# CHAPTER 19

# DAWN OF MODERN PHYSICS

## MULTIPLE CHOICE

1. **Einstein explained photoelectric effect on the following assumption that**
   A. light has a particle nature
   B. light consists of photons or quanta
   C. the energy of light increases with speed
   D. light has a wave nature
2. **The photoelectric threshold frequency depends upon**
   A. frequency
   B. nature of material
   C. intensity of light
   D. none of these
3. **In the equation E = hf, h is called**
   A. gravitational constant
   B. plank's constant
   C. gas constant
   D. none of these
4. **A positron is an anti particle of**
   A. Proton
   B. Electron
   C. Neutron
   D. Photon
5. **According to Maxwell theory, light was known to consists of oscillating:**
   A. Electric fields
   B. Magnetic field
   C. Both electric and magnetic
   D. None
6. **If an observer is moving in the same direction as sound wave, the velocity of wave seems to be:**
   A. More
   B. less
   C. Half
   D. Double
7. **A set of coordinate axes with respect to which measurements are made is called:**
   A. inertial frame of reference
   B. Non-inertial frame
   C. Frame of reference
   D. None
8. **The relativistic length of an object measured by an observer in the moving frame of reference is given by:**
   A. $\ell = \ell_0\sqrt{1-\frac{v^2}{c^2}}$
   B. $\ell = \ell_0\sqrt{1-\frac{c^2}{v^2}}$
   C. $\ell = \frac{\ell_0}{\sqrt{1-\frac{v^2}{c^2}}}$
   D. $\ell = \ell_0$
9. **The stopping potential for a certain metal is 10 V. The work function for the cathode is**
   A. 20 J
   B. $1.6 \times 10^{-18}$ J

C. $1.6 \times 10^{[illegible]}$ J
D. $1.6 \times 10^{[illegible]}$ J

**10. An observer sitting in aeroplane and moving with very high-speed observes a meter rod placed on earth. The rod appears to him:**
A. Less than one metre
B. Greater than one metre
C. One metre
D. Two metre

**11. Amount of energy liberated due to breaking of 1Kg of matter is:**
A. $9 \times 10^{9}$ J
B. $9 \times 10^{16}$ J
C. $9 \times 10^{20}$ J
D. $3 \times 10^{8}$ J

**12. Absorption power of perfect black body is:**
A. Zero
B. 0.5
C. 1
D. 100

**13. The rest mass of X-ray photon is**
A. $9.1 \times 10^{-31}$ kg
B. $1.67 \times 10^{-31}$ kg
C. $1.60 \times 10^{-31}$ kg
D. zero

**14. All motions are**
A. Absolute
B. uniform
C. Relative
D. variable

**15. The energy of photon is given by:**
A. $\frac{mv^2}{2}$
B. hf
C. $V_0e$
D. $m_0c^2$

**16. In photoelectric effect, the threshold frequency is:**
A. Different for different materials
B. same for all materials
C. Random
D. None

**17. The momentum of photon of frequency "f" is:**
A. $\frac{hc}{f}$
B. $\frac{f}{hc}$
C. $\frac{hf}{c}$
D. $\frac{h}{f\lambda}$

**18. Compton scattering experiment provides a proof that radiation has:**
A. Wave nature
B. Particle nature
C. Both particle and wave nature
D. None

**19. Photocells are used for**
A. Security system
B. counting system
C. Automatic door system
D. All of these

**20. Theory of relativity which deals with non inertial frames of reference is called**
A. Special theory of relativity
B. General theory of relativity
C. Quantum theory
D. Classical theory

**21. The physical quantity related to photon that does not change in Compton scattering is,**
A. energy
B. speed
C. frequency
D. wavelength

**22. Plank's Constant has dimensions**
A. $[ML^2T^{-2}]$
B. $[ML^2T^3]$
C. $[MLT^{-1}]$
D. $[MLT^{-2}]$

**23. In black body radiations at low temperature a body emits radiations of**
A. Long wavelength
B. Small wavelength
C. Medium Wavelength
D. High energy

**24. X-Ray diffraction implies that X-rays have**
A. Particle nature
B. wave nature

C. wave-particle nature D. None of these

**25. The materialization of energy takes place in the process of:**

A. Pair production B. Annihilation
C. Compton-effect D. Photoelectric effect

**26. The de-Broglie wavelength of particle is dependent on:**

A. Energy B. Momentum
C. Energy & Momentum D. None

**27. Which of the following phenomena can be studied with $\gamma$-rays:**

A. Photo-electric effect B. Compton effect
C. Pair production D. All

**28. The uncertainty principle points out that:**

A. Electrons can exist inside the nucleus
B. Cannot exist inside the nucleus
C. Both A & B
D. None

**29. Blue light has frequency $7.5 \times 10^{14}$ cps. Its energy is:**

A. 3.1 eV B. 6.2 eV C. 9.3 eV D. 7.5 eV

**30. The rest mass of photon is:**

A. $1.67 \times 10^{-27}$ kg B. $9.1 \times 10^{-31}$ kg
C. Zero D. None of these

**31. Who gave the idea of matter wave?**

A. de-Broglie B. Plank
C. Einstein D. Huygens

**Answers:**

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. B | 2. B | 3. B | 4. B | 5. C | 6. B | 7. C |
| 8. A | 9. B | 10. A | 11. B | 12. C | 13. D | 14. C |
| 15. B | 16. A | 17. C | 18. B | 19. D | 20. B | 21. B |
| 22. C | 23. A | 24. B | 25. A | 26. B | 27. C | 28. B |
| 29. A | 30. C | 31. A | | | | |

# SHORT & LONG QUESTIONS

**Q1: Briefly discuss the history of modern physics?**

**Ans: Classical physics:**

In the early part of the twentieth century, many experimental and theoretical problems remained unresolved. Attempts to explain the behaviour of matter on the atomic level with the laws of classical physics were not successful. Phenomena such as black body radiation, the photoelectric effect, the emission of sharp spectral lines by atoms in a gas discharge tube, and invariance of speed of light, could not be understood within the framework of classical physics.

**Quantum theory:**

To explain these observations a revolutionary framework of explanation was necessary which we call modern physics. Its two most significant features are relativity and quantum theory.

**Special theory of relativity:**

C. wave-particle nature    D. None of these

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**Answers:**

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| 8. A | 9. B | 10. A | 11. B | 12. C | 13. D | 14. C |
| 15. B | 16. A | 17. C | 18. B | 19. D | 20. B | 21. B |
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**Quantum theory:**

To explain these observations a revolutionary framework of explanation was necessary which we call modern physics. Its two most significant features are relativity and quantum theory.

**Special theory of relativity:**

The observations on objects moving very fast approaching the speed of light are well explained by the special theory of relativity. Quantum theory has been able to explain the behaviour of electromagnetic radiation as discrete packets of energy and the particles on a very small scale are dominated by wave properties

**Q2: Discuss the relative motion?**

**Ans: Relative motion:**

The motion of a body with respect to some reference point is called relative motion.

**Explanation:**

The rest position or the motion of an object is not same for different observers. **For example**, the walls of the cabin of a moving train are stationary with respect to the passengers sitting inside it but are in motion to a person stationary on the ground. So we cannot say whether an object is absolutely at rest or absolutely in motion. All motions are relative to a person or instrument observing it.

**Q3: What do you mean by frames of reference, inertial frame of reference and non-inertial frame of reference?**

**Ans: Frame of reference:**

A coordinates system relative to which measurements are taken is called a frame of reference.

The simplest frame of reference is the Cartesian coordinate system with consist of three mutually perpendicular lines (x-axis, y-axis and z-axis)

**Explanation:**

In fact, a frame of reference is any coordinate system relative to which measurements are taken. The position of a table in a room can be located relative to the walls of the room. A coordinate system based on these stars is then the frame of reference.

**Types of frames of reference:**

**1. Inertial frame of reference:**

An inertial frame of reference is defined as a coordinate system in which the law of inertia is valid.

**Explanation:**

**i.** That is, a body at rest remains at rest unless an unbalanced force produces acceleration in it. Other laws of nature also apply in such a system. If we place a body upon Earth it remains at rest unless an unbalanced force is applied upon it. This observation shows that Earth may be considered as an inertial frame of reference.

**ii.** A body placed in a car moving with a uniform velocity with respect to Earth also remains at rest, so that car is also an inertial frame of reference.

**iii.** Thus any frame of reference which is moving with uniform velocity relative to an inertial frame is also an inertial frame.

**Non-inertial frame of reference:**

A non-inertial frame of reference is defined as a coordinate system in which the law of inertia is not valid.

**Explanation:**

**i.** When the moving car is suddenly stopped the body placed in it no longer remains at rest. So is the case when the car is suddenly accelerated. In such a situation, the car is not an inertial frame of reference. Thus an accelerated frame is a non-inertial frame of reference.

**ii.** Earth is rotating and revolving and hence strictly speaking, the Earth is not an inertial frame. But it can often be treated as an inertial frame without serious error because of very small acceleration.

**Q4: Explain the basic postulates of special theory of relativity?**

**Ans: Special theory of relativity:**

**i.** The theory of relativity is concerned with the way in which observers who are in a state of relative motion describe physical phenomena.

**ii.** The special theory of relativity treats problems involving inertial or non-accelerating frames of reference.

**iii. General theory of relativity:**

There is another theory called general theory of relativity which treats problems involving frames of reference accelerating with respect to one another.

**Postulates of special theory of relativity:**

The special theory of relativity is based upon two postulates, which can be stated as follows

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

**2.** The speed of light in free space has the same value for all observers, regardless of their state of motion.

**Explanation of first postulates of special theory of relativity:**

The first postulate is the generalization of the fact that all physical laws are the same in frames of reference moving with uniform velocity with respect to one another. If the laws of physics were different for different observers in relative motion, the observer could determine from this difference that which of them were stationary in a space and which were moving. But such a distinction does not exist, so this postulate implies that there is no way to detect absolute uniform motion.

**Explanation of second postulates of special theory of relativity:**

The second postulate states an experimental fact that speed of light in free space is the universal constant 'c' ($c = 3 \times 10^8\ ms^{-1}$).

**Significance of special theory of relativity:**

These simple postulates have far-reaching consequences. These include such phenomena as the slowing down of clocks and contraction of lengths in moving reference frames as measured by a stationary observer.

**Q5: Discuss the result concluded from special theory of relativity?**

**Ans: Result concluded from special theory of relativity:**

Some interesting results of the special theory of relativity can be summarized as follows:

**1. Time dilation: (Time dilation means moving clocks run slowly):**

According to special theory of relativity, time is not absolute quantity. It depends upon the motion of the frame of reference.

**Explanation:**

Suppose an observer is stationary in an inertial frame. He measures the time interval between two events in this frame. Let it be $t_0$. This is known as proper time. If the observer is moving with respect to frame of events with velocity v or if the frame of events is moving with respect to observer with a uniform velocity v the time measured by the observer would not be $t_0$ but it would be t given by

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad (1)$$

As the quantity $\sqrt{1 - \frac{v^2}{c^2}}$ is always less than one, so t is greater than $t_0$ i.e time has dilated or stretched due to relative motion of the observer and the frame of reference of events.

