CHAPTER

18 DAWN OF THE MODERN PHYSICS

Q1: Distinguish between an inertial and a non-inertial frame of reference. Discuss that inertial frames of reference are equivalent.

Answer: **Frame of Reference:**

Definition: "Any coordinate system with respect to which we can determine the state of rest or motion of a body is known as frame of reference."

Types of Frame of Reference:

There are two types of frames of reference which are given below:

1. **Inertial Frame of Reference:**

A frame of reference which is moving with constant velocity with respect to another frame of reference (or) at rest with respect to another frame of reference is known as inertial frame of reference.

The inertial frames of reference are equivalent because the laws of physics are the same for all observes in case of inertial frames of reference.

2. **Non-Inertial Frame of Reference:**

"A frame of reference which is moving with certain acceleration with respect to another frame of reference is known as non-inertial frame of reference."

Q2: Discuss the difference between:
a) Absolute motion and relative motion
b) Absolute rest and relative rest

Answer: **a) Absolute Motion:**

A body is said to be in state of absolute motion, if someone judge its motion with respect to some reference point which is completely at rest.

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Relative Motion:

A body is said to be in state of relative motion, if someone judge its motion with respect to some reference point which is also in motion.

b) Absolute Rest:

A body is said to be in state of absolute rest, if someone observes its state of rest with respect to some reference point which is also at rest.

Relative Rest:

A body is said to be in state of relative rest, if someone observes its state of rest with respect to some reference point which is itself in motion.

NOTE: We always deals with relative rest and relative motion, because the planets are in state of motion.

Q3: (a) State and explain Einstein's postulates of special theory of relativity. (b) Discuss the results obtained from special theory of relativity. (ETEA 2005)

Answer: **a) Special Theory of Relativity:**

The special theory of relativity was put forward by Einstein in 1905. This theory deals with those bodies which are moving with constant velocity with respect to each other. This theory consists of the following postulates.

1. The laws of physics are the same in all inertial frames of reference:

Explanation:

The principle of relativity was first stated by Galileo and embodied in Newton's first law which states that it is impossible to perform an experiment within an inertial frame of reference to detect the motion of the frame of reference. The only way to detect the motion of an inertial frame of reference is by referring to another frame of reference.

For example, if we are in a space craft which is far away from any

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object [i.e. planet, star etc] then we cannot observe our motion. In other words we can say that we cannot detect or measure our velocity without referring to outside objects.

2. The speed of light in vacuum is a universal constant:

Explanation:

The 2nd postulates represent the principle of the constancy of the speed of light. It tells us that the speed of light in vacuum is the same in all inertial frames of reference, regardless of the motion of the source or observer.

b) Results Obtained from Special Theory of Relativity:

The following results were obtained from special theory of relativity.

1. The relativity of simultaneity:

If an observer judge two events in different places in a certain frame of reference simultaneously, then it cannot be judge by another observer simultaneously in another frame of reference in relative motion.

Explanation:

Consider a train which is fitted with light operated doors i.e. the door opens due to light signals. Let the light source is situated in the centre of the roof which is operated by an observer standing in the middle of the floor.

Let the observer turns-ON the light, when the train is travelling at half the speed of light. The light emitted from the source travels forwards and backwards with equal speed and reaches the two doors at the same time. The observer in the train observes that both doors open simultaneously.

Now another observer standing outside the train observes that both doors does not open simultaneously. It is because, the back door is advancing on the light waves coming from the light source, while the front door is moving away from the light waves.

From the above discussion it is clear that, whether or not two events are seen by us to be simultaneous depends upon where we are standing.

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2. The Equivalence between Mass and Energy:

The rest mass of an object is equivalent to certain quantity of energy. In other words, we can say that mass and energy are interconvertible.

Explanation:

The equivalence between mass and energy can expressed with the help of Einstein equation i.e.

$$E = mc^2 \quad \text{_____(1)}$$

Where "E" represents energy, "m" represents mass and "c" represents the converging factor. Equation (1) shows that mass can be converted into energy and energy can be converted into mass. Thus in special theory of relativity, the law of conversion of mass and law of conservation of energy have been replaced by the law of conservation of mass-energy due to their mutual relationship.

3. Length Contraction: (ETEA 2008)

The length of an object appears to be shorter to observers in different frames of reference in relative motion and is given by,

$$L = L_o\sqrt{1 - \frac{V^2}{C^2}} \quad \text{_____(2)}$$

Explanation:

In equation (2) "L_o" represents the length of an object measured within its rest frame of reference and is called proper length. "L" represents the length of the same object in relativistic motion. "C" represents the velocity of light and "V" represents the relativistic velocity.

Now consider a train whose length is 100 meter at rest. Let the train is moving with velocity of 0.8C, then the length of train measured by the observer present inside the train will be equal to 100m. While an observer standing outside by the side of the track will observe the length of the train to be 60m.

$L = L_o\sqrt{1 - v^2/c^2}$

Put $L_o = 100m$

$V = 0.8C$

$$\Rightarrow L = 100\sqrt{1 - \frac{(0.8C)^2}{C^2}}$$

$$\Rightarrow L = 100\sqrt{1 - \frac{0.64C^2}{C^2}}$$

$\Rightarrow L = 100\sqrt{1 - 0.64}$

$\Rightarrow L = 100 \times 0.6$

$\Rightarrow L = 60m$

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Thus the length of an object appears to decrease to an observer standing outside the train, when the train is moving with relativistic velocity.

4. Time Dilation: (ETEA 2008, 2011)

The time intervals between two events appear to increase to observers in different frames of reference in a relative motion and is given by,

$$t = \frac{t_o}{\sqrt{1 - \frac{V^2}{C^2}}} \qquad \text{(3)}$$

Explanation:

In equation (3) "t_o" represents the time interval for an event to occur within its rest frame of reference and is called proper time, "t" represent the time interval for the same event noted by an observer standing outside with respect to which the frame of reference is moving with relativistic velocity. "V" represents the relativistic velocity and "C" represents the velocity of light.

Now consider a train is travelling with a speed of 0.8C. An observer inside the train picks up and opens a newspaper in 1 second. So the proper time is t_o = 1sec. While an observer standing by the side of the track, note that the event takes 1.7 sec.

Put V = 0.8C, t_o = 1sec

$$t = \frac{t_o}{\sqrt{1 - \frac{V^2}{C^2}}}$$

$$\Rightarrow t = \frac{1}{\sqrt{1 - \frac{(0.8C)^2}{C^2}}}$$

$$\Rightarrow t = \frac{1}{\sqrt{1 - 0.64}}$$

$$\Rightarrow t = \frac{1}{\sqrt{0.36}}$$

$$\Rightarrow t = \frac{1}{0.6}$$

$$\Rightarrow t = 1.7\text{sec}$$

5. Mass Dilation: (ETEA 2007-8)

The mass of an object appears to increase when moving with relativistic speed and is given by,

$$m = \frac{m_o}{\sqrt{1 - \frac{V^2}{C^2}}} \qquad \text{(4)}$$

5. Explanation:

In equation (4), "m_o" represents the rest mass of an object, "m"

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represents its relativistic mass, "V" represents relativistic speed and "C" represents the speed of light.

For getting relativistic speed, the object is accelerated by using large amount of energy. Such energy is converted into mass due to which mass of the object increases. So the total energy of an object is then equal to its K.E plus the energy embodied in its mass.

Now consider a ball of mass 0.5kg is thrown with velocity 0.8C. Here 0.5kg represents the rest mass of the ball, so $m_o = 0.5kg$, $V = 0.8C$. Now the mass of the same ball during relativistic speed of 0.8C will be equal to 0.8kg.

Put $m_o = 0.5kg$, $V = 0.8C$

$$m = \frac{m_o}{\sqrt{1 - \frac{V^2}{C^2}}}$$

$$\Rightarrow m = \frac{0.5}{\sqrt{1 - \frac{(0.8C)^2}{C^2}}}$$

$$\therefore m = \frac{0.5}{\sqrt{1 - 0.64}}$$

$$\therefore m = \frac{0.5}{\sqrt{0.36}}$$

$$\Rightarrow m = \frac{(0.5)}{0.6}$$

$$\Rightarrow m = 0.83kg$$

6. Speed Limit:

The special theory of relativity tells us that the speed of light "C" is a universal constant and the speed of a material object "V" cannot be equal or greater than the speed of light. For example, the time dilation is given by,

$$T = \frac{T_o}{\sqrt{1 - \frac{V^2}{C^2}}} \quad \text{.....(1)}$$

Let suppose that a material object is moving with $v = c$ i.e. equal to velocity of light, then equation (1) becomes,

$$T = \frac{T_o}{\sqrt{1 - \frac{c^2}{c^2}}} = \frac{T_o}{\sqrt{1 - 1}} = \frac{T_o}{0}$$

$$\Rightarrow \boxed{T = \infty}$$

Which is impossible in practice. Thus the velocity of a material object cannot be equal to or greater than velocity of light. i.e.

$$\boxed{C > V \text{ or } V < C}$$

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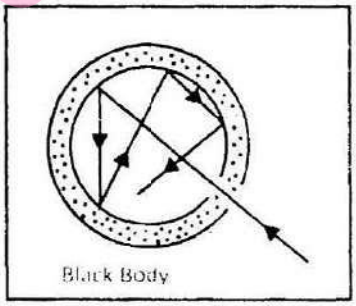
Application of time dilation and length contraction for space travel:
The special theory of relativity suggests that time dilation and length contraction enables the spaceship crew to reach a distant place or planet in a short time. It is because in relativistic speed, then the time interval for them will be dilated and length of the journey will be contracted.

Q4: What are the black body radiations? Discuss the features of thermal radiations from black body. Discuss Plank's quantum theory and its importance in physics.

Answer: **Black Body: (ETEA 2007, 2011)**

Definition: "A body which absorbs all types of the electromagnetic radiations falling on it when cold, and emits all the electromagnetic radiations when hot are known as black body."

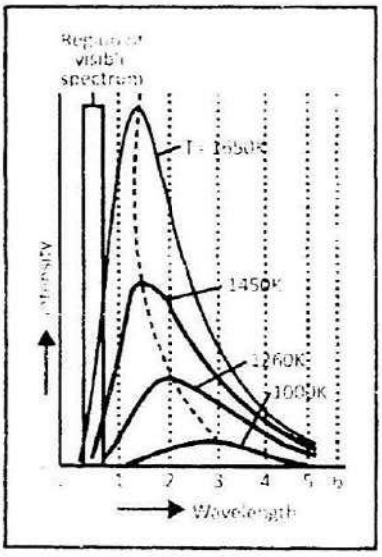
The radiations absorbed or emitted by a black body are called black body radiations.



Explanation:
Generally, a black body is in the form of a cavity having very narrow opening, as shown in the figure. The walls of the cavity are given a coating of good absorber of heat radiations.

Main Features of Thermal Radiation:

1. When these radiations enter the cavity of black body, they are absorbed in the cavity walls due to successive absorption.
2. These radiations can be emitted from the walls of the cavity by rising its temperature.
3. These radiations are also called cavity radiations or full wave radiations.
4. The intensity of the radiation emitted from the interior of the cavity is high



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as compared to the intensity of radiation emitted from outside the wall of the cavity.

5. The radiation emitted from the cavity has a wide range of wavelengths.
6. These radiations obey Wien's displacement law for shorter wavelengths.
7. These radiations obey Rayleigh-Jeans law for longer wavelengths.
8. These radiations obey Plank's law for all wavelengths.

