Date: ....
Page: ....

Chapter: 21

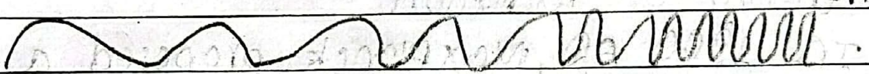
Photons

Photon is define as a each tiny discrete packets / bundles of radiation that carry certain amount of energy, is called quantum or photon.

Qunta: A quantum, on the other hand, is the tiniest possible particle of an substance at subatomic level.

$< \mathcal{E}_R < \mathcal{E}_m < \mathcal{E}_I < \mathcal{E}_V < \mathcal{E}_U < \mathcal{E}_X < \mathcal{E}_G$

$\rightarrow$ Energy



R M I V U X G

$> \lambda_R > \lambda_M > \lambda_I > \lambda_V > \lambda_U > \lambda_X > \lambda_G$

$\leftarrow$ frequency

* Intensity variable, Frequency constant
* Frequency variable, Intensity constant

Higher intensity means greater number of emitted photoelectrons & higher frequency means greater kinetic energy of emitted photoelectrons.

Date: ....
Page: ....

Classical Physics explains the phenomenon of nature on the basis of Newton's Laws of Motion. Maxwells Theory of electromagnetism explains about electricity & magnetism. The theory of classical physics could not explain black body radiation, photoelectric effect, spectral line of hydrogen atom etc.

The inadequacy of classical physics gave birth to the quantum physics.

Quantum theory of radiation

In 1900 AD, Max Planck proposed a theory which is known as quantum theory. According to which an accelerated electron does not emit radiation continuously ~~has~~ as proposed by electromagnetic theory of radiation. But electron emit energy in form of tiny packets known as quanta whose energy is given by $E = hf$ where h is Plank's constant & f is frequency of the ~~electron~~ radiation.

By the help of Quantum Physics, the phenomenon like photoelectric effect, black body radiation, spectral line of hydrogen atom are explained fruitfully.

Photon

The quantum radiation is known as a photon. where h is Plank's constant & f is the frequency of radiation.

i.e. $E = hf$ —— (1)

We know,

$c = \lambda f$ where, c = velocity of light

$\frac{c}{\lambda} = f$ — (iii) $\boxed{\therefore \frac{c}{f} = \lambda}$ λ = wavelength of wave

Also, from Einstein's Mass Energy relation,

$E = mc^2$

$\frac{E}{c^2} = m$ — (iii)

Now, solving eqⁿ (i) & (iii) we get

or, $m = \frac{E}{c^2}$

or, $m = \frac{hf}{c^2}$ — (iv)

Momentum (P) = mass × velocity

$P = m \times c$

$P = \frac{hf}{c^2} \times c$

$P = \frac{h}{\frac{c}{f}}$

$\boxed{\therefore P = \frac{h}{\lambda}}$ which is the momentum of photon.

Properties of photons:-

1) Energy of photon is given by $E = hf$ where h is Plank's constant & f is frequency of radiation
2) photon travels with the velocity of light i.e 3×10^8 m/s.
3) The momentum of photon is given by $P = \frac{h}{\lambda}$ where λ is the wavelength of wave.
4) When the wave travels from one medium to another medium, frequency always remains constant.

Photo-electric Effect:

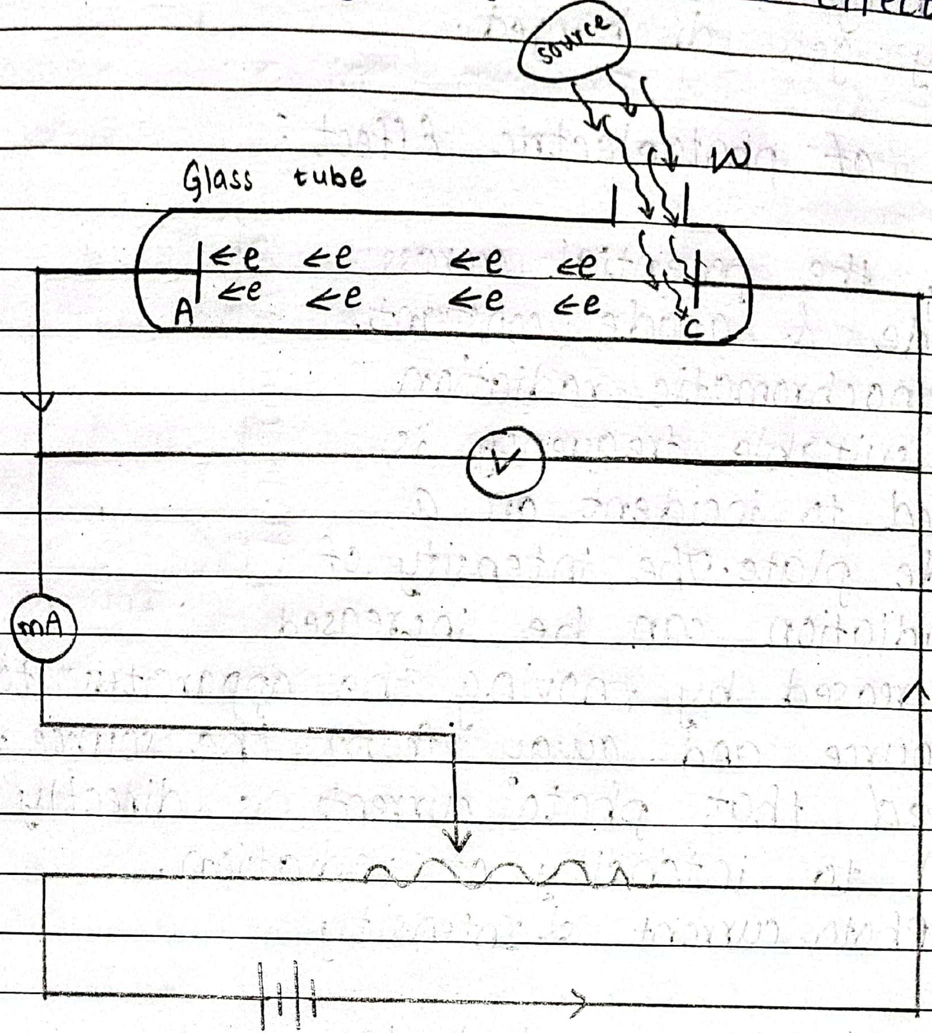
An insulated zinc plate which is charged negatively and exposed to ultra-violet rays, it is observed that electrons are emitted from metal surface. Similarly, when zinc plate is changed positively & exposed to ultraviolet rays, no electrons are obserbed to be emitted.

The process of emission of electrons from the metal surface is known as photo-electric effect. & the emitted electrons are known as photo electrons.

When ultra-violent rays incident on the metals like zinc, cadmium, selenium then photo-electric effects are observed. When visible light ray incident on the alkali metals like sodium, potassium, lithium then photo-electric effect is observed.

Not only in metals, also photo electric effect can be observed in non metals but high frequency radiation are required. Also, photo electric effect can observed in liquid & gas in form of ionization.

Experimental study of photoelectric effect.



An experimental study for photoelectric effect consists of a discharge tube having window W. Two metal plates cathode & anode are connected with negative & positive terminal of a battery. Milli ammeter measures the flow of current whereas potential is measured by voltmeter.

When a radiation or photon of suitable frequency incidents on cathode plate then electrons are emitted which are known as photo electrons. These electrons accelerates towards anode & the flow of current is measured by milli ammeter whose potential is measured by voltmeter. Then, these electrons reaches at the battery which neutralizes the charges. And the process continues until the battery gets discharged.