**Application:**

**i.** This astonishing result applies to all timing processes--physical, chemical and biological.

**ii.** Even aging process of the human body is slowed by motion at very high speeds.

**2. Length contraction:**

(Length contraction means faster objects will have shorter length).

**i.** The distance from Earth to a star measured by an observer in a moving spaceship would seem smaller than the distance measured by an observer on Earth. That is, if you are in motion relative to two points that are a fixed distance apart, the distance between the two points appears shorter than if you were at rest relative to them. This effect is known as length contraction.

**ii.** The length contraction happens only along the direction of motion. No such contraction would be observed perpendicular to the direction of motion.

**iii. Proper length ($\ell_0$):**

The length of an object or distance between two points measured by an observer who is relatively at rest is called proper length '$\ell_0$'. If an object and an observer are in relative motion with speed v, then the contracted length '$\ell$' is given by

$$\ell = \ell_0\sqrt{1 - \frac{v^2}{c^2}} \qquad (2)$$

**3. Mass variation:**

(Mass variation means faster objects will be heavier).

**i.** According to special theory of relativity, mass of an object is a varying quantity and depends upon the speed of the object.

**ii.** An object whose mass when measured at rest is $m_0$ will have an increased mass m when observed to be moving at speed v. They are related by

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad (3)$$

**iii.** The increase in mass indicates the increase in inertia the object has at high speeds.

**iv. Limit of the speed of a material object:**

As v approaches c, it requires a larger and larger force to change the speed of the object.

As $v \to c$, $\frac{v}{c} \to 1$ therefore $\sqrt{1 - \frac{v^2}{c^2}} \to 0$

Thus $m \to \infty$

An infinite mass would require an infinite force to accelerate it. Because infinite forces are not available, hence, an object cannot be accelerated to the speed of light 'c' in free space.

**v.** In our everyday life, we deal with extremely small speeds, compared to the speed of light. Even the Earth's orbital speed is only 30 $kms^{-1}$. On the other hand, the speed of light in free space is 300,000 $kms^{-1}$. This is the reason why Newton's laws are valid in everyday situations. However, when experimenting with atomic particles moving with velocities approaching speed of light, the relativistic effects are very prominent, and experimental results cannot be explained without taking Einstein's equations into account.

**Q6: Explain energy-mass relation?**

**Ans: Energy-mass relation:**

**i.** According to special theory of relativity, mass and energy are different entities but are interconvertible. The total energy E and mass m of an object are related by the expression

$$E = mc^2 \qquad (1)$$

where m depends on the speed of the object.

**ii.** At rest, the energy equivalent of an object's mass $m_0$ is called rest mass energy $E_0$

$$E_0 = m_0c^2 \qquad (2)$$

**iii.** As $mc^2$ is greater than $m_0c^2$, the difference of energy ($mc^2 - m_0c^2$) is due to motion; as such it represents the kinetic energy of the mass. Hence

$$K.E = (m - m_0)\,c^2 \qquad (3)$$

**iv.** From equation 1 above, the change in mass m due to change in energy $\Delta E$ is given by

$$\Delta m = \frac{\Delta E}{c^2}$$

**Note:**

Because $c^2$ is a very large quantity, this implies that small changes in mass require very large changes in energy. In our everyday world, energy changes are too small to provide measurable mass changes. However, energy and mass changes in nuclear reactions are found to be exactly in accordance with the above mentioned equations.

**Q7: Write a short note on NAVSTAR navigation system?**

**Ans: NAVSTAR navigation system (Global positioning system):**

**i.** The results of special theory of relativity are put to practical use even in everyday life by a modern system of navigation satellites called NAVSTAR.

**ii.** The location and speed anywhere on Earth can now be determined to an accuracy of about 2 $cms^{-1}$.

**iii.** However, if relativity effects are not taken into account, speed could not be determined any closer than about 20 $cms^{-1}$.

**iv.** Using these results the location of an aircraft after an hour's flight can be predicted to about 50 m as compared to about 760 m determined by without using relativistic effects.

**Q8: Briefly describe the black body radiation?**

**Ans: Black body radiation:**

A black body is a solid block having a hollow cavity within it. It has small hole and the radiation can enter or escape only through this hole.

Black body has the property to absorb all the radiation entering it. A black body is both an ideal absorber and an ideal radiator.

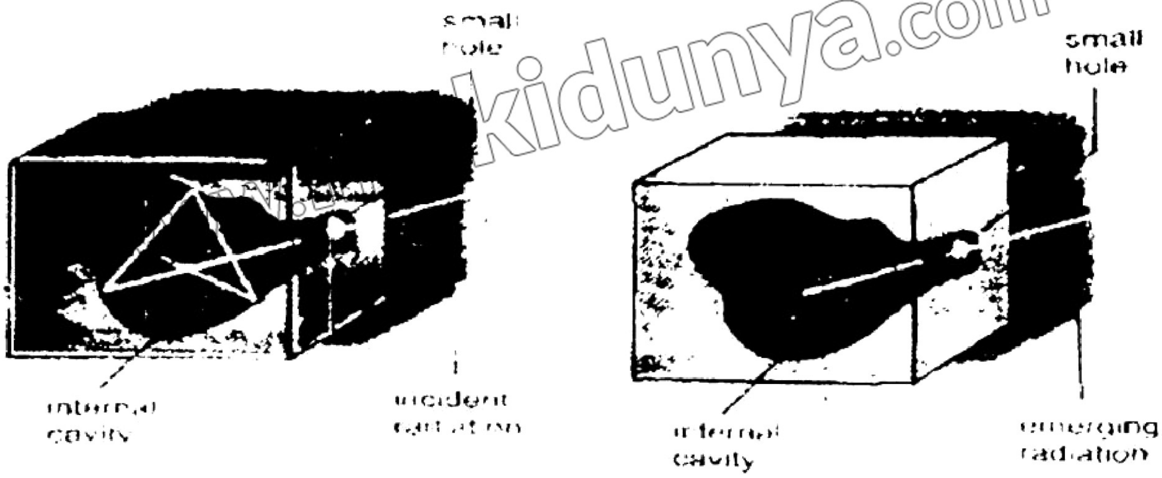
**Explanation:**

**i.** When a body is heated it emits radiation. The nature of radiation depends upon the temperature.

**ii.** **At low temperature** a body emits radiation which is principally of long wavelengths in the invisible infrared region.

**iii.** **At high temperature**, the proportion of shorter wavelength radiation increases. Furthermore, the amount of emitted radiation is different for different wavelengths.

For example, when platinum wire is heated, it appears dull red at about 500°C, changes to cherry red at 900°C, becomes orange red at 1100°C, yellow at 1300°C and finally white at about 1600°C. This shows that as the temperature is increased, the radiation becomes richer in shorter wavelengths.



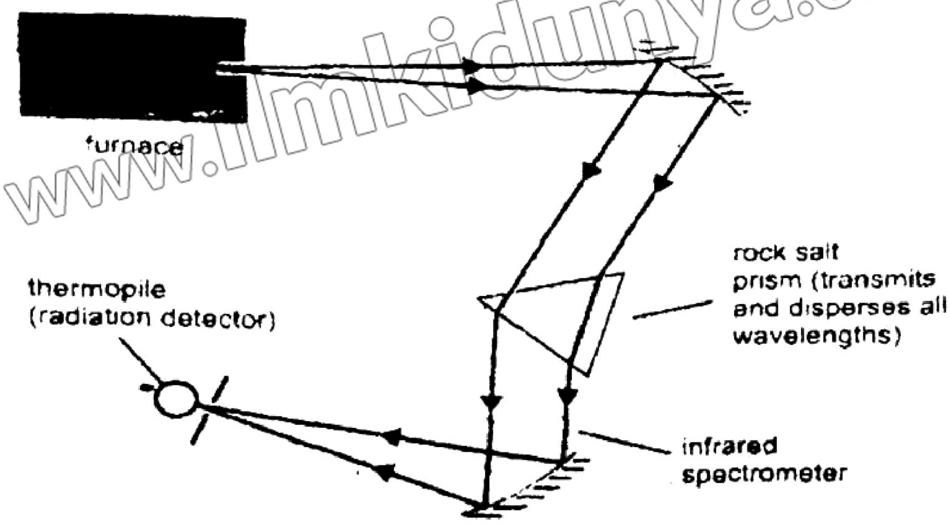

(a) Absorption of radiation (b) Emission of radiation

**Q9: Explain the distribution of energy in the black body radiation spectrum at various temperatures with the help of diagram?**

**Ans: Intensity distribution diagram:**

**i.** Lummer and Pringsheim measured the intensity of emitted energy with wavelength radiated from a black body at different temperatures by the apparatus shown in Fig.

**ii.** The amount of radiation emitted with different wavelengths is shown in the form of energy distribution curves for each temperature in the Fig.




**Results of Lummer and Pringsheim experiments:**

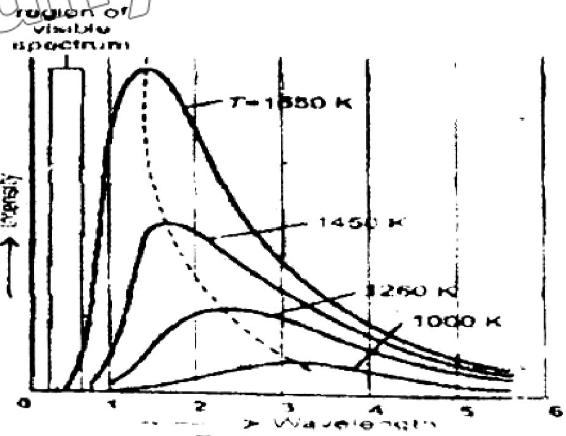
These curves reveal the following interesting facts.

**1.** At a given temperature, the energy is not uniformly distributed in the radiation spectrum of the body.

**2.** At a given temperature T, the emitted energy, has maximum value for a certain wavelength $\lambda_{max}$ and the product $\lambda_{max} \times T$ remains constant.

$\lambda_{max} \times T$ = Constant ........ (1)

The value of the constant known as **Wien's constant** is about $2.9 \times 10^{-3}$ mK. This equation means that as T increases, $\lambda_{max}$ shifts to shorter wavelength.




Results of Lummer and Pringsheim's experiments: graphs of intensity of radiated energy against wavelength from a blackbody

**3.** For all wavelengths, an increase in temperature causes an increase in energy emission. The radiation intensity increases with increase in wavelengths and at a particular wavelength $\lambda_{max}$, it has a maximum value. With further increase in wavelength, the intensity decreases.

**4. Stefen-Boltzmann law:**

The area under each curve represents the total energy (E) radiated per second per square metre over all wavelengths at a particular temperature. It is found that area is directly proportional to the fourth power of kelvin temperature T. Thus

$$E \propto T^4 \quad \text{or}$$

$$E = \sigma T^4 \quad \text{.........} \quad (2)$$

Where $\sigma$ is called Stefen's constant.