Laws of Black Body Radiations:

The radiations emitted by a black body obey certain laws, which are known as laws of black body radiations. These laws are given below:

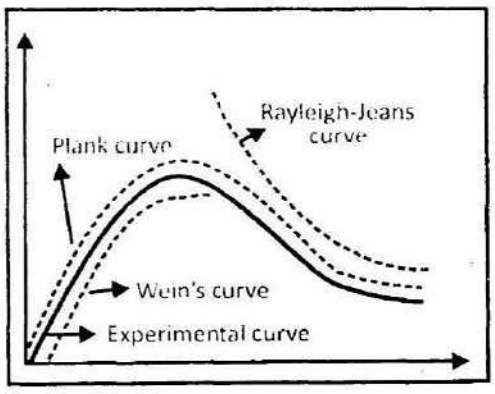
1) Wien's Law:

Definition: This law states that, "the wavelength of radiation is inversely proportional to the absolute temperature" i.e.

$$\lambda \propto \frac{1}{T} \Rightarrow \lambda = \text{constant} \cdot \frac{1}{T}$$

$$\Rightarrow \boxed{\lambda T = \text{constant}}$$

Explanation: On the basis of this law, Wien's was successful to explain the distribution of black body radiations for shorter wavelength only. i.e. the curve obtained by Wien's was fit with experimental curve for shorter wavelength only. It was not fit with experimental curve for longer wavelengths, as shown in the figure.



2) Rayleigh-Jeans Law:

Statement:

According to Rayleigh and Jeans, the radiations emitted by a black body are reflected back and forth by the walls of the black body to form a system of standing waves, just like transverse stationary waves in a stretched string.

Explanation: Rayleigh and Jeans also tried to explain the distribution of energy of black body radiations.

On the basis of this law, they developed the following formula for

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energy distribution of black body radiations· i·e·

$$\boxed{E_\lambda = \frac{8\pi kT}{\lambda^4}}$$

But the curve obtained from this law was fit with experimental curve only for longer wavelengths, as shown in the figure· It was not fit with experimental curve for shorter wavelengths·

3) Stefan-Boltzmann Law:

This law states that, "the amount of energy of all wavelengths radiated per second per unit area of a black body is directly proportional to the fourth power of absolute temperature" i·e·

$$E \propto T^4 \Rightarrow E = \text{constt} \cdot T^4$$

$$\Rightarrow \boxed{E = \sigma T^4}$$

Where "σ" is constant and is known as Stefan's constant·

4) Plank's Law (or) Plank's Quantum Theory: (ETEA 2011-12)

In 1900, Plank introduces his quantum theory for removing the deficiencies of Wien's and Rayleigh-Jeans laws· The curve obtained by Plank was fit with experimental curve both for shorter wavelength as well as for longer wavelength· For this handsome success, he was awarded with noble prize in 1918·

The Plank's quantum theory consists of the following two assumptions i·e:

1· The vibrating molecules which emits the radiations have only certain discrete amount of energy "E_n" and is given by,

$$\boxed{E_n = nhf} \quad \text{_____(1)}$$

Where "n" is a positive integer and is called a quantum number, "f" represents the frequency of vibration of the molecules, "h" is called Plank's constant and its value is $6{\cdot}626 \times 10^{-34}$ J·s· The energies of molecules are said to be quantized and the allowed energy state are called quantum states·

2· The molecules emit energy in discrete units of light energy which is called quanta or photon· They do so by jumping from one quan-

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tum state to another. If the quantum number changes by one unit, then we put n = 1, so equation (1) becomes,

$$E_1 = hf$$

Thus the energy of a molecule is equal to "hf". The molecule will absorbs or radiate energy if it changes its quantum states.

Importance of Plank's Quantum Theory:

The Plank's quantum theory has played an important role in the birth of modern physics. It gives us useful information about the distribution of energy of thermal radiations. In the light of this theory, Einstein explains the phenomenon of photo electric effect. Beside these, this theory can be use to explain many other phenomenon which cannot be explain by using the wave theory of light.

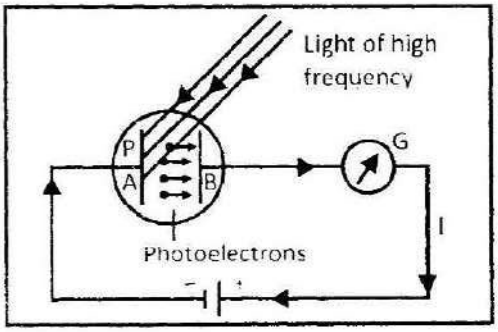
Q5: What is photo electric effect? Discuss in detail.

Answer: **Photoelectric Effect:**

It has been found that when light of high frequency fall upon a metal surface, then electrons are emitted from the metal surface. This phenomenon is known as photo electric effect.

Explanation:

Consider a circuit which consists of a metal plate "P", two electrodes "A" and "B", a battery, galvanometer etc as shown in the figure.



When light of high frequency is allowed to fall on metal plate "P", then electrons are emitted from metal plate. These electrons moves from electrode "A" towards the electrode "B" and as a result current is produced in the circuit. The galvanometer thus shows deflection. This phenomenon is known as photoelectric effect. The current produced is known as photoelectric current and the electrons are called photoelectrons.

Results Obtained from Photoelectric Effect: (ETEA 2010, 2013)

The following features or results have been observed in the phenom-

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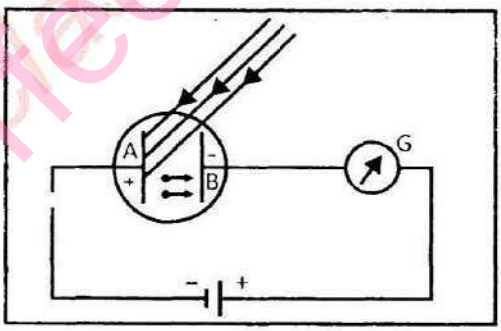
enon of photoelectric effect.

1. The electrons will be emitted only, if the frequency "f" of incident light is equal to or greater than the threshold frequency "f_o" i.e $f \geq f_o$
2. The threshold frequency "f_o" depends upon the nature of metals.
3. The ejection of electrons increases with increase in intensity of incident light.
4. The maximum K.E of photoelectrons depends upon the frequency of incident light.
5. No electron will be emitted from the metal surface if the frequency of incident light is less than the threshold frequency i.e. $f < f_o$

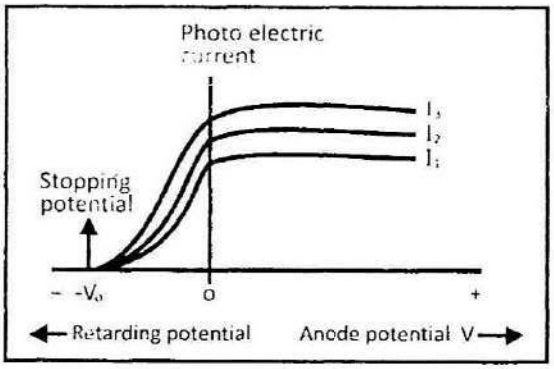
> The minimum frequency for a metal, for which the incident light can eject electrons from metal surface is called threshold frequency f_o.

Determination of Max. K.E of Photoelectrons: (ETEA 2006-8)

For finding the maximum K.E of photoelectrons, the polarity of electrodes is reversed i.e. the terminal "A" is made positive and the terminal "B" is made negative, as shown in the figure. Under such conditions, only those electrons wili move towards "B" whose K.E is maximum. Thus the number of electrons moving towards "B" will decrease and thus the galvanometer shows less current.



Now if the electrode "A" is made more positive and the electrode "B" is made more negative, then no electron will be able to move towards the electrode "B". Thus the current will be stop in the circuit and the galvanometer will show no deflection. This potential difference [workdone] which is applied for stopping most energetic



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electrons is known as stopping potential "V_o". Thus the workdone in stopping most energetic electrons will be equal to "$V_o e$" i.e.

$$\text{Workdone} = V_o e \quad \text{_____(1)}$$

This workdone is equal to maximum K.E of photoelectrons so equation (1) becomes,

$$\boxed{(K.E)_{max} = V_o e} \quad \text{_____(2)}$$

Q6: Discuss the failure of classical wave theory in explaining photoelectric effect.

Answer:

1. The wave theory tells us that the phenomenon of photoelectric effect can occur at any frequency of incident light, whereas the experimental fact shows that the phenomenon of photoelectric effect occurs only, if the frequency of incident light is equal to or greater than the threshold frequency "f_o" i.e. $f \geq f_o$.
2. The wave theory tells us that the maximum K.E of photoelectrons depends upon the intensity of incident light whereas the experimental facts shows that the maximum K.E of photoelectrons depends upon the frequency of incident light.
3. The wave theory tells us that the emission of electrons takes place by taking longer period of time. Whereas the experimental facts show that the phenomenon of photoelectric effect can occur instantaneously when light of high frequency falls upon the metal surface.

The above discussion shows that the wave theory cannot explain the phenomenon of photoelectric effect. That is why, Einstein use quantum theory to explain photoelectric effect.

Q7: Discuss the photon theory of photoelectric effect. (OR) Discuss the Einstein explanation of photoelectric effect. (ETEA 2010)

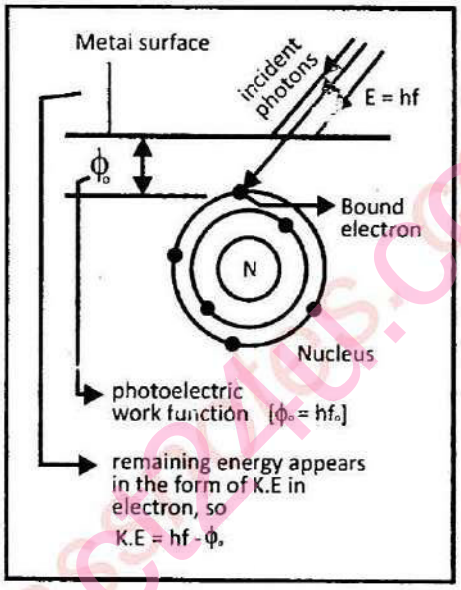
Answer:

As the wave theory was failed to explain the phenomenon of photoelectric effect, so Einstein use quantum theory to explain the phenomenon of photoelectric effect.

According to Einstein, this phenomenon occurs due to collision of incident photon and a bound electron, as shown in the figure.

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Consider light of high frequency "f" is allowed to fall on the metal surface. Let one of the incident photon of energy "E = hf" collides with electron in the atom of the metal, as shown in the figure.



Now if the photon gives whole of its energy "hf" to the electron and comes to rest and disappears, then the electron starts motion towards metal surface and finally comes out of it. But for this purpose, the electron must do work against the attractive force of the nucleus. This work which the electron has to do against the attractive force of the nucleus is known as photoelectric work function. It is represented by "ϕ_o" and is equal to the threshold energy "hf_o". i.e.

$$\phi_o = hf_o \quad \text{_____(1)}$$

Thus the electron spends energy out of "hf" energy which is equal to "ϕ_o". So, the remaining energy in electron will be equal to "$hf - \phi_o$" which appears in the form of K.E in electron. With this K.E, the electron leaves the metal surface. So we have,

$$\boxed{K.E = hf - \phi_o} \quad \text{_____(2)}$$

Putting equation (1) in equation (2), we get,

$$K.E = hf - hf_o$$

$$\Rightarrow \boxed{K.E = h(f - f_o)} \quad \text{_____(3)}$$

As $K.E = V_o e$, so equation (3) $\Rightarrow$

$$\boxed{V_o e = h(f - f_o)} \quad \text{_____(4)}$$

Equations (2), (3), (4) represents the various forms of Einstein equations of photoelectric effect.