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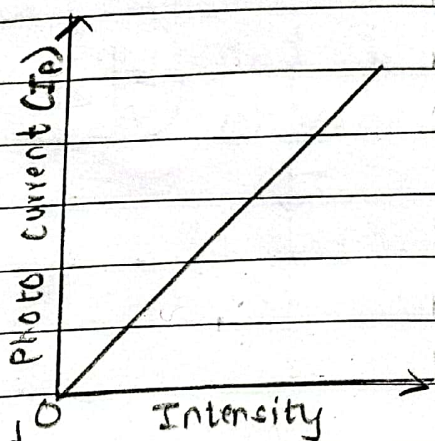
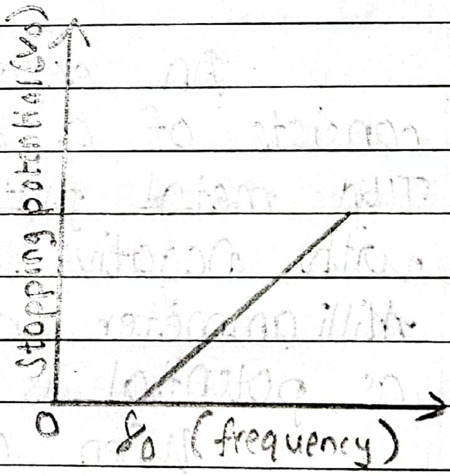
Laws of photoelectric Effect:

1) Keeping the potential across cathode & anode constant. A monochromatic radiation of a suitable frequency is allowed to incident on a cathode plate. The intensity of a radiation can be increased or decreased by moving the apparatus towards the source and away from the source. It is observed that photo current is directly proportional to intensity of radiation.



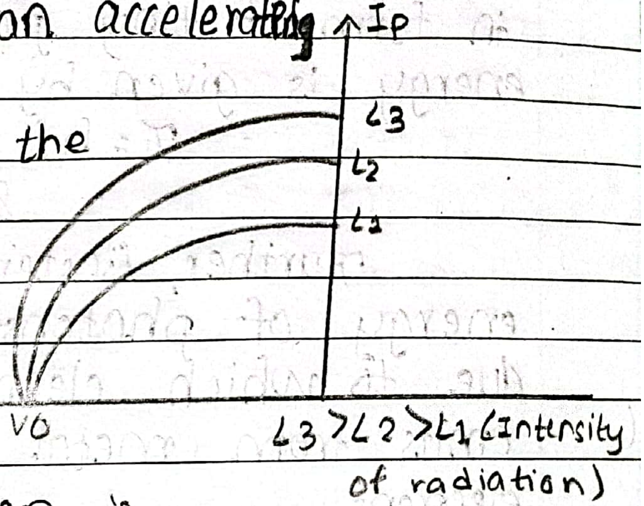
i.e. Photo current $\propto$ Intensity

2) Now, anode is connected to negative terminal of a battery whereas cathode is connected to positive terminal. The intensity of a various frequency radiation are allowed to incident on the cathode plate. The emitted electrons move towards anode & the current is measured by milli ammeter. Then, the potential of a battery is gradually increased, then reading on milli ammeter decreases. (Due to repealsion of ~~ano~~ electron by anode plate.) At certain potential, milliammeter ~~reading~~ ~~the~~ current is zero. Then,

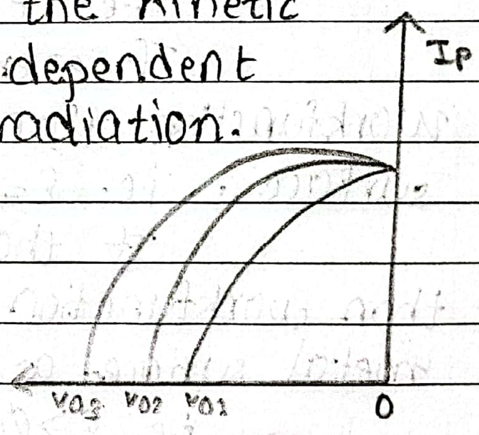


such potential is known as stopping potential. Below the certain frequency, the photo electric effect is not observed. The frequency of radiation which is suitable for photo electric effect is known as threshold frequency & the wave length is known as threshold wavelength.