Its value is $5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$ and the above relation is known as Stefen-Boltzmann law.

**Q10: Briefly describe the Planck's assumption?**

**Ans: Planck's assumption (quantum theory):**

**i.** In 1900, Max Planck founded a mathematical model resulting in an equation that describes the shape of observed curves exactly.

**ii.** He suggested that energy is radiated or absorbed in discrete packets, called quanta rather than as a continuous wave.

**iii.** Each quantum is associated with radiation of a single frequency. The energy E of each quantum is proportional to its frequency f, and

$$E = hf \quad \ldots\ldots \quad (1)$$

where h is Planck's constant. Its value is $6.63 \times 10^{-34}$ Js. This fundamental constant is as important in physics as the constant c, the speed of light in vacuum.

**iv.** Max Planck received the Nobel Prize in physics in 1918 for his discovery of energy quanta.

**Q11: Briefly describe about the photon. Drive a relation for the momentum of photon?**

**Ans: Photon:**

Einstein extended his idea and postulated that packets or tiny bundles of energy are integral part of all electromagnetic radiation and that they could not be subdivided. These indivisible tiny bundles of energy he called photons.

**Momentum of a photon:**

The beam of light with wavelength $\lambda$ consists of stream of photons travelling at speed c and carries energy hf. From the theory of relativity momentum p of the photon is related to energy as

$$E = mc^2 \quad (1)$$

Thus

$$E = hf \quad \ldots\ldots\ldots \quad (2)$$

By comparing 1 and 2, we get

$$mc^2 = hf$$

$$mc = \frac{hf}{c} \qquad \text{(dividing both sides by c)}$$

$$p = \frac{hf}{c} \qquad (3) \qquad \text{(Since mc = momentum)}$$

$$p = \frac{hf}{f\lambda} \qquad \text{(Since } c = f\lambda\text{)}$$

$$p = \frac{h}{\lambda} \quad \ldots\ldots\ldots \quad (4)$$

This equation shows the momentum of photon in terms of wavelength.

**Q12: What are some of the differences between photons and electrons?**

**Ans:** Electrons have mass, photons do not. Electrons have electric charge, photons do not. Electrons may be stationary, photons move only at the velocity of light. Electrons are constituents of ordinary matter, photons are not. The energy of a photon depends only on its frequency that of an electron depends on its velocity and position.

**Q13: Explain the electromagnetic spectrum?**

**Ans: Electromagnetic spectrum:**

**i.** At the high end, $\gamma$- radiation with energy ~ 1 MeV is easily detected as quanta by a radiation detector and counter.

**ii.** At the other end, the energy of photon of radio waves is only about $10^{-10}$ eV

**iii.** Millions of photons are needed to detect a signal and hence wave properties of radio waves predominate. The quanta are so close together in energy value that radio waves are detected as continuous radiation.

**iv.** The emission or absorption of energy in steps may be extended to include any system such as a mass oscillating on a spring. However the energy steps are far too small to be detected and so any granular nature is invisible

**v.** Quantum effects are only important when observing atomic sized objects where h is a significant factor in any detectable energy change

**Q14: Enlist the names of methods in which interaction of electromagnetic radiation with matter takes place?**

**Ans: Interaction of electromagnetic radiation with matter:**

Electromagnetic radiation or photons interact with matter in three distinct ways depending mainly on their energy

The three processes are

**i.** Photoelectric effect **ii.** Compton effect **iii.** Pair production

**Q15: Explain photoelectric effect? Discuss experimental arrangement to observe photoelectric effect and its important results?**

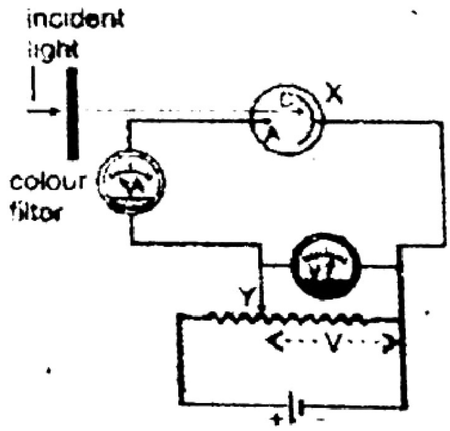
**Ans: Photoelectric effect:**

The emission of electrons from a metal surface when exposed to ultraviolet light of suitable frequency is called the photoelectric effect

**Photoelectrons:**

The emitted electrons are known as photoelectrons

**Experimental arrangement to observe photoelectric effect:**




**i.** The photoelectric effect is demonstrated by the apparatus shown in Fig.

**ii.** An evacuated glass tube X contains two electrodes.

**iii.** The electrode A connected to the positive terminal of the battery is known as anode. The electrode C connected to negative terminal is known as cathode

**iv.** When monochromatic light is allowed to shine on cathode, it begins to emit electrons. These photoelectrons are attracted by the positive anode and the resulting current is measured by an ammeter.

**v.** **Photoelectric current:**

The current stops when light are cut off, which proves, that the current flows because of incident light. This current is, hence, called photoelectric current.

**vi.** **Maximum energy of the photoelectrons:**

The maximum energy of the photoelectrons can be determined by reversing the connection of the battery in the circuit i.e. now the anode A is negative and cathode C is at positive potential. In this condition the photoelectrons are repelled by the anode and the photoelectric current decreases

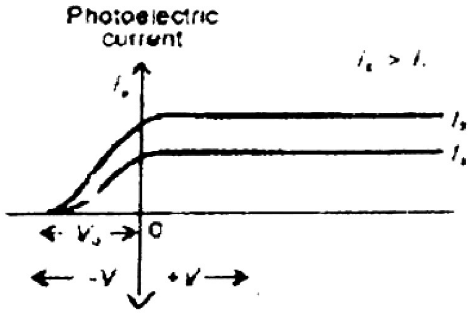
**Stopping potential $V_0$:**

If this potential is made more and more negative at a certain value, called stopping potential $V_0$ the current becomes zero. Even the electrons of maximum energy are not able to reach collector plate. The maximum energy of photoelectrons is thus where m is mass, v is velocity and e is the charge on electron

$$\frac{1}{2} m v_{max}^2 = V_0 e \quad \ldots (1)$$

**vii.** If the experiment is repeated with light beam of higher intensity the amount of current increases but the current stops for the same value of $V_0$

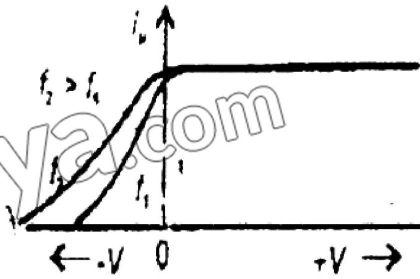
**Characteristic curve of photocurrent vs. applied voltage for two intensities of monochromatic light:**




The Fig. shows two curves of photoelectric current as a function of potential V where $I_2 > I_1$

**Characteristic curve of photocurrent vs. applied voltage for light of different frequencies:**

If, however, the intensity is kept constant and experiment is performed with different frequencies of incident light, we obtain the curves shown in Fig.




The current is same but stopping potential is different for each frequency of incident light, which indicates the proportionality of maximum kinetic energy with frequency of light $f$.

**Important experimental results of photoelectric effect:**

The important results of the experiments are

1. The electrons are emitted with different energies. The maximum energy of photoelectrons depends on the particular metal surface and the frequency of incident light.
2. There is a minimum frequency below which no electrons are emitted, however intense the light may be. This threshold frequency $f_0$ varies from metal to metal.
3. Electrons are emitted instantaneously; the intensity of light determines only their number.

These results could not be explained on the basis of electromagnetic wave theory of light. According to this theory, increasing the intensity of incident light should increase the K.E. of emitted electrons which contradicts the experimental result. The classical theory cannot also explain the threshold frequency of light.

**Q16: How did Einstein explain the photoelectric effect on the basis of quantum theory?**

**Ans: Explanation of photoelectric effect on the basis of quantum theory:**

**i.** Einstein extended the idea of quantization of energy proposed by Max Planck that light is emitted or absorbed in quanta, known as photons. The energy of each photon of frequency f as given by quantum theory is

$$E = hf \quad \ldots\ldots \quad (1)$$

A photon could be absorbed by a single electron in the metal surface.

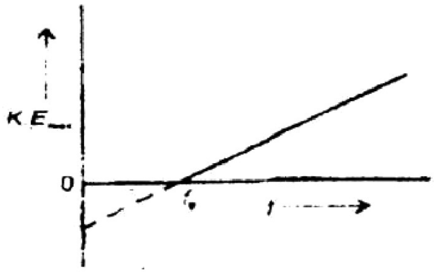
**ii. Work function '$\phi$':**

The electron needs a certain minimum energy called the work function '$\phi$' to escape from the metal surface. If the energy of incident photon is sufficient, the electron is ejected instantaneously from the metal surface. A part of the photon energy (work function) is used by the electron to break away from the metal and the rest appears as the kinetic energy of the electron.

That is,

Incident photon energy - Work function = Max K.E. of photoelectron

or $$hf - \phi = \frac{1}{2} m v^2_{max} \quad .......... \quad (2)$$



A graph of the maximum kinetic energy of photoelectrons vs light frequency. Below a certain frequency, $f_0$, no photoemission occurs.

**Note: This is known as Einstein's photoelectric equation.**

**iii.** When $K.E_{max}$ of the photoelectron is zero, the frequency f is equal to threshold frequency $f_0$, hence the Eq. 2 becomes

$$hf_0 - \phi = 0 \quad \text{or} \quad \phi = hf_0 \quad ......... (3)$$

Hence, we can also write Einstein's photoelectric equation as

$$K.E_{max} = hf - hf_0 \quad ......... (4)$$

Albert Einstein was awarded Nobel Prize in physics in 1921 for his explanation of photoelectric effect.

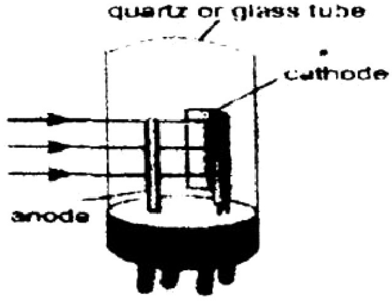
**Q17: How photoelectric effect proved the corpuscular nature of life?**

**Ans:** Phenomenon of photoelectric effect cannot be explained if we assume that light consists of waves and energy is uniformly distributed over its wavefront. It can only be explained by assuming light consists of corpuscles of energy known as photon. Thus it shows the corpuscular nature of light.

**Q18: What is photocell? Describe its working and applications?**

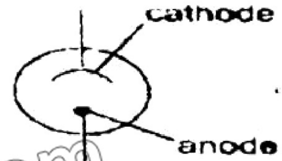
**Ans: Photocell:**

A photocell is based on photoelectric effect.




