42. Photoelectric Effect and Wave-Particle Duality

Short Answer

Answer.1

The formula p=mv is valid in classical mechanics where the object or say particle has significant mass or size. The photon does not have significant mass or size and hence classical mechanics is invalid and p=mv cannot be used to determine the mass of photon.

Answer.2

The number of photons crossing an area A in a given time t is given by

$n = \frac{E_{total}}{E} = \frac{I \times A \times t}{E}$ I=Intensity of source; E=Energy of a single photon.

If now, two sources have equal intensities, the number of photons emitted in a given time is dependent on the area crossed and the energy of each photon emitted from the two sources as described by the equation above. Hence, it is not always true that for two source of equal intensity, the number of photons emitted in a given time, are equal.

Answer.3

All photons of a light of particular wavelength have same energy and same linear momentum. This says that all photons travel with equal velocity which is equal to velocity of light. If the two photons are going in the same direction, then the relative speed between them will be zero since both are travelling in same direction with velocity of light. If the two photons are going in opposite directions, the relative speed between them will be equal to the velocity of light.

Answer.4

Photon is a charge-less particle and hence it is deflected neither by an electric field nor by a magnetic field.

Answer.5

A hot body placed in a closed room maintained at a lower temperature will lose its heat via convection and radiation. Heat waves will emanate from the hot body and these waves are made up of photons. Hence the number of photons in the room is increasing.

Answer.6

In Physics, the Energy-Momentum relation of a particle is given by

$$E^2 = (pc)^2 + (m_0c^2)^2$$

E=Energy; p=Momentum; c=Velocity of light; m_0=rest mass of particle. For Photon, m_0=0 and thus $E = pc$. Since momentum is associated with the energy of photon, we call the energy of photon as its kinetic energy and not its internal energy.

Answer.7

The photoelectron is emitted in the opposite direction to that of the direction of incident photon, does not violate the conservation of momentum. The conservation of momentum is based on the Newton's third law which says that the forces acting during collision are equal and opposite. Thus, during collision of photon and electron, the photoelectron is emitted in the opposite direction.

Answer.8

We know the famous mnemonic VIBGYOR (Violet-Indigo-Blue-Green-Yellow-Orange-Red) to remember visible light in increasing order of their wavelengths. It is given that λ_y (yellow light) does not cause photoelectric effect. This means that

$$\lambda_y > \lambda_0$$

and the energy $\frac{hc}{\lambda_y}$ supplied to the electron is smaller than the work function $\frac{hc}{\lambda_0}$ and hence no electron will come out of the metal. Wavelength of orange light λ_O is even greater than the wavelength of yellow light λ_y and thus $\lambda_O > \lambda_y > \lambda_0$. Therefore, Orange light also does not eject photoelectrons. Wavelength of green light λ_g is smaller than the wavelength of yellow light λ_y and thus green light may cause ejection of photoelectrons from a metal only if

$$\lambda_g \leq \lambda_0 < \lambda_y < \lambda_O.$$

Answer.9

It is given that photosynthesis starts in certain plants when exposed to the sunlight/visible light. This means that the photons of visible light have enough energy to initiate the process of photosynthesis. The wavelength of visible light is greater than the wavelength of infrared light. Therefore, infrared light will not have sufficient energy to initiate the process of photosynthesis. Hence photosynthesis does not start if the plant is exposed only to infrared light.

Answer.10

Since $\lambda \leq \lambda_0$, photoelectric effect takes place and free electrons present in the metal are emitted. This emission of free electrons is for some time and after that the emission stops. This is because all the free electrons from the metal are now exhausted and the energy of the incident light does not have enough energy to move out the tightly bounded electrons in the metal.

Answer.11

The Energy-Momentum relation of a particle is given by

$$E^2 = (pc)^2 + (m_0c^2)^2$$

E=Energy; p=Momentum; c=Velocity of light; m_0=rest mass of particle. For an electron, rest mass is not equal to 0($m_0 \neq 0$) hence p=E/c is invalid for an electron.

Answer.12

De Broglie wavelength is given by

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

Where h=Planck's constant; m=mass of the particle; p=momentum and v=velocity of the particle

Mass of electron $m_e = 9.1 \times 10^{-31}$kg; mass of proton $m_p = 1.6 \times 10^{-21}$kg

(a) Electron and Proton both have same speed

$$\therefore \lambda_e = \frac{h}{p} = \frac{h}{m_e v} \; \& \; \lambda_p = \frac{h}{p} = \frac{h}{m_p v}$$

$$\Longrightarrow \because m_p > m_e, \; \lambda_p < \lambda_e$$

The wavelength of proton is smaller than that of electron.

(b) Electron and Proton both have same momentum

$$\therefore \lambda_e = \frac{h}{p} \; \& \; \lambda_p = \frac{h}{p}$$

$$\Longrightarrow \quad \lambda_p = \lambda_e$$

The wavelength of proton is equal to that of electron.

(c) Electron and Proton have same energy

De Broglie Wavelength is also given by

$$\lambda_e = \frac{h}{\sqrt{2m_e E}} \; \& \; \lambda_p = \frac{h}{\sqrt{2m_p E}}$$

Where E=Energy of the particle

$$\because \; \lambda \propto \frac{1}{\sqrt{m}} \; \& \; m_e < m_p$$

$\therefore \lambda_p < \lambda_e$

The wavelength of proton is smaller than that of electron.

Answer.13

The wavelengths ranging from 400 nm to 700 nm are visible light i.e. we can see this wavelengths by our eyes. Typically no waves have color. It is because of our eyes that we see color in visible light. Therefore, waves made up of electron do not have color and we cannot see it.

Objective I

Answer.1

The value of Planck constant is 6.626×10^{-34} Joule-Second.

[Planck Constant]=J*T

Since, [Work] =N*L (Work=Force*Displacement)

Where J=Joule (Work), T=Time (second), N=Force (Newton) and L=Length (meter/distance/displacement)

Work has unit Joule i.e. [J]=N*L.

Therefore [Planck constant] =N*L*T=force*distance*time.

Answer.2

We know that all photons of light of a particular wavelength λ have the same energy $E = \frac{hc}{\lambda}$ and the same linear momentum $p = \frac{h}{\lambda}$. Therefore, the two photons with equal linear momentum will have equal wavelengths. We cannot say it otherwise because equal wavelengths (equal energies or equal frequencies) of two photons will represent light from two different sources.

Answer.3

We know,

$$E = h\nu = \frac{hc}{\lambda} \;\&\; p = \frac{h}{\lambda} = \frac{E}{c}$$

are the energy and linear momentum of a photon of light, where h=Planck constant, c=Velocity of photon, λ=Wavelength of light and ν=Frequency of light.

If the wavelength is decreased, both p and E increases since $E \propto 1/\lambda$ and $p \propto 1/\lambda$.

Answer.4

The number of photons crossing an area A in a given time t is given by

$n = \frac{E_{total}}{E} = \frac{I \times A \times t}{E} = \frac{IAt\lambda}{hc} \cdots \left(E = h\nu = {}^{hc}/_{\lambda}\right)$ I=Intensity of source or power density; E=Energy of a single photon; h=Planck constant; c=Velocity of photon; λ=Wavelength of light and ν=Frequency of light.