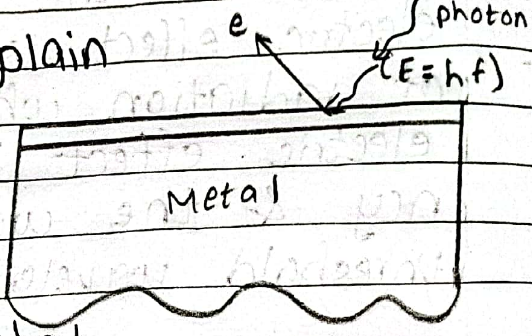
3) The kinetic energy of an accelerating electron is given as $\frac{1}{2}mv^2 = eV_0$ where V be the potential. keeping the frequency of a radiation constant & intensity is varied. Hence, kinetic energy of photo electron is independent of intensity of radiation.



4) Now, keeping the intensity of radiation constant & frequency is varied. Hence, the kinetic energy of photo electron dependent upon the frequency of radiation.



Einstein's photoelectric Equation :-



In 1905 AD, Einstein explain the photoelectric effect on the basis of Plank's Quantum Theory of radiation according to which energy is emitted or absorbed in form of tiny packets known as quanta whose energy is given by

$E = hf$ where h is a Plank's constant & f is the frequency of radiation.

Further, Einstein explained that the energy of photons are absorbed by electrons due to which electrons get exicted which emits from metal surface known as photo electrons.

If the energy of photon ~~work function~~ is less work function, then electrons get excited & just (vibrates) ~~accelerates~~ osscillates.

i.e. $E < \phi$

If energy of photon is equals to workfunction then electrons just emit from metal surface. i.e. $E = \phi$

If the energy of photon is greater than workfunction then electrons emit out from metal surface as well as gets accelerated.

i.e. $E > \phi$

Energy of photon = workfunction + K.E of photon electron

$$E = \phi_0 + KE$$

Workfunction is defined as the min^m energy of photon which is require to emit the electr

Threshold frequency is the minimum frequency of radiation which is required to emit electrons from metal surface.

Threshold Wavelength is the minimum wavelength of radiation which is required to emit electrons.