**Construction:**

It consists of an evacuated glass bulb with a thin anode rod and a cathode of an appropriate metal surface. The material of the cathode is selected to suit to the frequency range of incident radiation over which the cell is operated. For example sodium or potassium cathode emits electrons for visible light, cesium coated oxidized silver emits electrons for infrared light and some other metals respond to ultraviolet radiation.




**Working:**

When photo-emissive surface is exposed to appropriate light, electrons are emitted and a current flows in the external circuit which increases with the increase in light intensity. The current stops when the light beam is interrupted.

**Applications of photocell:**

The cell has wide range of applications. Some of these are to operate:

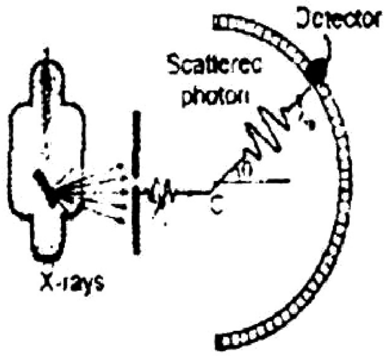
**1.** Security systems
**2.** Counting systems
**3.** Automatic door systems
**4.** Automatic street lighting
**5.** Exposure meter for photography
**6.** Sound track of movies

The cut off wavelength is in the green region of the visible spectrum.

**Q19: Explain Compton effect? OR Describe how Compton's experimental result proved striking confirmation of particle like interaction of electromagnetic waves with matter?**

**Ans: Compton effect:**

When X-rays are scattered by loosely bound electrons from a graphite target, it is known as Compton effect




**Explanation:**

**i.** Arthur Holly Compton at Washington University in 1923 studied the scattering of X-rays by loosely bound electrons from a graphite target.

**ii.** He measured the wavelength of X-rays scattered at an angel $\theta$ with the original direction. He found that wavelength $\lambda_S$ of the scattered X-rays is larger than the wavelength $\lambda_i$, of the incident X-rays. This is known as Compton effect.

**iii.** The increase in wavelength of scattered X-rays could not be explained on the basis of classical wave theory. Compton suggested that X-rays consist of photons and in the process of scattering the photons suffer collision with electrons like billiard balls. In this collision, a part of incident photon energy and momentum is transferred to an electron.

**iv. Compton shift ($\Delta\lambda$):**

Applying energy and momentum conservation laws to the process, he derived an expression for the change in wavelength $\Delta\lambda$ known as Compton shift for scattering angle $\theta$ as

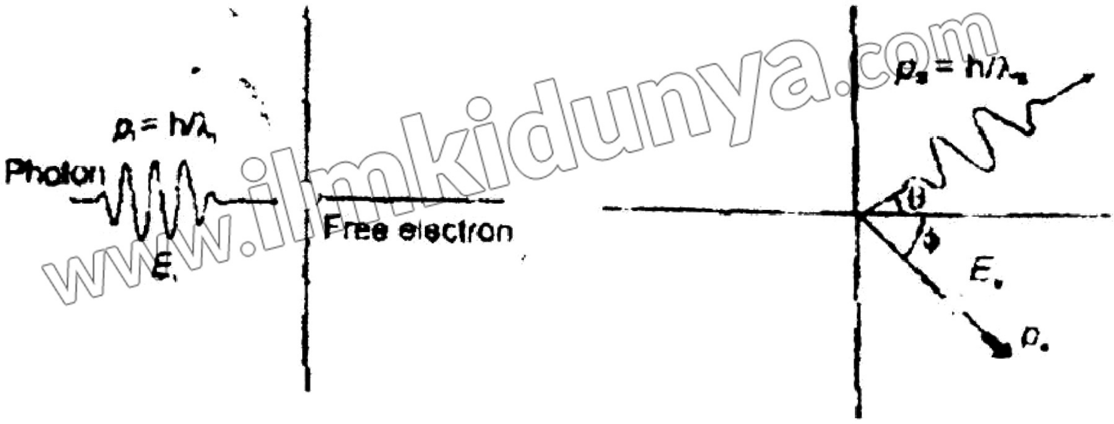
$$\Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta) \quad \ldots\ldots\ldots (1)$$

where $m_0$ is the rest mass of the electron.

**v. Compton wavelength ($\frac{h}{m_0 c}$):**

The factor $\frac{h}{m_0 c}$ has dimensions of length and is called Compton wavelength and has the numerical value

$$\frac{h}{m_0 c} = \frac{6\times10^{-34}\ \text{Js}}{9.1\times10^{-31}\ \text{kg}\times3\times10^{8}\ \text{ms}^{-1}} = 2.43\times10^{-12}\ \text{m}$$




**vi.** If the scattered X-ray photons are observed at $\theta = 90^\circ$ the Compton shift $\Delta\lambda$ equals the Compton wavelength

The Eq.1 was found to be in complete agreement with Compton's experimental result, which again is a striking confirmation of particle like interaction of electromagnetic waves with matter.

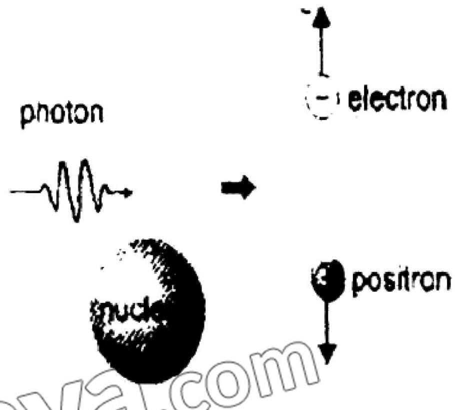
Arthur Holly Compton was awarded Nobel Prize in physics in 1927 for his discovery of the effect named after him.

**Q20: Write a short note on pair production?**

**Ans: Pair production:**

The change of very high energy photon into an electron, positron pair is called pair production.

**Explanation:**




Pair Production

**i.** A kind of interaction of very high energy photon such as that of $\gamma$-rays with matter is pair production in which photon energy is changed into an electron-positron pair

**ii. Positron:**

A positron is a particle having mass and charge equal to that of electron but the charge being of opposite nature i.e. positive. The creation of two particles with equal and opposite charges is essential for charge conservation in the universe. The positron is also known as antiparticle of electron or anti-electron.

**iii.** The interaction usually takes place in the electric field in the vicinity of a heavy nucleus as shown in the Fig so that there is a particle to take up recoil energy and momentum is conserved

**iv. Materialization of energy:**

In the process, radiant energy is converted into matter in accordance with Einstein's equation $E = mc^2$, and hence, is also known as materialization of energy.

**v. Energy during pair production:**

For an electron or positron, the rest mass energy $= m_0c^2 = 0.51$ MeV. Thus to create the two particles $2 \times 0.51$ MeV or 1.02 MeV energy is required.

**vi. Surplus energy in the form of Kinetic energy:**

For photons of energy greater than 1.02 MeV, the probability of pair production occurrence increases as the energy increases and the surplus energy is carried off by the two particles in the form of kinetic energy. The process can be represented by the equation

$$\text{Energy required} = \begin{bmatrix} \textit{Energy required} \\ \textit{for pair production} \end{bmatrix} + \begin{bmatrix} \textit{kinetic energy} \\ \textit{of the particles} \end{bmatrix}$$

$$hf = 2m_0c^2 + K.E.(e^-) + K.E.(e^+) \quad \ldots\ldots \quad (1)$$

**Q21: Describe the process of annihilation of matter?**

**Ans: Annihilation of matter:**

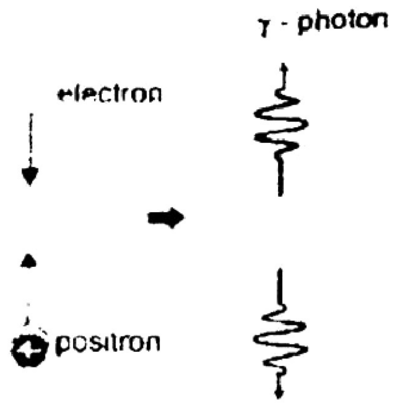
When a positron comes close to an electron, they annihilate and produce two photons in the $\gamma$-rays range. It is called annihilation of matter

**Explanation:**

**i.** It is converse of pair production when a positron comes close to an electron they annihilate or destroy each other

ii. The matter of two particles changes into electromagnetic energy producing two photons in the $\gamma$-rays range

$$e + e^{-} \rightarrow \gamma + \gamma$$




iii. The two photons are produced travelling in opposite directions so that momentum is conserved Each photon has energy 0 51 MeV equivalent to rest mass energy of a particle

iv. A particle and its antiparticle cannot exist together at one place Whenever they meet they annihilate each other That is, the particles disappear, their combined rest energies appear in other forms

v. Proton and antiproton annihilation has also been observed at Lawrence Berkeley Laboratory

**Q22: Describe the view of Louis de Broglie about light?**

**Ans:** Light is in short the most refined form of matter (Louis de Broglie 1892-1987)

**Q23: Who predicted the existence of positron?**

**Ans:** The existence of positron was predicted by Dirac in 1928 and it was discovered in the cosmic radiation in 1932 by Carl Anderson. It gradually became clear that every particle has a corresponding antiparticle with the same mass and charge (if it is a charged particle) but of opposite sign Particles and antiparticles also differ in the signs of other quantum numbers

**Q24: Discuss the wave nature of particles? OR Derive de Broglie relation?**

**Ans: Wave nature of particles:**

**i. Dual nature of light:**

It has been observed that light displays a dual nature, it acts as a wave and it acts as a particle

ii. Assuming symmetry in nature, the French physicist, Louis de Broglie proposed in 1924 that particles should also possess wavelike properties.

iii. As momentum p of photon is given by equation.

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

de Broglie suggested that momentum of a material particle of mass m moving with velocity v should be given by the same expression. Thus

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

$$\lambda = \frac{h}{p} = \frac{h}{mv} \quad (2)$$

where $\lambda$ is the wavelength associated with particle waves.

**Note:**

Hence an electron can be considered to be a particle and it can also be considered to be a wave The equation 2 is called de Broglie relation.

**Q25: Why diffraction effects for electrons are measurable whereas diffraction or interference effects for bullets are not?**

**Ans:** An object of large mass and ordinary speed has such a small wavelength that its wave effects such as interference and diffraction are negligible.

**For example:**

**i.** A **rifle bullet** of mass 20 g and flying with speed 330 $ms^{-1}$ will have a wavelength $\lambda$ given by

$$\lambda = \frac{6.63\times10^{-34}\ Js}{2\times10^{-2}\ kg\times330\ ms^{-1}} = 1\times10^{-34}\ m$$

This wavelength is so small that it is not measurable or detectable by any of its effects.

