

Chapter 13

Thermal Physics

Exercise Multiple Choice Questions

- 13.1 Which condition is necessary for most gases to behave nearly ideally?
 (a) Low temperature and low pressure (b) High temperature and low pressure
 (c) Constant temperature and low pressure (d) High temperature and constant pressure
- 13.2 v_{rms} of a gas molecule is 300 m s^{-1} . If its absolute temperature is reduced to half and molecular weight is doubled, then v_{rms} will become:
 (a) 75 m s^{-1} (b) 150 m s^{-1} (c) 300 m s^{-1} (d) 600 m s^{-1}
- 13.3 The rms speed of a gas at 27°C is v . If the temperature is raised to 327°C , the rms speed becomes:
 (a) v (b) $\frac{v}{\sqrt{2}}$ (c) $\sqrt{2} v$ (d) $3v$
- 13.4 Ratio of the rms velocities of O_2 and H_2 at equal temperature will be:
 (a) 1:1 (b) 1:4 (c) 2:1 (d) 4:1
- 13.5 In a closed room, there is a gas with pressure $3.2 \times 10^5 \text{ N m}^{-2}$. If the gas density is 6 kg m^{-3} , the effective speed of each gas particle is:
 (a) 400 m s^{-1} (b) 300 m s^{-1} (c) 250 m s^{-1} (d) 330 m s^{-1}
- 13.6 Which statement is not a statement of the kinetic theory of gases?
 (a) Molecules interact during collisions
 (b) Molecules are in continuous random motion
 (c) Collisions are of short duration
 (d) Molecules are tiny hard spheres undergoing inelastic collisions
- 13.7 Which equation ensures that a star remains stable against gravitational collapse?
 (a) Mass continuity equation (b) Energy gravitational equation
 (c) Hydrostatic equilibrium equation (d) Energy transport equation
- 13.8 What happens to a star when its gravitational force becomes greater than its internal pressure?
 (a) The star expands and becomes a red giant
 (b) The star contracts and its core temperature increases
 (c) The star remains stable with no changes
 (d) Nuclear fusion stops immediately

Answer Key

Q. No	Option	Q. No.	Option	Q. No.	Option
13.1	B	13.4	B	13.7	C
13.2	B	13.5	A	13.8	B
13.3	C	13.6	D		

Short Answer Questions

- 13.1 Do all gases have the same kinetic energy at the same temperature? If yes, give example.

Ans Yes, all the gasses have same K.E. at the same temperature.

The average translational K.E. of gas molecules depends only on absolute temperature according to the formula:

$$\langle \text{K.E.}_T \rangle = \frac{3}{2} k_B T$$

Example: O_2 and N_2 at 300 K have equal average translational kinetic energies.

- 13.2 A vessel is filled with a mixture of two different gases. Will the mean kinetic energy per molecule be equal?

Ans Yes, mean K.E. per molecule will be equal.

Since $\langle K.E.T \rangle = \frac{3}{2} k_B T$

Hence translational kinetic energy depends upon T. Therefore, in a mixture at thermal equilibrium, all molecules have the same temperature.

13.3 If density of a gas is doubled, keeping all other factors unchanged, what is the effect on pressure?

Ans From kinetic theory of gases; $P = \frac{1}{3} \rho \langle v^2 \rangle$

When speed is constant, pressure is directly proportional to density.

$$P \propto \rho$$

Hence if density is doubled the pressure will also be doubled.

13.4 A gas enclosed in a container is heated up. What is the effect on pressure?

Ans From kinetic theory of gases; $P = \frac{2}{3} N_0 \langle K.E.T \rangle$

Heating increases the average kinetic energy of molecules. Therefore, pressure will increase.

13.5 The number of molecules of a gas in a container is doubled. What will be the effect on the rms speed?

Ans The rms speed is given by; $v_{rms} = \sqrt{\frac{3k_B T}{m}}$

It depends only on temperature and mass. If the number of molecules doubles but temperature remains constant, the rms speed remains unchanged.

13.6 Explain briefly, why is it not possible to increase the temperature of a gas while keeping its volume and pressure constant.

Ans From the ideal gas law; $PV = nRT$

For a fixed amount of gas, if P and V remain constant, then T must also remain constant.

Increasing temperature would require a change in pressure, volume, or number of molecules.

13.7 On reducing the volume of a gas at constant temperature, the pressure of the gas increases. Explain briefly on the basis of kinetic theory of gases.

Ans On the basis of kinetic theory of gases at constant temperature, the pressure is inversely proportional to volume. By formula; $P = \frac{2}{3} \frac{N}{V} \langle \frac{1}{2} mv^2 \rangle$

Therefore, reducing the volume will increase the pressure at constant temperature.

13.8 How does the balance between gravitational force and internal pressure determine whether a star expands or contracts during its evolution?

Ans A star remains stable when gravitational force equals internal pressure. If gravity exceeds internal pressure, the star contracts and becomes denser. If internal pressure exceeds gravity, the star expands. This balance controls the star's evolution and stability.

Constructed Response Questions

13.1 What will be the kinetic energy near absolute zero? Explain.

Ans Average translational kinetic energy is given by; $\langle K.E.T \rangle = \frac{3}{2} k_B T$

Average translational kinetic energy is directly proportional to the temperature. As temperature approaches to absolute zero, the average kinetic energy approaches to zero too.

13.2 What is the average kinetic energy of oxygen and nitrogen molecules in a room at room temperature?

Ans The average translational K.E. of gas molecules depends only on absolute temperature.

At room temperature; $T = 300 \text{ K}$

$$\langle K.E.T \rangle = \frac{3}{2} k_B T = \frac{3}{2} (1.38 \times 10^{-23}) (300) = 6.2 \times 10^{-21} \text{ J}$$

Thus, both O_2 and N_2 molecules have the same average translational kinetic energy at room temperature.

13.3 Consider a gas enclosed in a sealed container. By what factor does gas temperature change if:

- (a) The volume and pressure are both doubled?
 (b) The volume is halved and the pressure is tripled?

Ans (a) The volume and pressure are both doubled

Using the ideal gas law: $PV = nRT$

Since n and R , are constants, $T \propto PV$

If pressure becomes $2P$ and volume becomes $2V$, then

$$\frac{T'}{T} = \frac{2P \times 2V}{PV}$$

which makes $T' = 4T$. Hence, the temperature becomes 4 times the original temperature.

(b) The volume is halved and the pressure is tripled

Using the ideal gas law; $PV = nRT$

Since n and R are constants, $T \propto PV$

If pressure becomes $3P$ and volume becomes $\frac{1}{2}V$

then
$$\frac{T'}{T} = \frac{3P \times \frac{1}{2}V}{PV}$$

which makes $T' = \frac{3}{2}T$. Hence, the temperature becomes $\frac{3}{2}$ times the original temperature.

13.4 Is it possible to boil water at room temperature without heating? Explain.

Ans Yes, it is possible to boil water at room temperature without heating.

Boiling occurs when vapor pressure equals external pressure. If the external pressure is reduced sufficiently (e.g., using a vacuum pump), water can boil at room temperature.

13.5 Explain how the drop of ink in a beaker containing water will behave.

Ans The ink gradually spreads throughout the water due to the Brownian motion of molecules. Water molecules continuously collide with ink particles, causing diffusion. Eventually, the ink becomes uniformly distributed in the water.

Numerical Problems

13.1 Calculate the rms velocity of hydrogen molecules at standard temperature and pressure (STP). Density of hydrogen at STP; $\rho = 8.957 \times 10^{-2} \text{ kg m}^{-3}$. Density of mercury $\rho = 13600 \text{ kg m}^{-3}$, $g = 9.8 \text{ m s}^{-2}$.

Given data:

$$\rho_H = 8.957 \times 10^{-2} \text{ kg m}^{-3}$$

$$\rho_M = 13600 \text{ kg m}^{-3}$$

$$g = 9.8 \text{ m s}^{-2}$$

$$P = 1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$$

To find:

$$v_{\text{rms}} \text{ of hydrogen molecule} = ?$$

Solution:

$$\text{As } P = \frac{1}{3} \rho_H v_{\text{rms}}^2$$

$$\text{So, } v_{\text{rms}} = \sqrt{\frac{3P}{\rho_H}} = \sqrt{\frac{3(1.013 \times 10^5)}{8.957 \times 10^{-2}}}$$

$$v_{\text{rms}} = 1.84 \times 10^3 \text{ m s}^{-1}$$

13.2 Determine the pressure of oxygen gas at 0°C if the density of oxygen is 1.44 kg m^{-3} at STP and rms speed at STP is 456.4 m s^{-1} .

Given data:

$$\rho = 1.44 \text{ kg m}^{-3}$$

$$v_{\text{rms}} = 456.4 \text{ m s}^{-1}$$

To find:

$$P = ?$$

Solution:

$$P = \frac{1}{3} \rho v_{\text{rms}}^2$$

$$P = \frac{1}{3} (1.44) (456.4)^2 = 99984.46 \text{ Pa}$$

$$P \approx 1.0 \times 10^5 \text{ N m}^{-2}$$

13.3 At what temperature will the rms speed of the molecules of gas be three times its value at STP?

Given data:

$$T = 273 \text{ K}$$

$$v'_{\text{rms}} = 3 v_{\text{rms}}$$

To find:

$$T' = ?$$

Solution:

As,

$$v_{\text{rms}} \propto \sqrt{T}$$

So,

$$\frac{v'_{\text{rms}}}{v_{\text{rms}}} = \sqrt{T'/T}$$

$$3 = \sqrt{T'/273}$$

$$T' = 2457 \text{ K} = (2457 - 273)^\circ\text{C}$$

$$T' = 2184^\circ\text{C}$$

13.4 If a gas is at temperature 80°C and pressure $5 \times 10^{-10} \text{ N m}^{-2}$, having 1 m^3 volume, what is the number of molecules per cubic metre, where Boltzmann's constant is $1.38 \times 10^{-23} \text{ J K}^{-1}$.

Given data:

$$P = 5 \times 10^{-10} \text{ N m}^{-2}$$

$$V = 1 \text{ m}^3$$

$$T = 80^\circ\text{C} = 80 + 273 \text{ K} = 353 \text{ K}$$

$$k_B = 1.38 \times 10^{-23} \text{ J K}^{-1}$$

To find:

$$N = ?$$

Solution:

$$PV = Nk_B T$$

$$N = \frac{PV}{k_B T}$$

$$N = \frac{(5 \times 10^{-10})(1)}{(1.38 \times 10^{-23})(353)}$$

$$N = 1.026 \times 10^{11} \text{ molecules}$$

13.5 The temperature and pressure in the Sun's atmosphere are $2.00 \times 10^6 \text{ K}$ and 0.0300 Pa respectively. Calculate the rms speed of free electrons (mass of the electron = $9.11 \times 10^{-31} \text{ kg}$).

Given data:

$$T = 2.00 \times 10^6 \text{ K}$$

$$m_e = 9.11 \times 10^{-31} \text{ kg}$$

$$k_B = 1.38 \times 10^{-23} \text{ J K}^{-1}$$

To find:

$$v_{\text{rms}} = ?$$

Solution:

$$v_{\text{rms}} = \sqrt{\frac{3k_B T}{m}} = \sqrt{\frac{3(1.38 \times 10^{-23})(2.00 \times 10^6)}{9.11 \times 10^{-31}}}$$

$$v_{\text{rms}} = 9.5 \times 10^6 \text{ m s}^{-1}$$

13.6 A star has a mass enclosed within radius r equal to 2.0×10^{30} kg, density 1500 kg m^{-3} and radius 7.0×10^8 m. Calculate the gravitational force inside the star.

Given data:

$$M_s = 2.0 \times 10^{30} \text{ kg}$$

$$r = 7.0 \times 10^8 \text{ m}$$

$$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

To find:

$$F_g = ?$$

Solution:

$$F_g = \frac{G M_s m}{r^2}$$

$$\frac{F_g}{m} = \frac{G M_s}{r^2}$$

(Here $m = 1 \text{ kg}$)

$$= \frac{G M_s}{r^2} = \frac{(6.67 \times 10^{-11})(2.0 \times 10^{30})}{(7.0 \times 10^8)^2}$$

$$= \mathbf{2.72 \times 10^2 \text{ N kg}^{-1} \text{ Ans}}$$

Chapter No 14

Simple Harmonic Motion

Exercise Multiple Choice Questions

14.1 While determining time period of simple pendulum, we keep the amplitude:

- (a) large (b) small (c) maximum (d) zero

14.2 In simple harmonic motion, the acceleration of a body is zero, when:

- (a) velocity is zero (b) displacement is zero
(c) both velocity and displacement are zero (d) both velocity and displacement are maximum

14.3 If a tunnel is bored through the centre of Earth and a stone is dropped into it, then:

- (a) stone will stop at the centre of Earth
(b) stone will move out from other side of the tunnel
(c) stone will perform S.H.M.
(d) none of the above

14.4 Which of the following variables has zero value at the extreme position in S.H.M?

- (a) Acceleration (b) Speed (c) Displacement (d) Angular frequency

14.5 Which of the following force is responsible for S.H.M?

- (a) Applied force (b) Frictional force (c) Restoring force (d) Elastic force

14.6 The velocity of a particle moving with S.H.M at the mean position is:

- (a) zero (b) minimum (c) maximum (d) none of these

14.7 A child swinging on a swing in sitting position, stands up, then time period of the swing will:

- (a) increase (b) decrease (c) remain same (d) become zero

14.8 The total energy of a particle executing S.H.M is proportional to:

- (a) frequency of oscillation (b) velocity of motion
(c) amplitude of motion (d) square of amplitude of motion

14.9 The period of simple pendulum increases how many times if its length is doubled?

- (a) $\sqrt{2}$ times (b) 2 times (c) 4 times (d) 8 times

Answer Key

Q. No.	Options	Q. No.	Options
14.1	B	14.6	C
14.2	B	14.7	B
14.3	C	14.8	D
14.4	B	14.9	A
14.5	C		

Short Answer Questions

14.1 Define Simple Harmonic Motion (SHM) and write its equation.

Ans: Simple Harmonic Motion (SHM):

It is the type of oscillatory motion in which the restoring force or acceleration is directly proportional to the displacement from the mean position and always directed towards the mean position.

$$a \propto -x$$

14.2 State the basic conditions for a frictionless system to execute SHM.

Ans:

- The restoring force shall be directly proportional to the displacement from the mean position.
- The force and displacement should follow Hooke's law ($F = -kx$) where k is spring constant depends upon the nature of spring material.
- Acceleration of oscillating objects should be proportional to the displacement and always directed towards mean position. The negative sign shows that acceleration is always directed towards mean position.

$$a \propto -x$$

14.3 Differentiate between free and forced oscillations.

Free Oscillations:

A body is said to be executing free oscillations if it oscillates with its natural frequency without the interference of an external force. In the absence of resistive forces, the amplitude and total energy of free oscillations remains constant.