We know the famous mnemonic VIBGYOR (Violet-Indigo-Blue-Green-Yellow-Orange-Red) to remember visible light in increasing order of their wavelengths. We observe that red light has greater wavelength than blue light i.e. $\lambda_r > \lambda_b$. From the above equation, we see that $n \propto \lambda$ and therefore $n_r > n_b$.

Answer.5

In Physics, the Energy-Momentum relation of a particle is given by

$$E^2 = (pc)^2 + (m_0c^2)^2$$

E=Energy; p=Momentum; c=Velocity of light; m_0=rest mass of particle. For Photon, m_0=0 and thus $E = pc$ is valid. For electron, $m_0 \neq 0$ and thus $E = pc$ is not valid.

Answer.6

The photoelectric effect takes place only if $\lambda \leq \lambda_0$ where λ_0 is the threshold wavelength.

$$\because \lambda = \frac{c}{\nu}$$

$$\lambda \leq \lambda_0 \implies \frac{c}{\nu} \leq \frac{c}{\nu_0}$$

$$\implies \nu_0 \leq \nu \; i.e. \nu \geq \nu_0$$

ν_0=threshold frequency; c=velocity of light; ν=frequency of wave.

Answer.7

If $\lambda > \lambda_0$, the energy hc/λ supplied to the electron is smaller than the work function hc/λ_0 and hence no electron will come out of the metal. Thus, when $\lambda \leq \lambda_0$, the energy hc/λ supplied to the electron is now larger than the work function hc/λ_0 and hence electron will come out of the metal. Therefore, the photoelectric effect takes place.

Answer.8

Stopping potential is the negative potential applied to the anode (collector) so that even the fastest photoelectron emitted from the cathode (emitter) does not reach to anode due to the repulsion. Hence no photocurrent is observed. This does not mean that emission of photoelectrons is stopped. These photoelectrons are accumulated near the emitter plate (cathode). Hence option A, C and D are not true. Therefore, it can be said that the photoelectrons are emitted but re-absorbed by the emitter plate.

Answer.9

The magnitude of stopping potential V_0 is given by

$$V_0 = \frac{hc}{e}\left(\frac{1}{\lambda}\right) - \frac{\varphi}{e} \cdots (1)$$

The frequency ν of light is given by

$$\nu = \frac{c}{\lambda}$$

$$\Rightarrow \frac{\nu}{c} = \frac{1}{\lambda} \cdots (2)$$

The work function φ of metal is given by

$$\varphi = \frac{hc}{\lambda_0} = h\nu_0 \cdots (3)$$

Where, h=Planck's constant; λ=Wavelength of light; λ_0=Threshold wavelength; ν_0 =Threshold frequency; c=Velocity of light and e=charge on electron

Put equation (2) and equation (3) in equation (1), we get

$$\Rightarrow V_0 = \frac{hc}{e}\left(\frac{\nu}{c}\right) - \frac{\varphi}{e} = \frac{h\nu}{e} - \frac{h\nu_0}{e}$$

$$\Rightarrow V_0 = \frac{h(\nu - \nu_0)}{e} \cdots (4)$$

Now, if the frequency of light ν is doubled, the stopping potential will be

$$V_0' = \frac{h(2\nu - \nu_0)}{e} \cdots (5)$$

To compare equation (4) and (5), we need to multiply 2 in equation (4) on both sides, we get

$$2V_0 = \frac{h(2\nu - 2\nu_0)}{e} \cdots (6)$$

Now, comparing equation (5) and equation (6),

$$\frac{h(2\nu - \nu_0)}{e} > \frac{h(2\nu - 2\nu_0)}{e}$$

$$\Rightarrow -\nu_0 > -2\nu_0$$

$$or\ V_0' > 2V_0$$

Therefore, the stopping potential becomes more than double when the frequency of light is doubled.

Answer.10

Intensity of light is doubled and therefore the photocurrent will be doubled since $i \propto I$. Also, at the same time, the frequency is doubled and therefore, the stopping potential increased by more than double. The increase in stopping potential decreases the photocurrent. Hence taking the above combined effect, the saturation current (photocurrent) thus remains almost same. So, the statement A is true.

The maximum kinetic energy K_{max} of photoelectron is given by

$$K_{max} = hv - \varphi \cdots (1)$$

Where, h=Planck's constant; v=frequency of the light and φ=Work function of the metal

Now, if frequency is doubled, the maximum kinetic energy is

$$K_{max}' = 2hv - \varphi \cdots (2)$$

Multiplying 2 on both sides of equation (1) and comparing with equation (2), we get

$$2hv - 2\varphi < 2hv - \varphi$$

$$\Rightarrow -2\varphi < -\varphi$$

$$or\ 2K_{max} < K_{max}'$$

Therefore, we conclude from above equation that the maximum kinetic energy will be more than double. Hence, statement B is false.

Answer.11

As the source is moved farther away from the emitting metal, the intensity of light decreases. Since we know that the stopping potential is independent of intensity of light, it remains constant.

Answer.12

As the distance between the source and the metal is increased, the intensity of light I decreases because

$$I \propto \frac{1}{(distance)^2}$$

Also, the photocurrent i is directly proportional to the intensity of light and also to the number of electrons emitted.

$$\therefore i \propto I \propto \frac{1}{(distance)^2}$$

Hence, the curve d is the appropriate curve representing above equation.

Answer.13

The stopping potential is related to the wavelength of the light incident. Since a non monochromatic light has mixture of wavelengths, the stopping potential will be related to the shortest wavelength. These shortest wavelength must be less than or equal to the threshold wavelength of the metal to carry out photoelectric effect experiment efficiently.

Answer.14

The de Broglie wavelength is given by

$$\lambda = \frac{h}{p} = \frac{h}{mv} \cdots (1)$$

Where h=Planck's constant; m=mass of the particle; p=momentum and v=velocity of the particle

Mass of electron $m_e = 9.1 \times 10^{-31}$kg; mass of proton $m_p = 1.6 \times 10^{-21}$kg

$$\because \lambda \propto \frac{1}{m} \Rightarrow m \propto \frac{1}{\lambda} \cdots [from\ equation\ (1)]$$

$$\Rightarrow \frac{1}{\lambda_e} < \frac{1}{\lambda_p} \cdots (\because m_e < m_p)$$

$$\Rightarrow \lambda_p < \lambda_e.$$

Therefore, the wavelength of electron is greater than the wavelength of proton

Objective II

Answer.1

Intensity is energy per unit time per unit area which is directly proportional to the no of photon falling in unit area in unit time. The formula for intensity is articulated by,

$$I = \frac{nE}{AT}$$

Where **I** is the intensity, **E/T** is the energy per unit time, **n** is the no. of photons and **A** is the area of cross section.

Therefore, if intensity is increased, the number of photons falling per unit area per unit time is also increased. Therefore, the no. of photons emitted by the source in unit time increases.

And increase in intensity results in increase in energy per unit time. And there is increase in total energy of photons emitted per unit time as number of photons increase.

Photons have kinetic energy which depends upon the frequency of photons.

