42. Photoelectric Effect and Wave-Particle Duality

Short Answer

1. Question

Can we find the mass of a photon by the definition p = mv?

Answer

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.

2. Question

Is it always true that for two sources of equal intensity, the number of photons emitted in a given time are equal?

Answer

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.

3. Question

What is the speed of a photon with respect to another photon if

(a) the two photons are going in the same direction and

(b) they are going in opposite directions?

Answer

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.

4. Question

Can a photon be deflected by an electric field? By a magnetic field?

Answer

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

5. Question

A hot body is placed in a closed room maintained at a lower temperature. Is the number of photons in the room increasing?

Answer

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.

6. Question

Should the energy of a photon be called its kinetic energy or its internal energy?

Answer

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.

7. Question

In an experiment on photoelectric effect, a photon is incident on an electron from one direction and the photoelectron is emitted almost in the opposite direction. Does this violate conservation of momentum?

Answer

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.

8. Question

It is found that yellow light does not eject photoelectrons from a metal. Is it advisable to try with orange light? With green light?

Answer

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

$$\lambda_g \le \lambda_0 < \lambda_y < \lambda_o.$$

9. Question

It is found that photosynthesis starts in certain plants when exposed to the sunlight but it does not start if the plant is exposed only to infrared light. Explain.

Answer

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.

10. Question

The threshold wavelength of a metal is λ_0. Light of wavelength slightly less than λ_0 is incident on an insulted plate made of this metal. It is found that photoelectrons are emitted for some time and after that the emission stops. Explain.

Answer

Since $\lambda \le \lambda_0$, 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.

11. Question

Is $p = E/c$ valid for electrons?

Answer

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.

12. Question

Consider the de Broglie wavelength of an electron and a proton. Which wavelength is smaller if the two particles have (a) the same speed (b) the same momentum (c) the same energy?

Answer

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.

13. Question

If an electron has a wavelength, does it also have a colour?

Answer

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

1. Question

Planck constant has the same dimensions as

A. force × time

B. force × distance

C. force × speed

D. force × distance × time

Answer

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.

2. Question

Two photons having

A. equal wavelengths have equal linear momenta

B. equal energies have equal linear momenta

C. equal frequencies have equal linear momenta

D. equal linear momenta have equal wavelengths.

Answer

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.

3. Question

Let p and E denote the linear momentum and energy of a photon. If the wavelength is decreased,

A. both p and E increase

B. p increase and E decreases

C. p decreases and E increase

D. both p and E decrease

Answer

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 $p \propto 1/\lambda$.

4. Question

Let n_r and n_b be respectively the number of photons emitted by a red bulb and a blue bulb of equal power in a given time.

A. $n_r = n_b$ B. $n_r < n_b$

C. $n_r > n_b$

D. The information is insufficient to get a relation between n_r and n_b.

Answer

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 $n_r > n_b$.

5. Question

The equation E = pc is valid

A. for an electron as well as for a photon

B. for an electron but not for a photon

C. for a photon but not for an electron

D. neither for an electron nor for a photon.

Answer

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.

6. Question

The work function of a metal is hv_0. Light of frequency v falls on this metal. The photoelectric effect will take place only if

A. $v \geq v_0$ B. $v > 2v_0$

C. $v < v_0$ D. $V < V_0/2$

Answer

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

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

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

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

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

7. Question

Light of wavelength λ falls on a metal having work function hc/λ_0. Photoelectric effect will take place only if

A. $\lambda \geq \lambda_0$ B. $\lambda \geq 2\lambda_0$

C. $\lambda \leq \lambda_0$ D. $\lambda < \lambda_0/2$

Answer

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.

8. Question

When stopping potential is applied in an experiment on photoelectric effect, no photocurrent is observed. This means that

A. the emission of photoelectrons is stopped

B. the photoelectrons are emitted but are re-absorbed by the emitter metal

C. the photoelectrons are accumulated near the collector plate

D. the photoelectrons are dispersed from the sides of the apparatus.

Answer

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.

9. Question

If the frequency of light in a photoelectric experiment is doubled, the stopping potential will

A. be doubled

B. be halved

C. become more than double

D. become less than double

Answer

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.

10. Question

The frequency and intensity of a light source are both doubled. Consider the following statements.

(A) The saturation photocurrent remains almost the same.

(B) The maximum kinetic energy of the photoelectrons is doubled.