Forced Oscillations:

When the oscillating body is subjected to a periodic external force (driving force), then such oscillations are called forced oscillations.

14.4 Why we cannot construct an ideal simple pendulum? Explain briefly.

Ans: An ideal simple pendulum cannot be constructed because:

- The bob cannot be a perfect point mass.
- The string cannot be perfectly massless and inextensible.
- Air resistance and friction at the support cannot be eliminated.
- Value of g is not same everywhere.

14.5 How does sharpness of resonance occur?

Ans: The amplitude and sharpness of resonance depend upon the damping. For smaller damping, the amplitude and sharpness of the resonance will be greater.

14.6 What would happen to the time period if the Earth suddenly stop rotating?

Ans: If the Earth suddenly stops rotating time period will decrease.

When the Earth stops rotating, the effective value of gravitational acceleration (g) would slightly increase. An increase in g would cause the time period to decrease as given by formula:

$$T = 2\pi \sqrt{\frac{l}{g}}$$

14.7 What is restoring force? What provides restoring force for simple harmonic oscillator in the case of simple pendulum and mass-spring system?

Ans: Restoring Force: It is a force that always brings the object back to its mean position.

- In case of simple pendulum, the restoring force is provided by the perpendicular component of weight i.e. $mg\sin\theta$.
- In case of mass spring system, the restoring force is provided by the elastic force of the spring given by Hooke's law: $F = -kx$

14.8 What role do shock absorbers play in the oscillations of vehicles on a bumpy road? Explain briefly.

Ans: Damping system is required to ensure a comfortable ride for the passengers when the vehicles are moving on a bumpy, rough road. The oscillations produced in such vehicles are damped by the using shock absorbers.

Constructed Response Questions

14.1 Why marching troops are asked to break their steps while crossing a bridge? Explain.

Ans: If the soldiers march in steps while crossing the bridge, it is possible that the frequency of their footsteps becomes equal to the natural frequency of the bridge. The bridge may be set into vibrations with large amplitude due to the resonance and it may collapse.

14.2 A girl is swinging in the sitting position. Describe, how will the period of swing be changed if she stands up?

Ans: If the girl stands up the time period will decrease. When the girl stands up on the swing, her centre of gravity rises. This decreases the effective length of the pendulum. As the time period of a simple pendulum is directly proportional to the square root of its effective length, the period of the swing will decrease.

14.3 Will a pendulum that keeps correct time at Karachi, be accurate at Murree or at the top of mount Everest? Explain.

Ans: No, the pendulum will not keep correct time at Murree or at the top of Mount Everest.

The time period of a simple pendulum is given by:

$$T = 2\pi \sqrt{\frac{l}{g}}$$

The value of g decreases with increasing height above sea level. At Murree and Mount Everest g is less than at Karachi (sea level). Therefore, the time period T will increase and the pendulum will oscillate slower.

14.4 A wire hangs from a dark high tower so that its upper end is not visible. How can we determine the length of a tower?

Ans: The length of the tower can be determined by making the hanging wire a simple pendulum. Attach a bob to the lower end of the wire and slightly displace it from the mean position. It will start oscillating. Measure the time for 20 oscillations with a stopwatch and find the time period T . The length of the tower can be calculated as:

$$l = \frac{T^2 g}{4\pi^2}$$

14.5 Will the period of vibrating spring increase, decrease or remain constant by addition of more mass? Explain.

Ans: The period of a vibrating spring will increase by the addition of more mass. The time period of a mass-spring system is given by:

$$T = 2\pi \sqrt{\frac{m}{k}}$$

When more mass is added, the value of m increases while k (spring constant) remains the same. Therefore, the time period T increases.

14.6 Can a simple pendulum vibrate at centre of the Earth? Explain.

Ans: No pendulum cannot vibrate at the centre of Earth. According to the formula of time period:

$$T = 2\pi \sqrt{\frac{l}{g}}$$

At the centre of Earth $g = 0$ So $T = \infty$
Thus, the pendulum will not vibrate.

Numerical Problems

**14.1 A body is executing S.H.M. of amplitude 0.05 m and frequency 10 Hz. Find:
(i) Maximum acceleration (ii) Maximum velocity**

Given Data:

$$x_0 = 0.05 \text{ m}$$

$$f = 10 \text{ Hz}$$

To Find:

$$(i) a_{\max} = ?$$

$$(ii) v_{\max} = ?$$

Solution:

$$\omega = 2\pi f$$

$$\omega = 2(3.14)(10) = 62.8 \text{ rad s}^{-1}$$

(i) Maximum Acceleration

$$\begin{aligned} a_{\max} &= \omega^2 x_0 \\ &= (62.8)^2 (0.05) \\ &= 3943.84 (0.05) \\ &= 197.2 \text{ m s}^{-2} \end{aligned}$$

$$a_{\max} = 1.97 \times 10^2 \text{ m s}^{-2}$$

(ii) Maximum Velocity

$$\begin{aligned}
 v_{\max} &= \omega x_0 \\
 &= (62.8)(0.05) \\
 v_{\max} &= 3.14 \text{ m s}^{-1}
 \end{aligned}$$

- 14.2** A mass of 0.5 kg is suspended from a spring. The spring is stretched 0.098 m. Find:
 (i) the period of oscillation of mass when it is given a small displacement.
 (ii) Frequency of oscillations of spring.

Given Data:

$$\begin{aligned}
 m &= 0.5 \text{ kg} \\
 x &= 0.098 \text{ m} \\
 g &= 9.8 \text{ m s}^{-2}
 \end{aligned}$$

To Find:

- (i) $T = ?$
 (ii) $f = ?$

Solution:

$$\begin{aligned}
 k &= \frac{mg}{x} \\
 k &= \frac{0.5 \times 9.8}{0.098} \\
 k &= 50 \text{ N m}^{-1}
 \end{aligned}$$

Time period $T = 2\pi \sqrt{\frac{m}{k}}$

$$\begin{aligned}
 &= 2(3.14) \sqrt{\frac{0.5}{50}} \\
 &= 6.28 \sqrt{0.01} \\
 &= 6.28(0.1) \\
 \mathbf{T} &= \mathbf{0.628 \text{ s}}
 \end{aligned}$$

Frequency $f = \frac{1}{T}$

$$\begin{aligned}
 &= \frac{1}{0.628} \\
 \mathbf{f} &= \mathbf{1.59 \text{ Hz}}
 \end{aligned}$$

- 14.3** A ball of mass 0.5 kg is attached to an elastic spring. The spring is compressed by 10 cm by a force of 45 N. Calculate the energy stored in the spring. What will be the maximum velocity of the ball if the compressing force is suddenly removed.

Given Data:

$$\begin{aligned}
 m &= 0.5 \text{ kg} \\
 x &= 10 \text{ cm} = 0.10 \text{ m} \\
 F &= 45 \text{ N}
 \end{aligned}$$

To Find:

- (i) P. E. = ?
 (ii) $v_0 = ?$

Solution:

$$\begin{aligned}
 k &= \frac{F}{x} \\
 &= \frac{45}{0.10} \\
 k &= 450 \text{ N m}^{-1} \\
 \text{P. E.} &= \frac{1}{2} kx^2 \\
 &= \frac{1}{2} (450)(0.10)^2 \\
 &= 225(0.01) \\
 \mathbf{P. E} &= \mathbf{2.25 \text{ J}}
 \end{aligned}$$

Since $K.E = P.E$

$$\frac{1}{2}mv_0^2 = 2.25$$

$$\frac{1}{2}(0.5)v_0^2 = 2.25$$

$$0.25v_0^2 = 2.25$$

$$v_0^2 = 9$$

$$v_0 = 3 \text{ m s}^{-1}$$

14.4 A 8.0 kg body executes S.H.M. with amplitude 30 cm. The restoring force is 60 N, when the displacement is 30 cm. Find: (i) Time period (ii) Acceleration, speed, K.E. and P.E. when displacement is 12 cm.

Given Data:

$$m = 8.0 \text{ kg}$$

$$x_0 = 30 \text{ cm} = 0.30 \text{ m}$$

$$F = 60 \text{ N}$$

$$x = 12 \text{ cm} = 0.12 \text{ m}$$

To Find:

(i) Time period=? (ii) Acceleration=? (iii) Speed=? (iv) K.E.=? (v) P.E.=?

Solution:

$$k = \frac{F}{x}$$

$$= \frac{60}{0.30}$$

$$k = 200 \text{ N m}^{-1}$$

$$\omega = \sqrt{\frac{k}{m}}$$

$$= \sqrt{\frac{200}{8}}$$

$$= \sqrt{25}$$

$$\omega = 5 \text{ rad s}^{-1}$$

Time period:

$$T = \frac{2\pi}{\omega}$$

$$= \frac{6.28}{5}$$

$$T = 1.26 \approx 1.3 \text{ s}$$

Acceleration:

$$a = \omega^2 x$$

$$= (5)^2 (0.12)$$

$$a = 3.0 \text{ m s}^{-2}$$

Speed:

$$v = \omega \sqrt{x_0^2 - x^2}$$

$$= 5 \sqrt{(0.30)^2 - (0.12)^2}$$

$$= 5(0.275)$$

$$v = 1.38 \approx 1.4 \text{ m s}^{-1}$$

Potential Energy:

$$P.E = \frac{1}{2}kx^2$$

$$= \frac{1}{2}(200)(0.12)^2$$

$$P.E = 1.44 \text{ J}$$

Kinetic Energy:

$$K.E = \frac{1}{2}k(x_0^2 - x^2)$$

$$= \frac{1}{2}(200)[(0.30)^2 - (0.12)^2]$$

$$K.E = 7.6 \text{ J}$$

14.5 A block of mass 5 kg is dropped from a height of 0.8 m onto a spring of spring constant 1960 N m⁻¹. Find the displacement through which the spring will be compressed.

Given Data:

$$\begin{aligned}m &= 5 \text{ k} \\h &= 0.8 \text{ m} \\k &= 1960 \text{ N m}^{-1} \\g &= 9.8 \text{ m s}^{-2}\end{aligned}$$

To Find:

$$x_o = ?$$

Solution:

$$\begin{aligned}mgh &= \frac{1}{2}kx_o^2 \\(5)(9.8)(0.8) &= \frac{1}{2}(1960)x_o^2 \\x_o^2 &= 0.04 \\x_o &= \mathbf{0.2 \text{ m}}\end{aligned}$$

Chapter 15

Physical Optics

Exercise Multiple choice questions

- 15.1 When the light from two lamps falls on a screen, no interference pattern can be obtained. Why is this?
(a) The lamps are not point sources (b) The lamps emit light of different amplitudes
(c) The light from the lamps is not coherent (d) The light from the lamps is white
- 15.2 Monochromatic light illuminates two narrow parallel slits. The interference pattern which results is observed on a screen some distance beyond the slits. Which change increases the separation between the dark lines of the interference pattern?
(a) Decreasing the distance between the screen and the slits
(b) Increasing the distance between the slits
(c) Monochromatic light of higher frequency
(d) Using monochromatic light of longer wavelength
- 15.3 Using monochromatic light, interference fringes are produced on a screen placed at a distance L from a pair of slits of separation d . The separation of the fringes is y . Both d and L are now doubled. What is the new fringe separation?
(a) $\frac{y}{2}$ (b) y (c) $2y$ (d) $4y$
- 15.4 Which of the following is not a necessary condition for two waves to produce interference?
(a) Waves must be of same type (b) Waves must be coherent
(c) Waves must have same amplitude (d) Waves must be moving in same direction
- 15.5 The colours observed on a soap bubble are due to which phenomenon of light?
(a) Reflection (b) Refraction (c) Interference in thin film (d) Diffraction
- 15.6 Continuous water waves are diffracted through a gap in a barrier in a ripple tank. Which change will cause the diffraction of the waves to increase?
(a) Increasing the frequency of the waves (b) Increasing the width of the gap
(c) Reducing the wavelength of the waves (d) Reducing the width of the gap
- 15.7 Which property of a light wave can be determined using a diffraction grating?
(a) Amplitude (b) Intensity (c) Speed (d) Wavelength
- 15.8 The central maximum in a diffraction grating is called:
(a) zero order (b) first order (c) second order (d) higher order

Answer Key					
Q. No.	Option	Q. No.	Option	Q. No.	Option
15.1	C	15.4	C	15.7	D
15.2	D	15.5	C	15.8	A
15.3	B	15.6	D		

Short Answer Questions

- 15.1 Can Huygen's principle be applied on sound and water waves? Explain briefly.