We can analyze the frequency relationship with the kinetic energy using the law of conservation of energy. The total energy of the incoming photon, E_{photon}, must be equal to the kinetic energy of the ejected electron, $KE_{electron}$, plus the energy required to eject the electron from the metal. The energy required to free the electron from a particular metal is called the metal's *work function*, which is represented by the symbol Φ :

$$E_{photon} = KE_{electron} + \Phi$$

We can now write the kinetic energy of the photon in terms of the light frequency using Planck's equation:

$$E_{photon} = h\nu = KE_{electron} + \Phi$$

Intensity increase does not change the nature of light, i.e. its frequency. Hence, kinetic energy of single photon is constant.

If there is no increase in kinetic energy, velocity does not change at all.

Answer.2

Light is quantized when absorbed in photo electric effect i.e. any radiation is not given out completely but released in packets. This packet of light is called Quanta and has energy equal to:

$E_{photon} = h\nu$ where h is plank's constant and *v is the frequency.*

Hence, energy of photon depends upon the frequency.

Now by the photoelectric equation

hv = K+ Φ

K=kinetic energy of electron.

Φ =work function. ($\Phi = h\nu_0 = constant$)

hv =energy of photon.

The minimum frequency (ν_0) is required to make electron emit and the maximum kinetic energy is also dependent on the frequency (v) of photon falling on the surface.

And if the light of suitable frequency which is greater than the minimum frequency (ν_0) falls on the metal surface, it surely emits photoelectron whether it is faintly illuminated or not)

By wave nature, photoelectrons energy depends on its intensity not frequency. By this, not a particular electron but all the electrons will get equal energy at any instant. Hence, electric charge of the photoelectrons is not quantized.

Answer.3

When the photon fall on surface its energy is absorbed in two ways, by the work function of metal (to kick out electron form the atom) and rest is used in the form of kinetic energy.

The total energy of the incoming photon, E_{photon}, must be equal to the kinetic energy of the ejected electron, KEelectron, plus the energy required to eject the electron from the metal. The energy required to free the electron from a particular metal is called the metal's *work function*, which is represented by the symbol Φ:

$$E_{photon} = KE_{electron} + \Phi$$

We can now write the kinetic energy of the photon in terms of the light frequency using Planck's equation:

$E_{photon} = h\nu = KE_{electron} + \Phi$

If a photon with energy greater than E_0 strikes the metal, then part of its energy is used to overcome the forces that hold the electron to the metal surface, and the excess energy appears as the kinetic energy of the ejected electron:

kinetic energy of ejected electron=$E - E_0 = hv - hv_0 = h(v - v_0)$

The equation in terms of the electron's kinetic energy is:

$KE_{electron} = h\nu - \Phi$

Therefore, the energy required to get the electron of the electron out from the surface is h*ν*– ϕ.

And if the electron is in the inside of a metal then it can collide with the others atom and lose its energy. If in collision it loses all its energy it does not come out.

Answer.4

if wavelength of the light is doubled then the photons emitted energy becomes half.

Energy of photon = hv = $\frac{hc}{\lambda}$

where h is plank's constant and *ν is the frequency which is* $\frac{c}{\lambda}$ where the c is the

speed of light and{\displaystyle \lambda } {\displaystyle \lambda } λ (Lambda) is wavelength.

∴ the stopping potential is the potential which is required to stop the max kinetic energy electron. if the energy of photon is decreased

the stopping potential also decreases.

Answer.5

increase in intensity increases the no of photons falling per unit area per unit time is also increased. ∴ the no of photoelectron emitted is also increased which increases the photocurrent.

The exposure time does not affect the no of photons emitted or the energy of photon.

Answer.6

when electric field is switched on a force acts on the photoelectron which is opposite to the direction of electric field which increases the velocity of electron hence kinetic energy.

The stopping potential and the threshold wavelength depends on the metal not on external conditions.

And in saturation condition, no current is increased by increase in the speed of photoelectron.

Answer.7

de Broglie wavelength is λ=$\frac{h}{mv}$=$\frac{h}{\sqrt{2mk}}$

where λ is wavelength, h is Planck's constant, m is the mass of a particle, moving at a velocity v and k is the momentum.

∴ According to above relation, If particle velocity, mass, momentum or its kinetic energy increases, de Broglie wavelength decreases.

Same momentum particles have same de Broglie wavelength.

If velocity is constant heavier mass particle will have smaller de Broglie wavelength. Similarly it applies for kinetic energy.

If particle falls from same height, velocity will be same irrespective of its mass.

Exercises

Answer.1

Given: wavelengths (λ) in the range of 400 nm to 780 nm

Energy of photon is =hv = $\frac{hc}{\lambda}$

where h is plank's constant and *ν* is the frequency which *is* $\frac{c}{\lambda}$ where the c is the

speed of light and{\displaystyle \lambda } {\displaystyle \lambda } λ (Lambda) is wavelength.

Energy of photon of wavelength 780 nm=$\frac{6.63\times10^{-34}\times3\times10^{8}}{780\times10^{-9}}J$

=$2.55 \times 10^{-19}J$

Energy of photon of wavelength 400 nm=$\frac{6.63\times10^{-34}\times3\times10^{8}}{400\times10^{-9}}J$

=$4.97\times10^{-19}J$

∴ the range from $2.55\times10^{-19}J$ to $4.97\times10^{-19}J$.

Answer.2

momentum of photon of wavelength λ is = $\frac{h}{\lambda}$

∴ the momentum of photon of wavelength of 500 nm is

$= \frac{6.63\times10^{-34}}{500\times10^{-9}}\frac{kg\ m}{sec}P\ = 1.32\times10^{-27}\frac{kg\ m}{sec}$

Answer.3

net energy absorbed by atom is equal to the energy of photon absorbed and subtracting the energy of photon it emits.

∴ Energy of photon atom absorbed $= \frac{hc}{\lambda}$.

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{500\times10^{-9}}J = 3.978\times10^{-19}J.$$

Energy of photon atom emit $= \frac{6.63\times10^{-34}\times3\times10^{8}}{700\times10^{-9}}J = 2.841\times10^{-19}J.$

Net absorbed energy$= 3.978\times10^{-19}J - 2.841\times10^{-19}J.$

$= 1.137\times10^{-19}J.$

Answer.4

energy used by lamp= 10 W.

Only 60% of energy given is converted into light

∴ 60% of 10 W=6 W is converted into light.

Energy of single photon=$\frac{6.63\times10^{-34}\times3\times10^{8}}{590\times10^{-9}}J$.

=$3.371\times10^{-19}J$.

No of photons (n) required to produce 6 W energy is

$$n = \frac{6}{3.371\times10^{-19}}$$

$= 1.779\times10^{19}$.

Answer.5

(a); intensity at the earth surface is 1.4 × 10^3 W m^{-2}

Energy of one photon is $= \frac{6.63\times10^{-34}\times3\times10^{8}}{500\times10^{-9}}J = 3.978\times10^{-19}J$.

Then the no of photon (n) required to produce 1.4×10^3J per square m^2 and per unit sec is

$$= \frac{1.4\times10^3}{3.978\times10^{-19}} = 3.519\times10^{21}$$

(b); as we have to calculate the photons in a cubic meter.

