

# JEE Main Physics Sample Paper-20

Duration: 1 Hour

Maximum Marks: 100

## Instructions

- This paper contains TWO sections: **Section A** (MCQs) and **Section B** (Numerical).
- Section A contains 20 Multiple Choice Questions.
- Section B contains 5 Numerical Value Questions.
- Each correct answer carries **+4 marks**.
- Each incorrect answer carries **-1 mark**.
- No negative marking for unattempted questions.

## Section A — Multiple Choice Questions

**Q1.** A photon of energy  $E$  ejects a photoelectron from a metal surface whose work function is  $\phi_0$ . If this electron enters a uniform magnetic field  $B$  in a direction perpendicular to the field and describes a circular path of radius  $r$ , then the radius  $r$  is given by: [JEE Main 2021]

- (A)  $\sqrt{\frac{2m(E-\phi_0)}{eB}}$   
(B)  $\frac{\sqrt{2m(E-\phi_0)}}{eB}$   
(C)  $\frac{\sqrt{2e(E-\phi_0)}}{mB}$   
(D)  $\frac{\sqrt{2mE}}{eB}$

**Q2.** In a hydrogen atom, an electron makes a transition from  $n = 3$  to  $n = 2$ . The frequency of emitted photon is  $f$ . If the electron makes a transition from  $n = 4$  to  $n = 2$ , the frequency of the emitted photon will be: [JEE Main 2019]

- (A)  $\frac{9}{16}f$   
(B)  $\frac{20}{27}f$   
(C)  $\frac{27}{20}f$   
(D)  $\frac{16}{9}f$

**Q3.** The half-life of a radioactive substance is 5 years. After  $x$  years, the fraction of the decayed substance is 93.75%. The value of  $x$  is: [JEE Main 2023]



- (A) 15 years
- (B) 20 years
- (C) 25 years
- (D) 10 years

**Q4.** The de Broglie wavelength of a proton and an alpha particle are equal. The ratio of their velocities ( $v_p : v_\alpha$ ) is: [JEE Main 2022]

- (A) 4 : 1
- (B) 1 : 4
- (C) 1 : 2
- (D) 2 : 1

**Q5.** An electric field is given by  $\vec{E} = 4\hat{i} + 3(y^2 + 2)\hat{j}$ . The flux passing through a square of side 2m lying in the  $x - z$  plane is: [JEE Main 2023]

- (A) 16 units
- (B) 20 units
- (C) 24 units
- (D) 32 units

**Q6.** A parallel plate capacitor with plate area  $A$  and distance  $d$  is filled with two dielectrics of constant  $K_1$  and  $K_2$  each of thickness  $d/2$  as shown. Find the equivalent capacitance: [JEE Main 2020]

- (A)  $\frac{\epsilon_0 A}{d} \frac{K_1 K_2}{K_1 + K_2}$
- (B)  $\frac{2\epsilon_0 A}{d} \frac{K_1 K_2}{K_1 + K_2}$
- (C)  $\frac{\epsilon_0 A}{2d} (K_1 + K_2)$
- (D)  $\frac{\epsilon_0 A}{d} (K_1 + K_2)$

**Q7.** Three charges  $+Q, q, +Q$  are placed at distances  $0, d/2, d$  from the origin on the  $x$ -axis. If the net force on  $+Q$  at  $x = 0$  is zero, then  $q$  is: [JEE Main 2019]

- (A)  $-Q/2$
- (B)  $-Q/4$
- (C)  $+Q/2$



(D)  $+Q/4$

**Q8.** In a meter bridge, the balance point is found at a distance  $l_1$  from the left end. If a resistance  $X$  is connected in series with the resistance in the left gap, the balance point shifts. This experiment is used to determine:

[JEE Main 2021]

- (A) Specific resistance
- (B) Unknown resistance
- (C) Internal resistance
- (D) Comparison of EMF