**ii.** On the other hand for an **electron** moving with a speed of $1\times10^{6}ms^{-1}$,

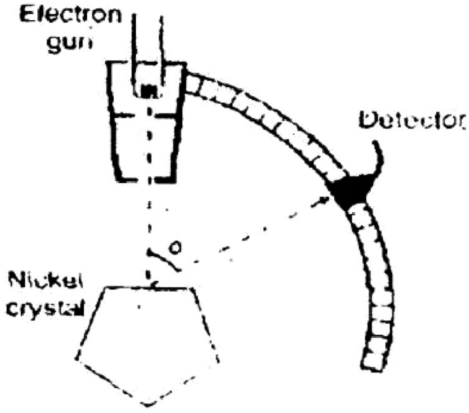
$$\lambda = \frac{6.63\times10^{-34}\ Js}{9.1\times10^{-31}\ kg\times1\times10^{6}\ ms^{-1}} = 7\times10^{-10}\ m$$

This wavelength is in the X-rays range. Thus, diffraction effects for electrons are measurable whereas diffraction or interference effects for bullets are not.

**Q26: Describe briefly Davisson and Germer experimental arrangement for electron diffraction with the help of de-Broglie's equation?**

**Ans: Davisson and Germer experiment:**

**i.** A convincing evidence of the wave nature of electrons was provided by Clinton J. Davisson and Laster H. Germer. They showed that electrons are diffracted from metal crystals in exactly the same manner as X-rays or any other wave.




**ii. Experimental arrangements:**

The apparatus used by them is shown in Fig., in which electrons from heated filament are accelerated by an adjustable applied voltage V.

**iii.** The electron beam of energy Ve is made incident on a nickel crystal. The beam diffracted from crystal surface enters a detector and is recorded as a current $I$.

**iv.** The gain in K.E. of the electron as it is accelerated by a potential V in the electron gun is given by

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

or $mv^2 = 2Ve$ ; $m^2v^2 = 2mVe$

or $mv = \sqrt{2mVe}$

From de Broglie equation

Thus $\lambda = \frac{h}{mv}$ .......... **(1)**

**v. For example:**

In one of the experiments, the accelerating voltage V was 54 volts, hence

$$\lambda = \frac{h}{\sqrt{2mVe}}$$

$$\lambda = \frac{6.63\times10^{-34}\ Js}{\sqrt{2\times9.1\times10^{-31}\ kg\times54\ JC^{-1}\times1.6\times10^{-19}\ C}} = 1.66\times10^{-10}\ m \quad \textbf{(2)}$$

This beam of electrons diffracted from crystal surface was obtained for a glancing angle of 65°

**Bragg's equation:**

According to Bragg's equation

$$2d\sin\theta = m\lambda$$

For 1st order diffraction $m = 1$

For nickel $d = 0.91 \times 10^{-10} m$

Thus $2 \times 0.91 \times 10^{-10} \times \sin 65° = \lambda$

Which gives $\lambda = 1.65 \times 10^{-10} m$ ..... **(3)**

Thus, experimentally observed wavelength (in eq.2) is in excellent agreement with theoretically predicted wavelength (in eq.3).

**Note:**

Diffraction patterns have also been observed with protons, neutrons, hydrogen atoms and helium atoms thereby giving substantial evidence for the wave nature of particles.

**Q27: Discuss wave particle duality?**

**Ans: Wave particle duality:**

Matter and radiation have a dual 'wave-particle' nature and this new concept is known as wave particle duality.

**Explanation:**

**i.** Interference and diffraction of light confirm its wave nature, while photoelectric effect proves the particle nature of light.

**ii.** The experiments of Davisson and Germer and G. P. Thomson reveal wave like nature of electrons

**iii.** The experiment of J. J. Thomson to find e/m we had to assume particle like nature of the electron. In the same way we are forced to assume both wavelike and particles like properties for all matter: electrons, protons, neutrons, molecules etc. and also light, X-rays, $\gamma$-rays etc. have to be included in this.

**iv. Principle of complementarity:**

Niels Bohr pointed out in stating his principle of complementarity that both wave and particle aspects are required for the complete description of both radiation and matter. Both aspects are always present and either may be revealed by an experiment. However, both aspects cannot be revealed simultaneously in a single experiment, which aspect is revealed is determined by the nature of the experiment being done.

**v.** If we put a diffraction grating in the path of a light beam, we reveal it as a wave. If we allow the light beam to hit a metal surface, we need to regard the beam as a stream of particles to explain your observations.

**vi.** There is no simple experiment that we can carry out with the beam that will require us to interpret it as a wave and as a particle at the same time

**vii.** Light behaves as a stream of photons when it interacts with matter and behaves as a wave in traveling from a source to the place where it is detected.

**Note:**

In effect, all micro-particles (electrons, protons, photons, atoms etc.) propagate as if they were waves and exchange energies as if they were particles - that is the wave particle duality.

**Q28: Describe the uses of wave nature of particles?**

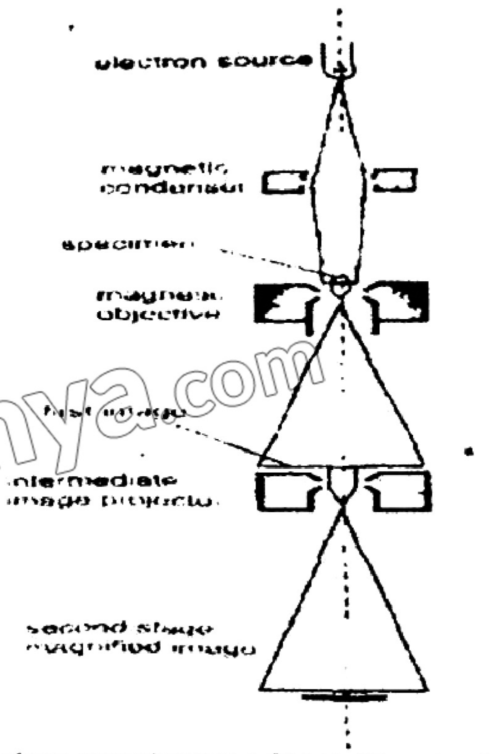
**Ans: Uses of wave nature of particles:**

The fact that energetic particles have extremely short de Broglie wavelengths has been put to practical use in many ultra-modern devices of immense importance such as electron microscope.

**Q29: Describe perception and working of electron microscope?**

**Ans: Electron microscope:**

Electron microscope makes practical use of the wave nature of electrons which is thousands of time shorter than visible light which enables the electron microscope to distinguish details not visible with optical microscope.



Electron microscope ( Block Diagram)

**Construction and working of Electron Microscope:**

**i.** In an electron microscope, electric and magnetic fields rather than optical lenses are used to focus electrons by means of electromagnetic forces that are exerted on moving charge. The resulting deflections of the electrons beams are similar to the refraction effects produced by glass lenses used to focus light in optical microscope.

**ii. Application of high voltage:**

The electrons are accelerated to high energies by applying voltage from 30 kV to several megavolts. Such high voltages give extremely short wavelength and also give the electron sufficient energy to penetrate specimen of reasonable thickness.

**Resolution of Electron Microscope:**

A resolution of 0.5 to 1 nm is possible with a 50 kV microscope as compared to best optical resolution of 0.2 nm. A schematic diagram of the electron microscope is shown in the Figure.

**Function of magnetic conducting lens:**

The magnetic conducting lens concentrates the beam from an electron gun on to the specimen. Electrons are scattered out of the beam from the thicker parts of the specimen. The transmitted beam therefore has spatial differences in density that correspond to the features of the specimen.

**Electron micrograph:**

The objective and intermediate lenses produce a real intermediate image and projection lens forms the final image which can be viewed on a fluorescent screen or photographed on special film known as electron micrograph.

**Scanning electron microscopes:**

A three dimensional image of remarkable quality can be achieved by modern versions called scanning electron microscopes.

**Q30: State and explain Heisenberg uncertainty principle?**

**Ans: Uncertainty principle:**

Position and momentum of a particle cannot both be measured simultaneously with perfect accuracy. There is always a fundamental uncertainty associated with any measurement. It's a consequence of the wave particle duality of matter and radiation. It is known as Heisenberg uncertainty principle.

**Explanation:**

**i.** When a stream of light photons scattering from a flying tennis ball hardly affects its path, but one photon striking an electron drastically alters the electron's motion.

**ii.** Since light has also wave properties, we would expect to be able to determine the position of the electron only to within one wavelength of the light being used. Hence, in order to observe the position of an electron with less uncertainty and also for minimizing diffraction effect, we must use light of short wavelength. But it will alter the motion drastically making momentum measurement less precise

**iii. Mathematical form of uncertainty principle:**

If light of wavelength $\lambda$ is used to locate a micro particle moving along x-axis, the uncertainty in its position measurement is

$$\Delta x \approx \lambda$$

At most, the photon of light can transfer all its momentum $\left(\frac{h}{\lambda}\right)$ to the micro particle whose own momentum will then be uncertain by an amount

$$\Delta p \approx \frac{h}{\lambda}$$

Multiplying these two uncertainties gives

$$\Delta x \,.\, \Delta p \approx \lambda\left(\frac{h}{\lambda}\right) \approx h \qquad .......... \qquad (1)$$

The equation 1 is the mathematical form of uncertainty principle.

**Planck's constant (h):**

It states that the product of the uncertainty $\Delta x$ in the position of a particle at some instant and the uncertainty $\Delta p$ in the x-component of its momentum at the same instant approximately equals Planck's constant h.

**Relation of uncertainty principle with energy:**

There is another form of uncertainty principle which relates the energy of a particle and the time at which it had the energy. If the $\Delta E$ is the uncertainty in our knowledge of the energy of our particle and if the time interval during which the particle had the energy $E \pm \frac{\Delta E}{2}$ is $t_0 \pm \frac{\Delta t}{2}$ then

$$\Delta E.\ \Delta t \approx h \qquad .......... \qquad (2)$$

**Note:**

Thus more accurately we determined the energy of a particle, the more uncertain we will be of the time during which it has that energy.

**Best form of Heisenberg uncertainty principle:**

According to Heisenberg's more careful calculations, he found that at the very best

$$\Delta x\ \Delta p \geq h \qquad (3)$$

and

$$\Delta E.\ \Delta t \geq h \qquad (4)$$

where

$$h = \frac{h}{2\pi} = 1.05 \times 10^{-34}\ \text{Js}$$

# SUMMARY

1. An inertial frame of reference is defined as a coordinate system in which the law of inertia is valid. A frame of reference that is not accelerating is an inertial frame of reference.
2. The special theory of relatively treats problems involving inertial or non-accelerating frames of reference. It is based upon two postulates
(i) The laws of physics are the same in all inertial frames.
(ii) The speed of light in free space has the same value for all observers, regardless of their state of motion.
3. $E = mc$ is an important result of special theory of relativity
4. A black body is a solid block having a hollow cavity within it. It has small hole and the radiation can enter or escape only through this hole.
5. Stephen Boltzmann law states that total energy radiated over all wave length at a particular temperature is directly proportional to the fourth power of that Kelvin temperature.
6. The emission of electrons from a metal surface when exposed to ultraviolet light is called photoelectric effect. The emitted electrons are known as photoelectrons.
7. When X-rays are scattered by loosely bound electrons from a graphite target, it is known as Compton effect.
8. The change of very high energy photon into an electron, positron pair is called pair production.
9. When a positron comes close to an electron, they annihilate and produce two photons in the $\gamma$-rays range. It is called annihilation of matter.
10. Position and momentum of a particle cannot both be measured simultaneously with perfect accuracy. There is always a fundamental uncertainty associated with any measurement. It is a consequence of the wave particle duality of matter and radiation. It is known as Heisenberg uncertainty principle.