We above calculated the no photons that are falls in unit square m^2 per sec.

In a unit sec all the photons which are at height [$3\times10^8\ m$] fall in unit m^2. ∴ The photons which fall from 1 m height will fall in $\frac{1}{3}\times10^{-8}sec$.

If there are 3.519×10^{21} photons which fall in 1 sec,

Then, no. of photons which fall in $\frac{1}{3}\times10^{-8}sec$ is $3.519\times10^{21}\times\frac{1}{3}\times10^{-8}$ = 1.173×10^{13}.

These 1.173×10^{13} photons are in the 1 m^3 near the earth surface.

(c); As explained above, the no. of photons falling in 1 m square area per sec on earth surface is 3.519×10^{21} . ∴ The no of photons which fall on the surface of sphere of radius (distance between the sun and the earth surface) is the total no of photons which will be emitted by sun in 1 sec.

By this, surface area of sphere is $4\pi(1.5 \times 10^{11})^2$ m square. Therefore, the no of photons will be

$= 4\pi(1.5 \times 10^{11})^2 \times 3.519 \times 10^{21}$.

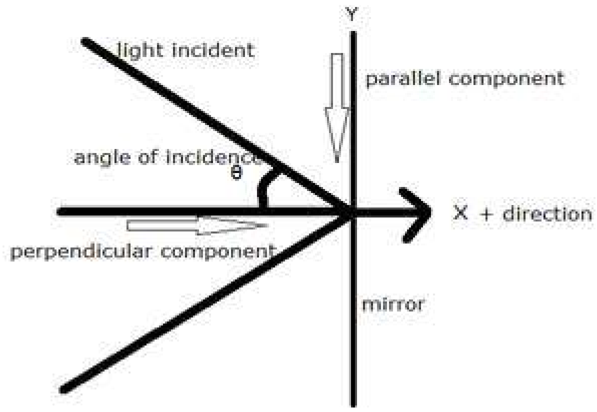
$= 9.89 \times 10^{44}$.

Answer.6

momentum (p) imparted by 1 photon on the mirror is

Momentum is a vector quantity which has magnitude and direction

So, in below formula we are considering only the component of momentum which is perpendicular to the mirror, note: that the parallel component does not make any contribution, as it is parallel therefore it does not fall any of the area of mirror.



mv is the momentum of light fall but its perpendicular component is mvcosθ and the change in momentum when it reflects is 2 mv cosθ.

p =mv cosθ – (-mv cosθ)

where p= momentum,

m=mass

v= velocity.

p =2mvcosθ

And the momentum of photon is given by its energy (E) speed of light (c). The quantity (mv) in above formula can be written for photon as $\frac{E}{c}$ it is equal to that[momentum of photon is defined to be as its $\frac{Energy}{speed\ of\ light}$]. So above formula becomes,

$\therefore$ p $= 2\frac{E}{C}$cosθ. Equation 1

$\rightarrow \frac{p}{t} = 2\frac{E}{C \times t}$cosθ. (Rate of change of momentum is force)

$\rightarrow$ Force by one photon is $= 2\frac{6.63 \times 10^{-34}}{663 \times 10^{-9} \times 1} \cos 60°$.

$=10^{-27} N$.

$\therefore$ Force by 1.0×10^{19} photons is $=10^{-27} \times 1.0 \times 10^{19} N$.

$=10^{-8} N$.

Answer.7

If the surface is fully reflecting surface, then force exerted will be

$$= 2\frac{power}{speed\ of\ light}$$

As 30% is reflecting surface then 3 W of power is used in force exerted by the reflecting surface.

Hence force by reflecting part is $F_1 = 2 \times \frac{3}{3} \times 10^{-8}$.

If the is fully absorbing then force exerted is

$=\frac{power}{speed\ of\ light}$.

As 70% is absorbing surface then 7 W of power is used in force exerted by the absorbing surface.

Hence force by absorbing part is $F_2 = \frac{7}{3} \times 10^{-8}$.

Hence total force is F=$F_1 + F_2$=2$\times \frac{3}{3} \times 10^{-8} + \frac{7}{3} \times 10^{-8}$.

$F = \frac{13}{3} \times 10^{-8}$.

$F = 4.33 \times 10^{-8}$.

Answer.8

The weight of the mirror is supported by the light.

The weight of mirror =mg.

Force exerted on mirror is, as mirror is fully reflecting and 30% of light which is passed through the lens is used

From equation 1 of question 6 we can write

$$p = 2\frac{E}{C}\cos\theta$$

we light fall at angle θ on mirror

taking derivative of above equation and putting θ =0 as perpendicular it is falling we get

$$\frac{dp}{dt} = 2\frac{dE}{dt \times c}$$

Where $\frac{dE}{dt}$ =power and $\frac{dp}{dt}$ =force ,c =speed of light.

∴ we get

Force = $2\frac{power}{speed\ of\ light}$

∴ The force exerted by light is = $2\frac{power}{speed\ of\ light}$.

And the power of light which is used is only 30% of original

→ for mirror to be in equilibrium the downward force and upward force must be equal.

The weight acting downwards = the force exerted by light

Weight acting downwards =Mg

Force exerted by light=$2\frac{power}{speed\ of\ light}$

As only 30% of light is fall on mirror, therefore only 30% of the power is in use.

Force exerted by light= $2\ \frac{30\%\ (power)}{3\times 10^8}$

$$Mg\ =\ 2\ \frac{30\%\ (power)}{3\times 10^8}$$

Where M= mass,

g = acceleration due to gravity.

Putting the values,

$20\times 10^{-3}\times 10=2\ \frac{30\%\ (power)}{3\times 10^8}$.

Hence, power is =$10^8 W$ =100MW.

Answer.9

If the is fully absorbing, then force exerted is

=$\frac{power}{speed\ of\ light}$.

60% of original power is used, ∴ 60W.

Then the force is =$\frac{60}{3\times 10^8}$.

Then the pressure is force /area.

And it is pressure $= 2\times \frac{10^{-7}}{4\pi(20\times 10^{-4})^2}$

$= 3.978\times 10^{-7}\,Pa.$

Answer.10

If the is fully absorbing then force exerted is

$=\frac{power}{speed\ of\ light}$.

Then $\text{power} = \text{I} \times \text{A}$

Where I= intensity.

A=area

In this area, is the perpendicular area in which it falls.

$\therefore \text{Power} = 0.50 \text{ W cm}-2 \times \pi(1.00\ cm)^2 = \frac{\pi}{2} \times 10^{-4} m^2$

Hence, force is

$=\frac{\pi \times 10^{-4}}{2 \times 3 \times 10^8} N$.

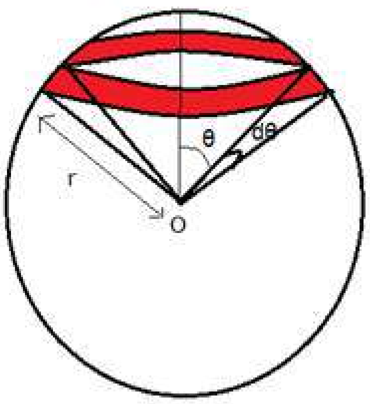
$=5.23 \times 10^{-9} N$

Answer.11

we assume a sphere of radius r and light falls on it.