Ans: Yes, Huygens' principle can be applied to sound and water waves.

According to Huygens' principle, every point on a wavefront acts as a source of new small wavelets, and their combination forms the next wavefront. For sound waves, it helps explain effects like diffraction and interference.

For water waves, it explains how waves spread and change direction, especially near obstacles or boundaries.

- 15.2 Why interference pattern is not produced due to headlights of a car? Explain briefly.

Ans: Interference pattern is not observed from car headlights because interference requires coherent sources (same frequency and constant phase difference). Car headlights act as independent and incoherent sources, so their light waves do not maintain a fixed phase relationship. As a result, any possible interference is random and not visible, so no clear pattern is formed.

15.3 Why interference pattern is observed on soap bubbles but not on window glass or windscreens of cars?

Ans: For detectable interference, the thickness of the medium must be of the order of the wavelength of incident light. Thickness of soap bubbles is small of order of the wavelength of incident light. Hence, the reflected rays satisfy the interference condition and produce colorful fringes. while the thickness of window glass or a car windscreen is much greater than the wavelength of incident light. Therefore, the path difference becomes very large, and no visible interference pattern is formed.

15.4 If the whole apparatus of Young's double-slit experiment is submerged in water, what will be the effect on fringes?

Ans: When the entire Young's double-slit experiment is placed in water, the fringe width decreases. According to formula

$$\Delta y = \frac{\lambda L}{d}$$

Fringe width depends on wavelength. When the whole arrangement is placed in water, the wavelength of light decreases, and the fringe becomes closer together. The central bright fringe remains at the same position, but the overall pattern becomes narrower.

15.5 Compare the double-slit experimental arrangements for light and sound waves, similarities and differences.

Ans: The double-slit experiment for light and sound shows similar wave behavior but differs in setup and nature.

Similarities:

- Both show interference and diffraction.
- Bright and dark fringes in light whereas loud and faint sound in case of sound waves.
- Both require coherent sources.

Differences:

Light Waves	Sound Waves
Electromagnetic wave	Mechanical wave
Small wavelength	Large wavelength
Seen on a screen	Detected using microphone

15.6 For a diffraction grating, what are the advantages of using:

(a) many slits (b) narrow slits (c) closely spaced slits?

Ans:

Many slits	Narrow slits	Closely spaced slits
Brighter and sharper maxima	Greater diffraction	Increased angular separation
Improved resolution	Clear and wider pattern	Clearly distinguishable colors

15.7 How the number of orders in a given diffraction grating can be increased?

Ans: From the grating equation;

$$d \sin \theta = n \lambda,$$

$$n = \frac{d}{\lambda} \quad (\text{For } \theta = 90^\circ)$$

n can be increased by increasing d and decreasing λ .

15.8 How the pattern would change if red light is replaced with blue light in a given diffraction grating?

Ans: From the grating equation;

$$d \sin \theta = n\lambda,$$
$$n = \frac{d}{\lambda} \quad (\text{For } \theta = 90^\circ)$$
$$n \propto \frac{1}{\lambda}$$

As wavelength of blue light is less than wavelength of red light, hence the diffraction pattern contracts.

15.9 Why central spot in Newton's rings is dark?

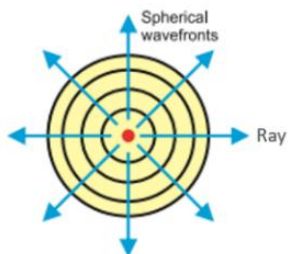
Ans: It is dark due to destructive interference. At the center, the air film thickness is zero, but one of the reflected rays undergoes a phase change of 180° on reflection from the denser surface. This causes the two rays to cancel each other, producing a dark spot.

Constructed Response Questions

15.1 Light is sometimes described as rays and sometimes as waves. Construct diagrams to explain differences in both.

Ans: **Ray:** A line at right angle to a wavefront which shows its direction of travel is called a ray.

Wave: The oscillating electric charges can produce changing electric and magnetic fields that mutually regenerate each other and propagate through vacuum.



15.2 Suppose white light is falling on a double slit arrangement, such that one slit is covered with red filter (650 nm) and other is with blue filter (450 nm), explain what would be observed on the screen?

Ans: No interference pattern will be observed on the screen only red and blue dots will appear behind the slits.

The necessary conditions for sustained interference are:

- The sources must be coherent, i.e., they must emit light of the same frequency or wavelength.
- There must be a constant phase difference.

The red and blue filters transmit light of different wavelengths. Therefore, the waves emerging from the two slits have different frequencies and are not coherent. So, the condition for stable interference is not fulfilled, a stable interference pattern is not produced on the screen.

15.3 What will be the effect on width and brightness of the fringes in a double-slit interference experiment, if we decrease the width of one slit to half keeping all other factors same?

Ans: According to the formula

$$\Delta y = \frac{\lambda L}{d}$$

- The fringe width remains unchanged, because λ , L and d are same.
- The brightness of the fringes decreases by one-fourth.

15.4 Why can we readily observe diffraction effects for sound waves and water waves, but not for light waves? Is this because light travels so much faster than these other waves? Explain.

- Ans:** No, it is not due to the speed of light. It is entirely dependent on the wavelength (λ) of the waves relative to the size of the obstacle or aperture (d).
 Diffraction is significant when the wavelength is comparable to the size of the obstacle or opening ($\lambda \approx d$) Where d is the width of the obstacle or opening.
 Sound and water waves have relatively long wavelengths, so they easily around obstacles. Light has a very short wavelength (about 400 nm to 700 nm), so noticeable diffraction requires extremely narrow slits or very small obstacles. Therefore, the difference is due to wavelength, not the speed of the waves.
- 15.5 What is the significance of path difference in deriving Bragg's equation? Explain.**
Ans: The path difference determines whether the reflected waves will interfere constructively or destructively.
 In Bragg's equation $2d \sin\theta = n\lambda$, constructive interference occurs only when the path difference equals an integer multiple of the wavelength.

Numerical Problems

- 15.1 Coherent light of wavelength 500 nm is incident on two very narrow and closely spaced slits. The interference pattern is observed on a very tall screen that is 2.00 m from the slits. Near the center of the screen the separation between two adjacent interference maxima is 3.53 cm. What is the distance on the screen between the $m = 49$ and $m = 50$ maxima?**

Given data:

$$\begin{aligned}\lambda &= 500 \text{ nm} = 500 \times 10^{-9} \text{ m} \\ L &= 2 \text{ m} \\ \Delta y &= 3.53 \text{ cm} = 3.53 \times 10^{-2} \text{ m}\end{aligned}$$

To Find:

$$\Delta y = y_{50} - y_{49} = ?$$

Solution:

We know that fringe spacing is given by

$$\begin{aligned}\Delta y &= y_{m+1} - y_m \\ \text{As, } m &= 49, \text{ So, } m + 1 = 50 \\ \Delta y &= y_{50} - y_{49}\end{aligned}$$

It is given that the separation between adjacent maxima is 3.53 cm,

$$\text{Therefore, } y_{50} - y_{49} = 3.53 \times 10^{-2} \text{ m} = 3.53 \text{ cm} \quad \text{Ans}$$

- 15.2 Young's experiment is performed with light from excited helium atoms $\lambda = 502 \text{ nm}$. Fringes are measured carefully on a screen 1.20 m away from the double slit, and the center of the 20th fringe (not counting the central bright fringe) is found to be 10.6 mm from the center of the central bright fringe. What is the separation of the two slits?**

Given data:

$$\begin{aligned}m &= 20 \\ L &= 1.20 \text{ m} \\ \lambda &= 502 \text{ nm} = 502 \times 10^{-9} \text{ m} \\ y_{20} &= 10.6 \text{ mm} = 10.6 \times 10^{-3} \text{ m}\end{aligned}$$

To Find:

$$d = ?$$

Solution:

$$\begin{aligned}d &= \frac{m\lambda L}{y_{20}} \\ &= \frac{20 \times 502 \times 10^{-9} \times 1.20}{10.6 \times 10^{-3}}\end{aligned}$$

$$= 1.1366 \times 10^{-3} \text{ m}$$

$$d = 1.14 \text{ mm} \quad \text{Ans}$$

15.3 Coherent light with wavelength 450 nm falls on a pair of slits. On a screen 1.80 m away, the distance between dark fringes is 3.90 mm. What is the slit separation?

Given data:

$$L = 1.80 \text{ m}$$

$$\lambda = 450 \text{ nm} = 450 \times 10^{-9} \text{ m}$$

$$\Delta y = 3.90 \text{ mm} = 3.90 \times 10^{-3} \text{ m}$$

To Find:

$$d = ?$$

Solution:

$$d = \frac{\lambda L}{\Delta y}$$

$$= \frac{450 \times 10^{-9} \times 1.80}{3.90 \times 10^{-3}}$$

$$d = 2.08 \times 10^{-4} \text{ m} \quad \text{Ans}$$

15.4 Two slits spaced 0.450 mm apart are placed 75.0 cm from a screen. What is the distance between the second and third dark lines of the interference pattern on the screen when the slits are illuminated with coherent light with a wavelength of 500 nm?

Given data:

$$L = 75.0 \text{ cm} = 75 \times 10^{-2} \text{ m}$$

$$\lambda = 500 \text{ nm} = 500 \times 10^{-9} \text{ m}$$

$$d = 0.450 \text{ mm} = 0.450 \times 10^{-3} \text{ m}$$

To Find:

$$\Delta y = ?$$

Solution:

$$\Delta y = \frac{\lambda L}{d}$$

$$= \frac{500 \times 10^{-9} \times 75 \times 10^{-2}}{0.450 \times 10^{-3}}$$

$$\Delta y = 0.833 \times 10^{-3} \text{ m} = 8.33 \times 10^{-4} \text{ m} \quad \text{Ans}$$

15.5 Two very narrow slits are spaced 1.80 mm apart and are placed 35.0 cm from a screen. What is the distance between the first and second dark lines of the interference pattern when the slits are illuminated with coherent light of wavelength 550 nm?

Given data:

$$L = 35.0 \text{ cm} = 35 \times 10^{-2} \text{ m}$$

$$\lambda = 550 \text{ nm} = 550 \times 10^{-9} \text{ m}$$

$$d = 1.80 \text{ mm} = 1.80 \times 10^{-3} \text{ m}$$

To Find:

$$\Delta y = ?$$

Solution:

$$\Delta y = \frac{\lambda L}{d}$$

$$= \frac{550 \times 10^{-9} \times 35 \times 10^{-2}}{1.80 \times 10^{-3}}$$

$$\Delta y = 1.07 \times 10^{-4} \text{ m} \quad \text{Ans}$$

15.6 Monochromatic light is at normal incidence on a plane transmission grating. The first-order maximum in the interference pattern is at an angle of 11.3°. What is the angular position of the fourth-order maximum?

Given data:

$$m = 4$$

$$\theta_1 = 11.3^\circ$$

To Find:

$$\theta_4 = ?$$

Solution:

$$d \sin \theta_m = m\lambda$$

For 4th order,

$$d \sin \theta_4 = 4\lambda$$

$$\sin \theta_4 = 4 \frac{\lambda}{d} \text{ --- (1)}$$

For 1st order,

$$d \sin \theta_1 = \lambda$$

$$\sin \theta_1 = \frac{\lambda}{d}$$

$$\frac{\lambda}{d} = \sin 11.30^\circ$$

$$\frac{\lambda}{d} = 0.195946 \text{ --- (2)}$$

Putting this value in eq. (1)

$$\sin \theta_4 = 4 \times 0.195946$$

$$\theta_4 = \sin^{-1} (0.7837785)$$

$$\theta_4 = 51.7^\circ \quad \text{Ans}$$

15.7 If a diffraction grating produces a third-order bright spot for red light of wavelength 700 nm at 65° from the central maximum, at what angle will the second-order bright spot be for violet light of wavelength 400 nm?