i.e. $E = \phi_0 + KE$

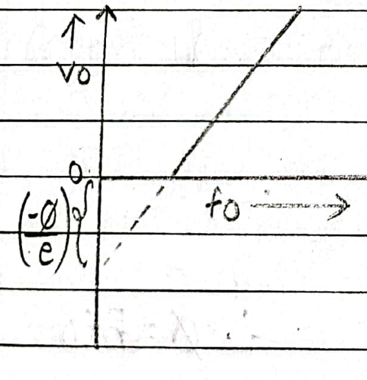
Now, $hf = hf_0 + \frac{1}{2}mv^2$

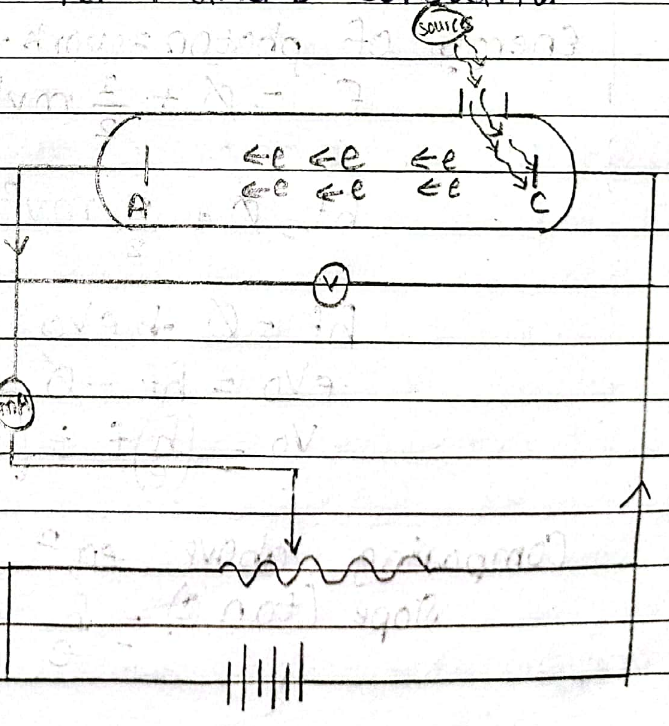
$hf - hf_0 = \frac{1}{2}mv^2$

$$\left(h\frac{c}{\lambda} - h\frac{c}{\lambda_0}\right) = KE$$

$$\boxed{hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) = KE}$$ where λ be the wavelength of incident photon.

Millikan's Experiment for planck's constant:





$\emptyset$ & $\emptyset_0$ are same.

Anode is connected to a negative potential of a battery whereas cathode is connected to the positive potential. When the photon of suitable frequency incidents on a ~~zinc~~ metal plate i.e. cathode, then photon electrons are produced which accelerates towards anode (Now, the potential of battery)* Then, electron flows through the circuit & current is measured by milliammeter. Now, the potential of a battery is graudually increased, the electrons get retarded also the flow of current decreases which is measured by milli ammeter. At certain specific voltage, the electrons are totally retarded i.e. milliammeter measures 0 current. Such potential is known as stopping potential.

The kinetic energy of retarded electrons is equals to potential applied i.e.

$$\frac{1}{2} mv^2 = eV_0$$

We know,

Energy of photon = work function + KE of photon electron

$$E = \emptyset + \frac{1}{2} mv^2$$

$$hf = \emptyset + \frac{1}{2} mv^2$$

$$hf = \emptyset + eV_0$$

$$eV_0 = hf - \emptyset$$

$$V_0 = \left(\frac{h}{e}\right) f + \left(\frac{-\emptyset}{e}\right) \qquad \therefore \emptyset = hf_0$$

Comparing above eq^n with $y = mx + c$

$$\text{Slope } (\tan\theta) = \frac{h}{e}$$

Date: ....
Page: ....

or, $\tan\theta = \frac{h}{e}$

$\boxed{\text{or, } h = e \tan\theta}$

Hence, the value of planck's constant is 6.62×10^{-34} Js.

Short Q/A:- Pg: 515-

1)a) What is photoelectric effect?
→ The phenomenon of emission of electrons from a metallic surface when radiation of suitable frequency falls on it called photoelectric effect.

2)a) Alkali metals are most suited for photoelectric emission. Why?
→ The emission of photoelectrons from a metal surface depends upon its work function. The work function of alkali metals is quite low (i.e for k, it is 2.3 ev & for Na it is 2ev). As a result, they show photoelectric effect even with visible light. For this reason, alkali metals are most suited for photoelectric emission.

b) Copper & sodium have work function 4.5 eV & 2.0 eV respectively. Radiation of wavelength 4000 A° fall on the two surfaces. Can there be photoelectric emission in both metals?
→ (Given) $h = 6.67 \times 10^{-34}$ Js, $1A° = 10^{-10}$ m & $c = 3\times10^{8}$ ms^{-1}). The energy of the incident radiation is given by $E = \frac{hc}{\lambda} = \frac{6.67\times10^{-34}\times3\times10^{8}}{4000\times10^{-10}\times1.6\times10^{-19}}$ eV $= 3.13$ ev.

Now, the work function for copper is $\phi_c = 4.5$ eV & that for sodium is $\phi_s = 2.0$ eV. For copper,

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$E_c < \phi_c$. Hence, no photoelectrons can be emitted. For sodium, $E > \phi_s$, hence photoelectric emission is possible.

1.b) What is photoelectric current?
→ The current formed due to photoelectrons is called photoelectric current. Metals like Cd, Na, Zn, K etc are photosensitive.

