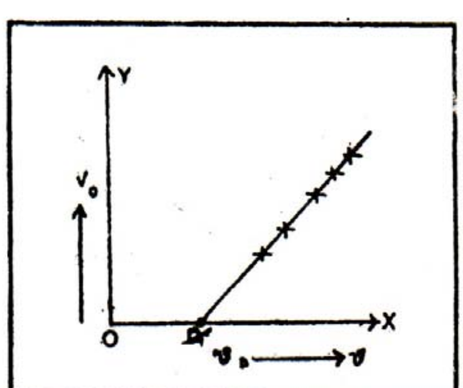
Light coming from a white source S_1 is passed through a prism and a slit, S_2. The required colour of light or light with required wavelength is made to fall on the photo surface through a quartz window 'M'. A hollow cylindrical copper gauze C is used as a collector whose inner side is oxidized to prevent photo emission. The collector is connected to a galvanometer E to detect the photo current. When light falls on the photo surface, photo electrons are emitted and reach the collector which is at a positive potential with respect to the photo metal. When collector potential reduces to zero then collector current will not be zero. This is due to K.E. of photo electrons liberated.

Now the collector is given a negative potential and it is increased until the collector current becomes zero. This is called stopping potential V_0.

The experiment is repeated for various frequencies of incident light υ and stopping potentials V_0 are measured each time. A graph is drawn between frequencies of incident light υ and stopping potentials V_0 and it is shown in the figure.

According to Einstein's photo electric equation

$$h\upsilon = W_0 + \frac{1}{2}mv^2 \Rightarrow h\upsilon = W_0 + eV_s \Rightarrow eV_s = h\upsilon - h\upsilon_0 \Rightarrow V_0 = \left(\frac{h}{e}\right)\upsilon - \left(\frac{W}{e}\right)$$



Variation of stopping potential with frequency

This represents a straight line with slope h/e. From slope of graph (h/e) he calculated the Planck's constant value. It's value obtained is $6.62 \times 10^{-34} J.\sec$. It coincides with 'h' value obtained in other experiment. Hence Millikan's experimentally verified Einstein's photo electric equation.

SHORT ANSWER QUESTIONS

1. **Define the terms work function and threshold frequency? (March2011) Explain the relation between them.**

A: **Work Function:** The minimum amount of energy required to just pluck out an electron from the surface of a given photo metal is defined as work function. It is denoted by W_0.

Threshold Frequency: The minimum frequency of the incident light required to liberate the electrons from the surface of a photo metal is defined as threshold frequency. It is denoted υ_0.

Relation between W_0 and υ_0: If W_0 is the work function of a metal and υ_0 is the threshold frequency, then $W_0 = h\upsilon_0$ Where h is the plank's constant. Its value is $6.62 \times 10^{-34} J - \sec$.

2. **What is a photo-electric cell? Give two applications of photoelectric cell.(June2010)**

A: **Photo-electric Cell:** The device which converts the light energy into electric energy is called photo-electric cell.

A photo electric cell uses the photoelectric effect. It converts light energy into electric energy. A photocell consists of a cathode coated with an alkali metal. A photocell consists of a cathode coated with an alkali metal. Opposite to it a collector is placed. These are arranged in an evacuated bulb.

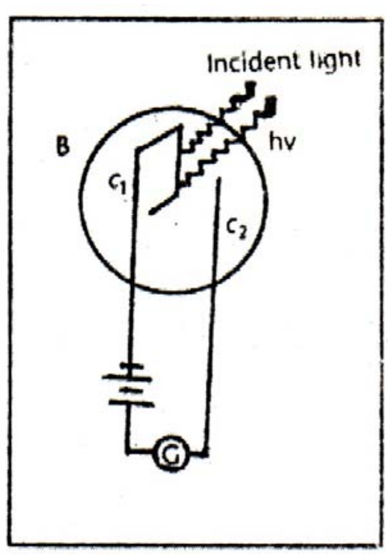


Photo electric cell

When light falls on alkali metal photoelectrons are liberated. They are attracted by the collector due to the positive potential on it and current flows through the circuit. The changes in current are according to the changes in the light falling on alkali metal.

Uses of photo cells:

1. In the recording and reproduction of sound on films.
2. In telephotography, they are used for long distance transmission of pictures.
3. In automatic switching on and off of street lights.
4. In photometry, they are used to compare the illuminating powers of 2 sources.
5. They are used in fire alarms and burglar's alarms.
6. They are used as counting devices.
7. In meteorology, they are used to record the intensity of day light.
8. to measure temperature and to study spectra of celestial bodies.

VERY SHORT ANSWER QUESTIONS

1. What is work function of a metal?

A: Work function (W_0) is defined as the minimum amount of energy required just to liberate an electron from the given photo surface. It depends only on the nature of metal surface.

4. Can X-rays produce photo-electric effect? Calculate the work function of a metal producing photo electrons with X-rays of wave length $1A^0$.