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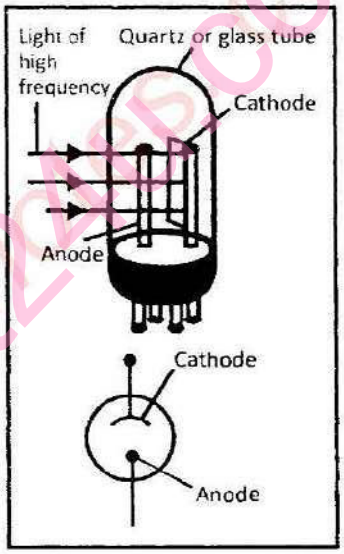
Q8: Discuss the applications of photoelectric effect. (OR)
Write a note on the following; (1) Photo cell (2) Solar cell

Answer: 1) Photo Cell:

Definition: It is a device which converts light energy into electrical energy.

Construction:

It consists of an anode, cathode which are enclosed in an evacuated glass bulb, as shown in the figure.



Working:

The working of photocell is based on the phenomenon of photoelectric effect. When light of high frequency falls on the cathode, then electrons are emitted which moves towards the anode. In this way, current is produced in the circuit. The current depends upon the intensity of incident light. i.e. the amount of current increases with an increase in intensity of incident light and vice versa.

Uses of Photocell:

1. It is used in security system.
2. It is used in counting system.
3. It is used in automobile door system.
4. It is used in sound track of movies.
5. It is used in photography.
6. It is used in automatic street lighting system.

2) Solar Cell:

A solar cell is a type of photocell whose working is based on photoelectric effect. It receives light energy from solar radiations. The light is focused from large area into the cell.

In 2006, a largest solar power station was built in Southern Portugal which produces an electric power of 11 mega watt. It consists of 52000 photovoltaic panels steered always to point to the sun during day light.

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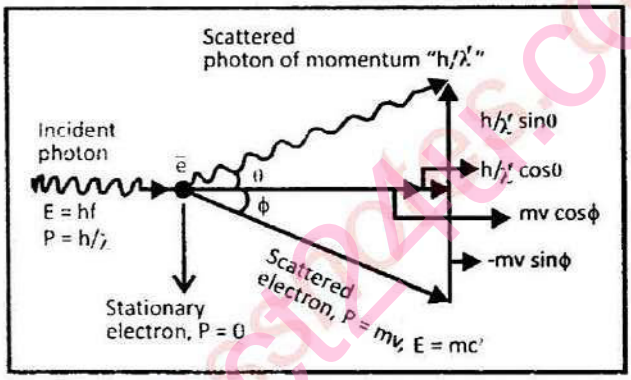
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Q9: What is Compton's effect? Develop a mathematical relation for the Compton's wave shift. (ETEA 2006-2008, 2011, 2015)

Answer: **Compton's Effect:**

Definition: It was found by Compton that when x-rays are scattered, then their frequency decreases and wavelength increases. This phenomenon is known as Compton's effect.

Explanation:



The Compton's effect occurs due to collision between a stationary electron and on incident x-ray photon, as shown in the figure.

During the collision, the photon transfers some of its energy to the electron and thus its energy decreases. As a result, its frequency decreases and wavelength increases. The increase in wavelength of photon is known as Compton's shift in wavelength. Now the change or decrease in energy of photon is given by,

Energy loss by photon = $hf - hf'$ _____(1)

While the change or increase in energy of electron is given by,

Energy gain by electron = $mc^2 - m_oc^2$ _____(2)

Now by the law of conservation of energy, we have,

Energy lost by proton = electron gain by electron

$\Rightarrow hf - hf' = mc^2 - m_oc^2$ _____(3)

Now we apply the law of conservation of momentum in two steps:

STEP-1: In 1st step, we apply the law of conservation of momentum to the initial direction of photon and electron i.e.

Total momentum before collision = Total momentum after collision

$$\Rightarrow \frac{h}{\lambda} + 0 = \frac{h}{\lambda'}\cos\theta + mv\cos\phi \quad \text{_____(4)}$$

STEP-2: In 2nd step, we apply the law of conservation of momentum to the direction perpendicular to the initial direction of photon and electron i.e.

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$$0 + 0 = \frac{h}{\lambda}\sin\theta + [-mv\sin\phi)$$

$$\Rightarrow 0 + 0 = \frac{h}{\lambda'}\sin\theta - mv\sin\phi \quad \text{_____(5)}$$

Solving equations (3), (4), (5), we get the following result.

$$\frac{1}{f'} - \frac{1}{f} = \frac{h}{m_o c^2}[1 - \cos\theta] \quad \text{_____(6)}$$

We know that,

$$c = f\lambda \Rightarrow f = \frac{c}{\lambda} \text{ and } f' = \frac{c}{\lambda'}$$

So equation (6) $\Rightarrow$

$$\frac{\lambda'}{c} = \frac{\lambda}{c} = \frac{h}{m_o c^2}[1 - \cos\theta]$$

$$\Rightarrow \lambda' - \lambda = \frac{h}{m_o c}[1 - \cos\theta]$$

Here $\lambda' - \lambda' = \Lambda\lambda$

$$\Rightarrow \boxed{\Delta\lambda = \frac{h}{m_o c}[1 - \cos\theta]} \quad \text{_____(7)}$$

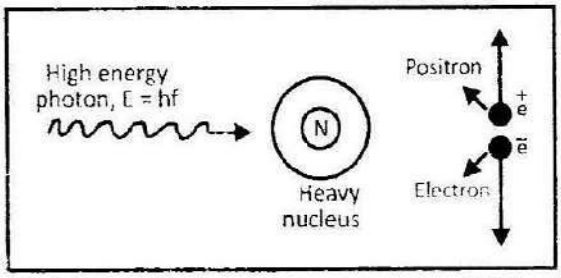
Equation (7) represents the Compton shift in wavelength. The quantity "$\frac{h}{m_o c} = 2.43 \times 10^{-12} m$" referred to as the Compton wavelength of electron. As $\cos\theta$ varies between +1 and -1 the wavelength shift "$\Delta\lambda$" may vary between "zero" and "$\frac{2h}{m_o c}$".

The experiments carried out by Compton to find "$\Delta\lambda$" were in agreement with the theoretical prediction. Thus we conclude that the photon concept of radiation is valid.

Q10: Write a note on pair production. (ETEA 2006-8)

Answer: Pair Production:

Definition: The process in which energy is converted into two particles of matter is known as "pair production".



Explanation:

The phenomenon of pair pro-

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duction is also known as materialization of energy. In this phenomenon, it is found that when a high energy photon passes near a heavy nucleus or collide with nucleus, then the nucleus makes an attempt to stop the photon. Due to this attempt, the photon losses its identity, disintegrates and is converted into two particles.

One of the two particles is an electron and the other one is called positron. The mass and rest mass energy of electron and positron are the same but are oppositely charged.

The rest mass energy of electron is $m_o c^2$. The rest mass energy of positron is also equal to $m_o c^2$. So the energy of the pair is equal to "$2m_o c^2$". Now the pair production will take place if the energy of photon is equal to or greater than "$2m_o c^2$". i.e.

$$\boxed{hf \geq 2m_o c^2}$$

No pair production will take place if $hf < 2m_o c^2$. Now if $hf > 2m_o c^2$, then out of "hf" energy equal to "$2m_o c^2$" will be used in the production of the pair and the remaining energy will be equally appears in the form of K.E in the pair.

$$\boxed{K.E = hf - 2m_o c^2}$$

The pair production phenomenon obeys the conservation of momentum i.e. momentum of photon must be equal to the momentum of electron plus the momentum of positron. i.e.

$$\boxed{\frac{hf}{c} = mv_e + mv_{e'}} \qquad \left[\begin{array}{l} v = f\lambda \\ \lambda = \frac{c}{f} \end{array}\right.$$

or $$\boxed{\frac{hf}{c} = mv_e + mv_{e'}}$$

The phenomenon of pair production also obeys the conservation of charge. It is impossible for a photon to produce single electron, single positron, two electrons or two positrons. Under such conditions, the net charge will not be zero, whereas photons have zero charge. Thus for conservation of charge, the pair must contain an electron and positron.

The pair production confirms the photon model of electromagnetic

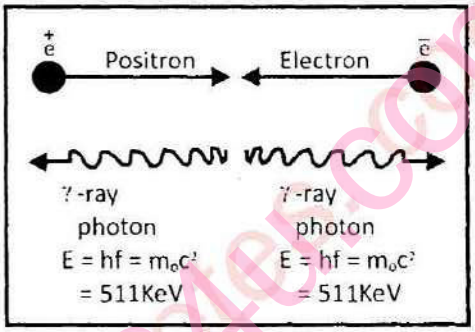
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radiations. It also clearly illustrates the Einstein's idea about mass and energy.

Q11: Write a note on pair annihilation.

Answer: Pair Annihilation:

Definition: "The process in which matter [positron and electron] is converted into energy is called pair annihilation or annihilation of matter."



Explanation:

It is found that when an electron and positron collide with each other, they loss their material nature and converted into two γ-rays photons. The energy of each photon is equal to the rest mass energy of electron i.e.

$$\text{Energy of each photon} = m_o c^2 = 511KeV = 0.511MeV$$

The pair annihilation obeys the conservation of momentum i.e.

$$\text{Total momentum of two photons} = \text{Total momentum of } \bar{e} \text{ \& } e^+$$

The pair annihilation also obeys the conservation of energy.

$$\text{Total energy of two photons} = \text{Total energy of } \bar{e} \text{ \& } e^+$$

The pair production and pair annihilation confirms the photon model and Einstein idea about mass and energy.

Q12: (a) Discuss the wave nature of particles. (OR) Discuss De-Broglie hypothesis.
(b) Discuss a set of experiment which gives us experimental verification of De-Broglie hypothesis. (ETEA 2012-14)

Answer: a) Wave Nature of Particles (or) De-Broglie Hypothesis:

In 1924, De-Broglie give the hypothesis that if light shows dual nature, then a material particle like electron, proton, neutron etc may also shows dual nature. i.e. if a photon can behave like a particle in motion, then a material particle can also behave like a wave in motion.

Thus we can compare the momentum "mv" of a particle with the momentum "$\frac{h}{\lambda}$" of a photon i.e.

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

$$\Rightarrow \boxed{\lambda = \frac{h}{mv}} \quad \text{_____(1)}$$

Equation (1) represents the wavelength equivalent to the particle of mass "m" and moving with velocity "V".

Let an electron is moving with velocity of 10^6 m/sec, then its De-Broglie wavelength can be calculated as,

$$\lambda = \frac{6.6 \times 10^{-34}}{(9.1 \times 10^{-31} \times 10^6)}$$

$$\Rightarrow \boxed{\lambda = 7.3 \times 10^{-10}\ m}$$

This represents the De-Broglie wavelength of electron moving with velocity 10^6 m/sec. Such wavelength approximates the distance between atoms in a crystal. Such wavelength is suitable for diffraction and interference. As diffraction and interference are wave phenomenons, thus the electron under such conditions behaves like a wave.