Given data:

$$m_1 = 3$$

$$m_2 = 2$$

$$\theta_1 = 65^\circ$$

$$\lambda_1 = 700 \text{ nm} = 700 \times 10^{-9} \text{ m}$$

$$\lambda_2 = 400 \text{ nm} = 400 \times 10^{-9} \text{ m}$$

To Find:

$$\theta_2 = ?$$

Solution:

$$d \sin \theta_m = m\lambda$$

For 1st order,

$$d \sin \theta_1 = m_1 \lambda_1$$

$$d = \frac{m_1 \lambda_1}{\sin \theta_1} \text{ --- (1)}$$

$$= \frac{3 \times 700 \times 10^{-9}}{\sin 65} = \frac{2100 \times 10^{-9}}{0.9063}$$

$$d = 2317.14 \text{ nm}$$

For 2nd order,

$$d \sin \theta_2 = m_2 \lambda_2$$

$$\sin \theta_2 = \frac{m_2 \lambda_2}{d}$$

$$= \frac{2 \times 400 \times 10^{-9}}{2317.14} = 0.34526$$

$$\theta_2 = \sin^{-1} (0.34526)$$

$$\theta_2 = 20.2^\circ \quad \text{Ans}$$

Chapter No 16

Electrostatics

Exercise Multiple Choice Questions

- 16.1 What is the work done on an electron by a potential difference of 100 volts?
 (a) 1.6×10^{-19} eV (b) 1.6×10^{-17} eV (c) 6.25×10^{-17} eV (d) 100 eV
- 16.2 A parallel plate capacitor of capacitance $50 \mu\text{F}$ is connected to a battery of 12 volts, the charge stored on each plate is:
 (a) $60 \mu\text{C}$ (b) $4.2 \mu\text{C}$ (c) 6×10^{-4} C (d) 4×10^4 C
- 16.3 If a dielectric is inserted between the plates of a charged capacitor, the potential difference across the plates:
 (a) increases (b) decreases (c) remains same (d) becomes zero
- 16.4 The potential energy of a system of two charges $8 \mu\text{C}$ and $-8 \mu\text{C}$ separated by a distance 2 m is:
 (a) $\frac{8 \times 10^{-12}}{\pi \epsilon_0}$ J (b) $\frac{+16 \times 10^{-12}}{\pi \epsilon_0}$ J (c) $\frac{-8 \times 10^{-12}}{\pi \epsilon_0}$ J (d) $\frac{-16 \times 10^{-12}}{\pi \epsilon_0}$ J
- 16.5 The electric potential at point A is 50 V and at B is 80 V. If the electric field between the charges is uniform, what can be said about the motion of positive charge from A to B?
 (a) No work is done (b) Work is done by the electric field
 (c) Work is done against the electric field (d) None of the above
- 16.6 The rate of charging or discharging the capacitor depends upon the product of the resistance and:
 (a) charge (b) potential difference (c) current (d) capacitance
- 16.7 In a charged capacitor, the energy resides in:
 (a) the positive plate (b) the negative plate
 (c) both positive and negative plates (d) the electric field between the plates
- 16.8 A capacitor of capacitance $1 \mu\text{F}$ is subjected to 4000 volts potential difference, the energy stored in it is:
 (a) 8 J (b) 16 J (c) 32 J (d) 64 J
- 16.9 The electric potential energy of a point charge q at some point in an electric field is equal to:
 (a) $\frac{1}{4\pi\epsilon_0} \frac{q}{r}$ (b) $\frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$ (c) qV (d) V^2
- 16.10 The time constant of a capacitor discharging through a resistor is the time in seconds in which the initial charge Q_0 drops to:
 (a) $0.25 Q_0$ (b) $0.37 Q_0$ (c) $0.50 Q_0$ (d) $0.69 Q_0$

Answer Key

Q. No.	Option	Q. No.	Option	Q. No.	Option
16.1	D	16.5	C	16.9	C
16.2	C	16.6	D	16.10	B
16.3	B	16.7	D		
16.4	C	16.8	A		

Short Answer Questions

- 16.1 If the absolute potential at a point is zero, what can you say about the electric intensity at that point?

Ans: Electric intensity at that point will not be zero.

Electric field intensity is given by:

$$E = \frac{\Delta V}{\Delta r}$$

As potential is zero but change in potential is not zero, hence $E \neq 0$. Electric field intensity can be zero in a case if electric potential is constant throughout a region of space.

16.2 Is electron volt, a unit of potential difference or energy? Explain Briefly.

Ans: Electron volt is a unit of energy.

As electron volt is the energy acquired or lost by an electron when it traverses through a potential difference of one volt. It is a smaller unit of energy.

$$\begin{aligned}\Delta(K.E) &= q\Delta V \\ &= 1e \times 1V \\ 1eV &= 1.6 \times 10^{-19}J\end{aligned}$$

16.3 Define capacitance and write its units.

Ans: The amount of charge stored on either plate necessary to raise potential difference of one volt is called capacitance.

The SI unit of capacitance is farad (F).

$$1\text{farad} = \frac{1\text{coulomb}}{1\text{volt}}$$

16.4 Define dielectric constant. Give its mathematical form.

Ans: The ratio of the capacitance of a parallel plate capacitor with an insulating material as medium between the plates to its capacitance with vacuum as medium between them is called dielectric constant.

Mathematically, $\epsilon = \frac{C_{\text{med}}}{C_{\text{vac}}}$

As it is a ratio of similar quantities, so it has no units.

16.5 How does the capacitance of a capacitor change if the separation between its plates is increased?

Ans: The capacitance of a capacitor decreases if separation between the plates is increased.

The capacitance of a parallel plate capacitor is given by:

$$C = \frac{A\epsilon_0}{d}$$

As capacitance is inversely related to the distance between the plates, so with the increase in separation, capacitance decreases.

16.6 When will the energy stored in three capacitors be greater?

(i) They are connected in series

(ii) They are connected in parallel

Ans: The energy stored in three capacitors will be greater when they are connected in parallel.

The equivalent capacitance in parallel combination is greater than the series combination.

As energy stored in capacitor is given by:

$$U = \frac{1}{2}CV^2$$

Greater is the capacitance, greater will be the energy stored.

16.7 What is the time constant? Write its formula.

Ans: It is the time required by the capacitor to deposit 0.63 times the equilibrium charge q_0 . It shows rate of charging or discharging of a capacitor.

Formula: $\tau = RC$

Its unit is second(s).

Constructed Response Questions

16.1 How is electric potential different from electrical potential energy? Give an example to explain the difference.

Ans.

Electric Potential	Electric Potential Energy
It is the amount of work done in bringing a unit positive charge from infinity to that point by keeping it in equilibrium.	The energy possessed by a charge in an electric field due to its position.
It is denoted by V and its formula is $V = \frac{kq}{r}$	$U = q\Delta V$
Its unit is volt.	Its unit is joule or eV.

16.2 How does the concept of electric potential help to understand the motion of charges in an electric field?

Ans: As the direction of electric field is always from positive to negative, this concept helps to understand the direction of motion of charges. Positive charges are considered at high potential, so they move towards low potential. In the same way negative charges are considered low potential, so they move towards the high potential.

16.3 The electric field is negative of gradient of potential. What does the negative sign indicate physically? Illustrate your answer with an example.

Ans: The negative sign indicates that the direction of electric field is towards the decreasing electric potential.

According to the formula:

$$\vec{E} = -\frac{\Delta V}{\Delta r}$$

A positive charge moves from high potential to low potential, losing potential energy as it gains kinetic energy.

Example: A person walking down a steep hill, the height of hill is potential (V). The decrease in gravitational potential energy is maximum at steepest slope. The steepness of the hill is maximum slope or gradient $\frac{\Delta V}{\Delta r}$

16.4 When a capacitor is charging, no actual charge flows across the gap between the plates. But the current is still said to be flowing. Explain.

Ans: When a capacitor is connected with a battery, it places a charge +Q on the plate connected with its positive terminal. Due to electrostatic induction an equal number of negative charges appear on the other plate. This creates the potential difference which establishes the electric field between the plates. This was done by conduction current which we say an actual current flowing one way. That is why a current is said to be flowing even though no actual charge flows across the gap.

16.5 Two capacitors can be connected in parallel or in series. Explain how does total energy stored differ in two configurations.

Ans: For the same applied voltage, more energy will be stored in parallel combination.

Capacitors connected in series	Capacitors connected in parallel
When they are connected in series, C_{eq} decreases by the following relation: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$ Energy stored is given as: $U = \frac{1}{2} CV^2$ As C_{eq} is smaller, so energy stored would be less in this configuration.	In this combination C_{eq} increases by the following relation $C_{eq} = C_1 + C_2 + C_3$ Energy stored is given as: $U = \frac{1}{2} CV^2$ As C_{eq} is greater, so energy stored would be greater in this configuration.

16.6 A capacitor stores energy. Is this energy stored on the plates, in the dielectric or in the electric field? Explain how does a capacitor stores energy.

Ans: A capacitor stores energy in an electric field between the plates.

During the charging process the positive charges are stored on one of the plates. Due to electrostatic induction an equal number of negative charges appear on the other plate. This creates the potential difference which establishes the electric field between the plates. The energy stored is given by:

$$U = \frac{1}{2} \epsilon_0 E^2 (Ad)$$

16.7 Why does capacitance increase on inserting a dielectric between the plates of a capacitor? Explain.

Ans: A dielectric increases the capacitance by reducing the electric field between the plates of capacitor. If a dielectric of relative permittivity ϵ_r is inserted between the plates, due to polarization net electric field and potential difference decreases. Hence capacitance increases.

$$C_{\text{med}} = \epsilon_r C_{\text{vac}}$$

Numerical Problems

16.1 A particle carrying a charge of $0.1 \mu\text{C}$ starts from rest in a uniform electric field of intensity 60 N C^{-1} . Find the kinetic energy acquired by the particle, when it has moved 2 m .

Given data:

$$\begin{aligned} q &= 0.1 \mu\text{C} = 0.1 \times 10^{-6} \text{ C} \\ E &= 60 \text{ N C}^{-1} \\ d &= 2 \text{ m} \end{aligned}$$

To find:

$$\text{K.E} = ?$$

Solution:

$$\begin{aligned} E &= \frac{F}{q} \\ F &= qE \\ F &= (0.1 \times 10^{-6})(60) \\ F &= 6.0 \times 10^{-5} \text{ N} \end{aligned}$$

Now, we know that $\text{K.E} = W$

$$\text{K.E} = Fd = 6.0 \times 10^{-5} \times 2$$

$$\text{K.E} = 1.2 \times 10^{-5} \text{ J} \quad \text{Ans}$$

16.2 What should be the potential difference through which an electron falls to acquire a speed of $2 \times 10^6 \text{ m s}^{-1}$?

Given data:

$$\begin{aligned} v &= 2 \times 10^6 \text{ m s}^{-1} \\ e &= 1.6 \times 10^{-19} \text{ C} \\ m &= 9.1 \times 10^{-31} \text{ kg} \end{aligned}$$

To find:

$$\Delta V = ?$$

Solution:

$$\begin{aligned} \text{K.E} &= q\Delta V \\ \frac{1}{2}mv^2 &= q\Delta V \\ \Delta V &= \frac{1}{q} \times \frac{1}{2}mv^2 \\ \Delta V &= \frac{1}{1.6 \times 10^{-19}} \times \frac{1}{2} (9.1 \times 10^{-31})(2 \times 10^6)^2 \\ \Delta V &= 11.4 \text{ V} \quad \text{Ans} \end{aligned}$$

16.3 The potential difference between points A and B is $V_A - V_B = 84 \text{ V}$, while the potential difference between points C and B is $V_C - V_B = 24 \text{ V}$. What should be the work done on moving a $40 \mu\text{C}$ charge from C to A?

Given data:

$$V_A - V_B = 84 \text{ V}$$

$$V_C - V_B = 24 \text{ V}$$

$$q = 40 \text{ } \mu\text{C} = 40 \times 10^{-6} \text{ C}$$

To find:

$$W = ?$$

Solution:

$$K.E = W = q\Delta V$$

$$W = q(V_C - V_A)$$

$$\Delta V = (V_A - V_B) - (V_C - V_B) \quad (\text{Here } \Delta V = V_C - V_A)$$

$$\Delta V = 84 - 24$$

$$\Delta V = 60 \text{ V}$$

$$W = 40 \times 10^{-6} \times (60)$$

$$W = 2.4 \times 10^{-3} \text{ J} \quad \text{Ans}$$

16.4 A parallel plate capacitor has a capacitance of $6 \text{ } \mu\text{F}$ when filled with a dielectric. The area of each plate is 1.2 m^2 and the separation between the plates is $9 \times 10^{-6} \text{ m}$. What is the dielectric constant?

Given data:

$$C = 6 \text{ } \mu\text{F} = 6 \times 10^{-6} \text{ F}$$

$$A = 1.2 \text{ m}^2$$

$$d = 9 \times 10^{-6} \text{ m}$$

$$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$$

To find:

$$\epsilon_r = ?$$

Solution:

$$C = \frac{A\epsilon_0\epsilon_r}{d}$$

$$\epsilon_r = \frac{C \times d}{A\epsilon_0}$$

$$\epsilon_r = \frac{(6 \times 10^{-6}) \times (9 \times 10^{-6})}{1.2 \times 8.85 \times 10^{-12}}$$

$$\epsilon_r = 5.1 \quad \text{Ans}$$

16.5 A $15 \text{ } \mu\text{F}$ capacitor is charged till the potential difference across its plates becomes 300 V . Find the energy stored in it.