3.a) Green light ejects electrons from a certain photosensitive surface, yellow light does not. What will happen for red & violet light?
→ The photoelectric emission takes place only if the wavelength of the incident light is less than the threshold wavelength λ_0 for the metal surface. Since green light ejects electrons from the surface, $\lambda_g < \lambda_0$. On the other hand, yellow light does not eject electrons means $\lambda_y > \lambda_0$. Since $\lambda_r > \lambda_y$, red light cannot cause photoelectric emission. But $\lambda_v < \lambda_g$. So, the violet light will cause photoelectric emission.

4.a) How is photoelectric effect used in fire alarms?
→ In buildings, photoelectric cells which are sensitive to flame of light (fire) are installed. Whenever a fire takes place, the light from the flame falls on the photoelectric cells & recently switches on the alarm circuit. As soon as the alarms ring, appropriate step are taken to control the fire.

5.a) Do X-rays show the phenomenon of photo-

Date: ....
Page: ....

electric affect?
→ Yes, x-rays show the phenomenon of photo-electric effect. Since it has very high energy as compared to the light of visible range, it can eject the photoelectrons from the metal surface & also give sufficient kinetic energy.

6.a) What is the threshold frequency for photoelectric emission? Does it depend on the intensity of light?
→ The minimum frequency of incident light which is just sufficient to eject an electron (i-e with zero velocity) from the surface of a metal is known as threshold frequency. Its value depends on the nature of the metal but not on the intensity of light.

7a) What is the difference between thermionic effect & photoelectric effect?
→ The phenomenon of ejection of electrons from substances by providing heat or thermal energy is called Thermionic Emission. Hence, it is temperature dependent i-e, the electrons acquire energy by heat. On the other hand, photoelectric emission is the process in which electrons are ejected when light of suitable frequency is made to strike on the substance. In this process the free electrons absorb light photons & acquire energy. The emission depends on the intensity of light.

Long Q/A:

2.a) Why it is difficult to remove a free electron from copper than sodium?

→ The minimum energy of photon required to eject an electron (with zero velocity) from the metal surface is known as work function for that metal. The work function of pure metals varies roughly from 2 to 6 ev. It is the characteristics of metal. If the frequency of the incident radiation is equal to the threshold frequency of the metal, then the emitted electron will have zero velocity. Now, the Einstein's photoelectric equation becomes $\phi_0 = hf_0$.

The work function of copper (4.5 ev) is greater than that of sodium (2 ev). Therefore, the radiation of more energy is required to remove a free electron from copper as compared to sodium.

3.a) Explain why photoelectric effect cannot be observed with all wavelength of light.

→ The amount of energy required to eject an electron just out of the surface of metal is called work function of the metal. The frequency of the light required for this purpose is called Threshold frequency f_0. Then we have $\phi_0 = hf_0$. It is clear that a frequency less than f_0 (i.e. wavelength greater than λ_0) will be unable to produce the photoelectric effect. This is the reason why photoelectric effect cannot be observed with all wavelengths of light.

Date: ....
Page: ....

Note: $1 eV = 1.6 \times 10^{-19} J$

4.a) Why do alkali metals show photoelectric effect even with visible light?

→ The work function - the minimum energy required for emission of photoelectron for alkali metals is smaller compared to other metals. For example, for sodium $\phi = 2$ ev & for potassium $\phi = 2.3$ ev. The energy of visible light is of the order of 2.5 ev (This can be calculated from $E = hc/\lambda$). Since, the energy of visible light is greater than the work function of the alkali metals, the alkali metals show photoelectric effect even with the visible light.

Neumericals:-

1) A ultraviolet light of a 400 nm (nanometer) strikes a cesium surface of workfunction 1.9 ev. Find the velocity of electron emitted from cesium surface.

$m_e = 9.1 \times 10^{-31}$ kg

$c = 3 \times 10^8$ m/s.