Note: The De-Broglie equation tells us that the wave nature of large particles cannot be observed due to their smallest wavelength. For example, the wavelength of a cricket ball of mass 0.25kg and velocity 20m/sec is given by,

$$\lambda = \frac{6.63 \times 10^{-34}}{(0.25 \times 20)}$$

$$\Rightarrow \lambda = 1.3 \times 10^{-34}\ m$$

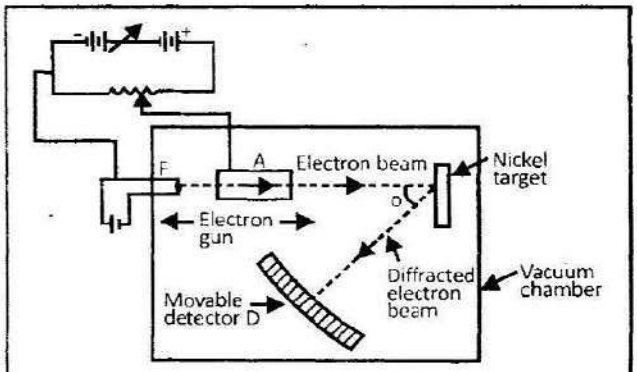
Such wavelength is very very small and cannot be observed.

b) Experimental Verification of De-Broglie Hypothesis:

The De-Broglie hypotheses were verified with the help of following experiment:

Davison and Germer Experiment:

Davison and Germer performed an experiment for the verification of De-Broglie hypothesis. The apparatus used by them were arranged in a vacuum chamber, as shown in the figure.



Davison and Germer experimental arrangement

A narrow beam of electrons was obtained from

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an electron gun. This beam of electron was allowed to fall on a single nickel crystal, as shown in the figure.

The electrons after falling on a crystal, were diffracted, which were detected by a movable electron detector, as shown in the figure.

As the diffraction occurs in case of waves only, so in this case the electrons behave like a wave. Therefore, this experiment verifies the De-Broglie hypothesis.

The De-Broglie hypothesis was also verified experimentally by G.P. Thomson. In this experiment, he obtained a diffraction pattern of electron beam. This diffraction pattern was similar to the diffraction pattern of x-rays. In this way, G.P. Thomson verified the De-Broglie hypothesis.

Q13: What is electron microscope? Discuss the principle, construction and working of electron microscope.

Answer: Electron Microscope:

Definition: It is a device which can be used for getting a magnified image of a certain specimen by falling a beam of electrons on that specimen.

Principle:

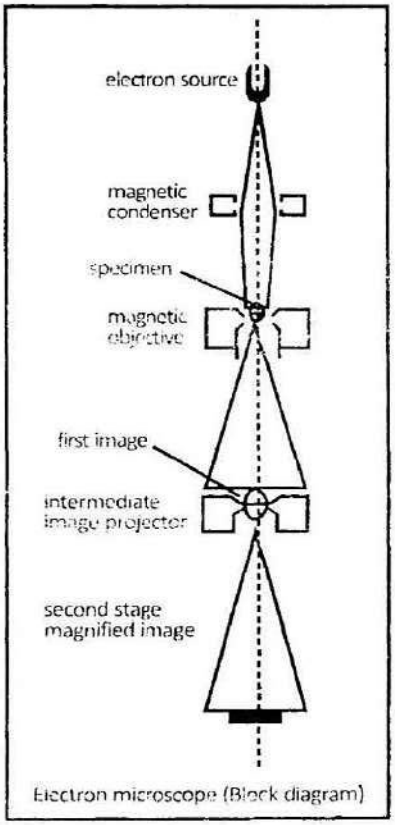
The principle of electron microscope is based on the wave nature of electrons.

Construction and Working:

The structure of electron microscope is shown in the figure.

For studying the nature of a certain specimen, a beam of electrons is focused on the specimen under the action of electric and magnetic fields. The working process of electron microscope is given below:

1. First of all, a beam of electrons is obtained from electron gun by appliy-



Electron microscope (Block diagram)

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ing very high voltage.

2. The beam of electrons is then focused on the specimen with the help of magnetic conduction lens.

3. When the electrons fall on the specimen, its beam becomes denser after passing through the specimen. The intensity of transmitted electrons depends upon the thickness and nature of the specimen.

4. There is objective lens which produces an intermediate image of the specimen.

5. There is a projective lens which produces the final image of the specimen. In this way, a large [magnified] image of the specimen is obtained on the screen which is called electron micrograph.

From the final magnified image, we can get information about the physical and chemical properties of the given specimen.

Q14: What is meant by wave-particle duality? Explain.

Answer: **Wave-Particle Duality:**

Light is electromagnetic radiations which shows dual nature. In some cases, it behaves like a wave and in some cases it behaves like a particle

For example, in case of interference, diffraction, reflection, refraction, polarization etc the light behaves like a wave. While in case of photoelectric effect, Compton effect, Raman effect etc the light behaves like a particle.

The wave nature of light can explain with the help of wave theory of light. While the particle nature of light can be explain with the help of quantum theory.

According to quantum theory, light is emitted from its source in the form of packets or bundle of energy which are known as quantas or photons. The energy of photon is equal to "hf". The quantum theory can be use to explain the phenomenon of Compton effect, photoelectric effect, Raman-effect etc successfully. In these phenomenons, the light behaves like a particle. Thus light shows dual

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nature which is called wave-particle duality.

In 1924, De-Broglie extended the dual nature of light to a material particle. He pointed out that if light shows dual nature, then a material particle like electron, proton, neutron, molecules etc can also shows dual nature. i.e. in some cases, it exhibit particle behaviour and in some cases they behave like a wave. The hypothesis of D-Broglie was experimentally verified by Davison and Germer, G.P Thomson in their experiments. Thus a material particle also shows wave-particle duality.

Q15: State and explain Heinsberg's uncertainty principle. (ETEA 2008)

Answer: Statement:

According to Heinsberg's uncertainty principle, it is impossible to find out an absolute correct value of a certain quantity such as momentum, energy, position etc of a particle, however high precise instrument we may use.

Explanation:

Actually an error or uncertainty is introduced during the process of measurement, which cannot be removed. This can be explains with the help of simple thought experiment given below.

Let we want to measure the momentum of an electron. For this purpose, we would fall some light upon the electron to make it visible for observation. Thus a photon of light may give some of its momentum which we measure is not the actual momentum of electron which it posses before the falling of light upon it. Thus an error or uncertainty is introduced in momentum which is at the most equal to the momentum of photon i.e.

$$\Delta P = \frac{h}{\lambda}$$

Similarly, an uncertainty is introduced during the measurement of position of electron, which is at the most equal to wavelength of photon i.e.

$$\Delta x \approx \lambda$$

Now if the position and momentum are measured at the same

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time, then the uncertainties are multiplied i·e·

$$\backslash P \cdot \Delta x \approx \frac{h}{\lambda} \cdot \lambda$$

$$\Rightarrow \boxed{\backslash P \cdot \Delta x \approx h}$$

Similarly, if the uncertainty is introduced in the measurement of energy at a certain instant of time, then the uncertainty in energy and time is given by,

$$\boxed{\Delta E \cdot \Delta t \approx h}$$

SOLUTIONS OF EXAMPLES & ASSIGNMENTS

EXAMPLE 18·1:

Alpha Centauri is nearest star to our sun· it is at 4·37 light years from earth, it means that it takes 4·37 years of light to reach from earth to Alpha Centauri· If a spaceship is sent to Alpha Centauri with a speed of v = 0·96c· How much time would have passed for the passengers, when they reach it? Assume that the earth and Alpha Centauri are stationary with respect to one another·

Solution:

Given Data:

Time for light to travel = $t' = 4{\cdot}37$ years

Relativistic speed = $v = 0{\cdot}96c$

Required:

Proper time = t_o = ?

Calculation:

First we calculate the time dilated for the person on earth, which is given by,

$$t = \frac{4{\cdot}37}{0{\cdot}96} \text{ years} = 4{\cdot}55 \text{ years}$$

Now we have,

$$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}} \Rightarrow t_o = t \times \sqrt{1 - \frac{v^2}{c^2}}$$

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$$\Rightarrow t_o = 4{\cdot}55 \times \sqrt{1 - \frac{(0{\cdot}96c)^2}{c^2}} = 4{\cdot}55 \times \sqrt{1 - 0{\cdot}9216}$$

$$= 4{\cdot}55 \times \sqrt{0{\cdot}0784}$$

$$\Rightarrow t_o = 4{\cdot}55 \times 0{\cdot}28 \Rightarrow \boxed{t_o = 1{\cdot}274 \text{ years}}$$

Thus the passenger in spaceship will have aged only 1·27 years when they reach Alpha Centauri, and not the 4·55 years an observer on earth has calculate·

ASSIGNMENT 18·1:
How fast must a meter stick be moving if its length is observed to shrink to one half of a meter?

Solution:

Given Data:

Original length of meter stick = $L_o = 1m$

Length appear during relativistic motion = $L = \frac{L_o}{2}$

Required:

Relativistic speed = $v = ?$

Calculation:

We know that,

$$L = L_o\sqrt{1 - \frac{v^2}{c^2}}$$

$$\Rightarrow \frac{L_o}{2} = L_o\sqrt{1 - \frac{v^2}{c^2}}$$

$$\Rightarrow \frac{1}{2} = \sqrt{1 - \frac{v^2}{c^2}} \quad \text{_____(1)}$$

Squaring both sides of equation (1), we get,

$$\frac{1}{4} = 1 - \frac{v^2}{c^2} \Rightarrow -\frac{v^2}{c^2} = \frac{1}{4} - 1$$

$$\Rightarrow \frac{v^2}{c^2} = 1 - \frac{1}{4} = \frac{4-1}{4} \Rightarrow \frac{v^2}{c^2} = \frac{3}{4}$$

$$\Rightarrow v^2 = \frac{3}{4} \times c^2 = \frac{3}{4} \times (3 \times 10^8)^2 \qquad \boxed{c = 3 \times 10^8 \text{ m / sec}}$$

$$\Rightarrow v^2 = \frac{3}{4} \times 9 \times 10^{16} \text{ m}^2/\text{sec}^2 = \frac{27}{4} \times 10^{16} \text{ m}^2/\text{sec}^2$$

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$\Rightarrow v^2 = 6.75 \times 10^{16}\ m^2/sec^2$

$\Rightarrow v^2 = \sqrt{6.75 \times 10^{16}\ m^2/sec^2} = 2.59 \times 10^8\ m/sec$

$\Rightarrow \boxed{v = 2.6 \times 10^8\ m/sec}$

EXAMPLE 18.2:
The temperature of the human skin is approximately 35°C. What is the wavelength at which the peak occurs in the radiation emitted from the skin?

Solution:

Given Data:

Wien's constant = $0.2898 \times 10^{-2}\ mK$

Temperature = $T = 35°C = 35 + 273K = 308K$

Required:

Wavelength = λ = ?

Calculation:

By Wien's displacement law, $\lambda_{max} T$ = constant

or $\lambda_{max} = \dfrac{\text{constant}}{T}$ _____(1)

putting the values in equation (1), we get,

$$\lambda_{max} = \frac{0.2898 \times 10^{-2}\ mK}{308K}$$

Therefore $\boxed{\lambda = 9.409 \times 10^{-6}\ m = 9.4\mu m}$

ASSIGNMENT 18.2:
A sodium surface is illuminated with light of wavelength 300nm. The work function for sodium is 2.46eV. Find (a) the K.E of ejected electron (b) the cut-off wavelength for sodium.