# SOLUTION OF EXERCISE

**19.1. What are the measurements on which two observers in relative motion will always agree upon?**

**Ans:** The two observers in relative motion will agree on the speed of light, direction and magnitude of acceleration, and direction and magnitude of force.

**19.2. Does the time dilation actually means that time really passes more slowly in moving system or that it only seems to pass more slowly?**

**Ans:** Since times not absolute quantity it depends upon the motion of the frame of reference. That is why time really passes more slowly due to relativistic effect.

**19.3. If you are moving in a spaceship at a very high speed relative to the earth. Would you notice a difference**
**(a) in your pulse rate (b) in the pulse rate of people on earth?**

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**19.3. If you are moving in a spaceship at a very high speed relative to the earth. Would you notice a difference**

**(a) in your pulse rate (b) in the pulse rate of people on earth?**

**Ans:** **(a)** No effect. because time dilation is possible only in two different frames of reference

**(b)** Pulse rate of people on earth will decrease relative to observer in the spaceship because in this case the condition of two different frames of reference is applicable

**19.4. If the speed of light were infinite, what would the equations of special theory of relativity reduce to?**

**Ans:** There will be no relativistic effect

Since $c = \infty$ therefore $v^2/c^2 = 0$ (1)

**i.** Since $t = \dfrac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$

From Eq. 1 $t = \dfrac{t_0}{\sqrt{1-0}}$ $\Rightarrow$ $t = t_0$

**ii.** Since $\ell = \ell_0\sqrt{1-\frac{v^2}{c^2}}$

From Eq. 1 $\ell = \dfrac{\ell_0}{\sqrt{1-0}}$ $\Rightarrow$ $\ell = \ell_0$

**iii.** Since $m = \dfrac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$

From Eq 1 $m = \dfrac{m_0}{\sqrt{1-0}}$ $\Rightarrow$ $m = m_0$

Therefore the relativistic equations become

$t = t_0$, $\ell = \ell_0$ and $m = m_0$.

**19.5. Since mass is a form of energy, can we conclude that a compressed spring has more mass than the same spring when it is not compressed?**

**Ans:** Since the Work done in compressing the spring have been changed into energy due to which mass of the compressed spring will increase.

But change in mass takes place only at velocities comparable to that of the velocity of light.

**19.6. As a solid is heated it begins to glow, why does it appear red first?**

**Ans:** When a solid is heated its electrons become excited and they jump into higher energy orbit and emit radiations in the form of light. this light is responsible to glow the solid.

When the temperature of solid is increased. it emits radiations of exceedingly smaller wavelength Starting from radio-waves. the first color that lies in visible region of spectrum is red so it is seen first and then the others having shorter wavelengths than that of red color light are seen

**19.7. What happens to the total radiations of a body if its absolute temperature is doubled?**

**Ans:** According to the Stephen. Boltzmann law:

$$E = \sigma T^4$$

If the temperature is doubled then

$$E = \sigma (2T)^4$$

$$E = 16\,\sigma T^4$$

Therefore when temperature is doubled than the radiation intensity, E becomes 16 times the initial intensity

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

**Ans:** Energy for single photon = E = hf

Energy for 'n' photons = E = n hf (1)

Since $c = f\lambda$ ⇒ $f = \frac{c}{\lambda}$ put in Eq. 1

$$E = nh \times \frac{c}{\lambda}$$

$$n = \frac{E\lambda}{hc} \Rightarrow n \propto \lambda$$

Therefore longer wavelengths will have greater number of photons. The wave length of red colour is greater than blue colour. Therefore red beam contains greater number of photons.

$$\lambda_{red} > \lambda_{blue}$$

**19.9. Which photon, red, green or blue carries the most (a) energy (b) momentum?**

**Ans:** The photon with highest frequency or smaller wavelength will have the most energy and momentum.

As frequency of blue light is greater than the frequency of green and red light. Therefore photon of blue light have most energy ($E = hf = \frac{hc}{\lambda}$) and most momentum ($P = \frac{h}{\lambda}$)

**19.10. Which has lower energy quanta; Radio-waves or x-rays?**

**Ans:** Since $E = \frac{hc}{\lambda}$ or $E \propto 1/\lambda$.

As wavelength of radio waves is greater than that of x-rays

Having much longer corresponding wavelength, radio-waves have much lower energy quanta. It is so because wavelength and energy are inversely proportional to each other.

**19.11. Does the brightness of a beam primarily depend on the frequency of photons or on the number of photons?**

**Ans:** The brightness primarily depends on the number of photons. Further the brightness depends upon intensity which is directly related with number of photons for a fixed value of frequency.

**19.12. When ultra violet light falls on certain dies, visible light is emitted. Why does this not happen when infrared light falls on these dies?**

**Ans:** When ultra violet rays fall on dies, a part of their energy is absorbed and the rest which lies in visible region is emitted. Since frequency of infrared light is very small so when infrared rays are incident, due to partial absorption of energy the reflected rays have energy which lies in far infrared region so it is not visible

**19.13. Will brighter light eject more number of electrons from a metal surface than the dimmer light of the same color?**

**Ans:** As in photoelectric effect the number of photoelectrons emitted is directly proportional to intensity of light used, so the bright light reject more electrons as compared to dimmer light.

**19.14. Will higher frequency light eject more number of electrons than low frequency light?**

**Ans:** The number of photoelectrons does not depend upon frequency but they depend upon intensity of light.

Higher frequency means higher energy photons which can result in the increased energy of photoelectrons and cannot increase the number of photoelectrons. So high and low frequency light rejects the same number of electrons.

**19.15. When light shines on a surface, is momentum transferred to the metal surface?**

**Ans:** Since $P = \frac{E}{c}$

During interaction of radiation with matter, energy as well as momentum is also shared. The example is of Compton Effect in which the recoil electrons take a portion of momentum of the incident photon. Therefore when light shines on a surface its momentum transferred to the metal surface.

**19.16. Why can red light be used in photographic dark room when developing films, but a blue or white light cannot be?**

**Ans:** We used red light because the frequency of red light is smallest as compared to blue and white light so it cannot affect the photographic plate.

**19.17. Photon A has twice the energy of photon B. What is the ratio of the momentum of A to that of B?**

**Ans:** Since energy of photon $= E = \frac{hc}{\lambda}$ or $E = pc$

Let energy of photon A $= E_1$

Let energy of photon B $= E_2$

Let momentum of photon A $= P_1$

Let momentum of photon B $= P_2$

Therefore $E_1 = P_1c$ (1) and $E_2 = P_2c$ (2)

Given that $E_1 = 2E_2$

Put in Eq. 1 $2E_2 = P_1c$ (3)

Dividing Eq. 3 by Eq. 2

$$\frac{2E_2}{E_2} = \frac{P_1c}{P_2c}$$

$$\frac{P_1}{P_2} = 2$$

Hence momentum of photon A is 2 times the momentum of photon B.

**19.18. Why don't we observe Compton effect with visible light?**

**Ans:** During interaction with matter the photon of visible light is completely absorbed showing photoelectric effect because in Compton effect $hf \gg \phi$. For Compton Effect energy of the particle has to be high enough so that during interaction only a part of its energy is absorbed and the rest is use for scattered.

**19.19. Can pair production take place in vacuum? Explain.**

**Ans:** Pair production cannot take place in vacuum. In pair production momentum and energy are conserved. Pair production takes place near a nucleus to conserve momentum. As nucleus does not exist in vacuum therefore pair production cannot take place in vacuum.

It will violate the law of conservation of momentum and this law is never violated hence it is not possible

**19.20. Is it possible to create a single electron from energy? Explain.**

**Ans:** A single electron cannot be created from energy Creation of electron will be against the law of conservation of charge which cannot be violated because single particle cannot be created from energy without its anti-particle (electron-positron pair)

**19.21. If electrons behaved only like particles, what would you expect on the screen after electrons pass through the double slit?**

**Ans:** When electrons behave like particles then they would passed through the slits and strike the screen to produce glow and exact image of double slit on the screen.

There will be no interference pattern (which is the property of wave only) and only the central portion of the screen would be having spots due to electrons.

**19.22. If a proton and an electron have the same de-Broglie wavelength, which particle has greater speed?**

**Ans:** According to de-Broglie Equation $\lambda = \frac{h}{mv}$

$v = \frac{h}{m\lambda} \Rightarrow v \propto \frac{1}{m}$

Hence for same wavelength the smaller mass has greater velocity Therefore electron will have greater speed because the mass of electron is smaller than that of protons

**19.23. We do not notice the de-Broglie wavelength for a pitched cricket ball. Explain why?**

**Ans:** According to de-Broglie Equation $\lambda = \frac{h}{mv}$

Due to smaller value of v and greater value of m, the wavelength ($\lambda$) associated with the moving cricket ball is very small. The diffraction produce by a cricket ball is too small, so it is not possible to measure the wavelength of a cricket ball

**19.24. If the following particles have the same energy, which has the shortest wavelength; Electron, alpha particle, neutron, proton?**

**Ans:** Energy of moving particle is given by:

$E = \frac{1}{2}mv^2 \Rightarrow v^2 = \frac{2E}{m} \qquad v = \sqrt{\frac{2E}{m}}$

According to de-Broglie Equation $\lambda = \frac{h}{mv}$ (1)

By putting the value of v in Eq. 1 we get

$\lambda = \frac{h}{m\sqrt{\frac{2E}{m}}} \Rightarrow \lambda = \frac{h}{\sqrt{2mE}} \Rightarrow \lambda \propto \frac{1}{m}$

This Eq. show that the particle which is heaviest, will have shortest wavelength. As mass of $\alpha$-particle is greatest so it will have the shortest wavelength. We have $\lambda = \frac{h}{mv}$ So, the particle with greatest mass will be having the shortest wavelength and clearly it is alpha particle

**19.25. When does light behave as a wave? When does it behave as a particle?**

**Ans:** When light propagates then it behaves as a wave The examples of wave behavior are Interference diffraction and polarization

When light interacts then it acts as particle. The examples of particle behavior are Photoelectric effect Compton Effect and pair production.

**Note:**

The two properties can never be seen at the same time this is called dual behavior of light.

**19.26. What advantages an electron microscope has over an optical microscope?**

**Ans:** **i.** Electron microscope makes practical use of the wave nature of electrons which is thousands of time shorter than visible light which enables the electron microscope to distinguish details not visible with optical microscope

**ii.** A resolution of 0 5 to 1 nm is possible with a 50 kV microscope as compared to best optical resolution of 0 2 nm

**iii.** Three dimensional image of remarkable quality can be achieved by modern versions called scanning electron microscopes. Such three dimensional image distinguish details not visible with optical microscope.