A. Both A and B are true

B. A is true but B is false

C. A is false but B is true

D. Both A and B are false

Answer

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; ν=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.

11. Question

A point source of light is used in a photoelectric effect. If the source is removed farther from the emitting metal, the stopping potential

A. will increase

B. will decrease

C. will remain constant

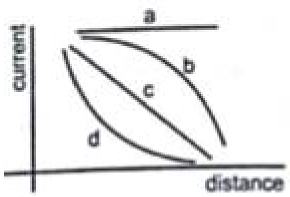
D. will either increase or decrease

Answer

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.

12. Question

A point source causes photoelectric effect from a small metal plate. Which of the following curves may represent the saturation photocurrent as a function of the distance between the source and the metal?



Answer

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.

13. Question

A nonmonochromatic light is used in an experiment on photoelectric effect. The stopping potential

A. is related to the mean wavelength

B. is related to the longest wavelength

C. is related to the shortest wavelength

D. is not related to the wavelength.

Answer

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.

14. Question

A proton and an electron are accelerated by the same potential difference. Let λ_e and λ_p denote the de Broglie wavelengths of the electron and the proton respectively.

A. $\lambda_e = \lambda_p$

B. $\lambda_e < \lambda_p$

C. $\lambda_e > \lambda_p$

D. The relation between λ_e and λ_p depends on the accelerating potential difference.

Answer

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

1. Question

When the intensity of a light source is increased,

A. the number of photons emitted by the source in unit time increases

B. the total energy of the photons emitted per unit time increases

C. more energetic photons are emitted

D. faster photons are emitted

Answer

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.

2. Question

Photoelectric effect supports quantum nature of light because

A. there is a minimum frequency below which no photoelectrons are emitted

B. the maximum kinetic energy of photoelectrons depends only on the frequency of light and not on its intensity.

C. even when the metal surface is faintly illuminated the photoelectrons leave the surface immediately.

D. electric charge of the photoelectrons is quantized.

Answer

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. (Φ =$h\nu_0 = constant$)

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.

3. Question

A photon of energy hv is absorbed by a free electron of a metal having work function ϕ < hv.

A. The electron is sure to come out.

B. The electron is sure to come out with a kinetic energy hv – ϕ.

C. Either the electron does not come out or it comes out with a kinetic energy hv – ϕ.

D. It may come out with a kinetic energy less than hv – ϕ.

Answer

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.

4. Question

If the wavelength of light in an experiment on photoelectric effect is doubled.

A. the photoelectric emission will not take place

B. the photoelectric emission may or may not take place

C. the stopping potential will increase

D. the stopping potential will decrease

Answer

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.

5. Question

The photocurrent in an experiment on photoelectric effect increases if

A. the intensity of the source is increased

B. the exposure time is increased

C. the intensity of the source is decreased

D. the exposure time is decreased

Answer

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.

6. Question

The collector plate in an experiment on photoelectric effect is kept vertically above the emitter plate. Light source is put on and a saturation photocurrent is recorded. An electric field is switched on which has a vertically downward direction.

A. The photocurrent will increase.

B. The kinetic energy of the electrons will increase

C. The stopping potential will decrease

D. The threshold wavelength will increase

Answer

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.

7. Question

In which of the following situations the heavier of the two particles has smaller de Broglie wavelength? The two particles.

A. move with the same speed

B. move with the same linear momentum

C. move with the same kinetic energy

D. have fallen through the same height.

Answer

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

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

1. Question

Visible light has wavelengths in the range of 400 nm to 780 nm. Calculate the range of energy of the photons of visible light.

Answer

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 *v* 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=$\frac{6.63\times10^{-34}\times3\times10^{8}}{780\times10^{-9}}J$

$=2.55\times10^{-19}J$

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

=$4.97 \times 10^{-19}J$

∴ the range from $2.55 \times 10^{-19}J$ to $4.97 \times 10^{-19}J$.

2. Question

Calculate the momentum of a photon of light of wavelength 500 nm.

Answer

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

∴ the momentum of photon of wavelength of 500 nm is

$= \frac{6.63\times10^{-34}}{500\times10^{-9}} \frac{kg\ m}{sec} P = 1.32 \times 10^{-27} \frac{kg\ m}{sec}$

3. Question

An atom absorbs a photon of wavelength 500 nm and emits another photon of wavelength 700 nm. Find the net energy absorbed by the atom in the process.