Solution:

Given Data:

Work function = $\phi_o = 2.46eV$

Plank's constant = $h = 6.63 \times 10^{-34}\ J \cdot sec$

Wavelength = $\lambda = 300nm = 300 \times 10^{-9}\ m$

Energy of light photon = $E = hf$

$$\Rightarrow E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{(300 \times 10^{-9})} \qquad \boxed{c = f\lambda}$$

$\Rightarrow E = 0.0663 \times 10^{-17}\ J \Rightarrow E = 6.63 \times 10^{-19}\ J$

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$$\Rightarrow E = \left[\frac{6.63 \times 10^{-19}}{1.6 \times 10^{-19}}\right] eV \Rightarrow E = 4.41eV$$

a) We know that,

$$(K.E)_{max} = E - \phi_o = (4.41 - 2.46)eV$$

$$\Rightarrow \boxed{(K.E)_{max} = 1.68eV} \text{ or } K.E_{max} = (1.68 \times 1.6 \times 10^{-19})J$$

$$\Rightarrow \boxed{K.E_{max} = 2.688 \times 10^{-19} J}$$

$$\boxed{\begin{aligned}\phi_o &= 2.46eV \\ \phi &= 2.46 \times 1.6 \times 10^{-19} J\end{aligned}}$$

b) We know that,

$$\phi_o = hf_o = \frac{hc}{\lambda_o}$$

$$\Rightarrow \lambda_o = \frac{hc}{\phi_o}$$

$$\Rightarrow \lambda_o = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{(2.46 \times 1.6 \times 10^{-19})}$$

$$\Rightarrow \lambda_o = 5.05 \times 10^{-7} m$$

$$\Rightarrow \boxed{\lambda_o = 505 \times 10^{-9} m}$$

$\boxed{10^{-9} = \text{nano}}$

or $\boxed{\lambda_o = 505nm}$

EXAMPLE 18.3:
The work function for tungsten metal is 4.52eV. (a) What is the cutoff wavelength λ_c for tungsten? (b) What is the maximum kinetic energy of the electrons when radiation of wavelength 198nm is used? (c) What is the stopping potential in this case?

Solution:

Given Data:

Work function = $\phi = 4.52eV$

$\phi = 4.52 \times 1.6 \times 10^{-19} J = 7.232 \times 10^{-19} J$

Wavelength = $\lambda = 198nm = 198 \times 10^{-9} m$

Required:

a) Cutoff wavelength = λ_c = ?

b) Maximum kinetic energy = $K.E_{max}$ = ?

c) Stopping potential = V_o = ?

Calculation:

a) The cutoff wavelength = λ_c is given by,

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$$\lambda_c = \frac{hc}{\phi} \quad \text{_____(1)}$$

Putting the values in equation (1), we get,

$$\lambda_c = \left(\frac{6.626 \times 10^{-34} \times 2.998 \times 10^{8}}{7.232 \times 10^{-19}}\right) m = 2.75 \times 10^{-7}\, m$$

$$\Rightarrow \lambda_c = 275 \times 10^{-9}\, m$$

$$\Rightarrow \boxed{\lambda_c = 275 nm}$$

$\boxed{10^{-9} = \text{nano}}$

b) The maximum kinetic energy "$K.E_{max}$" at shorter wavelength "λ" is given by,

$$KE_{max} = hf - \phi \Rightarrow KE_{max} = \frac{hc}{\lambda} - \phi \quad \text{_____(2)} \qquad \boxed{f = \frac{c}{\lambda}}$$

Putting the values in equation (2), we get,

$$KE_{max} = \left(\frac{6.626 \times 10^{-34} \times 2.998 \times 10^{8}}{198 \times 10^{-9}} - 7.232 \times 10^{-19}\right) J$$

$$\Rightarrow \boxed{KE_{max} = 2.79 \times 10^{-19}\, J}$$

c) We know that,

$$K.E_{max} = V_o e$$

$$\Rightarrow V_o = \frac{K.E_{max}}{e} \quad \text{_____(3)}$$

Putting the values in equation (3)

$$V_o = \frac{2.79 \times 10^{-19}\, J}{1.6 \times 10^{-19}\, C}$$

$$\Rightarrow \boxed{V_o = 1.74 V}$$

ASSIGNMENT 18.3:
X-rays of wavelength 0.140nm are scattered from a very thin slice of carbon. What will be the wavelengths of x-rays scattered at (a) 0°, (b) 90°, (c) 180°?

Solution:

Given Data:

Wavelength of x-rays = λ = 0.140nm

$$\Rightarrow \lambda = 0.140 \times 10^{-9}\, m$$

Velocity of light = $c = 3 \times 10^{8}$ m/sec

Plank's constant = $h = 6.663 \times 10^{-34}$ J·sec

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Rest mass of electron = $m_e = 9{\cdot}1 \times 10^{-31}$kg

Required:

Wavelength of scattered x-rays at ($\theta = 0°$, $90°$ and $180°$) = $\lambda' = ?$

Calculation:

We know that,

$$\lambda' = \frac{h}{m_e c}(1 - \cos\theta) \Rightarrow \lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

$$\Rightarrow \lambda' = \lambda + \frac{h}{m_e c}(1 - \cos\theta)$$

$$\therefore \lambda' = 0{\cdot}140 \times 10^{-9} + \frac{6{\cdot}63 \times 10^{-34}}{9{\cdot}1 \times 10^{-31} \times 3 \times 10^{8}}(1 - \cos\theta)$$

$$\Rightarrow \lambda' = 0{\cdot}140 \times 10^{-9} + 0{\cdot}24 \times 10^{-11}(1 - \cos\theta) \quad \text{---------- (1)}$$

a) For $\theta = 0°$, equation (1) becomes,

$$\lambda' = 0{\cdot}140 \times 10^{-9} + 0{\cdot}24 \times 10^{-11}(1 - \cos 0°)$$

$$\Rightarrow \lambda' = 0{\cdot}140 \times 10^{-9} + 0{\cdot}24 \times 10^{-11}(1 - 1)$$

$$\Rightarrow \lambda' = (0{\cdot}140 \times 10^{-9} + 0)\,m$$

$$\Rightarrow \boxed{\lambda' = 0{\cdot}140 \times 10^{-9}\,m} \text{ or } \boxed{\lambda' = 0{\cdot}140\,nm}$$

b) For $\theta = 90°$, equation (1) becomes,

$$\lambda' = 0{\cdot}140 \times 10^{-9} + 0{\cdot}24 \times 10^{-11}(1 - \cos 90°)$$

$$\Rightarrow \lambda' = \left[0{\cdot}140 \times 10^{-9} + 0{\cdot}24 \times 10^{-11}(1 - 0)\right] m$$

$$\Rightarrow \lambda' = \left(0{\cdot}140 \times 10^{-9} + 0{\cdot}24 \times 10^{-11}\right) m$$

$$\Rightarrow \lambda' = 0{\cdot}140 \times 10^{-9} + 0{\cdot}0024 \times 10^{-9}$$

$$\Rightarrow \lambda' = (0{\cdot}140 + 0{\cdot}0024) \times 10^{-9}\,m$$

$$\Rightarrow \lambda' = 0{\cdot}142 \times 10^{-9}\,m$$

$$\Rightarrow \boxed{\lambda' = 0{\cdot}142 \times 10^{-9}\,m} \text{ or } \boxed{\lambda' = 0{\cdot}142\,nm}$$

c) For $\theta = 180°$, equation (1) becomes,

$$\lambda' = 0{\cdot}140 \times 10^{-9} + 0{\cdot}24 \times 10^{-11}(1 - \cos 180°)$$

$$\Rightarrow \lambda' = 0{\cdot}140 \times 10^{-9} + 0{\cdot}24 \times 10^{-11}(1 + 1)$$

$$\Rightarrow \lambda' = \left(0{\cdot}140 \times 10^{-9} + 0{\cdot}24 \times 10^{-11} \times 2\right) m$$

$$\Rightarrow \lambda' = \left(0{\cdot}140 \times 10^{-9} + 0{\cdot}48 \times 10^{-11}\right) m$$

$$\Rightarrow \lambda' = \left(0{\cdot}140 \times 10^{-9} + 0{\cdot}0048 \times 10^{-9}\right) m$$

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$\Rightarrow \lambda' = (0.140 + 0.0048) \times 10^{-9} m$

$\Rightarrow \lambda' = 0.1448 \times 10^{-9} m = 0.145 \times 10^{-9} m$

$\Rightarrow \boxed{\lambda' = 0.145 \times 10^{-9} m}$ or $\boxed{\lambda' = 0.145 nm}$

EXAMPLE 18.4:
X-rays of wavelength $\lambda = 0.20nm$ are scattered from a block of carbon. The scattered x-rays are observed at an angle of 45° to the incident beam. Calculate the wavelength of the scattered x-ray at this angle.

Solution:

Given Data:

Angle $= \theta = 45°$

Plank's constant $= h = 6.626 \times 10^{-34} Js$

Rest mass of electron $= m_o = 9.11 \times 10^{-31} kg$

Speed of light $= c = 3 \times 10^{8} ms^{-1}$

Wavelength $= \lambda = 0.20nm = 0.20 \times 10^{-9} m$

Required:

Wavelength after scattering $= \lambda' = ?$

Calculation:

By Compton's scattering formula we have, $\Delta\lambda = \frac{h}{m_o c}(1 - \cos\theta)$

$\Rightarrow \lambda' - \lambda = \frac{h}{m_o c}(1 - \cos\theta) \Rightarrow \lambda' = \lambda + \frac{h}{m_o c}(1 - \cos\theta)$ _____(1)

Putting the values in equation (1), we get,

$$\lambda' = 0.20 \times 10^{-9} m + \frac{6.626 \times 10^{-34} Js}{9.11 \times 10^{-31} kg \times 3 \times 10^{8} ms^{-1}}(1 - \cos 45°)$$

Or $\lambda' = 0.20 \times 10^{-9} m + 7.11 \times 10^{-13} m$

$= 0.20 \times 10^{-9} m + 0.00711 \times 10^{-9} m$

$\Rightarrow \lambda' = (0.20 + 0.00711) \times 10^{-9}$

$\Rightarrow \lambda' = 0.20711 \times 10^{-9} m \Rightarrow \boxed{\lambda' = 0.20711 nm}$

ASSIGNMENT 18.4:
Compute the De-Broglie wavelength of the following: (a) A cricket ball of mass 160g, traveling at 45m/s (b) A smoke particle of mass 10^{-9}g moving at 1cm/s. (c) An electron moving with a typical speed of 10^{6}m/s.