$h = 6.62 \times 10^{-34}$ Js

Soln: Given,

We know,

wavelength $(\lambda) = 400 nm = 400 \times 10^{-9} m$

$\phi = 1.9 ev = 1.9 \times 1.6 \times 10^{-19} J$

$m_e = 9.1 \times 10^{-31}$ kg

$c = 3 \times 10^8$ m/s

$h = 6.62 \times 10^{-34}$ Js

$v = ?$

We know that,

Date: ....

Page: ....

Energy of photon = workfunction + KE

$$hf = \phi + \frac{1}{2}mv^2$$

$$h\frac{c}{\lambda} = 1.9\times1.6\times10^{-19} + \frac{1}{2}\times9.1\times10^{-31}\times v^2$$

$$\text{or, } 6.62\times10^{-34}\times\frac{3\times10^8}{400\times10^{-9}} = 1.9\times1.6\times10^{-19} + \frac{1}{2}9.1\times10^{-31}\times$$

$$\text{or, } \frac{6.62\times3\times10^{-34+8+9}}{400} = \frac{2\times1.9\times1.6\times10^{-19}+1\times9.1\times10^{-31}\times}{2}$$

$$\text{or, } 0.04965\times10^{-17} = \frac{6.08\times10^{-19}+9.1\times10^{-31}v^2}{2}$$

$$\text{or, } 9.93\times10^{-19} - 6.08\times10^{-19} = 9.1\times10^{-31}v^2$$

$$\text{or, } \frac{3.85\times10^{-19}}{9.1\times10^{-31}} = v^2$$

$$\text{or, } 4.23\times10^{11} = v^2$$

$$\text{or, } \sqrt{4.23\times10^{11}} = v$$

$$\therefore v = 650384.5017$$

$$= 6.5\times10^5 \text{ m/s}$$

2) The work function of surface of aluminium is 4.2 ev. How much potential difference will be required to stop the emission of maximum energy electrons emitted by the light of wavelength 2000 A°. $h = 6.62\times10^{-34}$ Js

soln: Given,

$\phi = 4.2\text{ eV} = 4.2\times1.6\times10^{-19}\text{ J} = 6.72\times10^{-19}\text{ J}$

$h = 6.62\times10^{-34}$ Js

$\lambda = 2000\text{ A}^\circ = 2000\times10^{-10}$ m

$c = 3\times10^8$ m/s

~~$m = 9.1\times10^{-31}$~~

We know,

$$hf = \phi_0 + eV_0$$

or, $6.62\times10^{-34}\times\frac{c}{\lambda}=6.72\times10^{-19}+1.6\times10^{-19}\times V_0$

or, $6.62\times10^{-34}\times\frac{3\times10^{8}}{2000\times10^{-10}}=6.72\times10^{-19}+1.6\times10^{-19}\times V_0$

or, $\frac{9.93\times10^{-19}-6.72\times10^{-19}}{1.6\times10^{-19}}=V_0$

$\therefore V_0=2$ m/s

3) Light of wave length 4×10^{-7} m falls on the sodium surface. What is the maximum energy of emitted electrons in electron volt

Sol^n: Given,

Workfunction (ϕ) $=2.3$ eV $=2.3\times1.6\times10^{-19}$ J $=3.68\times10^{-19}$ J

$h=6.62\times10^{-34}$ Js

$\lambda=4\times10^{-7}$ m

We know that,

$hf=\phi+\frac{1}{2}mv^2$

$6.62\times10^{-34}\times\cancel{3.68\times10^{-19}} \Rightarrow \frac{c}{\lambda}=3.68\times10^{-19}+KE$

$6.62\times10^{-34}\times\frac{3\times10^{8}}{4\times10^{-7}}=3.68\times10^{-19}+KE$

or, $\frac{6.62\times3\times10^{-34+8+7}}{4}-3.68\times10^{-19}=KE$

or, $4.965\times10^{-19}-3.68\times10^{-19}=KE$

or, $1.285\times10^{-19}J=KE$

or, $\frac{1.285\times10^{-19}}{1.6\times10^{-19}}=KE$

$\therefore KE=0.8$ eV

Hence, maximimum energy of the emitted electron is 0.8 eV.