Answer

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 $= \frac{hc}{\lambda}$.

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{500 \times 10^{-9}} J = 3.978 \times 10^{-19} J.$$

Energy of photon atom emit $= \frac{6.63\times10^{-34}\times3\times10^{8}}{700\times10^{-9}} J = 2.841 \times 10^{-19} J.$

Net absorbed energy$= 3.978 \times 10^{-19}J - 2.841 \times 10^{-19}J.$

$= 1.137 \times 10^{-19}J.$

4. Question

Calculate the number of photons emitted per second by a 10 W sodium vapour lamp. Assume that 60% of the consumed energy is converted into light. Wavelength of sodium light = 590 nm.

Answer

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

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

$=1.779\times10^{19}$.

5. Question

When the sun is directly overhead, the surface of the earth receives 1.4 × 10^3 W m^{-2} of sunlight. Assume that the light is monochromatic with average wavelength 500 nm and that no light is absorbed in between the sun and the earth is 1.5 × 10^{11} m.

(a) Calculate the number of photons falling per second on each square meter of earth's surface directly below the sun.

(b) How many photons are there is each cubic meter near the earth's surface at any instant?

(c) How many photons does the sun emit per second?

Answer

(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 $3.519\times10^{21}\times\frac{1}{3}\times10^{-8}=1.173\times10^{13}$.

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

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

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

6. Question

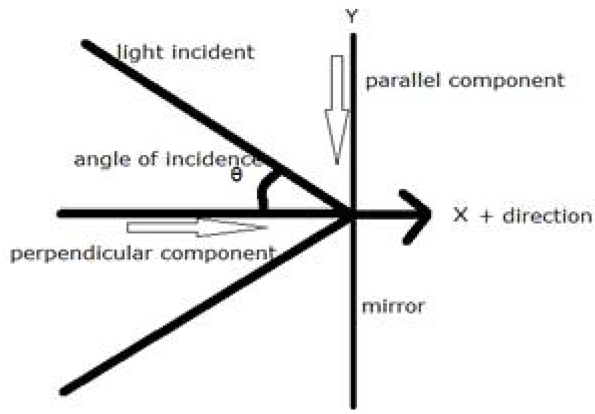
A parallel beam of monochromatic light of wavelength 663 nm is incident on a totally reflecting plane mirror. The angle of incidence is 60° and the number of photons striking the mirror per second is 1.0×10^{19}. Calculate the force exerted by the light beam on the mirror.

Answer

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,

$\therefore p = 2\frac{E}{c}\cos\theta$. Equation 1

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

$\rightarrow$ Force by one photon is $= 2\ \frac{6.63\times10^{-34}}{663\times10^{-9}\times1}\cos 60°$.

$=10^{-27}N$.

$\therefore$ Force by 1.0×10^{19} photons is $=10^{-27}\times1.0\times10^{19}N$.

$=10^{-8}N$.

7. Question

A beam of white light is incident normally on a plane surface absorbing 70% of the light and reflecting the rest. If the incident beam carries 10 W of power, find the force exerted by it on the surface.

Answer

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 $F_1 = 2\times\frac{3}{3}\times10^{-8}$.

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 $F_2=\frac{7}{3}\times10^{-8}$.

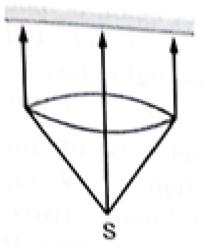
Hence total force is $F=F_1+F_2=2\times\frac{3}{3}\times10^{-8}+\frac{7}{3}\times10^{-8}$.

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

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

8. Question

A totally reflecting, small plane mirror placed horizontally faces a parallel beam of light as shown in figure. The mass of the mirror is 20g. Assume that there is no absorption in the lens and that 30% of the light emitted by the source goes through the lens. Find the power of the source needed to support the weight of the mirror. Take g = 10 m s^{-2}.



Answer

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.

9. Question

A 100 W light bulb is placed at the center of a spherical chamber of radius 20 cm. Assume that 60% of the energy supplied to the bulb is converted into light and that the surface of the chamber is perfectly absorbing. Find the pressure exerted by the light on the surface of the chamber

Answer

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

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

0. Question

A sphere of radius 1.00 cm is placed in the path of a parallel beam of light of large aperture. The intensity of the light is 0.50 W cm^{-2}. If the sphere completely absorbs the radiation falling on it, find the force exerted by the light beam on the sphere.