**Q9.** A carbon resistor has color bands: Brown, Black, Brown and Gold. The value of resistance is:

[JEE Main 2020]

- (A)  $100\Omega \pm 5\%$
- (B)  $1000\Omega \pm 2\%$
- (C)  $10\Omega \pm 5\%$
- (D)  $1\Omega \pm 10\%$

**Q10.** In the circuit shown, two  $2\Omega$  resistors are connected in parallel, which are then connected in series with a  $3\Omega$  resistor. The equivalent resistance between the ends of the circuit is:

[JEE Main 2024]

- (A)  $5\Omega$
- (B)  $4\Omega$
- (C)  $7\Omega$
- (D)  $3.5\Omega$

**Q11.** A long straight wire carries a current of 35 A. The magnitude of the magnetic field  $B$  at a point 20 cm from the wire is:

[JEE Main 2022]

- (A)  $3.5 \times 10^{-5}T$
- (B)  $7 \times 10^{-5}T$
- (C)  $3.5 \times 10^{-4}T$
- (D)  $1.75 \times 10^{-5}T$



- Q12.** A square loop of side 10 cm and resistance  $0.5\Omega$  is placed vertically in the east-west plane. A uniform magnetic field of 0.10 T is set up across the plane in north-east direction. If the field is reduced to zero in 0.7 seconds, the induced EMF is: [JEE Main 2021]
- (A) 1.0 mV  
(B) 0.5 mV  
(C) 2.0 mV  
(D) 0.1 mV
- Q13.** In an LCR series circuit, at resonance, the phase difference between current and voltage is: [JEE Main 2023]
- (A)  $\pi/2$   
(B)  $\pi/4$   
(C) Zero  
(D)  $\pi$
- Q14.** An object is placed at a distance of 20 cm from a concave mirror of focal length 10 cm. The image formed is: [JEE Main 2022]
- (A) Real, inverted and same size  
(B) Real, inverted and magnified  
(C) Virtual, erect and magnified  
(D) Real, inverted and diminished
- Q15.** In YDSE, the intensity of light at a point on the screen where the path difference is  $\lambda$  is  $I$ . The intensity at a point where the path difference is  $\lambda/3$  is: [JEE Main 2024]
- (A)  $I/4$   
(B)  $I/2$   
(C)  $3I/4$   
(D)  $I$
- Q16.** A ray of light passes through an equilateral glass prism such that the angle of incidence is equal to the angle of emergence. If the angle of emergence is  $3/4$  times the angle of the prism, the angle of deviation is: [JEE Main 2021]



- (A)  $30^\circ$
- (B)  $45^\circ$
- (C)  $60^\circ$
- (D)  $120^\circ$

**Q17.** The temperature at which the root mean square velocity of hydrogen molecules equals the escape velocity from the earth is (Escape velocity =  $11.2 \text{ km/s}$ ): [JEE Main 2024]

- (A)  $10^4 K$
- (B)  $5 \times 10^3 K$
- (C)  $10^5 K$
- (D)  $8.3 \times 10^3 K$

**Q18.** A Carnot engine has efficiency of  $50\%$ . If the temperature of the sink is reduced by  $40^\circ\text{C}$ , its efficiency increases by  $10\%$ . The temperature of the source is: [JEE Main 2023]

- (A)  $400 \text{ K}$
- (B)  $600 \text{ K}$
- (C)  $800 \text{ K}$
- (D)  $500 \text{ K}$

**Q19.** A particle executes SHM with an amplitude  $A$ . At what displacement from the mean position is its kinetic energy equal to its potential energy?