Given data:

$$C = 15 \text{ } \mu\text{F} = 15 \times 10^{-6} \text{ F}$$

$$\Delta V = 300 \text{ V}$$

To Find:

$$U = ?$$

Solution:

$$U = \frac{1}{2} CV^2$$

$$U = \frac{1}{2} \times (15 \times 10^{-6}) \times (300)^2$$

$$U = 0.675 \text{ J} \quad \text{Ans}$$

16.6 Two capacitors of $2.0 \text{ } \mu\text{F}$ and $8.0 \text{ } \mu\text{F}$ capacitances are connected in series and a potential difference of 300 volts is applied. Find the charge and potential difference for each capacitor.

Given data:

$$C_1 = 2.0 \text{ } \mu\text{F} = 2.0 \times 10^{-6} \text{ F}$$

$$C_2 = 8.0 \text{ } \mu\text{F} = 8.0 \times 10^{-6} \text{ F}$$

$$V = 300 \text{ V}$$

To find:

$$Q_1 = ?$$

$$Q_2 = ?$$

$$V_1 = ?$$

$$V_2 = ?$$

Solution:

For Series Combination,

$$Q_1 = Q_2 = Q$$

$$Q = C_{eq} V$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C_{eq}} = \frac{1}{2.0 \times 10^{-6}} + \frac{1}{8.0 \times 10^{-6}}$$

$$C_{eq} = 1.6 \times 10^{-6} \text{ F}$$

$$Q = (1.6 \times 10^{-6}) \times 300$$

$$Q_1 = Q_2 = 4.8 \times 10^{-4} \text{ C}$$

Now,

$$V_1 = \frac{Q_1}{C_1} = \frac{4.8 \times 10^{-4}}{2.0 \times 10^{-6}}$$

$$V_1 = 240 \text{ V}$$

$$V = V_1 + V_2$$

$$V_2 = V - V_1$$

$$V_2 = 300 - 240$$

$$V_2 = 60 \text{ V}$$

$$V_1 = 240 \text{ V and } V_2 = 60 \text{ V} \quad \text{Ans}$$

16.7 A capacitor has a capacitance of $3 \mu\text{F}$. It is charged by a battery. When the potential difference between the plates is 240 volts, how many electrons have been removed from one plate and placed on the other plate?

Given data:

$$C = 3 \mu\text{F} = 3 \times 10^{-6} \text{ F}$$

$$\Delta V = 240 \text{ V}$$

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

To Find:

$$n = ?$$

Solution:

$$Q = CV$$

$$ne = CV$$

$$\therefore Q = ne$$

$$n = \frac{CV}{e}$$

$$n = \frac{(3 \times 10^{-6}) \times 240}{1.6 \times 10^{-19}}$$

$$n = 4.5 \times 10^{15} \text{ electrons} \quad \text{Ans}$$

16.8 Two positive point charges are held at two points 1.2 m apart. They are then moved towards each other so that their electrical potential energy becomes double of its previous value. How much are they apart at their new positions?

Given data:

$$r_1 = 1.2 \text{ m}$$

$$U_2 = 2U_1$$

To Find:

$$r_2 = ?$$

Solution:

$$U_1 = k \frac{q_1 q_2}{r_1}$$

$$U_2 = 2U_1$$

$$k \frac{q_1 q_2}{r_2} = 2k \frac{q_1 q_2}{r_1}$$

$$\frac{1}{r_2} = \frac{2}{r_1}$$

$$r_2 = \frac{1}{2} r_1$$

$$r_2 = \frac{1}{2} \times 1.2$$

$$r_2 = 0.6 \text{ m} \quad \text{Ans}$$

16.9 A $100 \mu\text{F}$ capacitor is initially charged to 8 V . It is allowed to discharge through a 500Ω resistor. Find the voltage across the capacitor after 0.5 s .

Given data:

$$C = 100 \mu\text{F}$$

$$V_0 = 8 \text{ V}$$

$$R = 500 \Omega$$

$$t = 0.5 \text{ s}$$

To Find:

$$V = ?$$

Solution:

$$RC = \tau$$

$$500 \times (100 \times 10^{-6}) = \tau$$

$$\tau = 0.05 \text{ s}$$

Now,

$$V = V_0 e^{-\frac{t}{RC}}$$

$$V = 8 \times e^{-\frac{0.5}{0.05}}$$

$$V = 3.6 \times 10^{-4} \text{ V} \quad \text{Ans}$$

Chapter 17

Alternating Current

Exercise Multiple Choice Questions

- 17.1** Name of device that is used as a part of charging circuit for mobile phones is:
 (a) full-wave bridge rectifier (b) half-wave rectifier (c) AC generator (d) battery
- 17.2** A $10\ \mu\text{F}$ capacitor is plugged into a $110\ \text{V}_{\text{rms}}$, $60\ \text{Hz}$ voltage source, with an ammeter in series. The value of I_{rms} that passes through the capacitor is:
 (a) $0.0415\ \text{A}$ (b) $0.415\ \text{A}$ (c) $415\ \text{A}$ (d) $0.0415\ \text{mA}$
- 17.3** In an RC-circuit, a $10\ \text{k}\Omega$ resistance is connected in series to a capacitor of $0.05\ \mu\text{F}$. The applied voltage for charging is $36\ \text{V}$, the RC-time constant to charge capacitor is:
 (a) $0.0578\ \text{ms}$ (b) $0.009\ \text{ms}$ (c) $0.500\ \text{ms}$ (d) $5.49\ \text{ms}$
- 17.4** In a purely inductive or capacitive circuit, the average power consumed is:
 (a) equal to apparent power (b) minimum (c) maximum (d) zero
- 17.5** Through which of the AC-circuit elements both emf and current are in phase?
 (a) resistance (b) inductor (c) capacitor (d) LED
- 17.6** If magnetic field is doubled in an inductor, then magnetic energy density becomes:
 (a) 6 times (b) half (c) 4 times (d) constant
- 17.7** RC-time constant is measured in:
 (a) ohm (b) henry (c) volt (d) second
- 17.8** The magnitude of mutual inductance M between two coils when current changes at $20\ \text{A s}^{-1}$ in one coil induces an emf of $50\ \text{mV}$ in the other is:
 (a) $5\ \text{mH}$ (b) $2.5\ \text{mH}$ (c) $0.0025\ \mu\text{H}$ (d) $25\ \text{mH}$

Answer Key					
Q. No.	Option	Q. No.	Option	Q. No.	Option
17.1	A	17.4	D	17.7	D
17.2	B	17.5	A	17.8	B
17.3	C	17.6	C		

Short Answer Questions

17.1 What impacts does resistance have on capacitance?

Ans: Resistance has no impact on capacitance

As $C = \frac{Q}{V}$

Hence by changing the resistance, capacitance does not change.

17.2 What happens when an AC line touches a DC line?

Ans: When AC line touches DC line, it results in a superposition of both signals, creating a fluctuating DC voltage. This can lead to heavy flow of currents and a severe short circuit.

17.3 What is the difference between peak to peak and amplitude in case of sine wave?

Ans: Peak-to-Peak Value: This is the total distance from the positive peak to the negative peak of the waveform. For a symmetrical sine wave:

$$V_{P-P} = 2V_0$$

Amplitude: It is the highest value that an AC waveform reaches during one cycle. It is represented by V_0 .

17.4 Why are RC-circuits used in timing circuits?

Ans: As time constant is given by

$$\tau = RC$$

Here time constant depends on R and C. Therefore, RC-circuits are useful for controlling time intervals in timing circuits like motion of wind screen wipers.

17.5 Why are choke coils preferred over resistors for limiting current in AC circuits?

Ans:

- It has very high self-inductance and very low resistance.
- It limits current with no power dissipation as heat.

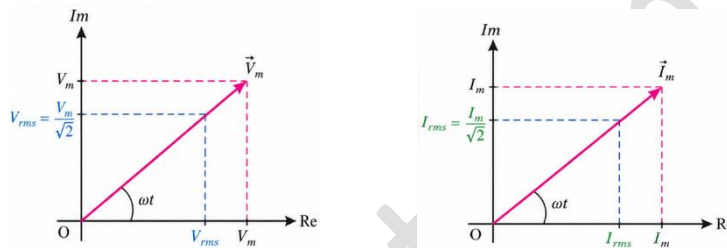
17.6 Define rms values of voltage and current with their phasor diagrams.

Ans: The rms value of AC is equivalent value of direct current that would produce same heat in given resistor as AC in complete cycle.

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}} = 0.707 V_0$$

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0$$

Phasor Diagram:



Constructed Response Questions

17.1 What do you mean by rating of electrical appliances? Explain briefly.

Ans: The rating of an electrical appliance specifies the value of voltage, current, and power consumption for its safe and efficient operation. It indicates the conditions under which the appliance gives its best performance without being damaged.

17.2 The energy stored in an inductor is analogous to the kinetic energy of a moving mass? Justify.

Ans: Yes, because both are associated with motion and oppose sudden changes.

When current flows through an inductor, a magnetic field is produced around it, and energy is stored in this magnetic field. Similarly, a moving object stores energy in the form of kinetic energy due to its motion. The energy stored in an inductor is given by:

$$U_m = \frac{1}{2} L I^2$$

This equation is similar to the kinetic energy of a moving body:

$$\text{K. E.} = \frac{1}{2} m v^2$$

Thus, inductance (L) plays a role similar to mass (m), and current (I) is analogous to velocity (v). Just as a massive body resists a change in its velocity, an inductor resists a change in the current flowing through it.

17.3 What are safety measures to take when working with AC or DC?

Ans: **Safety Measures When Working with AC or DC**

The following safety measures should be observed when working with AC or DC circuits:

- Always switch OFF the power supply before working on any electrical circuit or appliance.
- Never touch electrical wires or equipment with wet hands or while standing on a wet surface.
- Use insulated tools and ensure that all wires are properly insulated.
- Do not overload electrical circuits and always use the correct fuse or circuit breaker.
- Replace damaged or exposed wires immediately to prevent electric shock.

vi. Keep electrical appliances away from water and follow safety instructions.

17.4 How does self-induction manifest when a current is switched on or off in a circuit?

- When the current is switched ON, the current begins to increase, producing a changing magnetic field. This changing magnetic field induces a back emf in the coil, which opposes the increase in current. As a result, the current rises gradually instead of instantly.
- When the current is switched OFF, the magnetic field around the coil falls rapidly. This changing magnetic field induces an emf in the same direction as the original current, trying to keep the current flowing. As a result, a high induced voltage may be produced, which can cause a spark across the switch.

17.5 Is it possible to achieve mutual inductance using a combination of four coils? If yes, justify your answer.

Ans: Yes, it is possible to achieve mutual inductance using a combination of four coils. When four coils are placed close to one another, a change in current in any one coil produces a changing magnetic field. This changing magnetic field links with the other coils and induces an emf in them according to Faraday's law of electromagnetic induction. Thus, each coil can have mutual inductance with the other coils.

17.6 The currents of the order of 0.1 A through human body is fatal; what causes death; heating due to current or something else?

Ans: A current of about 0.1 A (100 mA) passing through the human body can be fatal. Death is not mainly caused by the heating effect of the current. It occurs because the electric current disturbs the normal heartbeat. The heart may stop pumping blood properly, which can lead to death.

Numerical Problems

17.1 AC circuit configured by a resistance of $20\ \Omega$, capacitor of capacitance $40\ \mu\text{F}$ is connected to an AC supply of 110 V having frequency 50 Hz. Calculate: (a) capacitive reactance. (b) current in the circuits. (c) suggest phase between the voltage and current in a capacitive circuit.

Given data:

$$\begin{aligned}R &= 20\ \Omega \\C &= 40\ \mu\text{F} = 40 \times 10^{-6}\ \text{F} \\V &= 110\ \text{V} \\f &= 50\ \text{Hz}\end{aligned}$$

To find:

$$\begin{aligned}\text{(a) } X_C &=? \\ \text{(b) } I &=? \\ \text{(c) } \theta &?\end{aligned}$$

Solution:

(a) Capacitive Reactance:

$$\begin{aligned}X_C &= \frac{1}{2\pi fC} \\X_C &= \frac{1}{2\pi(50)(40 \times 10^{-6})} \\X_C &= 79.58\ \Omega\end{aligned}$$

(b) Current in the circuit:

$$\begin{aligned}Z &= \sqrt{X_C^2 + R^2} \\Z &= \sqrt{(79.58)^2 + (20)^2} \\Z &= \sqrt{6732.97} \\Z &= 82\ \Omega\end{aligned}$$

$$I = \frac{V}{Z}$$

$$I = \frac{110}{82}$$

$$I = 1.34 \text{ A}$$

(c) Phase difference:

$$\theta = \tan^{-1} \left(\frac{X_c}{R} \right)$$

$$\theta = \tan^{-1} \left(\frac{79.58}{20} \right)$$

$$\theta = \tan^{-1}(3.97)$$

$$\theta = 75.9^\circ$$

Current leads voltage by 75.9°

17.2 An alternating current I is represented by the equation: $I = 420 \sin(100\pi t)$.

Find: (a) the rms current (b) the frequency

Given data:

$$I = 420 \sin(100\pi t)$$

To find:

- (a) The rms current
- (b) The frequency

Solution:

$$I = 420 \sin(100\pi t)$$

Comparing with

$$I = I_0 \sin \omega t = I_0 \sin 2\pi f t$$

Peak value of current

$$I_0 = 420 \text{ A}$$

Angular frequency

$$\omega = 100\pi$$

(a) The rms Current:

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

$$I_{\text{rms}} = \frac{420}{1.414}$$

$$I_{\text{rms}} = 296.94 \text{ A}$$

(b) Frequency:

$$\omega = 2\pi f$$

$$100\pi = 2\pi f$$

$$f = 50 \text{ Hz}$$

17.3 A 50 Hz AC of peak value 1 A flows through the primary coil of a transformer. If the mutual inductance between the primary and secondary be 1.5 H, then find the mean value of induced voltage.