A: No. X-rays cannot produce photo electric effect. Due to their extremely small wave length X-rays will penetrate through the alkali metals.

$$W_0 = hv_0 = \frac{hc}{\lambda_0} = \frac{12400}{1A^0} = 12400eV$$

SOLVED PROBLEMS

3. The work function of a metal is 3.0 eV. It is illuminated by a light or wave length $3\times10^{-7}\ m$. **Calculate (i) threshold frequency, ii) the maximum energy of photoelectrons iii) the stopping potential .(** $h = 6.63\times10^{-34}\ Js$ and $c = 3\times10^{8}\ m/s$).

Sol: i) $W = h\upsilon_0 = 3.0\,eV = 3\times1.6\times10^{-19}\ J$

$$v_0 = \frac{W_0}{h} = \frac{3\times1.6\times10^{-19}}{6.63\times10^{-34}} = 0.72\times10^{15}\,Hz\ .$$

ii) $\lambda = 3\times10^{-7}\, m,\ \nu = \frac{c}{\lambda} = \frac{3\times10^{8}}{3\times10^{-7}} = 1\times10^{15}\, Hz$.

$K_{\max} = h(\nu - \nu_0) = 6.63\times10^{-34}\,(1-0.72)\times10^{15}\, J = 1.86\times10^{-19}\, J$.

iii) $K_{\max} = 1.86\times10^{-19}\, J$ and $e = 1.6\times10^{-19}\, C$

$K_{\max} = eV_0$ Where V_0 is stopping potential

$V_0 = \frac{K_{\max}}{e}$ Or $V_0 = \frac{1.86\times10^{-19}\, J}{1.6\times10^{-19} C} = 1.16V$

4. The work function of a photosensitive element is 2eV. Calculate the maximum velocity of photoelectrons when the element is exposed to a light of wavelength of $4\times10^{3}\, \overset{0}{A}$ ($h = 6.62\times10^{-34}\, Js$, $c = 3\times10^{8}\, ms^{-1}$, $m = 9.1\times10^{-31}\, kg$).

Sol: Einstein's photoelectric equation $\frac{1}{2}mv_{\max}^2 = h\nu - W_0$

$\frac{1}{2}mv_{\max}^2 = h\frac{c}{\lambda} - W_0$.

$\frac{hc}{\lambda} = \frac{6.62\times10^{-34}\times3\times10^{8}}{4\times10^{3}\times10^{-10}} J$ and $W_0 = 2\,eV = 2\times1.6\times10^{-19} J$.

$\mathrm{v}_{\max} = \sqrt{\frac{1.765\times2}{9.1}}\times10^{6} = 6.228\times10^{5}\, ms^{-1}$

5. A metal of work function 4eV is exposed to a radiation of wavelength $140\times10^{-9}\, m$ **.Find the stopping potential by it (** $h = 6.62\times10^{-34}\, Js$ and $c = 3\times10^{8}\, ms^{-1}$)

Sol: $W_0 = 4eV$; $\lambda = 140\times10^{-19} m$

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

$E = \frac{6.62\times3\times10^{8}\times10^{-34}}{140\times10^{-9}} J$ = 8.86eV

But, $eV_0 = E - W_0$ = 886-4 = 4.86eV

$V_0 = 4.86V$

6. The wave length of L_α **line from an element of atomic number 78 is** $'\lambda'$**. If the atomic number is 48, what is the corresponding wavelength of** L_α **line Given b = 6.4 for** L_α **lines**

Sol: $\sqrt{v} = a(Z-b)$, $\sqrt{\frac{v_1}{v_2}} = \frac{(Z_1-b)}{(Z_2-b)} = \frac{78-6.4}{48-6.4} = \frac{71.6}{41.6}$

$\frac{v_1}{v_2} = \frac{5127}{1731} = \frac{\lambda_2}{\lambda_1}$ $\left(\because v = \frac{c}{\lambda}\right)$

$\Rightarrow \lambda_2 = \frac{5127}{1731}\lambda_1$

$\lambda_2 = 2.96\ \lambda_1 = 2.96\lambda$

13. The work function of a metal is 2.5eV. What will be the maximum kinetic energy of the photoelectrons emitted of a radiation of wavelength $3000\overset{0}{A}$ flals on it.
($c = 3\times10^{8}\ ms^{-1}$, $h = 6.63\times10^{-34}\ Js$)

Sol: $W_0 = 2.5eV = 2.5\times1.6\times10^{-19} = 4.0\times10^{-19}\ J$.

$\lambda = 3000\overset{0}{A} = 3000\times10^{-10}\ m$; $\frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{3000\times10^{-10}} = 6.63\times10^{-19}\ J$

$\therefore K_{\max} = \frac{hc}{\lambda} - W_0 = 6.63\times10^{-19} - 4\times10^{-19} = 2.23\times10^{-19}\ J$

<u>UNSOLVED PROBLEMS</u>

7. Work function of a metal is 3.0eV. It is illuminated by light of the wavelength $3\times10^{-7}\ m$ .Calculate the maximum energy of the electron.