[JEE Main 2019]

- (A)  $A/2$
- (B)  $A/\sqrt{2}$
- (C)  $A/\sqrt{3}$
- (D)  $A/4$

**Q20.** A siren emitting a sound of frequency  $800 \text{ Hz}$  moves away from an observer towards a cliff at a speed of  $15 \text{ m/s}$ . The frequency of sound heard by the observer as reflected from the cliff is (velocity of sound =  $330 \text{ m/s}$ ):

[JEE Main 2022]

- (A)  $800 \text{ Hz}$



- (B) 838 Hz
- (C) 765 Hz
- (D) 845 Hz



## Section B — Numerical Value Questions

- Q21.** A projectile is fired from horizontal ground with speed  $v$  at an angle  $\theta$ . If the maximum height is equal to the horizontal range, the value of  $\tan \theta$  is:  
[JEE Main 2021]
- 
- Q22.** Three identical solid spheres of mass  $M$  and radius  $R$  are placed such that they touch each other, forming an equilateral triangle pattern. The moment of inertia of this system about an axis passing through the center of mass of the system and perpendicular to the plane of the spheres is  $\frac{X}{5}MR^2$ . The value of  $X$  is:  
[JEE Main 2023]
- 
- Q23.** The weight of a body on the surface of earth is 72 N. What is the gravitational force on it at a height equal to half the radius of the earth? (In Newtons):  
[JEE Main 2020]
- 
- Q24.** A wire of length  $L$  and radius  $r$  is clamped at one end. On stretching it with a force  $F$ , the extension is  $l$ . Another wire of same material but of length  $2L$  and radius  $2r$  is stretched with a force  $2F$ . The extension will be \_\_\_\_\_ times  $l$ .  
[JEE Main 2022]
- 
- Q25.** A block of mass 2 kg is dropped from a height of 40 cm onto a spring of spring constant  $k = 1960\text{N/m}$ . The maximum compression of the spring (in cm) is:  
[JEE Main 2024]
- 



## Detailed Solutions

Q1.

## Solution

**Concept:** Einstein's photoelectric equation and the motion of a charged particle in a uniform magnetic field.

**Solution:** 1. Photoelectric Effect: When a photon of energy  $E$  hits a metal with work function  $\phi_0$ , the maximum kinetic energy  $K$  of the ejected electron is:

$$K = E - \phi_0$$

2. Magnetic Motion: An electron of charge  $e$  and mass  $m$  entering a magnetic field  $B$  perpendicularly experience a centripetal force  $evB = \frac{mv^2}{r}$ . 3. Radius Formula: Rearranging for  $r$ , we get  $r = \frac{mv}{eB}$ . 4. Momentum Relation: Since kinetic energy  $K = \frac{p^2}{2m}$ , the momentum is  $p = mv = \sqrt{2mK}$ . 5. Substitution: Substituting  $p$  into the radius formula:

$$r = \frac{\sqrt{2mK}}{eB} = \frac{\sqrt{2m(E - \phi_0)}}{eB}$$

**Answer:** (B)

Q2.

## Solution

**Concept:** Bohr's Atomic Model and the Rydberg formula for photon frequency.

**Solution:** The frequency  $f$  of an emitted photon during a transition from  $n_2$  to  $n_1$  is given by:

$$f \propto \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

1. Case 1 ( $n = 3$  to  $n = 2$ ):

$$f = k \left( \frac{1}{2^2} - \frac{1}{3^2} \right) = k \left( \frac{1}{4} - \frac{1}{9} \right) = k \left( \frac{5}{36} \right) \implies k = \frac{36f}{5}$$

2. Case 2 ( $n = 4$  to  $n = 2$ ):

$$f' = k \left( \frac{1}{2^2} - \frac{1}{4^2} \right) = k \left( \frac{1}{4} - \frac{1}{16} \right) = k \left( \frac{3}{16} \right)$$

3. Final Calculation: Substitute the value of  $k$  from Case 1:

$$f' = \left( \frac{36f}{5} \right) \left( \frac{3}{16} \right) = \frac{9 \times 3}{5 \times 4} f = \frac{27}{20} f$$

**Answer:** (C)



Q3.