We assume a ring on it with breath rdθ (as dθ is very small), dθ is the angle which forms with the center as origin and the breath of strip.

The red colour shaded is the strip we selected.



Area of strip =length × breath

Length =$2\pi r sin\theta$

Breath=$r\ d\theta$

∴ It's area is $2\pi r^2 sin\theta d\theta$

∴ The energy falling on ring in dt time will be

dE=I dt da cosθ .... equation (1)

and the momentum it imparts will be

dp =$2\frac{dEcos\theta}{c}$ from equation 1 of question 6 we have this formula.

Putting the value of dE from equation 1 in above equation,

Hence the force is

df =$2\frac{I}{c}\ da\ \cos^2\theta$

Component of force onto the straight line which is passing through center of sphere and the origin of source.

=$2\frac{I}{c}\ da\ \cos^3\theta$

Hence force on entire sphere, by applying proper limits of θ from 0 to π

Force =$\int_0^{\pi/2} 2\frac{I}{c}\ (2\pi r^2 sin\theta d\theta\ )\ \cos^3\theta$

=$\int_0^{\pi/2} 2\frac{I}{c}\ 2\pi r^2\ sin\theta \cos^3\theta\ d\theta$

= $4\frac{I}{c}\pi r^2 \int_0^{\pi/2}\ sin\theta \cos^3\theta\ d\theta$ [put cosθ =t and solve by replacing it as $d\theta = -dt/sin\theta$ and replacing limits 1 to 0]

=$\frac{\pi r^2 I}{c}$

i.e. this is same for above also.

Answer.12

In any collision of electron and photon the collision will be elastic.

∴ Energy and momentum will be conserved.

Energy of photon = $\frac{hc}{\lambda}$.(λ is wavelength of photon)

Momentum of photon (p)= $\frac{h}{\lambda}$

Rest mass energy of electron =m_0c^2.($m_0$is the rest mass of electron)

Energy of electron after collision =mc^2.(m is relativistic mass of electron)

Where 'c' is speed of light.

By use of conservation of energy,

$E_{initial} = E_{final}$

∴ Initial energy is sum of photon energy and electron energy

Initial photon energy = pc, rest mass of photon is zero therefore its rest mass energy is zero.

Initial electron energy = rest mass energy of it =m_0c^2

Final energy = energy of electron as it gains velocity. $\sqrt{p^2c^2 + m_0^2c^4}$ is its relativistic energy, when electron moves with momentum p.

By applying the conservation of energy, we get

∴ $pc + m_0c^2$= $\sqrt{p^2c^2 + m_0^2c^4}$

Squaring both side and solving.

Solving this we get $p\ and\ m_0$ vanish.

∴ it is not possible for a photon to be completely absorbed by a free electron.

Answer.13

if we assume q charge appear on the particle then the potential energy between them is =$\frac{kq^2}{r}$.

Where, r is the distance between two particles. (r=1m)

The energy between particles is transferred into photon form.

∴ $\frac{kq^2}{r} = \frac{hc}{\lambda}$

$$\lambda = \frac{hcr}{kq^2}$$

For wavelength to maximum the charge should be electronic charge

e $= 1.6 \times 10^{-19} c$

∴ Maximum wavelength is

$$\lambda_m = \frac{6.6\times10^{-34}\times3\times10^8\times1}{9\times10^9\times(1.6\times10^{-19})^2}$$

=863m.

Next shortest wavelength is

$$\lambda = \frac{\lambda_m}{4}$$

$$= \frac{863}{4} = 215.7m$$

Answer.14

Given, wavelength λ =350nm =350 $\times 10^{-9}$m

Work function of cesium Φ =1.9eV

From Einstein photoelectric equation,

hf=Kmax +Φ

where Kmax is maximum kinetic energy,

h is Planck's constant

f is frequency (f=c/λ where c is speed of light and

λ is the wavelength of light).

$$\therefore Kmax = \frac{hc}{\lambda} - \Phi$$

$$\Rightarrow \frac{6.63\times10^{-34}\times3\times10^8}{350\times10^{-9}\times1.6\times10^{-19}} - 1.9$$

$$\Rightarrow (0.0355 \times 100) - 1.9$$

$$\Rightarrow 3.5 - 1.9$$

$\therefore Kmax = 1.65\ eV.$

Answer.15

Given, work function W0 (Φ) = 2.5×10^{-19}J

(a)We know that, Wo = hf

Where h is the Planck's constant,

f is the threshold frequency

$\Rightarrow 2.5 \times 10^{-19} = 6.63 \times 10^{-34} \times f$

$\Rightarrow \frac{2.5\times10^{-19}}{6.63\times10^{-34}} = f$

$\therefore threshold\ frequency = 3.77 \times 10^{14} Hz.$

(b) From photoelectric equation, hf =Kmax +Φ

⇒ hf =eVstop +Φ

Where Vstop is the stopping potential,

Φ is the work function,

f is the frequency of light beam,

h is Planck's constant,

e is the charge on electron

$\Rightarrow 6.63 \times 10^{-34} \times 6 \times 10^{14} = (1.6 \times 10^{-19} \times Vstop\ ) + (2.5 \times 10^{-19})$

$\Rightarrow 39.78 \times 10^{-20} = (1.6 \times 10^{-19} \times Vstop\ ) + (2.5 \times 10^{-19})$

$\Rightarrow (3.978 \times 10^{-19}) - (2.5 \times 10^{-19}) = 1.6 \times 10^{-19} \times Vstop$

$\Rightarrow 1.478 \times 10^{-19} = 1.6 \times 10^{-19} \times Vstop$

$$\therefore Vstop = \frac{1.478 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$Vstop = 0.923\ V$

Answer.16

(a) Given, work function W0 (Φ) =4 eV

We know that, W_0=hf=hc/λ

where, λ is the threshold wavelength,

h is Planck's constant,

c is the speed of light,

$$\Rightarrow 4 \times 1.6 \times 10^{-19} = \frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda}$$

$$\Rightarrow \frac{6.4\times10^{-19}}{19.89\times10^{-26}} = \frac{1}{\lambda}$$

$$\therefore \text{threshold wavelength}, \lambda = 3.1 \times 10^{-7} m.$$

(b) Given, stopping potential, Vstop = 2.5V

∴ From photoelectric equation, hf =Kmax +Φ

$$\Rightarrow \frac{hc}{\lambda} = eV_{stop} + \Phi$$

Where Φ is the work function,

λ is the wavelength of light,

h is Planck's constant,

c is the speed of light,

e is the charge on electron,

V_0 is the stopping potential

$$\Rightarrow \frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda} = (1.6 \times 10^{-19} \times 2.5) + (4 \times 1.6 \times 10^{-19})$$

$$\Rightarrow \frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda} = 10.4 \times 10^{-19}$$

$$\Rightarrow \lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{10.4\times10^{-19}}$$

$$\therefore \text{wavelength}, \lambda = 1.912 \times 10^{-7} m$$

Answer.17

Given, wavelength λ =400× 10^{-9}

Work function=2.5eV

From photoelectric equation, $\frac{hc}{\lambda} = K + \Phi$

Where K is kinetic energy,

h is Planck's constant,

c is speed of light,

Φ is the work function,

λ is the wavelength of light.