Given data:

$$f = 50 \text{ Hz}$$

$$I_0 = 1 \text{ A}$$

$$M = 1.5 \text{ H}$$

To find:

$$\mathcal{E}_{\text{mean}} = ?$$

Solution:

Angular frequency:

$$\omega = 2\pi f$$

$$\omega = 314 \text{ rad s}^{-1}$$

Maximum induced emf:

$$\mathcal{E}_0 = M\omega I_0$$

$$\mathcal{E}_0 = 1.5(314)(1)$$

$$\mathcal{E}_0 = 471 \text{ V}$$

The mean value of a value of induced emf over one cycle:

$$\begin{aligned}\mathcal{E}_{\text{mean}} &= \frac{2}{\pi} \mathcal{E}_0 \\ \mathcal{E}_{\text{mean}} &= 0.637(471) \\ \mathcal{E}_{\text{mean}} &= \mathbf{300V}\end{aligned}$$

17.4 A 220 V AC source of frequency 2 kHz is connected across a capacitor of 10 μF . Find out:(a) the reactance X_C of capacitor (b) the current in the circuit.

Given data:

$$\begin{aligned}V &= 220 \text{ V} \\ f &= 2 \text{ kHz} = 2000\text{Hz} \\ C &= 10 \mu\text{F} = 10 \times 10^{-6}\text{F}\end{aligned}$$

To find:

- (a) $X_C = ?$
(b) $I = ?$

Solution:

(a) The reactance X_C of capacitor:

$$\begin{aligned}X_C &= \frac{1}{2\pi fC} \\ &= \frac{1}{2\pi(2000)(10 \times 10^{-6})} \\ X_C &= \mathbf{7.96\Omega}\end{aligned}$$

(b) The current in the circuit:

$$\begin{aligned}I &= \frac{V}{X_C} = \frac{220}{7.96} \\ I &= \mathbf{27.63A}\end{aligned}$$

17.5 In a coil of inductance 150 mH, a current changes steadily from 50 mA to 30 mA in 164 ms, find: (a) the magnitude (b) direction of induced emf.

Given data:

$$\begin{aligned}L &= 150 \text{ mH} = 150 \times 10^{-3}\text{H} = 0.150 \text{ H} \\ \Delta I &= 50 \text{ mA} - 30 \text{ mA} = 20 \text{ mA} = 0.020 \text{ A} \\ \Delta t &= 164\text{ms} = 0.164 \text{ s}\end{aligned}$$

To find:

- (a) The magnitude of induced emf
(b) Direction of induced emf

Solution:

(a) The magnitude of induced emf:

$$\begin{aligned}\mathcal{E}_L &= L \frac{\Delta I}{\Delta t} \\ &= 0.150 \left(\frac{0.020}{0.164} \right) \\ \mathcal{E}_L &= 0.01829\text{V} \\ \mathcal{E}_L &= \mathbf{18.29mV}\end{aligned}$$

(b) Direction of induced emf:

Since the current is decreasing, according to Lenz's law, the induced emf opposes the decrease by maintaining the current. Same direction as the original current.

17.6 A choke coil is needed to operate a lamp at 160 V_{rms} and 50 Hz. The lamp has a resistance of 5 Ω when running at 10 A_{rms} . Calculate the inductance of the choke coil.

Given data:

$$\begin{aligned}V_{\text{rms}} &= 160 \text{ V} \\ f &= 50\text{Hz} \\ R &= 5 \Omega \\ I_{\text{rms}} &= 10 \text{ A}\end{aligned}$$

To find:

$$L = ?$$

Solution:

$$Z = \frac{V_{\text{rms}}}{I_{\text{rms}}}$$

$$Z = \frac{160}{10} = 16\Omega$$

$$Z = \sqrt{R^2 + X_L^2}$$

$$16^2 = 5^2 + X_L^2$$

$$X_L = \sqrt{256 - 25}$$

$$X_L = 15.20\Omega$$

$$X_L = 2\pi fL$$

$$L = \frac{15.20}{2\pi(50)}$$

$$L = 0.0484\text{H}$$

$$\mathbf{L = 48.4mH}$$

Chapter 18

Quantum Physics

Exercise Multiple Choice Questions

- 18.1. Which particle is emitted when UV light is made incident on a zinc surface?
(a) Photon (b) Positron (c) Electron (d) Alpha Particle
- 18.2. The wave nature of electrons is supported by experiments on:
(a) line spectrum of atoms (b) the production of X-rays
(c) photoelectric effect (d) electron diffraction by crystalline material
- 18.3. The dimensions of Planck's constant are same as that of:
(a) momentum (b) torque (c) gravitational constant (d) angular momentum
- 18.4. Which of the following has the most energetic photons?
(a) Light waves (b) Microwave (c) X-rays (d) Gamma rays
- 18.5. de-broglie waves are associated with:
(a) moving charged particles only (b) moving neutral particles only
(c) all moving particles (d) all particles whether in motion or at rest
- 18.6. An electron microscope employs the principle:
(a) electron have a wave nature (b) electron can be focused by an electric field
(c) electron can be focused by a magnetic field (d) all of the above
- 18.7. Electron, proton, neutron and alpha particle, all have the same speed, which particle will have the shortest wavelength?
(a) Electron (b) Proton (c) Neutron (d) Alpha particle
- 18.8. The Balmer series is obtained when all the transitions of electrons terminate at:
(a) $n = 1$ (b) $n = 2$ (c) $n = 3$ (d) $n = 4$
- 18.9. The spectrum in which different colours are not diffused into each other and are separated by dark spaces is usually known as:
(a) line spectrum (b) Continuous spectrum (c) band spectrum (d) absorption spectrum
- 18.10. Using uncertainty principle, it can be proved that:
(a) light has particle nature (b) light has wave nature
(c) electron lies out of the nucleus
(d) there is always uncertainty in measuring accurately energy and momentum for atomic particles
- 18.11. According to uncertainty principle, in order to observe the position of an electron with greater accuracy, we must use light of:
(a) longer wavelength (b) shorter wavelength (c) single wavelength (d) any wavelength

Answer Key

Q. No.	Option	Q. No.	Option	Q. No.	Option	Q. No.	Option
18.1	C	18.4	D	18.7	D	18.10	C
18.2	D	18.5	C	18.8	B	18.11	B
18.3	D	18.6	D	18.9	A		

Short Answer Questions

- 18.1 How energy of a packet is related to its frequency according to quantum theory? Describe briefly.

Ans: According to quantum theory, energy of a packet is related to its frequency as:

$$E = hf$$

$$E \propto f$$

Max Planck suggested that energy is radiated or absorbed in discrete packets of energy called quanta rather than as a continuous wave. Higher the frequency of the wave, greater is the energy of each packet and vice versa.

18.2 How does the photoelectric current vary with intensity of incident light on a metal surface?

Ans If frequency of incident light is kept constant then photoelectric current increases with increase in intensity of light and it decreases with decrease in intensity of light.

18.3 Which has more energy, a photon of UV radiation or a photon of yellow light? Describe briefly.

Ans: The photon of UV radiation has more energy than yellow light.

The energy of photon depends on frequency of radiation as:

$$E = hf$$

Since, frequency of UV is higher than yellow light, hence photon of UV radiation has more energy.

18.4 Is work function of a metal related to threshold frequency in a photoelectric emission? State briefly.

Ans: Yes, work function of a metal is related to threshold frequency in a photoelectric emission.

The work function ϕ and threshold frequency f_0 are related as,

$$\phi = hf_0 \quad (\text{where } h = 6.63 \times 10^{-34} \text{ J s})$$

$$\phi \propto f_0$$

It means work function is directly proportional to threshold frequency.

18.5 Explain briefly, why we can observe the wave-like properties of electrons but not for a flying tennis ball.

Ans: The de Broglie wavelength is given by:

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

The speed of flying tennis ball is very small, and its mass is relatively larger as compared to mass of an electron. The de Broglie wavelength of a flying tennis ball is very small as compared to electron. Hence, we can observe the wave-like properties of electrons but not for a flying tennis ball.

18.6 Radiation with a certain frequency causes electrons to be emitted from the surface of one metal and not from the surface of another metal. Why?

Ans: For every metal there is a suitable value of frequency of incident electromagnetic radiation which causes electrons to be emitted from the surface of metal. This frequency is called threshold frequency. Threshold frequency is different for different metals and it depends upon nature of metal surface.

18.7 Will high frequency light has more number of electrons than a low frequency light? Describe briefly.

Ans. No, the number of electrons does not depend on frequency of light.

The number of electrons depends only on the intensity of light. Therefore, higher frequency or lower frequency will not change the number of electrons.

18.8. When does light behave as a wave and when does it behave as a particle?

Ans: The light behaves as a wave in diffraction, interference and polarization.

It behaves as a particle in photoelectric effect, Compton effect and pair production.

18.9. Name two possible spectral line series in the spectrum of atomic hydrogen. In which region of electromagnetic spectrum each lies?

Ans: In atomic hydrogen, two possible spectral line series are:

(i) Lyman series. Its wavelengths are given by the formula:

$$\frac{1}{\lambda} = R_H \left(\frac{1}{1^2} - \frac{1}{n^2} \right), \text{ where } n = 2, 3, 4, \dots$$

$$R_H = \text{Rydberg constant} = 1.097 \times 10^7 \text{ m}^{-1}$$

It lies in ultraviolet region of electromagnetic spectrum.

(ii) Balmer series. Its wavelengths are given by the formula:

$$\frac{1}{\lambda} = R_H \left(\frac{1}{2^2} - \frac{1}{n^2} \right), \text{ where } n = 3, 4, 5, \dots$$

It lies in visible region of electromagnetic spectrum.

18.10 What is meant by shift, and on which factors does it depend?

Ans: The change in wavelength $\Delta\lambda$ of incident photon after collision with an electron is known as Compton shift. It is given by the formula

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

It depends only on scattering angle θ .

Constructed Response Questions

18.1 Why do solids give rise to a continuous spectrum while hot vapours emit line spectrum?

Ans: Continuous or line spectrum depends on the arrangement of atoms and their interaction with each other. Solids give rise to a continuous spectrum because atoms are closely packed and constantly interacting with each other. Whereas in hot vapours, atoms are far apart and hence they emit line spectrum.

18.2 Light can emit electrons from a metal surface and light can also be diffracted. Comment on the statement.

Ans: Light has dual nature.

When it emits electrons from a metal surface, it behaves as a particle.

In diffraction, it behaves as a wave.

18.3 Why X-rays have different properties from light even though both originate from the transition of electrons between different energy levels in excited atoms? Describe briefly.

Ans: **X-rays:** They are emitted due to the inner shell transition of electrons. These electrons are tightly bound to the nucleus, so they have large energy.

Ordinary light: It is emitted due to the outer shell transition. These electrons are loosely bound to nucleus, so they have less energy.

18.4 Is energy conserved when an atom emits a photon of light? Describe how.

Ans: Yes, energy is conserved when an atom emits a photon of light.

An atom is excited when it absorbs the energy from some external source. The same energy is emitted in the form of photon when it is deexcited.

18.5 How can spectrum of hydrogen atom contains many spectral lines when hydrogen atom contains one electron only?

Ans: There are infinite energy levels around the nucleus of hydrogen atom. Although hydrogen atom contains one electron but its transition can take place from different energy levels. For each transition the electron will emit a spectral line which will have different energy from other spectral line.

18.6 What should be the speed of an electron if it is to be confined in a box of the size of a nucleus?

Ans: $\Delta x = 10^{-15} \text{ m}$
 $m = 9.1 \times 10^{-31} \text{ kg}$
 $\Delta v = ?$

Using Heisenberg uncertainty principle

$$\Delta p \cdot \Delta x = h$$

$$m \Delta v \cdot \Delta x = h \Rightarrow \Delta v = \frac{h}{m \Delta x}$$

$$\Delta v = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 10^{-15}}$$

$$\Delta v = 0.73 \times 10^{12} = 7.3 \times 10^{11} \text{ m s}^{-1}$$

18.7 An incident X-ray on a metal surface is scattered. What is the wavelength, frequency, energy and speed of the scattered X-ray as compared to incident X-ray?

Ans: According to Compton's effect

- (i) Wavelength of scattered X-ray is greater than wavelength of incident X-ray photon.
- (ii) Frequency of scattered X-ray is less than frequency of incident X-ray photon.
- (iii) Energy of scattered X-ray is less than energy of incident X-ray photon.

- (iv) Speed of scattered X-ray is equal to speed of incident X-ray photon. It happens because, for electromagnetic waves $c = f\lambda$.

18.8 Why does energy and momentum conservation play a key role in driving Compton's effect?

Ans: Compton's scattering is considered as an elastic collision between two particles i.e., photon and electron. Therefore, particle collision must obey the laws of conservation of energy and momentum. Energy conservation shows how much energy a photon transfers to an electron. The momentum conservation depends on angle of scattering. If we ignore either one of these, we will not get Compton's shift at all.