**Solution**

**Concept:** Radioactive decay law and the relationship between half-life and decayed fraction.

**Solution:** 1. Determine Remaining Fraction: If 93.75% of the substance has decayed, the remaining amount  $N$  relative to the initial amount  $N_0$  is:

$$\frac{N}{N_0} = 100\% - 93.75\% = 6.25\%$$

2. Convert to Ratio:  $6.25\% = \frac{6.25}{100} = \frac{1}{16}$ .

3. Apply Decay Formula: The number of half-lives  $n$  is found via  $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$ :

$$\frac{1}{16} = \left(\frac{1}{2}\right)^4 \implies n = 4$$

4. Calculate Total Time: Given  $T_{1/2} = 5$  years:

$$x = n \times T_{1/2} = 4 \times 5 = 20 \text{ years}$$

**Answer: (B)**

Q4.

**Solution**

**Concept:** de Broglie wavelength relation to particle mass and velocity.

**Solution:** The de Broglie wavelength is given by  $\lambda = \frac{h}{p} = \frac{h}{mv}$ . 1. Equality of Wavelengths: Since  $\lambda_p = \lambda_\alpha$ , their momenta must be equal:

$$m_p v_p = m_\alpha v_\alpha \implies \frac{v_p}{v_\alpha} = \frac{m_\alpha}{m_p}$$

2. Mass Relation: An alpha particle consists of two protons and two neutrons, so its mass  $m_\alpha \approx 4m_p$ . 3. Ratio Calculation:

$$\frac{v_p}{v_\alpha} = \frac{4m_p}{m_p} = \frac{4}{1}$$

**Answer: (A)**



Q5.

### Solution

**Concept:** Electric flux calculation using the dot product of the electric field and area vector.

**Solution:** 1. Identify Area Vector: The square lies in the  $x - z$  plane. The normal to this plane is the  $y$ -axis.

$$\vec{A} = (\text{side}^2)\hat{j} = (2^2)\hat{j} = 4\hat{j}$$

2. Calculate Flux:  $\Phi = \vec{E} \cdot \vec{A}$ .

$$\Phi = [4\hat{i} + 3(y^2 + 2)\hat{j}] \cdot 4\hat{j}$$

Since  $\hat{i} \cdot \hat{j} = 0$  and  $\hat{j} \cdot \hat{j} = 1$ :

$$\Phi = 12(y^2 + 2)$$

3. Evaluate at the Plane: For a square in the  $x - z$  plane (at  $y = 0$ ):

$$\Phi = 12(0^2 + 2) = 24 \text{ units}$$

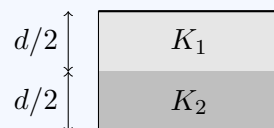
**Answer: (C)**

Q6.

### Solution

**Concept:** Capacitance of a parallel plate capacitor with dielectrics in series.

**Solution:** When dielectrics are stacked between plates, the system acts as two capacitors in series.



1. Individual Capacitances:

$$C_1 = \frac{K_1 \epsilon_0 A}{d/2} = \frac{2K_1 \epsilon_0 A}{d}, \quad C_2 = \frac{2K_2 \epsilon_0 A}{d}$$

2. Series Equivalent:  $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$ .

$$\frac{1}{C_{eq}} = \frac{d}{2\epsilon_0 A} \left( \frac{1}{K_1} + \frac{1}{K_2} \right) = \frac{d}{2\epsilon_0 A} \left( \frac{K_1 + K_2}{K_1 K_2} \right)$$

3. Final Result:  $C_{eq} = \frac{2\epsilon_0 A}{d} \frac{K_1 K_2}{K_1 + K_2}$

**Answer: (B)**

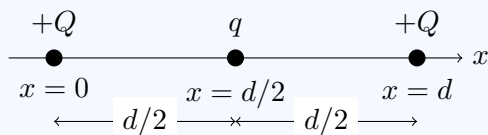


Q7.