$\Rightarrow \frac{6.63\times10^{-34}\times3\times10^{8}}{(400\times10^{-9}\times1.6\times10^{-19})} = K + 2.5$

$\Rightarrow \frac{19.89}{6.4} = K + 2.5$

$\Rightarrow 3.1078 - 2.5 = K$

$\therefore kinetic\ energy, K = 0.607\ eV$

We also know that, $K = \frac{p^2}{2m}$

Where P is linear momentum and m is mass of electron

$\Rightarrow 0.607 \times 1.6 \times 10^{-19} = \frac{p^2}{2\times9.1\times10^{-31}}$

$\Rightarrow 0.607 \times 1.6 \times 10^{-19} \times 2 \times 9.1 \times 10^{-31} = p^2$

$\Rightarrow p^2 = 17.675 \times 10^{-50}$

$\Rightarrow linear\ momentum, P = 4.20 \times 10^{-25} \frac{kg\ m}{s}$.

Answer.18

Given, wavelength $\lambda = 400nm = 400 \times 10^{-9}\, m.$

Potential (i.e.; stopping potential) =1.1V

From Einstein's photoelectric equation, $\frac{hc}{\lambda} = K + \Phi$

$$\Rightarrow \frac{hc}{\lambda} = eV_0 + \frac{hc}{\lambda_0}$$

Where λ_0 is the threshold wavelength,

λ is the wavelength of light,

h is Planck's constant,

c is the speed of light,

e is the charge on electron,

V_0 is the stopping potential

$$\Rightarrow \frac{6.63\times10^{-34}\times3\times10^{8}}{400\times10^{-9}} = \frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda_0} + (1.6 \times 10^{-19} \times 1.1)$$

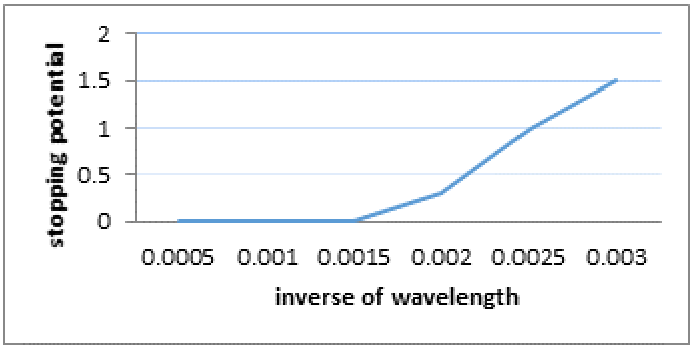
$$\Rightarrow 4.97 \times 10^{-19} = \frac{19.89\times10^{-26}}{\lambda_0} + (1.76 \times 10^{-19})$$

$$\Rightarrow 3.21 \times 10^{-19} = \frac{19.89\times10^{-26}}{\lambda_0}$$

$$\Rightarrow \lambda_0 = \frac{19.89\times10^{-26}}{3.21\times10^{-19}}$$

$\therefore \lambda_0$ (threshold frequency) $= 6.19 \times 10^{-7}$ m.

Answer.19



(a) from the given table ,

When λ =$350 \times 10^{-9} m$ then V =1.45

∴ from Einstein's photoelectric equation, $\frac{hc}{\lambda} = K + \Phi$

$\Rightarrow \frac{hc}{350} = e1.45 + \Phi$.....(1)

Again when λ=$400 \times 10^{-9} m$ then V = 1

Then again the equation becomes $\frac{hc}{400} = e \times 1 + \Phi$...... (2)

∴ subtracting eq (1) & (2) we get,

$\Rightarrow hc \times 10^9 \left[\left(\frac{1}{350}\right) - \left(\frac{1}{400}\right)\right] = e(1.45 - 1)$

$\Rightarrow hc \times 10^9 \times 0.00035 = 0.45\, e$

$\Rightarrow h \times 3 \times 10^8 \times 10^9 \times 0.00035 = 0.45$

∴ Planck's constant, $h = 4.2 \times 10^{-15}\ eV\, s.$

(b) Substituting the values of h, c (speed of light),

We get the value of Φ (work function) as

$$\Phi = \frac{4.2 \times 10^{-15} \times 3 \times 10^8}{350 \times 10^{-9}} - 1.45$$

$\Phi = (0.036 \times 10^2) - 1.45$

∴ Work function, Φ =2.15eV.

(c) We know that work function, $\Phi = \frac{hc}{\lambda}$

Where λ is the threshold wavelength

h is the Planck's constant

c is the speed of light

$\Rightarrow \lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{2.15}$

$= 578.8\ nm.$

Answer.20

NOTE: In one complete oscillation electric field become zero twice.

Therefore, if electric field becomes zero 1.2×10^{15} times per second, then number of oscillations per second will be $\frac{1.2\times10^{15}}{2}$ =0.6×10^{15}

∴ Frequency of the monochromatic light will be 0.6×10^{15} Hz

From Einstein's photoelectric equation, hf=Kmax +Φ

Where h is Planck's constant,

f is the frequency of light,

Kmax is the maximum kinetic energy,

Φ is the work function

∴ putting the values in the equation we have,

$\Rightarrow (6.63 \times 10^{-34} \times 0.6 \times 10^{15}) = K + (2 \times 1.6 \times 10^{-19})$

$\Rightarrow 3.978 \times 10^{-19} = K + (3.2 \times 10^{-19})$

$\Rightarrow K = (3.978 \times 10^{-19}) - (3.2 \times 10^{-19})$

∴ Maximum kinetic energy, Kmax =0.77×10^{-19} J.

Answer.21

Given, work function Φ =1.9 eV

$E = E_0 \sin[(1.57 \times 10^7 m^{-1})(x - ct)]$...... (1)

$E = E_0 \sin[\left(\frac{2\pi}{\lambda}\right)(x - ct)]$ ... . (2)

On comparing the above two equations, we get

$\left(\frac{2\pi}{\lambda}\right) = 1.57 \times 10^7$.... (3)

We know that λ=c/f....... (4)

Where λ is the wavelength of light,

C is the speed of the light,

f is the frequency of the light.

∴ From eq (3) & (4)we get the value of frequency

$\therefore f = \frac{1.57\times10^7\times3\times10^8}{2\pi}$

Now, from Einstein's photoelectric equation

$hf = eV_0 + \Phi$....(5)

Where h is the Planck's constant,

f is the frequency of light,

e is the charge on an electron ,

V_0 is the stopping potential,

Φ is the work function.