Answer

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

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

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

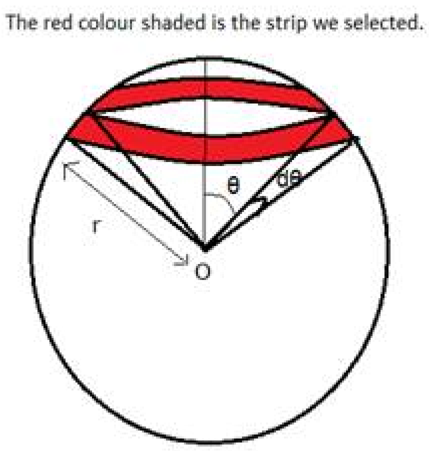
11. Question

Consider the situation described in the previous problem. Show that the force on the sphere due to the light falling on it is the same even if the sphere is not perfectly absorbing

Answer

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.



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.

12. Question

Show that it is not possible for a photon to be completely absorbed by a free electron

Answer

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 =$m_0 c^2$.($m_0$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 =$m_0 c^2$

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.

13. Question

Two neutral particles are kept 1m apart. Suppose by some mechanism some charge is transferred from one particle to the other and the electric potential energy lost is completely converted into a photon. Calculate the longest and the next smaller wavelength of the photon possible.

Answer

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

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

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

14. Question

Find the maximum kinetic energy of the photoelectrons ejected when light of wavelength 350 nm is incident on a cesium surface. Work function of cesium = 1.9 eV.

Answer

Given, wavelength λ =350nm =350 ×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).

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

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

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

$\Rightarrow 3.5 - 1.9$

$\therefore Kmax\ = 1.65\ eV.$

15. Question

The work function of a metal is 2.5 × 10^{-19} J.

(a) Find the threshold frequency for photoelectric emission.

(b) If the metal is exposed to a light beam of frequency 6.0 × 10^{14} Hz, what will be the stopping potential?

Answer

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

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

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

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

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

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

$Vstop = 0.923\ V$

16. Question

The work function of a photoelectric material is 4.0 eV.

(a) What is the threshold wavelength?

(b) Find the wavelength of light for which the stopping potential is 2.5 V.

Answer

(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,

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

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

$\therefore$ *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

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

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

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

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

17. Question

Find the maximum magnitude of the linear momentum of a photoelectron emitted when light of wavelength 400 nm falls on a metal having work function 2.5 eV.

Answer

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

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

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

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

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

18. Question

When a metal plate is exposed to a monochromatic beam of light of wavelength 400 nm, a negative potential of 1.1 V is needed to stop the photocurrent. Find the threshold wavelength for the metal.

Answer

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

$$\Rightarrow \frac{6.63\times10^{-34}\times3\times10^{8}}{400\times10^{-9}} = \frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda_0} + (1.6\times10^{-19}\times1.1)$$

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

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

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

$\therefore \lambda_0$ (threshold frequency) $= 6.19\times10^{-7}$ m.

19. Question

In an experiment on photoelectric effect, the stopping potential is measured for monochromatic light beams corresponding to different wavelength. The data collected are as follows:

Wavelength (nm):	350	400	450	500	550
Stopping potential (V):	1.45	1.00	0.66	0.38	0.16

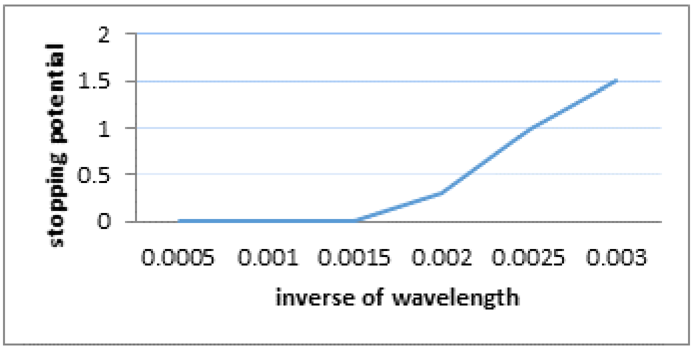
Plot the stopping potential against inverse of wavelength (1/λ) on a graph paper and find

(a) the Planck constant,

(b) the work function of the emitter and

(c) the threshold wavelength.