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Solution:

Given Data:

Mass of cricket ball = $m_1 = 160gm = 10^{-9} \times 10^{-3} kg = 10^{-12} kg$

Speed of cricket ball = $v_1 = 45m/sec$

Mass of smoke particle = $m_2 = 10^{-9} gm = 10^{-12} kg$

Speed of smoke particle = $v_2 = 1cm/sec = 0.01m/sec$

Mass of electron = $m_3 = 9.11 \times 10^{-31} kg$

Speed of electron = $v_3 = 10^6 m/sec$

Plank's constant = $h = 6.63 \times 10^{-34} J.s$

Required:

a) De-Broglie wavelength for cricket ball = $\lambda_1 = ?$

b) De-Broglie wavelength for smoke particle = $\lambda_2 = ?$

c) De-Broglie wavelength for electron = $\lambda_3 = ?$

Calculation:

a) We know that,

$$\lambda = \frac{h}{p} \Rightarrow \lambda_1 = \frac{h}{m_1 v_1} \quad \text{_____(1)} \qquad [p = mv]$$

Putting the values in equation (1), we get,

$$\lambda_1 = \frac{6.63 \times 10^{-34}}{0.16 \times 45} = 0.92 \times 10^{-34} m$$

$$\Rightarrow \boxed{\lambda_1 = 9.2 \times 10^{-35} m}$$

b) For m_2, v_2 equation (1) becomes,

$$\lambda_2 = \frac{h}{m_2 v_2} = \left(\frac{6.63 \times 10^{-34}}{10^{-12} \times 0.01}\right) m = 663.0 \times 10^{-22} m$$

$$\Rightarrow \lambda_2 = 6.63 \times 10^{-20} m$$

$$\Rightarrow \boxed{\lambda_2 = 6.6 \times 10^{-20} m}$$

c) For m_3, v_3 equation (1) becomes,

$$\lambda_3 = \frac{h}{m_3 v_3} = \left(\frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 10^6}\right) m$$

$$\Rightarrow \lambda_3 = 0.73 \times 10^{-34+31-6}$$

$$\Rightarrow \lambda_3 = 0.73 \times 10^{-9} m$$

$$\Rightarrow \boxed{\lambda_3 = 7.3 \times 10^{-10} m}$$

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EXAMPLE 18·5:

Determine the wavelength of electron that has been accelerated through a potential difference of (a) 50V (b) 200V

Solution:

Given Data:

Potential difference = $\Delta V_1 = 50V$

Potential difference = $\Delta V_2 = 200V$

Rest mass of electron = $m_e = 9{\cdot}11 \times 10^{-31} kg$

Charge on electron = $q_e = 1{\cdot}6 \times 10^{-19} C$

Plank's constant = $h = 6{\cdot}63 \times 10^{-34} J{\cdot}s$

Required:

a) Wavelength = $\lambda_1 = ?$

b) Wavelength = $\lambda_2 = ?$

Calculation:

a) We know that,

$$\lambda = \frac{h}{m_e V} \Rightarrow \lambda_1 = \frac{h}{m_e V_1} \quad \text{_____(1)}$$

We also know that,

$$K{\cdot}E_{max} = q\Delta V \Rightarrow \frac{1}{2} m V_1^2 = q_e \Delta V_1$$

$$\Rightarrow V_1^2 = \frac{2q_e \Delta V_1}{m} \Rightarrow V_1 = \sqrt{\frac{2q_e \Delta V_1}{m_e}} \quad \text{_____(2)}$$

Putting equation (2) in equation (1), we get,

$$\lambda_1 = \frac{h}{m_e \sqrt{2q_e \Delta V_1}} \sqrt{m_e} \quad \text{_____(3)}$$

Putting the values in equation (3), we get,

$$\lambda_1 = \frac{6{\cdot}63 \times 10^{-34}}{9{\cdot}11 \times 10^{-31}} \sqrt{\frac{9{\cdot}11 \times 10^{-31}}{2 \times 1{\cdot}6 \times 10^{-19} \times 50}}$$

$$\Rightarrow \lambda_1 = 0{\cdot}73 \times 10^{-34+31} \sqrt{0{\cdot}057 \times 10^{-31+19}}$$

$$\Rightarrow \lambda_1 = \left[0{\cdot}73 \times 10^{-3} \sqrt{0{\cdot}057 \times 10^{-12}}\right] m$$

$$\Rightarrow \lambda_1 = 0{\cdot}73 \times 10^{-3} \times 0{\cdot}24 \times 10^{-6} m = 0{\cdot}175 \times 10^{-9} m$$

$$\Rightarrow \boxed{\lambda_1 = 0{\cdot}175 \times 10^{-9} m} \text{ or } \boxed{\lambda_1 = 0{\cdot}175 nm}$$

b) For "ΔV_2" equation (3) can be written as,

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$$\lambda_2 = \frac{h}{m_e}\sqrt{\frac{m_e}{2q_e\Delta V_2}} \quad \text{_____(4)}$$

Putting the values in equation (4), we get,

$$\lambda_2 = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31}}\sqrt{\frac{9.11 \times 10^{-31}}{2 \times 1.6 \times 10^{-19} \times 200}}$$

$$\Rightarrow \lambda_2 = \left[0.73 \times 10^{-3}\sqrt{0.0142 \times 10^{-12}}\right] m$$

$$\Rightarrow \lambda_2 = 0.73 \times 10^{-3} \times 0.119 \times 10^{-6}\, m$$

$$\Rightarrow \lambda_2 = 0.0868 \times 10^{-9}\, m$$

$$\Rightarrow \boxed{\lambda_2 = 0.087 \times 10^{-9}\, m} \text{ or } \boxed{\lambda_2 = 0.087 nm}$$

ASSIGNMENT 18.5:
The life time of electron in the excited state is about 10^{-8}s. What is the uncertainty in energy during this time?

Solution:

Given Data:

$\Delta t = 10^{-8}$ sec, Plank's constant = $h = 6.63 \times 10^{-34}$ J.s

Required:

Uncertainty in energy = ΔE = ?

Calculation:

We know that,

$$\Delta E \cdot \Delta t \approx h \Rightarrow \Delta E \approx \frac{h}{\Delta t}$$

$$\Rightarrow \Delta E \approx \left(\frac{6.63 \times 10^{-34}}{10^{-8}}\right) J = 6.63 \times 10^{-26} J$$

$$\Rightarrow \boxed{\Delta E = 6.63 \times 10^{-26} J}$$

EXAMPLE 18.6:
An electron moves in a straight line with a constant speed 6.61×10^6 m/s which has been measured to a precision of 0.10%. What is the maximum precision with which its position could be simultaneously measured?

Solution:

Given Data:

Speed = $v = 6.61 \times 10^6$ m/s

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Mass of electron = $m = 9{\cdot}11 \times 10^{-31}$ kg

Precision = 0·10% = 0·001

Plank's constant = $h = 6{\cdot}626 \times 10^{-34}$ Js

Required:

Position precision = $\Delta x = ?$

Calculation:

The momentum "P" of the electron is = $P = mv$

$\Rightarrow P = \left(9{\cdot}11 \times 10^{-31} \times 6{\cdot}61 \times 10^{6}\right)$ kg·m/sec

$\Rightarrow P = 6{\cdot}02 \times 10^{-24}$ kg·m/sec

Now the uncertainty in momentum is given by,

$\Delta P = P \times$ precision $= 6{\cdot}02 \times 10^{-24} \times 0{\cdot}001$

$= 6{\cdot}02 \times 10^{-24} \times 10^{-3}$ kg

$\Rightarrow \Delta P = 6{\cdot}02 \times 10^{-27}$ kg

Now we know that,

$$\Delta P \cdot \Delta x \approx h \Rightarrow \Delta x \approx \frac{h}{\Delta P}$$

$$\Rightarrow \Delta x \approx \left(\frac{6{\cdot}63 \times 10^{-34}}{6{\cdot}02 \times 10^{-27}}\right) m$$

$$\Rightarrow \boxed{\Delta x \approx 1{\cdot}10 \times 10^{-7}\ m}$$

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Exercise

Choose the best possible answer:

1. Triplets A and B board spaceships and head away from earth in opposite directions, each traveling the same distance at the same speed before returning to earth. Triplet C remains on earth. Which expression describes the triplet's relative ages once they're reunited on earth?
   a) $A < B < C$ b) $A = B > C$
   c) $A = B < C$ ✓ d) $A = B = C$

2. If a spaceship travels from earth to a planet in the Alpha Centauri star system, which observer measures the proper time for the trip?
   a) An observer on earth
   b) An observer on the planet in the Alpha Centauri star system
   c) An observer on the spaceship ✓
   d) An observer deep in space far from the planet and earth

3. When you compress a spring between your fingers, its mass:
   a) Increases b) Decreases
   c) Stay the same ✓ d) Turns negative

4. By doubling the absolute temperature of black-body, the total energy radiated will change by a factor of:
   a) 0.5 b) 2 c) 4 d) 16 ✓

Solution:

According to Stefan Boltzmann law, we have,

$$E = \sigma T^4 \quad \text{_____(1)}$$

If the temperature becomes double, then equation (1) becomes,

$$E' = \sigma T'^4 \quad \text{_____(2)}$$

Put $T' = 2T$ in equation (2), we get,

$$E' = \sigma(2T)^4 = 16(\sigma T^4)$$

$$\Rightarrow E' = 16(\sigma T^4) \quad \text{_____(3)}$$

$$\Rightarrow \boxed{E' = 16E} \qquad [E = \sigma T^4]$$

5. According to Einstein, increasing the brightness of a beam of

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light without changing its color will increase:

a) The number of photons✓
b) The energy of each photon
c) The speed of the photons
d) The frequency of the photons

6. Sources of red, blue and yellow light each emit light with a power of 50mW. The source which emits more photons is:

a) Red ✓ b) Blue c) Yellow
d) They all emit the same number per second

7. Of the following energies for photons, which is the least energy that could result in photoelectron production if the work function is 3.00eV?

a) 1.50eV b) 2.90eV
c) 3.50eV ✓ d) 6.01eV

Solution:

$$hf = \phi + K.E \quad \text{_____(1)}$$

If we put $\phi = 3.00eV$ and $K.E = 0.5eV$ then equation (1) becomes,

$$hf = 3.00 + 0.5 \Rightarrow hf = 3.50eV$$

Which represents the least energy for causing photoelectric effect.

8. In a Compton scattering experiment at which angle the electron can have maximum energy? (Assume that initially the target electron is at rest)

a) 0° b) 90° c) 135° d) 180°✓

9. If x-rays are scattered from protons instead of electrons, the change in its wavelength for a given angle of scattering:

a) Increases b) Decreases✓
c) Is unchanged d) Is one radian

Solution:

$$\Delta\lambda = \frac{h}{m_o c}(1 - \cos\theta) \quad \text{_____(1)}$$

Equation (1) shows that change in wavelength is inversely proportional to mass of the particle. As the mass of proton is greater than the mass of electron, so according to equation (1) the change

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in wavelength for proton will decrease.

10. Pair production cannot take place in vacuum because:
   a) Mass is not conserved
   b) Momentum is not conserved✓
   c) Energy is not conserved
   d) Charge is not conserved

11. According to De-Broglie equation which one has the smallest wavelength associated with it?
   a) Proton b) Neutron
   c) α-particle✓ d) Electron

Solution:

We know that,

$$\lambda = \frac{h}{mv} \quad \text{_____(1)}$$

Equation (1) shows that wavelength is inversely proportional to mass of the particle. As the mass of α-particle is greater than the mass of proton, neutron and electron, so α-particle will have shortest wavelength.