### Solution

**Concept:** Equilibrium of charges and Coulomb's Law of electrostatic force.

**Solution:** We have three charges placed on the x-axis:  $+Q$  at  $x = 0$ ,  $q$  at  $x = d/2$ , and  $+Q$  at  $x = d$ .



The net force on the charge  $+Q$  at the origin ( $x = 0$ ) is the vector sum of forces exerted by the other two charges. 1. Force from  $q$  ( $F_1$ ): According to Coulomb's law,  $F = k \frac{q_1 q_2}{r^2}$ .

$$F_1 = k \frac{Q \cdot q}{(d/2)^2} = \frac{4kQq}{d^2}$$

2. Force from the second  $+Q$  ( $F_2$ ): This charge is at a distance  $d$ .

$$F_2 = k \frac{Q \cdot Q}{d^2} = \frac{kQ^2}{d^2}$$

3. Condition for Equilibrium: For the net force to be zero:

$$F_1 + F_2 = 0 \implies \frac{4kQq}{d^2} + \frac{kQ^2}{d^2} = 0$$

4. Solving for  $q$ : Factor out  $\frac{kQ}{d^2}$ :

$$\frac{kQ}{d^2} (4q + Q) = 0 \implies 4q = -Q \implies q = -Q/4$$

The negative sign indicates that  $q$  must be an attractive charge to cancel the repulsion from the other  $+Q$ .

**Answer: (B)**

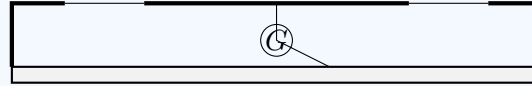


Q8.

### Solution

**Concept:** Wheatstone Bridge principle applied in a Meter Bridge.

**Solution:** A meter bridge is a practical apparatus used to determine the value of an unknown resistance.



Wire Length (100 cm)

1. Initial State: The balance point  $l_1$  obeys the ratio:  $\frac{R}{S} = \frac{l_1}{100-l_1}$ . 2. Experiment Procedure: When a resistance  $X$  is added in series to the left gap, the total resistance in that gap becomes  $R + X$ . This changes the ratio and causes the jockey to balance at a new position. 3. Purpose: By measuring the shift in the balance point, we can solve for the value of the Unknown Resistance. 4. While specific resistance can be calculated later using the dimensions of the wire ( $R = \rho L/A$ ), the primary quantity measured by the bridge is the resistance.

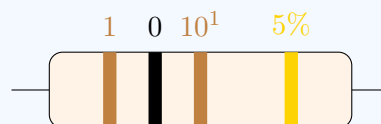
**Answer: (B)**

Q9.

### Solution

**Concept:** Standard color coding for resistors (BBROYGBVGV).

**Solution:** The resistance is determined by the sequence of color bands using the formula:  $R = (AB \times 10^C)\Omega \pm D\%$ .



1. 1st Band (Brown): Represents the first significant digit, which is 1. 2. 2nd Band (Black): Represents the second significant digit, which is 0. 3. 3rd Band (Brown): Represents the decimal multiplier ( $10^n$ ). For Brown,  $n = 1$ , so the multiplier is  $10^1$ . 4. 4th Band (Gold): Represents the tolerance. Gold indicates  $\pm 5\%$ . 5. Calculation:

$$R = 10 \times 10^1 \Omega \pm 5\% = 100 \Omega \pm 5\%$$

**Answer: (A)**



Q10.

**Solution****Concept:** Analysis of combined series and parallel resistive circuits.**Solution:** The circuit consists of a parallel combination followed by a series resistor.

1. Parallel Segment: The two  $2\Omega$  resistors are connected in parallel. Their equivalent resistance ( $R_p$ ) is calculated as:

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{2} + \frac{1}{2} = 1$$

$$R_p = 1\Omega$$

2. Series Segment: This  $1\Omega$  equivalent resistance is now in series with the  $3\Omega$  resistor. The total resistance ( $R_{eq}$ ) is the sum of the individual resistances:

$$R_{eq} = R_p + R_3$$

$$R_{eq} = 1\Omega + 3\Omega = 4\Omega$$

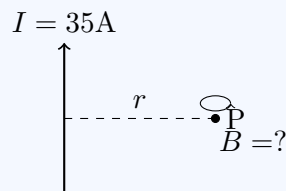
The total equivalent resistance between terminals A and B is  $4\Omega$ .