Answer



(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

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

$= 578.8\ nm.$

20. Question

The electric field associated with a monochromatic beam becomes zero 1.2 × 10^{15} times per second. Find the maximum kinetic energy of the photoelectrons when this light falls on a metal surface whose work function is 2.0 eV.

Answer

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.

21. Question

The electric field associated with a light wave is given by

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

Find the stopping potential when this light is used in an experiment on photoelectric effect with the emitter having work function 1.9 eV.

Answer

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

$\therefore f = \frac{1.57 \times 10^7 \times 3 \times 10^8}{2\pi}$

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,

$\Rightarrow \frac{6.63 \times 10^{-34} \times 1.57 \times 10^7 \times 3 \times 10^8}{2\pi} = e(V_0 + 1.9)$

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

$\Rightarrow 3.10 - 1.9 = V_0$

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

22. Question

The electric field at a point associated with a light wave is E = (100 V m^{-1}) sin [(3.0 × 10^{15} s^{-1}) t] sin [(6.0 × 10^{15} s^{-1}) t]. If this light falls on a metal surface having a work function of 2.0 eV, what will be the maximum kinetic energy of the photoelectrons?

Answer

Given, work function Φ =2 eV

$E = (100Vm^{-1})\sin[(3\times10^{15}s^{-1})t]\sin[(6\times10^{15}s^{-1})t]$

Solving the above equation using formula,

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

$\therefore E = 50[\cos[(9\times10^{15}s^{-1})t] - \cos[(3\times10^{15}s^{-1})t]]$

From the above equation there are two values of W

9×10^{15} *and* 3×10^{15}

∴ for maximum kinetic energy W should be maximum

$\because f = \frac{W}{2\pi} = \frac{9\times10^{15}}{2\pi}$

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.

23. Question

A monochromatic light source of intensity 5 mW emits 8 × 10^{15} photons per second. This light ejects photoelectrons from a metal surface. The stopping potential for this setup is 2.0 V. Calculate the work function of the metal.

Answer

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 $\Phi = hf - K$

$\Rightarrow \Phi = E - eV$

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

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

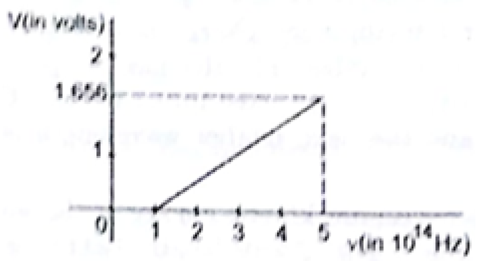
$= (0.625 \times 10^{-18}) - (3.2 \times 10^{-19})$

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

∴ Work function Φ =1.906eV

24. Question

Figure in the plot of the stopping potential versus the frequency of the light used in an experiment on photoelectric effect. Find (a) the ratio h/e and (b) the work function



Answer

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)

∴ from eq (1) & (3) we have

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

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

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

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,

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

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

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

25. Question

A photographic film is coated with a silver bromide layer. When light falls on this film, silver bromide molecules dissociate and the film records the light there. A minimum of 0.6 eV is needed to dissociate a silver bromide molecule. Find the maximum wavelength of light that can be recorded by the film.

Answer

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

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

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

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

26. Question

In an experiment on photoelectric effect, light of wavelength 400 nm is incident on a cesium plate at the rate of 5.0 W. The potential of the collector plate is made sufficiently positive with respect to the emitter so that the current reaches its saturation value. Assuming that on the average one out of every 10^6 photons is able to eject a photoelectron, find the photocurrent in the circuit.

Answer

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 $= \frac{5 \times 400 \times 1.6 \times 10^{-19}}{1.6 \times 10^{-19} \times 1242 \times 10^6}$

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

27. Question

A silver ball of radius 4.8 cm is suspended by a thread in a vacuum chamber. Ultraviolet light of wavelength 200 nm is incident on the ball for some time during which a total light energy of 1.0×10^{-7} J falls on the surface. Assuming that on the average one photon out of every ten thousand is able to eject a photoelectron, find the electric potential at the surface of the ball assuming zero potential at infinity. What is the potential at the centre of the ball?

Answer

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

$=9.94\times10^{-19J}$

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

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

It is given that one photon out of every ten thousand

is able to eject a photoelectron.