18.9 Describe how a line emission spectrum leads to understand the existence of discrete electron energy levels in atoms?

Ans: The spectrum which consists of radiation of discrete frequencies within the certain limit of frequencies is called line spectrum. For example, atomic spectra. The differences between energy levels of the atom are unique for a particular element. Therefore, line emission spectrum can be used to understand the existence of discrete electron energy levels in atoms.

18.10 Mass of a photon is considered zero, then how does the photon possess momentum? Describe.

Ans: A photon possesses momentum because it depends on energy not its mass. From quantum theory,

$$E = hf = \frac{hc}{\lambda} \text{-----(1)}$$

From theory of relativity,

$$E = mc^2 = (mc)c$$

$$E = pc \text{-----(2)}$$

Comparing equation (1) and (2),

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

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

Since, photons have energy, so they possess momentum.

Numerical Problems

18.1 A photon has wavelength 350 nm. What is its energy in joules and also in eV?

Given data:

$$\lambda = 350 \text{ nm} = 350 \times 10^{-9} \text{ m}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

$$c = 3 \times 10^8 \text{ m s}^{-1}$$

To find:

$$E = ?$$

Solution:

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

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{350 \times 10^{-9}} = 0.0568 \times 10^{-17}$$

$$E = 5.68 \times 10^{-19} \text{ J}$$

$$E = 5.68 \times 10^{-19} \times \frac{1}{1.6 \times 10^{-19}} \text{ eV} \quad (\because 1\text{eV} = 1.6 \times 10^{-19} \text{ J})$$

$$E = 3.55 \text{ eV}$$

18.2 A certain atom has a separation in energy of $3 \times 10^{-18} \text{ J}$ between two of its energy levels. What frequency photon is required to make the atom change from the lower state to higher state?

Given data:

$$E_n - E_p = 3 \times 10^{-18} \text{ J}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

To find:

$$f = ?$$

Solution:

$$E_n - E_p = \Delta E = hf$$

$$f = \frac{\Delta E}{h}$$

$$f = \frac{3 \times 10^{-18}}{6.63 \times 10^{-34}}$$

$$= \frac{3}{6.63} \times 10^{-18+34}$$

$$= 0.45 \times 10^{16}$$

$$f = 4.5 \times 10^{15} \text{ Hz}$$

18.3 What is the wavelength of photon with an energy of $10 \times 10^{-19} \text{ J}$?

Given data:

$$E = 10 \times 10^{-19} \text{ J}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

$$c = 3 \times 10^8 \text{ m s}^{-1}$$

To find:

$$\lambda = ?$$

Solution:

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

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

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

$$= 6.63 \times 3 \times 10^{-34+8+19-1}$$

$$= 19.9 \times 10^{-8} \text{ m}$$

$$\lambda = 1.99 \times 10^{-7} \text{ m}$$

18.4 Calculate the threshold frequency for sodium metal whose work function is 2.28 eV and the value of h is $6.63 \times 10^{-34} \text{ J s}$.

Given data:

$$\phi = 2.28 \text{ eV} = 2.28 \times 1.6 \times 10^{-19} \text{ J}$$

$$h = 6.63 \times 10^{-34} \text{ J-s}$$

To find:

$$f_0 = ?$$

Solution:

$$\phi = hf_0$$

$$f_0 = \frac{\phi}{h}$$

$$f_0 = \frac{3.65 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$= 0.55 \times 10^{-19+34}$$

$$= 0.55 \times 10^{15}$$

$$f_0 = 5.5 \times 10^{14} \text{ Hz}$$

18.5. What can be the longest wavelength for photoelectric emission from tungsten if its work function is 4.54 eV.

Given data:

$$\phi = 4.54 \text{ eV} = 4.54 \times 1.6 \times 10^{-19} \text{ J}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

$$c = 3 \times 10^8 \text{ m s}^{-1}$$

To find:

$$\lambda_o = ?$$

Solution:

$$E = hf_o$$

$$\phi = \frac{hc}{\lambda_o} \quad (\because c = f_o \lambda_o \Rightarrow f_o = \frac{c}{\lambda_o})$$

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

$$\lambda_o = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{7.26 \times 10^{-19}}$$

$$= \frac{6.63 \times 3}{7.26} \times 10^{-34+8+19}$$

$$= 2.73 \times 10^{-7} \text{ m} = 2.73 \times 10^2 \times 10^{-2-7} \text{ m}$$

$$= 2.73 \times 10^{-9} \text{ m}$$

$$\lambda_o = 273 \text{ nm}$$

18.6 An electron is accelerated in an evacuated tube from rest through a potential difference of 550 V. What will be its final momentum? Calculate the wavelength associated with this electron.

Given data:

$$\lambda = 350 \text{ nm} = 350 \times 10^{-9} \text{ m}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

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

$$m = 9.11 \times 10^{-31} \text{ kg}$$

To find:

$$p = ?$$

$$\lambda = ?$$

Solution:

For p $p = mv$ -----(1)

For λ , $\lambda = \frac{h}{mv}$ ----- (2)

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

$$v^2 = \frac{2Ve}{m}$$

$$v^2 = \frac{2 \times 550 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}$$

$$= \frac{2 \times 550 \times 1.6}{9.11} \times 10^{-19+31}$$

$$v^2 = 193.2 \times 10^{12}$$

$$v = 13.9 \times 10^6$$

$$v = 1.39 \times 10^7 \text{ ms}^{-1}$$

Putting values in (1) to find p

$$p = 9.11 \times 10^{-31} \times 1.39 \times 10^7$$

$$p = 12.7 \times 10^{-31+7} = 12.7 \times 10^{-24}$$

$$p = 1.27 \times 10^{-23} \text{ N s}$$

Putting values in (2) to find λ ,

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

$$= \frac{6.63 \times 10^{-34}}{1.27 \times 10^{-23}}$$

$$= 5.22 \times 10^{-34+23}$$

$$\lambda = 5.22 \times 10^{-11} \text{ m}$$

18.7 The position of a free electron is determined with an uncertainty of 10^{-7} m . What is the uncertainty in its velocity? What would be the position of an electron after one second?

Given data:

$$\Delta x = 10^{-7} \text{ m}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

$$m = 9.11 \times 10^{-31} \text{ kg}$$

To find:

$$\Delta v = ?$$

Solution:

$$\Delta x \cdot \Delta p \geq h$$

$$\Delta x \cdot m \Delta v = h$$

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

$$= \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 10^{-7}}$$

$$= \frac{6.63}{9.1} \times 10^{-34+31+7}$$

$$= 0.7 \times 10^4$$

$$\Delta v = 7 \times 10^3 \text{ m s}^{-1}$$

The position of electron after 1 s will be anywhere within a distance of $7 \times 10^3 \text{ m}$.

18.8 A stationary nickel nucleus of mass $9.95 \times 10^{-26} \text{ kg}$ emits a photon of energy 1.17 MeV. Find:

- (i) the wavelength of the photon and its momentum.
(ii) the speed of the nucleus after the emission of photon.

Given data:

$$m = 9.95 \times 10^{-26} \text{ kg}$$

$$E = 1.17 \text{ MeV} = 1.17 \times 10^6 \times 1.6 \times 10^{-19}$$

$$= 1.87 \times 10^{-13} \text{ J}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

$$c = 3 \times 10^8 \text{ m s}^{-1}$$

To find:

- (i) $\lambda = ?$
(ii) $p = ?$
(iii) $v = ?$

Solution:

(i) For λ , $E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E}$

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.87 \times 10^{-13}} = \frac{6.63 \times 3}{1.87} \times 10^{-34+8+13}$$

$$\lambda = 10.6 \times 10^{-13} \text{ m}$$

$$\lambda = \mathbf{1.06 \times 10^{-12} \text{ m}}$$

(ii) For p , $E = pc \Rightarrow p = \frac{E}{c}$

$$p = \frac{1.87 \times 10^{-13}}{3 \times 10^8} = \frac{1.87}{3} \times 10^{-13-8}$$

$$p = 0.623 \times 10^{-21}$$

$$p = \mathbf{6.23 \times 10^{-22} \text{ N s}}$$

(iii) For v , $p = mv \Rightarrow v = \frac{p}{m}$

$$v = \frac{6.23 \times 10^{-22}}{9.95 \times 10^{-26}} = \frac{6.23}{9.95} \times 10^{-22+26}$$

$$v = 0.626 \times 10^4$$

$$v = \mathbf{6.26 \times 10^3 \text{ m s}^{-1}}$$

18.9 The work function of a metal is 3.5 eV. Light of wavelength 450 nm is incident on the surface. Find out whether electrons will be emitted by the photoelectric effect, from the surface.

Given data:

$$\phi = 3.5 \text{ eV}$$

$$\lambda = 450 \text{ nm} = 450 \times 10^{-9} \text{ m}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

$$c = 3 \times 10^8 \text{ m s}^{-1}$$

To find:

Whether electron will be emitted = ?

Solution:

$$\begin{aligned} E &= \frac{hc}{\lambda} \\ E &= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{450 \times 10^{-9}} = \frac{6.63 \times 3}{450} \times 10^{-34+8+9} \\ &= 0.0442 \times 10^{-17} \text{ J} \\ &= 0.0442 \times 10^{-17} \times \frac{1}{1.6 \times 10^{-19}} \text{ eV} \\ &= 0.0276 \times 10^{-17+19} \text{ eV} = 0.0276 \times 10^2 \text{ eV} \\ E &= 2.76 \text{ eV} \end{aligned}$$

Since, $E < \phi$,

Hence, electron will not be emitted from the surface of metal.

18.10 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° .

Given data:

$$\begin{aligned} E_0 &= 90 \text{ keV} = 90 \times 10^3 \times 1.6 \times 10^{-19} \text{ J} \\ &= 144 \times 10^{-16} \text{ J} = 1.44 \times 10^{-14} \text{ J} \\ h &= 6.63 \times 10^{-34} \text{ J s} \\ c &= 3 \times 10^8 \text{ m s}^{-1} \end{aligned}$$

(a) $\theta_1 = 30^\circ$

(b) $\theta_2 = 60^\circ$

To find:

$\lambda_0 = ?$

$\lambda_1 = ?$

$\lambda_2 = ?$

Solution:

For λ_0 $E_0 = \frac{hc}{\lambda_0} \Rightarrow \lambda_0 = \frac{hc}{E_0}$ -----(1)

$$\begin{aligned} \lambda_0 &= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.44 \times 10^{-14}} = \frac{6.63 \times 3}{1.44} \times 10^{-34+8+14} \\ &= 13.8 \times 10^{-12} \text{ m} \end{aligned}$$

$\lambda_0 = 13.8 \text{ pm}$

For Compton's scattering $\lambda = \lambda_0 + \frac{h}{m_0 c} (1 - \cos\theta)$ ----- (2)

$$\begin{aligned} \frac{h}{m_0 c} &= \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 3 \times 10^8} = \frac{6.63 \times 3}{9.1 \times 3} \times 10^{-34-8+31} = 0.243 \times 10^{-11} \text{ m} \\ &= 2.43 \times 10^{-12} \text{ m} \end{aligned}$$

For λ_1 , putting values in (2) when $\theta_1 = 30^\circ$

$$\begin{aligned} \lambda_1 &= 13.8 \times 10^{-12} + 2.43 \times 10^{-12} (1 - \cos 30^\circ) \\ &= 13.8 \times 10^{-12} + 2.43 \times 10^{-12} (1 - 0.87) \\ &= (13.8 + 2.43 \times 0.13) \times 10^{-12} \\ &= (13.8 + 0.316) \times 10^{-12} \text{ m} \end{aligned}$$

$\lambda_1 = 14.1 \text{ pm}$

For λ_2 , putting values in (2) when $\theta_1 = 60^\circ$

$$\begin{aligned} \lambda_2 &= 13.8 \times 10^{-12} + 2.43 \times 10^{-12} (1 - \cos 60^\circ) \\ &= 13.8 \times 10^{-12} + 2.43 \times 10^{-12} (1 - 0.5) \\ &= (13.8 + 2.43 \times 0.5) \times 10^{-12} \\ &= (13.8 + 1.2) \times 10^{-12} \text{ m} \end{aligned}$$

$\lambda_2 = 15 \text{ p}$

Chapter 19

Nuclear and Particle Physics

Exercise Multiple Choice Questions

- 19.1 What is the half-life of a radio nuclide if 1/16 of its mass is present after 2h?
(a) 15min. (b) 30 min. (c) 45 min. (d) 60 min.
- 19.2 Gamma radiations are emitted due to:
(a) de-excitation of atoms (b) excitation of atoms
(c) de-excitation of nuclei (d) excitation of nuclei
- 19.3 Cadmium rods are used in nuclear reactor for:
(a) slowing down fast neutron (b) speeding up slow neutron
(c) absorbing neutrons (d) starting the nuclear reaction
- 19.4 The mass of fissionable material needed for self-sustaining chain reaction is called:
(a) supercritical mass (c) critical mass (b) fermi mass (d) sub-critical mass
- 19.5 Graphite and heavy water are two common moderators used in a nuclear reactor. The function of the moderator is:
(a) to slow down the neutrons to thermal energies
(b) to absorb the neutrons and stop the chain reaction
(c) to cool the reactor (d) to control the energy release in the reactor
- 19.6 The mass of a nucleus is always:
(a) an integral number of proton masses
(b) equal to the mass of all other nuclei of the same element
(c) equal to the sum of the masses of proton and neutron
(d) less than the sum of masses of the constituent particles
- 19.7 Binding energy per nucleon is:
(a) greater for heavy nuclei (b) least for heavy nuclei
(c) greater for light nuclei (d) greater for medium weight nuclei
- 19.8 What remains unchanged in a fusion event?
(a) Energy (b) Mass of nucleons (c) Number of nucleons (d) Temperature
- 19.9 Radioactive tracers are also employed to follow the path that various chemicals or food constituents take in:
(a) human bodies (b) animals (c) plants (d) all of these
- 19.10 The K.E. of the fission fragments is ultimately converted to:
(a) potential energy (b) heat energy (c) magnetic energy (d) chemical energy

Answer Key

Q. No.	Option	Q. No.	Option	Q. No.	Option	Q. No.	Option
19.1	B	19.4	C	19.7	D	19.10	B
19.2	C	19.5	A	19.8	C		
19.3	C	19.6	D	19.9	D		

Short Answer Questions

- 19.1 Define binding energy and how is it calculated?