12. An electron and a proton have the same De-Broglie wavelength, then kinetic energy of the electron is:
   a) Zero b) Infinity
   c) Equal to the kinetic energy of the proton
   d) Greater than the kinetic energy of the proton✓

Solution:

We know that,

$$\lambda = \frac{h}{p} \Rightarrow \lambda = \frac{h}{mv} \quad \text{_____(1)}$$

Also $K.E = \frac{1}{2}mv^2 \Rightarrow V = \sqrt{\frac{2K.E}{m}}$ _____(2)

Putting equation (2) in equation (1), we get,

$$\lambda = \frac{h}{m\sqrt{\frac{2K.E}{m}}} = \frac{h}{\sqrt{\frac{2m^2 \times K.E}{m}}}$$

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$$\Rightarrow \lambda = \frac{h}{\sqrt{2m \times K{\cdot}E}} \Rightarrow \lambda^2 = \frac{h^2}{2m \times K{\cdot}E}$$

$$\Rightarrow K{\cdot}E = \frac{h^2}{2m \times \lambda^2} \quad \text{_____(3)}$$

As "h" is constant and "λ" for both electron and proton is also same, so equation (3) becomes,

$$K{\cdot}E = \text{constant} \times \frac{1}{m}$$

$$\Rightarrow \boxed{K{\cdot}E \propto \frac{1}{m}} \quad \text{_____(4)}$$

As mass of electron is lesser than mass of proton, so according to relation (4) the K·E of electron will be greater than that of proton.

13. In electron microscope, light source is replaced by a beam of very fast moving:
a) Electron✓ b) Neutron c) Proton d) Photon

14. According to Heisenberg, as the uncertainty in the measurement of particle's momentum is reduced by a factor of 2, by what factor is uncertainty in that same particle's position changed?
a) ½ b) 1 c) 2 d) 4

Solution:

$$\Delta p \cdot \Delta x \simeq h$$

$$\Rightarrow \Delta x = \frac{h}{\Delta p} \quad \text{_____(1)}$$

For change in momentum equation (1) can be written as,

$$\Delta x' = \frac{h}{\Delta p'} \quad \text{_____(2)}$$

As momentum is reduced by a factor of "2", so we have

$$\Delta p' = \frac{\Delta p}{2}$$

So equation (2) becomes,

$$\Delta x' = \frac{h}{\left(\frac{\Delta p}{2}\right)} \Rightarrow \Delta x' = 2\left(\frac{h}{\Delta p}\right)$$

$$\Rightarrow \boxed{\Delta x' = 2\Delta x}$$

So particle position change by a factor "2".

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CONCEPTUAL QUESTIONS

Q1: Imagine a world in which speed of light is only 50m/sec. How would the everyday events appear to us?

Answer:

If the speed of light is reduce to 50m/sec, then relativistic effects for material object will appear at a speed lower than 50m/sec.

Reason and Explanation:

According to Lorentz transformation, the value of velocity of material object must be less than the velocity of light "C" i.e. $V < C$. Now if the speed of light is reduced to 50m/sec, then under such condition we say that the velocity of material object will not exceed 50m/sec nor reach at 50m/sec. It will always become less than 50m/sec. So under such circumstance, a material object will show relativistic effects at low speeds i.e. at a speed less than 50m/sec.

Q2: Some stars are observed to be reddish, and some are blue. Which stars have the higher surface temperature? Explain.

Answer:

The starts which are observed to be blue will have higher surface temperature.

Reason and Explanation:

The astronomers use the color of starts to estimate their temperature by using Wien's displacement law. According to Wien's law, we have,

$$\lambda T = \text{constant}$$

$$\Rightarrow T = \frac{\text{constant}}{\lambda} \quad \text{_____(1)}$$

Here constant = 0.002898 meter·Kelvin

Now for red light we have,

$$\lambda_R = 700nm = 700 \times 10^{-9} m$$

While for blue light, we have,

$$\lambda_B = 475nm = 475 \times 10^{-9} m$$

For red light, equation (1) becomes,

$$T_{red} = \left(\frac{0.002898}{700 \times 10^{-9}} K \right) = 4.14 \times 10^{3} K$$

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$\Rightarrow$ $\boxed{T_{red} = 4140{\cdot}0K}$ _____(2)·

For blue light, equation (1) becomes,

$$T_{blue} = \left(\frac{0{\cdot}002898}{475 \times 10^{-9}}\right)K = 6{\cdot}1 \times 10^{3}K$$

$\Rightarrow$ $\boxed{T_{blue} = 6100{\cdot}0K}$ _____(3)

Comparing equation (2) and equation (3), we get,

$T_{blue} > T_{red}$

Thus the stars appear to be blue will have higher surface temperature·

Q3: If the photoelectric effect is observed for one metal, can you conclude that the effect will also be observed for another metal under the same conditions?

Answer:

It is not possible for the photoelectric effect to be observed for different metal surfaces under the same conditions·

Reason and Explanation:

The ejection of electrons from a metal surface depends upon its work function which is defined as "**the minimum energy required to eject the electron from the metal surface is known as photoelectric work function**"· It is represented by "ϕ" and is equal to threshold energy i·e· $\phi = hf_o$ _____(1)

In terms of wavelength equation (1) can be written as,

$$\phi = \frac{hc}{\lambda}$$ _____(2)

Now different elements have different work functions, so will require radiations of different wavelengths and frequencies· Thus it is not possible for the photoelectric effect to be observed for different metals surfaces under the same conditions·

Q4: Does a light bulb at a temperature of 2500K produce as white light as the sun at 6000K?

Answer:

No, a light bulb at 2500K does not produce as white light as the sun at 6000K·

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Reason and Explanation:

According to Wien's displacement law, we have,

$$\lambda_{max} T = \text{constant}$$

$$\Rightarrow \lambda_{max} = \frac{\text{constant}}{T} \quad \text{_____(1)}$$

Putting constant = 2898μm·K and T = 2500K in equation (1), we get,

$$\lambda_{max} = \frac{2898}{2500}\,\mu m = 1{\cdot}160\,\mu m$$

$$\Rightarrow \lambda_{max} = 1{\cdot}160 \times 10^{-6}\,m = 1160 \times 10^{-9}\,m$$

$$\Rightarrow \boxed{\lambda_{max} = 1160nm} \quad \text{_____(2)}$$

Equation (2) represents the wavelength of light emitted by the bulb at 2500K. But this range of wavelength does not exist in the visible range (white light). It is mostly exist in infrared region.

Now putting T = 6000K in equation (1), we get,

$$\lambda_{max} = \frac{2898}{6000}\,\mu m = 0{\cdot}483\,\mu m = 0{\cdot}483 \times 10^{-6}\,m$$

$$\Rightarrow \lambda_{max} = 483 \times 10^{-9}\,m = 483nm$$

$$\Rightarrow \boxed{\lambda_{max} = 483nm} \quad \text{_____(3)}$$

Equation (3) represents the wavelength of light emitted by the sun at 6000K. This range of wavelength exists in visible range (white light). Thus we can say that a light bulb at 2500K cannot produce as white light as the sun at 6000K.

Q5: A beam of red light and a beam of blue light have exactly the same energy. Which light contains the greater number of photons?

Answer:

For same energy, the red light will contain more number of photons as compare to blue light.

Reason and Explanation:

We know that the energy of n-number of photons is given by,

$$E = nhf \quad \text{_____(1)}$$

For red light equation (1) can be written as,

$$E_{red} = n_{red} h f_{red} \quad \text{_____(2)}$$

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For blue light equation (2) can be written as,

$$E_{blue} = n_{blue} h f_{blue} \quad \text{_____(3)}$$

For same energy, we have,

$$E_{red} = E_{blue} \Rightarrow n_{red} h f_{red} = n_{blue} h f_{blue}$$

$$\Rightarrow n_{red} f_{red} = n_{blue} f_{blue} \Rightarrow n_{red} = \left(\frac{f_{blue}}{f_{red}}\right) n_{blue} \quad \text{_____(4)}$$

We know that frequency of blue light is greater than the frequency of red light, so we have,

$$f_{blue} > f_{red} \Rightarrow \frac{f_{blue}}{f_{red}} > 1$$

So equation (4) shows that,

$$\boxed{n_{red} > n_{blue}}$$

Thus for same energy, the red light will contain more number of photons than blue light.

Q6: Why must the rest mass of a photon be zero?

Answer:

The rest mass of photon must be equal to zero.

Reason and Explanation:

According to Einstein's special theory of relativity, we have,

$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}} \quad \text{_____(1)}$$

While the energy of photon is given by,

$$E = mc^2 \quad \text{_____(2)}$$

Now the photon travel with speed of light, so we put $v = c$ in equation (1), we get,

$$m = \frac{m_o}{\sqrt{1 - \frac{c^2}{c^2}}} = \frac{m_o}{\sqrt{1-1}} = \frac{m_o}{0} = \infty$$

$$\Rightarrow \boxed{m = \infty} \quad \text{_____(4)}$$

As the photon does not passes infinite energy and mass, so we conclude that the rest mass of photon must be equal to zero.

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Q7: Why do not we observe Compton's effect with visible light?

Answer:

We do not observe Compton's effect with visible light.

Reason and Explanation:

The Compton's effect occurs if the minimum energy of photon is from 0.1MeV to 1.0MeV. We cannot observe Compton's effect with visible light. It is because the energy of visible light photon is less than 0.1MeV. The energy of visible light photon is comparable to the binding energy of electron. i.e. during interaction the visible light photon will give whole of its energy to the electron and itself will disappear. While in Compton's effect the photon does not disappear. It retains some energy and scattered through certain angle with certain frequency and wavelength. Thus we cannot observe Compton's effect with visible light. It can be observed with x-rays and γ-rays which posses high energy than the binding energy of electron.

Q8: If an electron and a proton have the same De-Broglie wavelength, which particle has greater speed?

Answer:

For same De-Broglie wavelength the speed of electron will be greater than the speed of proton.

Reason and Explanation:

We know that the De-Broglie wavelength is given by,

$$\lambda = \frac{h}{mV} \quad \text{(1)}$$

For electron, equation (1) can be written as,

$$\lambda_e = \frac{h}{m_e V_e} \quad \text{(2)}$$

For proton, equation (1) can be written as,

$$\lambda_p = \frac{h}{m_p V_p} \quad \text{(3)}$$

For same De-Broglie wavelength, we have,

$$\lambda_e = \lambda_p \Rightarrow \frac{h}{m_e V_e} = \frac{h}{m_p V_p}$$

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$$\Rightarrow m_e V_e = m_p V_p \Rightarrow V_e = \left(\frac{m_p}{m_e}\right) V_p \quad \text{_____(4)}$$

As mass of proton is greater than mass of electron i.e.

$$m_p > m_e \Rightarrow \frac{m_p}{m_e} > 1$$

So equation (4) becomes,

$$\boxed{V_e > V_p}$$

Thus for same De-Broglie wavelength the speed of electron will be greater than the speed of proton.

Q9: An electron and a proton are accelerated from rest through the same potential difference. Which particle has the longer wavelength?

Answer:

The electron will have longer wavelength than a proton for same potential difference.