**19.27. If measurements show a precise position for an electron, can those measurements show precise momentum also? Explain.**

**Ans:** Position and momentum of a particle cannot both be measured simultaneously with perfect accuracy. There is always a fundamental uncertainty associated with any measurement. It is a consequence of the wave particle duality of matter and radiation It is known as Heisenberg uncertainty principle.

$$\Delta x . \Delta p \approx \lambda \left(\frac{h}{\lambda}\right) \approx h \quad .......... \quad (1)$$

The equation 1 is the mathematical form of uncertainty principle.

It is not possible to measure position and momentum at the same time. If one quantity is precise then other becomes uncertain because it will violate Heisenberg's uncertainty principle.

# SOLUTION OF EXAMPLES

**Example 19.1:** **The period of a pendulum is measured to 3.0 s in the inertial reference frame of the pendulum. What is its period measured by an observer moving at a speed of 0.95c with respect to the pendulum?**

**Solution:**

Time period in inertial frame $= t_0 = 3.0$ s

Speed of the observer $= v = 0.95$ c

Time period is accelerated frame $= t = ?$

Time dilation $= t = \dfrac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$$t = \frac{3.0}{\sqrt{1-\frac{(0.95c)^2}{c^2}}} = \frac{3.0}{\sqrt{1-(0.95)^2}} = \frac{3.0}{\sqrt{1-0.902}} = \frac{3.0}{0.313} = 9.6\ s$$

**Example 19.2:** **A bar 1.0m in length and located along x-axis moves with a speed of 0.75 c with respect to a stationary observer. What is the length of the bar as measured by the stationary observer?**

**Solution:**

Length of bar = $\ell_0$ = 1.0 m

Speed of bar = v = 0.75 c

Length of bar measured by stationary observer = $\ell$ = ?

Length contraction = $\ell = \ell_0 \sqrt{1-\frac{v^2}{c^2}}$

$$\ell = 1.0\times\sqrt{1-\frac{(0.75c)^2}{c^2}} = 1.0\times\sqrt{1-\frac{(0.75)^2c^2}{c^2}} = 1.0\times\sqrt{1-(0.75)^2}$$

$$\ell = 1.0\times\sqrt{1-0.56} = 0.66\ m$$

**Example 19.3:** **Find the mass 'm' of a moving object with speed 0.8c.**

**Solution:**

Speed of mass = v = 0.8 c

Mass of moving object = m = ?

Mass variation = $m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$$m = \frac{m_0}{\sqrt{1-\frac{(0.8c)^2}{c^2}}} = \frac{m_0}{\sqrt{1-(0.8)^2}} = \frac{m_0}{\sqrt{1-0.64}} = \frac{m_0}{\sqrt{0.36}} = 1.67\ m_0$$

**Example 19.4:** **Assuming you radiate as does a blackbody at your body temperature about 37°C, at what wavelength do you emit the most energy?**

**Solution:**

Temperature = T = 37°C = 37 + 273 = 310 K

Wien's Constant = $2.9\times10^{-3}$ m K

Wavelength = $\lambda_{max}$ = ?

For black body:

$$\lambda_{max}\times T = \text{Wien's constant}$$

$$\lambda_{max} = \frac{Wien's\ Constant}{T}$$

$$\lambda_{max} = \frac{2.9\times10^{-3}}{310} = 9.35\times10^{-6} = 9.35\ \mu m$$

**Example 19.5:** **What is the energy of a photon in a beam of infrared radiation of wavelength 1240 nm?**

**Solution:**

Wavelength = $\lambda$ = 1240nm = $1240\times10^{-9}$ m

Planck's constant = h = $6.673\times10^{-34}$ Js

c = $3.0\times10^{8}\ ms^{-1}$

Energy of photon = E = ?

We have,

$$E = hf$$

But,

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

$$\Rightarrow \qquad E = \frac{hc}{\lambda}$$

$$E = \frac{6.63\times10^{-34}\times3\times10^{8}}{1240\times10^{-9}} = \frac{19.89\times10^{-26}}{1240\times10^{-9}}$$

$$E = 1.6\times10^{-19}\,J \qquad (\because 1.6\times10^{-19}\,J = 1.0\,eV)$$

$$E = 1.0\,eV$$

**Example 19.6: A sodium surface is illuminated with light of wavelength 300nm. The work function of sodium metal is 2.46 eV.**

**(a) Find the maximum K.E. of the ejected electron.**

**(b) Determine the cut off wavelength of sodium.**

**Solution:**

Wavelength $= \lambda = 300\ nm = 300\times10^{-9}\ m$

Work function $= \phi = 2.46\ eV$

**(a)** Max. K.E of electron $= E = ?$

**(b)** Cut off wavelength $= \lambda_0 = ?$

**(a) Find the maximum K.E. of the ejected electron.**

We have,

$$E = hf$$

$$\Rightarrow \qquad E = \frac{hc}{\lambda} \qquad (\because f = \frac{c}{\lambda})$$

$$E = \frac{6.63\times10^{-34}\times3\times10^{8}}{300\times10^{-9}} = \frac{19.89\times10^{-26}}{300\times10^{-9}} = 6.63\times10^{-19}\,J$$

$$E = \frac{6.63\times10^{-19}}{1.6\times10^{-9}} \qquad (\because 1eV = 1.6\times10^{-19}\,J)$$

$$E = 4.14\,eV$$

According to Einstein's equation for Photoelectric effect:

$$K.E_{max} = E - \phi$$

$$K.E_{max} = -4.14 - 2.46 = 1.68\,eV$$

**(b) Determine the cut off wavelength of sodium.**

Since

$$\phi = hf_0$$

$$\phi = \frac{hf}{\lambda_0}$$

$$\lambda_0 = \frac{hc}{\phi}$$

Here $\phi = 2.46\,eV = 3.94\times10^{-9}\,J \qquad (\because 1eV = 1.6\times10^{-19}J)$

$$\lambda_0 = \frac{6.63\times10^{-34}\times3\times10^{8}}{3.94\times10^{-19}} = 5.05\times10^{-7}\,m = 505\,nm$$

**Example 19.7: A 50 keV photon is Compton scattered by a quasi-free electron. If the scattered photon comes off at 45°, what is its wavelength?**

**Solution:**

Energy of photon $= E = 50\ k\ eV = 50\times10^{3}\times1.6\times10^{-19}\ J$

Energy of photon $= E = 80\times10^{-16}\ J$

Angle $= \theta = 45°$

Wavelength of scattered photon $= \lambda = ?$

Wavelength of incident photon can be calculated by using the relation

$$E = hf$$

or

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

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

$$\lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{80\times10^{-16}} = \frac{19.89\times10^{-26}}{80\times10^{-16}} = 0.0248 \text{ nm}$$

Now, the relation for change in wavelength is

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_0 c}(1 - \cos\theta)$$

$$\lambda' - \lambda = \frac{6.63\times10^{-34}}{9.1\times10^{-31}\times3\times10^{8}} \times (1 - \cos45^0)$$

$$\lambda' - \lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{27.3\times10^{-23}} \times (1 - 0.707)$$

$$\lambda' - \lambda = 0.2429 \times 10^{-11} \times 0.293 = 0.0007 \text{ nm}$$

$$\lambda' = \lambda + 0.0007 = 0.0248 + 0.0007 = 0.0255 \text{ nm}$$

**Example 19.8: A particle of mass 5.0 mg moves with speed of $8.0 ms^{-1}$. Calculate its de Broglie wavelength.**

**Solution:**

Mass = m = 5.0 mg = $5 \times 10^{-6}$kg

Speed = v = 8.0 $ms^{-1}$ h = $6.63 \times 10^{-34}$ Js

De Broglie wavelength = $\lambda$ = ?

The de-Broglie relation is,

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

$$\lambda = \frac{6.63\times10^{-34}}{5.0\times10^{-6}\times8.0} = 1.66 \times 10^{-29} \text{ m}$$

**Example 19.9: An electron is accelerated through a potential difference of 50 V, Calculate its de Broglie wavelength.**

**Solution:**

Potential difference = V = 50 V

h = $6.63 \times 10^{-34}$ Js

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

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

De-Broglie wavelength = $\lambda$ = ?

Since $\frac{1}{2} mv = V_0e$

or $mv^2 = 2V_0e$

Multiplying by 'm' on both sides, we have

$$m^2v^2 = 2mV_0e$$

Taking square root on both sides, we have

$$mv = \sqrt{2mV_0e} \quad (\because p = mv)$$

$$p = \sqrt{2mV_0e} \quad \ldots\ldots (1)$$

We know that

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

Substituting the value of p from eq. (1) we have

$$\lambda = \frac{h}{\sqrt{2mV_0e}}$$

$$\lambda = \frac{6.63\times10^{-34}}{2\times9.1\times10^{-31}\times50\times1.6\times10^{-19}} = 1.74 \times 10^{-10} \text{ m}$$

**Example 19.10:** **The life time of an electron in an excited state is about $10^{-8}$s. What is its uncertainty in energy during this time?**

**Solution:**

Life time of electron = $\Delta t$ = $10^{-8}$ s

Uncertainty is energy = $\Delta E$ = ?

By using uncertainty principle,

$$\Delta E.\ \Delta t \approx \hbar$$

or

$$\Delta E \approx \frac{\hbar}{\Delta t}$$

$$\Delta E = \frac{1.05\times10^{-34}}{10^{-8}} = 1.05 \times 10^{-26}\ J$$

**Example 19.11:** **An electron is to be confined to a box of the nucleus ($1.0 \times 10^{-14}$ m). What would the speed of the electron be if it were so confined?**

**Solution:**

Maximum uncertainty in the location of electron equals the size of the nucleus of the box itself that is $\Delta x = 1.0 \times 10^{-14}$ m. The minimum uncertainty in the velocity of electron is found from Heisenberg uncertainty principle

$$\Delta p \approx \frac{\hbar}{\Delta x}$$

$$m\Delta v \approx \frac{\hbar}{\Delta x}$$

$$\Delta v = \frac{\hbar}{m\Delta x} = \frac{1.05\times10^{-34}}{9.1\times10^{-31}\times1.0\times10^{-14}} = 1.15\times10^{10}\ ms^{-1}$$

# SOLUTION OF PROBLEMS

**19.1 A particle called the pion lives on the average only about $2.6 \times 10^{-8}$ when at rest in the laboratory. If then changes to another form. Howe long would such a particle live when shooting through the space at 0.95c?**

**Solution:**

Proper time = $t_0$ = $2.6 \times 10^{-8}$ s

v = 0.95 c

time dilated = t = ?

Time dilation = $t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$$t = \frac{2.6\times10^{-8}}{\sqrt{1-\frac{(0.95c)^2}{c^2}}} = \frac{2.6\times10^{-8}}{\sqrt{0.312}} = 8.326 \times 10^{-8} = 8.3 \times 10^{-8}\ s$$

**19.2 What is the mass of a 70 kg man in a space rocket travelling at 0.8c from us as measured from Earth?**

**Solution:**

Rest mass = $m_0$ = 70 kg

v = 0.80 c

m = ?