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

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

$\therefore q\ =1\times10^{7}\times1.6\times10^{-19}$

$=1.6\times10^{-12}C$

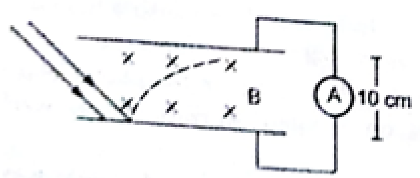
∴ required potential $=\frac{kq}{r}$

$$=\frac{(9\times10^{9}\times1.6\times10^{-12})}{(4.8\times10^{-2})}$$

$=0.3V$

28. Question

In an experiment on photoelectric effect, the emitter and the collector plates are placed at a separation of 10 cm and are connected through an ammeter without any cell figure.



A magnetic field B exists parallel to the plates. The work function of the emitter is 2.39 eV and the light incident on it has wavelengths between 400 nm and 600 nm. Find the minimum value of B for which the current registered by the ammeter is zero. Neglect any effect of space charge.

Answer

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,

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

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

$$= 3.10 - 2.39\ eV$$

$$\therefore E = 0.71 eV.$$

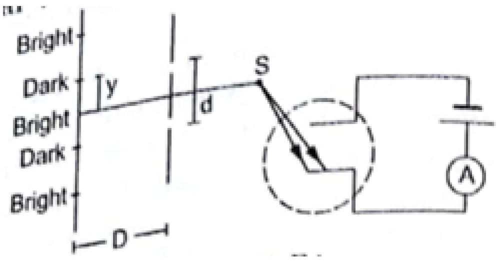
Now, putting the value in eq (2) we get,

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

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

29. Question

In the arrangement shown in figure y = 1.0 mm, d = 0.24 mm and D = 1.2 m. The work function of the material of the emitter is 2.2 eV. Find the stopping potential V needed to stop the photocurrent.



Answer

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 $eV_0 = E - \Phi$

$= 3.105 - 2.2$

$= 0.905 eV$

30. Question

In a photoelectric experiment, the collector plate is at 2.0 V with respect to the emitter plate made of coper (ϕ = 4.5 eV). The emitter is wavelength 200 nm. Find the minimum and maximum kinetic energy of the photoelectrons reaching the collector.

Answer

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)]

31. Question

A small piece of cesium metal (ϕ = 1.9 eV) is kept at a distance of 20 cm from a large metal plate having a charge density of 1.0 × 10^{-9} C m^{-2} on the surface facing the cesium piece. A monochromatic light of wavelength 400 nm is incident on the cesium piece. Find the minimum and the maximum kinetic energy of the photoelectrons reaching the large metal plate. Neglect any change in electric field due to the small piece of cesium present.

Answer

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

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

$$\Rightarrow eV_0 = 3.10 - 1.9$$

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

$\therefore V_0 = 1.20\ V$

$\because V_0 \lll V$

∴ Minimum kinetic energy required to reach the large

Metal =22.6eV

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

32. Question

Consider the situation of the previous problem. Consider the fastest electron emitted parallel to the large metal plate. Find the displacement of this electron parallel to its initial velocity before it strikes the large metal plate.

Answer

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)]

∴ 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

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

33. Question

A horizontal cesium plate (ϕ = 1.9 eV) is moved vertically downward at a constant speed v in a room full of radiation of wavelength 250 nm and above. What should be the minimum value of v so that the vertically upward component of the velocity is non-positive for each photoelectron?

Answer

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

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

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

34. Question

A small metal plate (work function ϕ) is kept at a distance d from a singly ionized, fixed ion. A monochromatic light beam is incident on the metal plate and photoelectrons are emitted. Find the maximum wavelength of the light beam so that some of the photoelectrons may go round the ion along a circle.

Answer

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,

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

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

35. Question

A light beam of wavelength 400 nm is incident on a metal plate of work function 2.2 eV.

(a) A particular electron absorbs a photon and makes two collisions before coming out of the metal. Assuming that 10% of the extra energy is lost to the metal in each collision, find the kinetic energy of this electron as it comes out of the metal.

(b) Under the same assumptions, find the maximum number of collisions the electron can suffer before it becomes unable to come out to the metal.

Answer

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

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

$= 0.31\ eV$

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

$= 0.31eV$ ∴ 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

∴ In third collision it just comes out of the metal and in fourth collision it is unable to come out of the metal.

∴ Maximum number of collisions required =4.