**Answer: (B)**

Q11.

**Solution****Concept:** Magnetic field due to an infinitely long straight current-carrying conductor.**Solution:** The magnitude of the magnetic field  $B$  at a distance  $r$  from a long straight wire carrying current  $I$  is given by Ampere's Law:

$$B = \frac{\mu_0 I}{2\pi r}$$



1. Given Values: - Current  $I = 35\text{ A}$  - Distance  $r = 20\text{ cm} = 0.2\text{ m}$  - Permeability of free space  $\mu_0 = 4\pi \times 10^{-7}\text{ T} \cdot \text{m/A}$  2. Calculation:

$$B = \frac{4\pi \times 10^{-7} \times 35}{2\pi \times 0.2}$$

$$B = \frac{2 \times 10^{-7} \times 35}{0.2} = \frac{70 \times 10^{-7}}{0.2}$$

$$B = 350 \times 10^{-7} = 3.5 \times 10^{-5}\text{ T}$$

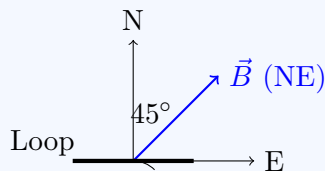
**Answer: (A)**

Q12.

**Solution**

**Concept:** Faraday’s Law of Electromagnetic Induction and Magnetic Flux.

**Solution:** 1. Area calculation: Square loop side  $a = 10 \text{ cm} = 0.1 \text{ m}$ . Area  $A = a^2 = 0.01 \text{ m}^2$ . 2. Angle calculation: The loop is in the East-West plane, so its normal is along the North-South axis. The magnetic field is in the North-East direction ( $45^\circ$  from North). Thus,  $\theta = 45^\circ$ .



3. Flux Change: Initial flux  $\Phi_i = BA \cos \theta = (0.10)(0.01) \cos 45^\circ = \frac{10^{-3}}{\sqrt{2}} \text{ Wb}$ . Final flux  $\Phi_f = 0$  (field reduced to zero). 4. EMF Calculation:

$$|e| = \frac{\Delta\Phi}{\Delta t} = \frac{10^{-3}/\sqrt{2}}{0.7} \approx \frac{0.001}{0.7 \times 1.414} \approx \frac{0.001}{0.99} \approx 0.001 \text{ V} = 1.0 \text{ mV}$$

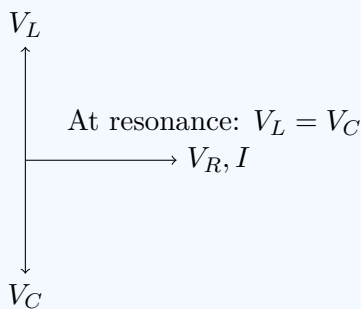
**Answer: (A)**

Q13.

**Solution**

**Concept:** Resonance in a Series LCR Circuit.

**Solution:** In an LCR series circuit, the impedance  $Z$  is given by  $Z = \sqrt{R^2 + (X_L - X_C)^2}$  and the phase difference  $\phi$  is given by  $\tan \phi = \frac{X_L - X_C}{R}$ .



1. At Resonance: The inductive reactance equals the capacitive reactance ( $X_L = X_C$ ). 2. Impedance: The reactive part becomes zero, so  $Z = R$ . The circuit behaves as a purely resistive circuit. 3. Phase Difference:

$$\tan \phi = \frac{0}{R} = 0 \implies \phi = 0$$

This means that current and voltage are in the same phase at resonance.