Mass variation = $m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$

**Example 19.10:** **The life time of an electron in an excited state is about $10^{-8}$s. What is its uncertainty in energy during this time?**

**Solution:**

Life time of electron = $\Delta t$ = $10^{-8}$ s

Uncertainty is energy = $\Delta E$ = ?

By using uncertainty principle,

$$\Delta E.\,\Delta t \approx \hbar$$

or
$$\Delta E \approx \frac{\hbar}{\Delta t}$$

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$$m\Delta v \approx \frac{\hbar}{\Delta x}$$

$$\Delta v = \frac{\hbar}{m\Delta x} = \frac{1.05\times10^{-34}}{9.1\times10^{-31}\times1.0\times10^{-14}} = 1.15\times10^{10}\ ms^{-1}$$

# SOLUTION OF PROBLEMS

**19.1 A particle called the pion lives on the average only about $2.6 \times 10^{-8}$ when at rest in the laboratory. If then changes to another form. Howe long would such a particle live when shooting through the space at 0.95c?**

**Solution:**

Proper time = $t_0$ = $2.6 \times 10^{-8}$ s

v = 0.95 c

time dilated = t = ?

Time dilation = $t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$$t = \frac{2.6\times10^{-8}}{\sqrt{1-\frac{(0.95c)^2}{c^2}}} = \frac{2.6\times10^{-8}}{\sqrt{0.312}} = 8.326 \times 10^{-8} = 8.3 \times 10^{-8}\ s$$

**19.2 What is the mass of a 70 kg man in a space rocket travelling at 0.8c from us as measured from Earth?**

**Solution:**

Rest mass = $m_0$ = 70 kg

v = 0.80 c

m = ?

Mass variation = $m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$$m = \frac{70}{\sqrt{1-\frac{(0.80c)^2}{c^2}}} = \frac{70}{\sqrt{0.36}} = 116.666 = 116.7\ kg$$

**19.3 Find the energy of photon in:**

**(a) Radio wave of wavelength 100m**

**(b) Green light of wavelength 550nm**

**(c) x-ray with wavelength 0.2nm**

**Solution:**

Wavelength of radio wave = $\lambda_1$ = 100 m

Wavelength of green light = $\lambda_2$ = 550 nm

Wavelength of x-rays = $\lambda_3$ = 0.2 nm

$E_1 = ?$ $E_2 = ?$ $E_3 = ?$

**(a) Radio wave of wavelength 100 m**

$$E_1 = \frac{hc}{\lambda_1}$$

$$E_1 = \frac{6.63\times10^{-34}\times3\times10^{8}}{100} = 3\times6.63\times10^{-28}\ J$$

$$E_1 = \frac{3\times6.63\times10^{-28}}{1.6\times10^{-19}} = 12.42\times10^{-9} = 1.242\times10^{-8}\ eV$$

**(b) Green light of wavelength 550 nm**

$$E_2 = \frac{hc}{\lambda_2}$$

$$E_2 = \frac{6.63\times10^{-34}\times3\times10^{8}}{550\times10^{-9}} = 0.036\times10^{-17} J$$

$$E_2 = \frac{0.036\times10^{-17}}{1.6\times10^{-19}} = 2.25\ eV$$

**(c) X-ray with wavelength 0.2 nm**

$$E_3 = \frac{hc}{\lambda_3}$$

$$E_3 = \frac{6.63\times10^{-34}\times3\times10^{8}}{0.2\times10^{-9}} = 99.456\times10^{-17}$$

$$E_3 = \frac{99.45\times10^{-17}}{1.6\times10^{-19}} = 62.156\times10^{2} = 6215.6\ eV$$

**19.4 Yellow light of 577 nm wavelength is incident on a cesium surface. The stopping voltage is found to be 0.25 V. Find**

**(a) The maximum K.E. of Photoelectrons**

**(b) The work function of Cesium**

**Solution:**

$\lambda$ = 577 nm = $577\times10^{-9}$ m

$V_0$ = 0.25 volts

$(K.E)_{max}$ = ?

$\phi_0$ = ?

**(a) The maximum K.E. of Photoelectrons**

For an accelerating potential $V_0$,

$$(K.E)_{max} = V_0 e$$

$$(K.E)_{max} = 0.25\times1.6\times10^{-19} = 0.400\times10^{-19} = 4\times10^{-20}\ J$$

**(b) The work function of Cesium**

The Einstein's equation for photoelectric effect is,

$$\phi_0 = hf - (K.E)_{max}$$

$$\phi_0 = \frac{hc}{\lambda} - (K.E)_{max}$$

$\phi_0 = \left(\frac{6.63\times10^{-34}\times3\times10^{8}}{577\times10^{-9}} - 4\times10^{-20}\right)$

$\phi_0 = 0.03447\times10^{-17} - 0.004\times10^{-17} = (0.03447 - 0.004)\times10^{-17}$

$\phi_0 = 0.03407\times10^{-17}$ J

$\phi_0 = \frac{0.03407\times10^{-17}}{1.6\times10^{-19}} = 0.0191\times10^{2}$ eV $= 1.191$ eV

**19.5 X-rays of wavelength 22 pm are scattered from a carbon target. The scattered radiation being viewed at 85° to the incident beam. What is Compton shift?**

**Solution:**

$\lambda = 22\text{pm} = 22\times10^{-12}$ m

$\theta = 85°$

$\Delta\lambda = ?$

Compton shift $= \Delta\lambda = \frac{h}{m_0c}(1-\cos\theta)$

$\Delta\lambda = \frac{6.63\times10^{-34}}{9.11\times10^{-31}\times3\times10^{8}}(1-\text{Cos }85^{0})$

$\Delta\lambda = 0.2426\times10^{-11}\times(1-0.087) = 0.2215\times10^{-11}$

$\Delta\lambda = 2.215\times10^{-12}$ m

**19.6 A 90 keV X-ray photon is fired at a carbon target and Compton scattering occurs. Find the wavelength of the incident photon and the wavelength of the scattered photon for scattering angle of (a) 30° (b) 60°.**

**Solution:**

$\theta = 30°$

E $= 90$ k eV $= 90\times10^{3}\times1.6\times10^{-19}$ J

E $= 144\times$
$10^{-16}$ J

$\lambda = ?$

$\lambda' = ?$

**(a) Energy of photon is,**

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

$\Rightarrow \quad \lambda = \frac{hc}{E} \quad \Rightarrow \lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{144\times10^{-16}}$

$\lambda = 0.138\times10^{-10} = 13.8\times10^{-12}$ m $= 13.8$ pm

**(b) The formula for the wavelength of a scattered photon is**

$$\lambda' = \lambda + \frac{h}{m_0c}(1-\cos\theta) \quad \ldots\ldots (1)$$

**(i) When $\theta = 30°$**

By using values in equation (1) we get,

$\lambda = 13.8\times10^{-12}\,\frac{6.63\times10^{-34}}{9.11\times10^{-31}\times3\times10^{8}}(1-\cos 30°)$

$\lambda = 13.8\times10^{-12} + 0.2426\times10^{-11}\times0.86$

$\lambda = 14.1\times10^{-12}$m $= 14.1$ pm

**(b) When $\theta = 60°$**

By using values in equation (1) we get,

$\lambda' = 13.8 \times 10^{-12} \frac{6.63\times10^{-34}}{9.11\times10^{-31}\times3\times10^{8}}(1-\cos 60°)$

$\lambda' = (13.8 \times 10^{-12} + 0.2426 \times 10^{-11} \times 0.5$

$\lambda' = 15.01 \times 10^{-12} m = 15\ pm$

**19.7 What is the maximum wavelength of the two photons produced when a positron annihilates an electron? The rest mass energy of each is 0.51MeV.**

**Solution:**

$E = 0.51\ M\ eV$

$E = 0.51 \times 10^{6} \times 1.6 \times 10^{-19}\ J$

$\lambda = ?$

Wavelength of photons $= \lambda = \frac{hc}{E}$

$\lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{0.51\times10^{6}\times1.6\times10^{-19}} = 24.375 \times 10^{-13} = 2.44\times10^{-12} m$

$\lambda = 2.44\ pm$

**19.8 Calculate the wavelength of**

**(a) a 140g ball moving at 40 $ms^{-1}$**

**(b) a proton moving at the same speed**

**(c) an electron moving at the same speed**

**Solution:**

$m = 140\ gm = 140 \times 10^{-3}\ kg$

$V = 40\ ms^{-1}$

(a) Wavelength of ball $= \lambda_1 = ?$

(b) Wavelength of proton $= \lambda_2 = ?$

(c) Wave length of electron $= \lambda_3 = ?$

De-Broglie wavelength is,

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

(a) $\lambda_1 = \frac{h}{mv}$

$\lambda_1 = \frac{6.63\times10^{-34}}{140\times10^{-3}\times40} = 1.184 \times 10^{-34}\ m$

(b) $\lambda_2 = \frac{h}{mv}$

$\lambda_2 = \frac{6.63\times10^{-34}}{1.67\times10^{-27}\times40} = 0.09925 \times10^{-7} = 9.925\times10^{-9} m$

$\lambda_2 = 9.925 nm$

(c) $\lambda_3 = \frac{h}{mv}$

$\lambda_3 = \frac{6.63\times10^{-34}}{9.11\times10^{-31}\times40} = 0.018\times10^{-5} = 1.8\times10^{-5}\ m$

**19.9 What is the de Broglie wavelength of an electron whose kinetic energy is 120 eV?**

**Solution:**

$m = 9.11\times10^{-34}\ Kg$

$e = 1.6\times10^{19}\ c$

$K.E = 120\ k\ eV = 120 \times 10^{3} = 120 \times 10^{3} \times 1.6 \times 10^{-19}$

$K.E = 192 \times 10^{-16} J$

$V = ?$

Since $\frac{1}{2}mv^2 = K.E$

$$v^2 = \frac{2 \times K.E}{m}$$

$$v = \sqrt{\frac{2 \times K.E}{m}}$$

$$v = \frac{\sqrt{2 \times 192 \times 10^{-16}}}{\sqrt{9.11 \times 10^{-31}}} = \sqrt{4.219 \times 10^{13}} = 6.5 \times 10^6 ms^{-1}$$

De-Broglie wavelength is,

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

$$\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 6.5 \times 10^6} = 0.112 \times 10^{-9} = 1.12 \times 10^{-10} m$$

**19.10 An electron is placed in a box about the size of an atom that is about 1.0 × $10^{-10}$m. What is the velocity of the electron?**

**Solution:**

Size of atom $= \Delta x = 1 \times 10^{-10} m$

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

$\Delta v = ?$

According to Heisenberg uncertainty principle,

$$\Delta p \cdot \Delta x \approx h$$

$$\Delta p \approx \frac{h}{\Delta x} \Rightarrow m\Delta v \approx \frac{h}{\Delta x}$$

$$\Delta v = \frac{h}{m \times \Delta x}$$

$$\Delta v = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1 \times 10^{-10}} = 0.729 \times 10^7 = 7.29 \times 10^6 ms^{-1}$$