Sol: W_0 = 3 e.V ; $\lambda = 3\times10^{-7}\ m = 3000A^0$

K.E $= \frac{1}{2}mv^2 = \frac{hc}{\lambda} - W$

$\frac{1}{2}mv^2 = \frac{19.86\times10^{-26}}{3\times10^{-7}} - 3(1.6\times10^{-19})$

K.E= $(6.62\times10^{-19}) - (4.8)\times10^{-19} = 1.13eV$

8. Photo-electrons are ejected from the surface of the metal having work function 4.5 eV. Find the impulse transmitted to the surface of the metal when electron flies off due to collision of light quanta of energy 4.9eV.

Sol: Work function W=4.5 eV

Energy of light quanta E=4.9 eV

Mass of electron m= $9.11\times19^{-31}\,kg$

K.E of electron=4.9 - 4.5 = 0.4 eV

$P=\sqrt{2Em}$

$\therefore P=\sqrt{2\times9.11\times10^{-31}\times0.4\times1.6\times10^{-19}}=3.41\times10^{-25}\,kgMs^{-1}/m$

$\therefore$ Impulse P = 3.43×10^{-25} Kg m/s

9. What will be the minimum frequency of light source to get photo current, from a metal surface having the work function 2 eV.

Sol: work function of surface W_0 = 2 eV

$$v_0=\frac{W}{h}=\frac{2\times1.6\times10^{-19}}{6.6\times10^{-34}}=4.8\times10^{14}\,Hz$$

10. The threshold wavelength for emission of photo electrons from a metal surface is $6\times10^{-7}\,m.$ what is the work function of the material of the metal surface.

Sol: Threshold wavelength = $\lambda_0=6\times10^{-7}\,m.$

$$\lambda_0=6000\,A^0$$

Work function of metal surface W = ?

Work function $W=\frac{hc}{\lambda_0}$ $\quad\Rightarrow W=\frac{12,400}{6000}=2.067\,eV=3.33\times10^{-19}\,J$

11. A metal sheet of silver is exposed to ultraviolet radiations of wave length $1810A^0$. The threshold wavelength of silver is $2640A^0$. Then calculate of emitted electron $(1A=10^{-10}m)$.

Sol: $\lambda=1810A^0$; $\lambda_0=2640A^0$; K.E. = ?

From Einstein's equation $\frac{1}{2}mv^2=hv-hv_0$

K.E= $hc(\frac{1}{\lambda}-\frac{1}{\lambda_0})=6.62\times10^{-34}\times3\times10^8\left[\frac{1}{1810\times10^{-10}}-\frac{1}{2640\times10^{-10}}\right]=3.45\times10^{-19}\,J$

16. A metal of work function 4.5eV is illuminated by monochromatic light of wavelength$1.4\times10^{-7}m$. Calculate (i) The threshold wavelength, (ii) The threshold

frequency (iii) The maximum energy of photo-electrons (iv) The cutoff potential. $(c = 3\times10^8 ms^{-1}, h = 6.62\times10^{-34} Js, e = 1.6\times10^{-19} C)$

Sol: W_0 = 4.5 eV $= 4.5\times1.6\times10^{-19} J$; $\lambda = 1.4\times10^{-7}$ m.

(i) $W_0 = \frac{hc}{\lambda_0} \Rightarrow \lambda_0 = \frac{hc}{W_0} = \frac{19.86}{7.2}\times10^{-7} = 2758A^0$

(ii) $\omega_0 = h\nu_0$

$$\Rightarrow \nu_0 = \frac{\omega_0}{h} = \frac{4.5\times1.6\times10^{-19}}{6.62\times10^{-34}} = \frac{7.2}{6.62}\times10^{15} = 1.087\times10^{15} Hz$$

(iii) $\frac{hc}{\lambda} = W + KE_{\max}$

$$\Rightarrow K.E_{\max} = \frac{hc}{\lambda} - \omega_0 = \frac{(6.62\times10^{-34}\times3\times10^8)}{(1.4\times10^{-7})} \_ (4.5\times1.6\times10^{-19}) = 6.99\times10^{-19} J$$

(iv) $K.E_{\max} = eV_0$

$$\Rightarrow V_0 = \frac{K.E_{\max}}{e} = \frac{6.985\times10^{-19}}{1.6\times10^{-19}} = 4.37 Volts$$

ASSESS YOURSELF

7. A radiation of wavelength $5000A^0$ is incident on a metal surface whose work function is 4 eV. Do you observe the phenomenon of photoelectric effect?

A. No, because the given wave length is more than the threshold wave length.

8. Why are alkali metals most suited for photoelectric emission?

A. These metals have less work function.

9. Is photoelectric emission possible at all frequencies?

A. No. Photoelectric emission is possible for the frequencies is more than the threshold frequencies.

10. If the intensity of incident radiation in a photocell is increased, does the stopping potential vary?

A. No. The stopping potential is independent of intensity of incident radiation.

11. What is the effect on the velocity of the photoelectrons, if the wavelengths of incident light is decreased?

A. Velocity increases.

12. It is harder to remove a free electron from copper than sodium. Which metal has greater work function?

A. Copper.

13. It is found that yellow light does not eject photoelectrons from a metal can we use orange light to emit photoelectron from what metal?

A. No.