Putting the values in eq(5) we have,

$\Rightarrow \frac{6.63\times10^{-34}\times1.57\times10^7\times3\times10^8}{2\pi} = e(V_0 + 1.9)$

$\Rightarrow 4.97 \times 10^{-19} = 1.6 \times 10^{-19}(V_0 + 1.9)$

$\Rightarrow 3.10 - 1.9 = V_0$

$\Rightarrow \; stopping\ potential, V_0 = 1.2\ V$

Answer.22

Given, work function Φ =2 eV

$E = (100Vm^{-1}) \sin[(3\times 10^{15}s^{-1})t]\sin[(6\times 10^{15}s^{-1})t]$

Solving the above equation using formula,

$2\sin c \times \sin d = \cos(c-d) - \cos(c+d)$

$\therefore E = 50[\cos[(9\times 10^{15}s^{-1})t] - \cos[(3\times 10^{15}s^{-1})t]]$

From the above equation there are two values of W

$9 \times 10^{15}\ and\ 3 \times 10^{15}$

∴ for maximum kinetic energy W should be maximum

$\because f = \frac{W}{2\pi} = \frac{9\times 10^{15}}{2\pi}$

And also from Einstein's photoelectric equation,

$hf = K + \Phi$

$\Rightarrow K = hf - \Phi$

∴ Kinetic energy will be maximum when f (frequency) is

Maximum and f will be maximum when W is maximum.

$\Rightarrow K = \frac{6.63\times10^{-34}\times9\times10^{15}}{2\pi\times1.6\times10^{-19}} - 2$

$\Rightarrow K = 5.93 - 2$

K= 3.93 eV.

Answer.23

Given, intensity I =5mW,

No. of photons emitted per second n=8×10^{15}

Stopping potential V =2V

From Einstein's photoelectric equation, $hf = K + \Phi$

$\Rightarrow$ work function $\Phi = hf - K$

$\Rightarrow \Phi = E - eV$

$= \left(\frac{I}{n}\right) - eV$

$= \frac{5\times10^{-3}}{8\times10^{15}} - (1.6 \times 10^{-19} \times 2)$

$= (0.625 \times 10^{-18}) - (3.2 \times 10^{-19})$

$\Phi = 3.05 \times 10^{-19}\ V$

$\therefore$ Work function Φ =1.906eV

Answer.24

from the above graph we see that,

When V_0=1.656V then $\nu = 5 \times 10^{14}\,Hz$...... (1)

When V_0=0 then $\nu = 1 \times 10^{14}\ Hz$.... (2)

Where $V_0$the stopping potential and ν is the frequency

Of the light.

From Einstein's photoelectric equation,

$hf = K + \Phi$

$\Rightarrow\ hf = eV_0 + \Phi$ ....(3)

$\therefore$ from eq (1) & (3) we have

$1.656e = h \times 5 \times 10^{14} - \Phi$..... (4)

Again from eq(2) & (3) we have

$0 = 5 \times h \times 10^{14} - 5\Phi$...... (5)

On solving eq (4) & (5) we get

$\Rightarrow 1.656e = 4\Phi$

Work function, $\Phi = 0.414eV$.

Now, to find the ratio h/e we put the value of Φ

In eq (5) we get,

$\Rightarrow h = (5 \times 0.41)/(5 \times 10^{14})$

$\Rightarrow h = 4.14 \times 10^{-15}\ eV\ s$

$\Rightarrow\ h/e = 4.14 \times 10^{-15} Vs.$

Answer.25

Given, work function Φ=0.6eV

We know that Φ=hc/λ

Where h is the Planck's constant

C is the speed of the light

λ is the wavelength of the light.

∴ for λ to be maximum Φ should be minimum

$\Rightarrow \lambda\ = \frac{hc}{\Phi}$

$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{0.6 \times 1.6 \times 10^{-19}}$

$\therefore\ \lambda = 20.71 \times 10^{-7} m$

Answer.26

Given, wavelength of light λ=400nm

Power P=5W

Energy of photon $E = \frac{hc}{\lambda}$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{(400 \times 10^{-9} \times 1.6 \times 10^{-19})} \ eV$$

$$= \frac{1242}{400} eV$$

We know that, no. of electrons per second

$= power/\ energy$

$$= \frac{5 \times 400}{1.6 \times 10^{-19} \times 1242}$$

It is given that on average one out of every 10^{6}

Photons is emitted (i.e.; 1 per 10^{6} photons).

∴ No. of photoelectrons emitted $= \frac{5 \times 400}{1.6 \times 10^{-19} \times 1242 \times 10^{6}}$

∴ Photocurrent in the circuit $= \frac{5 \times 400 \times 1.6 \times 10^{-19}}{1.6 \times 10^{-19} \times 1242 \times 10^{6}}$

$=1.6 \times 10^{-6} A$

Answer.27

Given, radius of the silver ball r=4.8cm

Wavelength of light λ=200nm

Energy falling on surface e=$1 \times 10^{-7} J$

Energy of one photon =hc/λ

Where h is Planck's constant

C is speed of light

λ is the wavelength of light

∴ Energy =$\frac{6.63\times10^{-34}\times3\times10^{8}}{200\times10^{-9}}$

=9.94×10^{-19J}

$$no. of\ photons = \frac{energy\ falling\ on\ surface}{energy\ of\ one\ photon}$$

=$\frac{1\times10^{-7}}{9.94\times10^{-19}}$ =1×10^{11}

It is given that one photon out of every ten thousand

is able to eject a photoelectron.

∴ No. of photoelectrons= $\frac{1\times10^{11}}{10^{4}}$ =1×10^{7}

It is given that potential at infinity is zero

Potential at the centre and at the surface of the ball are

Equal i.e; =Kq/r

Where K is the constant (9×10^{9})

q is the charge on ball

r is the radius of ball

q =ne where n is the no.of photoelectrons

and e is charge on electron

∴ $q\ = 1 \times 10^{7} \times 1.6 \times 10^{-19}$

$= 1.6 \times 10^{-12}C$

∴ required potential $= \frac{kq}{r}$

$$= \frac{(9 \times 10^{9} \times 1.6 \times 10^{-12})}{(4.8 \times 10^{-2})}$$

$= 0.3V$

Answer.28

Given, work function Φ=2.39 eV

Wavelengths $\lambda_1 = 400nm\ , \lambda_2 = 600\ nm$

Radius of the path = 10cm =0.1 m

From Einstein's photoelectric equation, $hf = K + \Phi$

$\Rightarrow \frac{hc}{\lambda} = E + \Phi$ …. (1)

Where h is Planck's constant

c is the speed of light

λ is the wavelength of light

E is the energy (kinetic energy)

Φ is the work function

We know that radius of the path traversed by the particle

In the magnetic field B is given by-

$r = \frac{mv}{qB} = \frac{\sqrt{2mE}}{qB}$ ….. (2)

Where m is the mass of an electron

E is the energy

q is the charge on an electron

B is the magnetic field

∴ for B to be minimum energy E should be maximum and for E to be maximum λ should be minimum.