Ans: **Binding Energy:** The work done on the nucleus to break it into constituents neutrons and protons is called the binding energy B.E.

Calculation: This energy can be calculated from Einstein's mass-energy equation

$$\Delta E = (\Delta m)c^2$$

- 19.2 Comment on the statement. "In radioactive decay, if the probability of decay per unit time is doubled; its half-life will also be doubled".

Ans: The probability of decay per unit time is the decay constant (λ). The relationship between half-life ($T_{1/2}$) and decay constant is:

$$T_{1/2} = \frac{0.693}{\lambda}$$

This shows that half-life is inversely proportional to the decay constant. If λ is doubled, the half-life becomes halved. Therefore, the statement is incorrect.

19.3 After four half-lives, what percentage of a radioactive sample remains?

Ans: According to the formula of half life

$$\begin{aligned}\text{Life after 4 half-lives} &= \frac{1}{(2)^4} \times 100 \\ &= \frac{1}{16} \times 100 \\ &= 6.25\%\end{aligned}$$

Only 6.25% of radioactive sample remains after four half-lives.

19.4 Why natural uranium is said to be low grade nuclear fuel? Describe briefly.

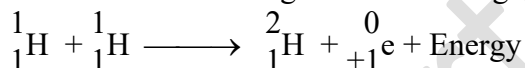
Ans: Natural uranium contains only 0.7 % of U-235 and 99.3% of U-238. U-238 is not easily fissionable by thermal neutrons. That is not good for fission chain reaction, so natural uranium is said to be low grade fuel.

19.5 Give an application of a radioactive tracers in medicines.

Ans: Radioactive Iodine-131 is also used to combat cancer of the thyroid gland.

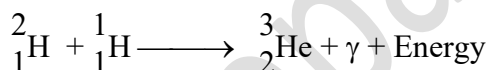
19.6 How is energy generated in the Sun? Describe briefly.

Ans: The production of energy in the Sun is due to the fusion of hydrogen atoms to form helium atoms. This process occurs according to the following reactions:

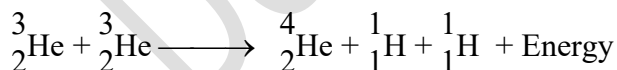


During this process two hydrogen nuclei or two protons fuse to form deuteron.

With the fusion reaction of deuteron with proton, ${}_2^3\text{He}$ an isotope of helium is formed i.e;



In the last stage the two nuclei ${}_2^3\text{He}$ react in the following way:



In this reaction six protons take part and finally a helium nucleus and two protons are formed.

19.7 What is meant by the half-life of a radioactive material?

Ans: Half-life ($T_{1/2}$) is the time required for half of the radioactive nuclei in a sample to decay.

After n half-life; $N = N_0 \left(\frac{1}{2^n}\right)$

19.8 What is meant by controlled and uncontrolled fission chain reaction? Describe briefly.

Ans: Uncontrolled Chain reaction: During fission reaction, a nucleus of uranium-235 absorbs a neutron and breaks into two nuclei of almost equal masses besides emitting two or three neutrons. By properly using these neutrons, fission reaction can be produced in more uranium atoms such that a fission reaction can continuously maintain itself. This process is called uncontrolled chain reaction. This process happens in atomic bomb.

Controlled chain reaction: It is possible to produce such conditions in which only one neutron, out of all the neutrons created in one fission reaction, becomes the cause of further fission reaction. The other neutrons either escape out or are absorbed by cadmium or boron rods. This reaction takes place in nuclear reactor.

Constructed Response Questions

19.1 In what ways a nuclear power station is different to a fossil fuel burning power station

called thermal power station?

Ans: In a thermal reactor, coal or oil is burnt in very large amount to produce heat which is cause of air pollution. In nuclear reactor, fission reaction produces heat. And very small amount of uranium is required. There is no air pollution in nuclear reactor.

19.2 If fusion reactors are developed, what advantage are they likely to have over fission nuclear reactors?

Ans: Advantages:

In fusion, hydrogen form water is used as a fuel which is easily available.

1. No radioactive waste.
2. Fusion process produces four times more energy than fission reaction.
3. It is safer than fission reaction.

19.3 The activity of a radioactive sample decays by 10% in a year. What will be the activity after another year? Explain.

Ans: Radioactive decay follows the law: $N = N_0 e^{-\lambda t}$

It does not decay by fixed amount each year, but by fixed percentage of what remains, So in the second year, 10% of the remaining 90% decays = 9% of original

Total decayed = 10% + 9% = 19%, so 81% remains.

19.4 A source has an activity of 10×10^4 Bq and a half-life of 20 minutes. What will be the activity of the source after one hour?

Ans: Given data:

Initial activity, $A_0 = 10 \times 10^4$ Bq = 10^5 Bq

Half-life, $T_{1/2} = 20$ minutes

Time $t = 1$ hour = 60 minutes

$$\begin{aligned}\text{Number of half-lives} = n &= \frac{t}{T_{1/2}} = \\ &= \frac{60}{20} = 3\end{aligned}$$

Source has spent three half-lives. Now we will calculate activity

$$\begin{aligned}\text{After } n \text{ half-lives, activity } = A &= A_0 \times (1/2)^n \\ &= 10^5 \times (1/2)^3 \\ &= 12500 \text{ Bq}\end{aligned}$$

19.5 What factors make a fusion reaction difficult to achieve?

Ans: High temperature and energy is needed to overcome high repulsive force between nucleons to form a heavy nucleus. To overcome this electrostatic force of repulsion we need fast moving nuclei, which can be produced from an accelerator.

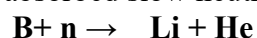
19.6 In what way a nuclear reaction is different from chemical reaction? Explain.

Ans

Chemical Reaction	Nuclear Reaction
Electrons are involved	Atomic nucleus changes are involved
Element remains same	Element may transform into another element
Small amount of energy released	Large amount of energy released
Chemical bonding is involved	Nuclear forces are involved
Affected by Physical conditions like temperature, pressure	Not affected by physical conditions
Easily controlled	Not easily controlled

19.7 Suggest a reason why neutrons are absorbed in the boron rods and the rods become hot as a result of this reaction.

Ans Boron absorbed slow neutron and resultantly, Li and alpha particles are emitted.



The rods become hot because the kinetic energy of the emitted lithium and alpha particles, plus absorbed gamma radiation, converts to thermal energy within the rod material.

Numerical Problems

19.1 Find the mass defect and the binding energy for deuterium. The mass of deuteron is 3.3435×10^{-27} kg. (Mass of proton = $m_p = 1.6726 \times 10^{-27}$ kg, Mass of neutron = $m_n = 1.6749 \times 10^{-27}$ kg)

Given Data:

$$\text{Mass of deuteron} = m = 3.3435 \times 10^{-27} \text{ kg}$$

$$\text{Mass of proton} = m_p = 1.6726 \times 10^{-27} \text{ kg}$$

$$\text{Mass of neutron} = m_n = 1.6749 \times 10^{-27} \text{ kg}$$

To find:

- (i) Mass defect = $\Delta m = ?$
- (ii) Binding Energy = $\Delta E = ?$

Solution:

According to formula:

$$\begin{aligned} \text{i) } \Delta m &= Zm_p + (A-Z)m_n - m_d \\ \text{Charge number of deuterium} &= Z = 1 \\ \text{Mass number of deuterium} &= A = 2 \\ \Delta m &= 1.6726 \times 10^{-27} + 1.6749 \times 10^{-27} - 3.3435 \times 10^{-27} \\ \Delta m &= 0.004 \times 10^{-27} \text{ kg} \end{aligned}$$

$$\begin{aligned} \text{ii) For binding energy} \\ \Delta E &= (\Delta m)c^2 \\ &= 3.6 \times 10^{-13} \text{ J} \\ \Delta E &= \frac{3.6 \times 10^{-13}}{1.6 \times 10^{-19}} \text{ MeV} \\ \Delta E &= 2.25 \text{ MeV} \quad \text{Ans.} \end{aligned}$$

19.2 The decay constant of Strontium is $1.99 \times 10^{-5} \text{ s}^{-1}$. Find its half-life.

Given Data:

$$\text{Decay constant} = 1.99 \times 10^{-5} \text{ s}^{-1}$$

To find:

$$\text{Half-life} = T_{1/2} = ?$$

Solution:

According to formula:

$$\begin{aligned} T_{1/2} &= \frac{0.693}{\lambda} \\ &= \frac{0.693}{1.99 \times 10^{-5}} \end{aligned}$$

$$\text{Half-life of Strontium} = 0.348 \times 10^5 \text{ seconds} = 0.348 \times 10^5 / 3600 = 9.7 \text{ hours} \quad \text{Ans.}$$

19.3 Half-life of Krypton is 3.16 minutes. Out of 40 g of Krypton, how much will be left after 12.64 minutes?

Given data:

$$\text{Half-life of Krypton} = T_{1/2} = 3.16 \text{ minutes}$$

$$\text{Quantity of Krypton} = 40 \text{ g}$$

$$\text{Total time} = 12.64 \text{ minutes}$$

To find:

$$\text{Remaining quantity} = ?$$

Solution:

$$\text{Number of half-lives} = n = \frac{t}{T_{1/2}} = \frac{12.64}{3.16} = 4$$

$$\text{Remaining quantity after four half-lives} = N = N_0 \left(\frac{1}{2^n}\right)$$

$$= 40 \times (1/2)^4 = 2.5 \text{ g} \quad \text{Ans.}$$

19.4 A 2048 g (≈ 2 kg) sample of a radioactive material decreases to 32 g in 18 years. What is its half-life?

Given data:

Remaining quantity of sample = $N = 32\text{g}$

Total time = $t = 18$ years

To find:

$$T_{\frac{1}{2}} = ?$$

Solution:

According to formula:

$$\frac{N}{N_0} = \frac{32}{2048} = \frac{2^5}{2^{11}}$$

$$\frac{N}{N_0} = \frac{1}{2^6}$$

Also,

$$\frac{N}{N_0} = \frac{1}{2^n}$$

Comparing

$$\frac{1}{2^6} = \frac{1}{2^n} = n = 6$$

Half life is given by

$$T_{\frac{1}{2}} = \frac{t}{n} = \frac{18}{6}$$

$$T_{\frac{1}{2}} = 3 \text{ years}$$

19.5 An alpha particle has an energy of 5.56 MeV when released from the Radium atom. Determine its velocity.

Given data:

$$E = 5.56 \text{ MeV} = 5.56 \times 10^6 \times 1.6 \times 10^{-19}$$

$$= 8.896 \times 10^{-13} \text{ J}$$

$$\begin{aligned} \text{Mass of alpha particle} &= m_\alpha = 2m_p + 2m_n \\ &= 6.64 \times 10^{-27} \text{ kg} \end{aligned}$$

To find:

$$v = ?$$

Solution:

$$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2(8.896 \times 10^{-13})}{6.64 \times 10^{-27}}}$$

$$v = 1.64 \times 10^7 \text{ m s}^{-1}$$

Ans.

19.6 Find the energy released during the nuclear reaction: ${}^7_3\text{Li} + {}^1_1\text{H} \rightarrow 2{}^4_2\text{He}$

Mass of ${}^4_2\text{He} = 4.00388 \text{ u}$, Mass of ${}^1_1\text{H} = 1.00814 \text{ u}$ and mass of ${}^7_3\text{Li} = 7.01823 \text{ u}$

Given data:

Mass of ${}^4_2\text{He} = 4.00388 \text{ u}$,

Mass of ${}^1_1\text{H} = 1.00814 \text{ u}$

Mass of ${}^7_3\text{Li} = 7.01823 \text{ u}$

To find:

Energy released in reaction = $E = ?$

Solution:

According to formula:

$$\Delta m = (\text{Mass of } {}^7_3\text{Li} + \text{Mass of } {}^1_1\text{H}) - 2 \times \text{Mass of } {}^4_2\text{He}$$

$$\begin{aligned} \Delta m &= [(7.01823) + (1.00814)] - 2(4.00388) \\ &= 0.01861 \text{ u} \end{aligned}$$

$$\Delta E = 0.01861 \times 931$$

$$\Delta E = 17.3 \text{ MeV}$$

Ans.