Reason and Explanation:

We know that the De-Broglie wavelength associated with a moving particle is given by,

$$\lambda = \frac{h}{p} \quad \text{_____(1)}$$

We know that the momentum of a charged particle in terms of potential difference "V_o" is given by,

$$P = \sqrt{2qmV_o} \quad \text{_____(2)}$$

$K.E = qV_o$

$\Rightarrow \frac{1}{2}mv^2 = qV_o$

$\Rightarrow mv^2 = 2qV_o$

$\Rightarrow m^2v^2 = 2qV_o m$

$\Rightarrow P^2 = 2qmV_o$

$\Rightarrow P = \sqrt{2qmV_o}$

Putting equation (2) in equation (1), we get,

$$\lambda = \frac{h}{\sqrt{2qmV_o}} \quad \text{_____(3)}$$

In equation (3), h, q and V_o are constant, so equation (3) becomes,

$$\lambda \propto \frac{1}{\sqrt{m}} \quad \text{_____(4)}$$

Relation (4) shows that the wavelength is inversely proportional to the square root of the mass of the charge particle i.e. greater the mass, smaller will be the wavelength and vice versa. Now the mass

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of electron is less than the mass of proton, so electron will have longer wavelength than proton for same potential difference.

Q10: Why ultraviolet radiations are harmful to skin while visible light is not?

Answer:

Ultraviolet radiations are harmful to skin while visible light is not.

Reason and Explanation:

We know that the energy of photon is given by,

$$E = hf \Rightarrow E \propto f \quad \text{_____(1)}$$

Equation (1) shows that the energy of photon is directly proportional to the frequency i.e. greater the frequency of radiations, greater will be its energy and vice versa.

Now we know that the frequency of ultraviolet light is greater than the frequency of visible light. So ultraviolet radiations are more energetic and can penetrate very far in the body. They can damage living cells and tissues. They can cause various skin diseases. While visible light is less energetic due to their low frequency. They are safe as compare to ultraviolet radiations.

COMPREHENSIVE QUESTIONS

Q1: What are inertial and non-inertial frame of references? Explain with examples.

Answer: See answer of question # 1 in the text.

Q2: State Einstein's postulates of the special theory of relativity. Discuss its various results.

Answer: See answer of question # 3 in the text.

Q3: What are the main features of thermal radiations from a black body? Discuss Plank's quantum theory and its importance in physics.

Answer: See answer of question # 4 in the text.

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Q4: What is photoelectric effect? Discuss the failure of classical physics and success of photon concept in explaining this effect.

Answer: See answer of question # 5, 6 in the text.

Q5: What is Compton's effect? Develop a mathematical relation for the Compton's wave shift.

Answer: See answer of question # 9 in the text.

Q6: Write note on pair production and annihilation of matter.

Answer: See answer of question # 10, 11 in the text.

Q7: What is De-Broglie hypothesis? Describe an experiment to show that particle has wave characteristics.

Answer: See answer of question # 12 in the text.

Q8: What is meant by wave-particle duality? Explain.

Answer: See answer of question # 14 in the text.

Q9: State and explain Heisenberg's uncertainty principle. Justify the validity of this principle by a thought experiment.

Answer: See answer of question # 15 in the text.

NUMERICAL QUESTIONS

Q1: The length of a spaceship is measured to be exactly one-third of its proper length. What is the speed of the spaceship relative to the observer?

Solution:

Given Data:

Proper length of spaceship = L_o

Length of spaceship during relativistic speed = $L = \frac{L_o}{3}$

Required:

Relativistic speed = $V = ?$

Calculation:

We know that,

$$L = L_o\sqrt{1 - \frac{v^2}{c^2}}$$

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$$\Rightarrow L^2 = L_o^2\left(1 - \frac{v^2}{c^2}\right) \Rightarrow \left(\frac{L_o}{3}\right)^2 = L_o^2\left(1 - \frac{v^2}{c^2}\right)$$

$$\Rightarrow \frac{L_o^2}{9} = L_o^2\left(1 - \frac{v^2}{c^2}\right) \Rightarrow \frac{1}{9} = 1 - \frac{v^2}{c^2}$$

$$\Rightarrow -\frac{v^2}{c^2} = \frac{1}{9} - 1 = \frac{1-9}{9} = \frac{-8}{9}$$

$$\Rightarrow -\frac{v^2}{c^2} = \frac{-8}{9} \Rightarrow \frac{v}{c} = \sqrt{\frac{8}{9}}$$

$$\Rightarrow \frac{v}{c} = 0.9428 \Rightarrow \boxed{v = 0.9428c}$$

Q2: *The time period of a pendulum is measured to be 3s in inertial frame of the pendulum. What is the period when measured by an observer moving with a speed of 0.95c with respect to the pendulum?*

Solution:

Given Data:

Relativistic speed = $V = 0.95c$

Proper time = $t_o = 3sec$

Required:

Period in motion = $t = ?$

Calculation:

We know that,

$$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{3}{\sqrt{1 - \frac{(0.95c)^2}{c^2}}} = \frac{3}{\sqrt{1 - (0.95)^2}}$$

$$\Rightarrow t = \frac{3}{\sqrt{1 - 0.9025}} = \frac{3}{\sqrt{0.0975}} = \frac{3}{0.3122}$$

$$\Rightarrow \boxed{t = 9.60sec}$$

Q3: *A metal, whose work function is 3.0eV, is illuminated by light of wavelength 3×10^{-7}m. Calculate the (a) threshold frequency, (b) maximum energy of photo-electrons and (c) stopping potential.*

Solution:

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Given Data:

Work function = ϕ = 3eV

$\phi = 3{\cdot}16 \times 10^{-19}\,J = 4{\cdot}8 \times 10^{-19}\,J$

Wavelength = $\lambda = 3 \times 10^{-7}\,m$

Required:

a) Threshold frequency = f_o = ?

b) $(K{\cdot}E)_{max}$ = ?

c) Stopping potential = V_o = ?

Calculation:

a) We know that,

$$\phi = hf_o$$

$$\Rightarrow f_o = \frac{\phi}{h} = \frac{4{\cdot}8 \times 10^{-19}}{6{\cdot}625 \times 10^{-34}}$$

$$\Rightarrow \boxed{f_o = 0{\cdot}72 \times 10^{15}\,Hz}$$

b) From Einstein equation, we have,

$$(K{\cdot}E)_{max} = hf - \phi \qquad \boxed{f = \frac{c}{\lambda}}$$

$$\Rightarrow (K{\cdot}E)_{max} = \frac{hc}{\lambda} - \phi$$

$$\Rightarrow (K{\cdot}E)_{max} = \frac{6{\cdot}625 \times 10^{-34} \times 3 \times 10^{8}}{3 \times 10^{-9}} - 4{\cdot}8 \times 10^{-19}$$

$$\Rightarrow (K{\cdot}E)_{max} = \left[6{\cdot}625 \times 10^{-19} - 4{\cdot}8 \times 10^{-19}\right] J$$

$$= (6{\cdot}625 - 4{\cdot}8) \times 10^{-19}\,J$$

$$= 1{\cdot}825 \times 10^{-19}\,J$$

$$= \left(\frac{1{\cdot}825 \times 10^{-19}}{1{\cdot}6 \times 10^{-19}}\right) eV$$

$$= 1{\cdot}14eV$$

$$\Rightarrow \boxed{(K{\cdot}E)_{max} = 1{\cdot}14eV}$$

c) We know that,

$$(K{\cdot}E)_{ma} = V_o e$$

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$$\Rightarrow V_o = \frac{(K.E)_{max}}{e} = \frac{1.825 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$\Rightarrow \boxed{V_o = 1.14V}$$

Q4: A 50keV x-ray is scattered through an angle of 90°. What is the energy of x-ray after Compton scattering?

Solution:

Given Data:

Energy of x-ray = $E = 50keV = 50 \times 10^3 eV$ $\quad [1eV = 1.6 \times 10^{-19} J]$

$$\Rightarrow E = 50 \times 10^3 \times 1.6 \times 10^{-19} J = 80 \times 10^{-16} J$$

Scattering angle = $\theta = 90°$

Required:

Energy of photon after scattering = $E' = ?$

Calculation:

We know that,

$$\Delta\lambda = \frac{h}{m_o c}[1 - \cos\theta]$$

$$\lambda' - \lambda = \frac{h}{m_o c}[1 - \cos\theta]$$

$$\Rightarrow \frac{c}{f'} - \frac{c}{f} = \frac{h}{m_o c}[1 - \cos\theta]$$

$$\Rightarrow \frac{1}{h}\left[\frac{c}{f'} - \frac{c}{f}\right] = \frac{1}{m_o c}[1 - \cos\theta]$$

$$= c\left(\frac{1}{hf'} - \frac{1}{hf}\right) = \frac{1}{m_o c^2}[1 \cos - \theta]$$

$$\Rightarrow \frac{1}{hf'} - \frac{1}{hf} = \frac{1}{m_o c^2}[1 - \cos 90°]$$

$$\Rightarrow \frac{1}{E'} - \frac{1}{E} = \frac{1}{m_o c^2}$$

$$\Rightarrow \frac{1}{E'} = \frac{1}{m_o c^2} + \frac{1}{E}$$

$hf = E$
$hf' = E'$
$\cos 90° = 0$

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$$\Rightarrow \frac{1}{E'} = \frac{1}{9.11 \times 10^{-31} \times (3 \times 10^{8})^2} + \frac{1}{80 \times 10^{-16}}$$

$$\Rightarrow \frac{1}{E'} = \frac{1}{81.99 \times 10^{-15}} + \frac{1}{8.0 \times 10^{-15}}$$

$$= \left[\frac{1}{81.99} + \frac{1}{8}\right] \times 10^{15}$$

$$\Rightarrow \frac{1}{E'} = \left[\frac{1}{82} + \frac{1}{8}\right] \times 10^{15} = (0.012 + 0.125) \times 10^{15}$$

$$\Rightarrow \frac{1}{E'} = 0.137 \times 10^{15}$$

$$\Rightarrow E' = \frac{1}{0.137} \times 10^{-15}\, J = 7.28 \times 10^{-15}\, J \qquad [1eV = 1.6 \times 10^{-19}\, J]$$

$$\Rightarrow E' = \left[\frac{7.28 \times 10^{-15}}{1.6 \times 10^{-19}}\right] eV$$

$$\Rightarrow E' = 4.56 \times 10^{4}\, eV$$

$$\Rightarrow E' = 45.6 \times 10^{3}\, eV$$

$$\Rightarrow \boxed{E' = 45.6 KeV}$$

Q5: The speed of electron is measured to be $5 \times 10^{3} ms^{-1}$ to an accuracy of 0.003%. Find the uncertainty in determining the position of this electron.

Solution:

Given Data:

$V = 5 \times 10^{3}$ m/sec

Accuracy = 0.003%

Uncertainty in speed = $\Delta V = V \times 0.003\%$

$$\Rightarrow \Delta V = 5 \times 10^{3} \times 0.003 \times \frac{1}{100}$$

$$= 0.15 \frac{m}{sec} = 15.0 \times 10^{-2} \frac{m}{sec}$$

Required:

Uncertainty in position = Δx = ?

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Calculation:

We know that,

$$\Delta x \cdot \Delta P \approx h$$

$$\Rightarrow \Delta x \cdot m\Delta V \approx h$$

$$\Rightarrow \Delta x \approx \frac{h}{m\Delta V} \qquad [\Delta p = m\Delta v]$$

$$\Rightarrow \Delta x \approx \frac{6{\cdot}63 \times 10^{-34}}{9{\cdot}11 \times 10^{-31} \times 15 \times 10^{-2}}$$

$$\Rightarrow \Delta x \approx 0{\cdot}0484 \times 10^{-1}\, m$$

$$\Rightarrow \boxed{\Delta x \approx 4{\cdot}84 \times 10^{-3}\, m}$$

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