Hence we will consider the smallest value of λ

and put the values in eq (1) we get,

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{400 \times 10^{-9}} - 2.39$$

$$= \frac{0.0497 \times 10^{-17}}{1.6 \times 10^{-19}} - 2.39$$

$$= 3.10 - 2.39\ eV$$

$$\therefore E = 0.71 eV.$$

Now, putting the value in eq (2) we get,

$$B = \frac{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 0.71}}{0.1 \times 1.6 \times 10^{-19}}$$

∴ Magnetic field, $B = 2.85 \times 10^{-5}\ T.$

Answer.29

Given, y=1mm

∴ Fringe width y=2× 1 =2mm

d=0.24mm

D =1.2m

Work function Φ =2.2eV

We know that fringe width $y = \frac{\lambda D}{d}$

$\therefore \lambda = \frac{yd}{D}$

Putting the values in above equation we get,

$$\lambda = \frac{2 \times 10^{-3} \times 0.24 \times 10^{-3}}{1.2}$$

$$\lambda = 4 \times 10^{-7} m$$

We also know that $E = \frac{hc}{\lambda}$

$E = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{4 \times 10^{-7}}$ [h=$6.63 \times 10^{-34} J/s \; or \; 4.14 \times 10^{-15} eV/s$]

$$E = 3.105 eV$$

From Einstein's photoelectric equation,

Stopping potential $eV_0 = E - \Phi$

$$= 3.105 - 2.2$$

$$= 0.905 eV$$

Answer.30

Given, stopping potential =2V

Work function Φ =4.5eV

Wavelength λ=200nm

∴ From Einstein's photoelectric equation

$$K = \frac{hc}{\lambda} - \Phi$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{200 \times 10^{-9} \times 1.6 \times 10^{-19}} - 4.5$$

$$= 0.062 \times 10^{2} - 4.5$$

$$= 6.2 - 4.5$$

$$= 1.7 eV$$

∴ Minimum kinetic energy of photoelectron is 1.7eV

And maximum kinetic energy $= (2 + 1.7) eV = 3.7 eV$

[∵ Electric potential of 2V is applied for the electrons to accelerate ∴ it is (2+1.7)]

Answer.31

Given, work function $\Phi = 1.9eV$

Charge density $\sigma \ = 1 \times 10^{-9} C\ m^{-2}$

Distance d=20cm

Wavelength λ=400nm

We know that electric potential due to charged plate

is given by ,$V = E \times \ d$

where E is the electric field due to charged plate

and d is the distance between two plates

$$\because \ E = \frac{\sigma}{E_0}$$

$$\therefore \ V = \frac{\sigma \times \ d}{E_0}$$

$$= \frac{1 \times 10^{-9} \times 20}{8.85 \times 10^{-12} \times 100}$$

= 59V

Now, from Einstein's photoelectric equation

$$K = hf - \Phi$$

$$\Rightarrow eV_0 = \frac{hc}{\lambda} - \Phi$$

Now putting the values of h, c, λ, Φ we get

$$\Rightarrow eV_0 = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{400 \times 10^{-9} \times 1.6 \times 10^{-19}} - 1.9$$

$$\Rightarrow eV_0 = 3.10 - 1.9$$

$$\Rightarrow eV_0 = 1.20eV \ldots\ldots (1)$$

$\therefore V_0 = 1.20\ V$

$\because V_0 \lll V$

$\therefore$ Minimum kinetic energy required to reach the large

Metal =22.6eV

Next, maximum kinetic energy $= V_0 + V = 23.8\ V$

Answer.32

electric field $E = \frac{\sigma}{E_0}$

$$E = \frac{1 \times 10^{-9}}{8.85 \times 10^{-12}} \frac{V}{m}$$

$$= 113 \frac{V}{m}$$

Acceleration of charged particle is given by,

$$a = \frac{qE}{m}$$

Where q is the charge on electron

E is the electric field

m is the mass of electron

$\therefore a = \frac{1.6 \times 10^{-19} \times 113}{9.1 \times 10^{-31}}$

$a = 19.87 \times 10^{12} m\, s^{-2}$

To calculate time, we know that $t = \frac{\sqrt{2d}}{a}$

$\therefore t = \frac{\sqrt{2 \times 20 \times 10^{-2}}}{19.87 \times 10^{12}}$

$t = 1.41 \times 10^{-7} s.$

From Q: 31 the value of kinetic energy =1.2eV [from eq (1)]

$\therefore$ K.E. $= 1.2 \times 1.6 \times 10^{-19}$ J

We also know that $K.E. = \frac{1}{2}mv^2$

$$\therefore v = \frac{\sqrt{2KE}}{m}$$

$$v = \frac{\sqrt{2 \times 1.2 \times 1.6 \times 10^{-19}}}{4.1 \times 10^{-31}} = 0.66 \times 10^{-6} \frac{m}{sec}$$

∴ Displacement, S=v× t

$$= 0.66 \times 10^{-6} \times 1.4 \times 10^{-7} = 0.092\, m$$

Answer.33

Given, wavelength λ=250nm

Work function Φ =1.9eV

We know that energy of photon $=\frac{hc}{\lambda}$

$$= \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{250 \times 10^{-9}}$$

$$= 4.96\, eV$$

From Einstein's photoelectric equation

$$KE = \frac{hc}{\lambda} - \Phi$$

$$= 4.96 - 1.9$$

$$= 3.06\, eV$$

For minimum value of v so that the vertically upward

Component of the velocity is non-positive for each

Photoelectron. We know that,

Velocity of photoelectron$= \sqrt{\frac{2KE}{m}}$

$$= \sqrt{\frac{3.06 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}}$$

$= 1.04 \times 10^6 \frac{m}{sec}.$

Answer.34

Given, work function=Φ

Distance=d

It is also given that particle is moving in a circle

Now, from Einstein's photoelectric equation,

$$eV_0 = \frac{hc}{\lambda} - \Phi$$

$$\Rightarrow V_0 = \left(\frac{hc}{\lambda} - \Phi\right)\left(\frac{1}{e}\right)$$

$$\Rightarrow \frac{ke}{2d} = \left(\frac{hc}{\lambda} - \Phi\right)\left(\frac{1}{e}\right)$$

$$\Rightarrow \frac{ke^2}{2d} + \Phi = \frac{hc}{\lambda}$$

$$\Rightarrow \frac{hc}{\lambda} = \left(\frac{ke^2 + 2d\Phi}{2d}\right)$$

On solving the above equation we get,

$$\lambda = \frac{hc2d}{ke^2 + 2d\Phi}$$

$$\therefore \lambda = \frac{8\pi E_0 hcd}{e^2 + 8\pi E_0 d\Phi}$$

Answer.35

Given, wavelength $\lambda = 400nm$

Work function $\Phi = 2.2eV$

(a) We know that energy of photon $= \frac{hc}{\lambda}$

$$= \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{400 \times 10^{-9}}$$

$= 3.1eV$

As it is given that 10% extra energy is lost to the metal

In each collision

$\therefore$ Energy lost after first collision $= 3.1eV \times 10\%$

$= 0.31\ eV$

Now, energy lost after secomd collision $= 3.1 \times 10\%$

$= 0.31eV$ $\therefore$ total energy lost in collision $= 0.31 + 0.31 = 0.62eV = E$

Hence, Kinetic energy of photoelectron = $\frac{hc}{\lambda} - \Phi - E$

$= 3.1 - 2.2 - 0.62$

$= 0.31eV.$

(b) For third collision energy lost =0.31eV

Hence, we see that energy lost in third collision =kinetic

energy of photoelectron

$\therefore$ In third collision it just comes out of the metal

and in fourth collision it is unable to come out

of the metal.

$\therefore$ Maximum number of collisions required =4.