**Answer: (C)**

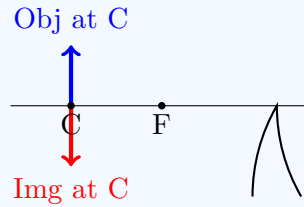


Q14.

**Solution**

**Concept:** Image formation by a concave mirror using the mirror formula.

**Solution:** 1. Identify parameters: Focal length  $f = -10$  cm, Object distance  $u = -20$  cm. 2. Observation: Since  $u = 2f$ , the object is placed exactly at the Center of Curvature (C) of the mirror.



3. Mirror Formula:  $\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \implies \frac{1}{v} = \frac{1}{-10} - \frac{1}{-20} = -\frac{1}{20}$ .  $v = -20$  cm. 4. Magnification:  $m = -\frac{v}{u} = -\frac{-20}{-20} = -1$ . The negative sign indicates the image is inverted, and the magnitude 1 indicates it is the same size as the object. Since  $v$  is negative, it is a real image.

**Answer:** (A)



Q15.

### Solution

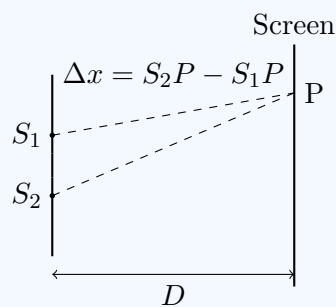
**Concept:** Intensity distribution and the relationship between path difference ( $\Delta x$ ) and phase difference ( $\phi$ ) in Young's Double Slit Experiment (YDSE).

**Solution:** The intensity  $I'$  at any point on the screen where two waves interfere is given by the formula:

$$I' = I_{max} \cos^2 \left( \frac{\phi}{2} \right)$$

where  $\phi$  is the phase difference between the two waves. The phase difference is related to the path difference  $\Delta x$  by the relation:

$$\phi = \frac{2\pi}{\lambda} \Delta x$$



1. First Case: The path difference is  $\Delta x = \lambda$ . - Phase difference:  $\phi_1 = \frac{2\pi}{\lambda} \times \lambda = 2\pi$ .  
- Intensity:  $I = I_{max} \cos^2 \left( \frac{2\pi}{2} \right) = I_{max} \cos^2(\pi) = I_{max} \times (-1)^2 = I_{max}$ . - Thus, the intensity  $I$  given in the question is the maximum intensity.

2. Second Case: The path difference is  $\Delta x' = \lambda/3$ . - Phase difference:  $\phi_2 = \frac{2\pi}{\lambda} \times \frac{\lambda}{3} = \frac{2\pi}{3}$  (or  $120^\circ$ ). - Intensity:  $I' = I_{max} \cos^2 \left( \frac{2\pi/3}{2} \right) = I_{max} \cos^2 \left( \frac{\pi}{3} \right)$ . - Since  $\cos(\pi/3) = \cos(60^\circ) = 1/2$ :

$$I' = I \times \left( \frac{1}{2} \right)^2 = \frac{I}{4}$$

The intensity at the point where the path difference is  $\lambda/3$  is one-fourth of the maximum intensity.

**Answer: (A)**

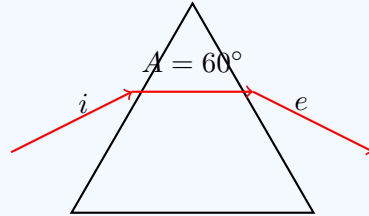


Q16.

**Solution**

**Concept:** Refraction through a prism and the relation between angles of incidence, emergence, and deviation.

**Solution:** 1. Identify Prism Properties: For an equilateral prism, the angle of the prism  $A = 60^\circ$ . 2. Given Conditions: - Angle of incidence  $i =$  Angle of emergence  $e$ . - Angle of emergence  $e = \frac{3}{4}A = \frac{3}{4} \times 60^\circ = 45^\circ$ . - Therefore,  $i = 45^\circ$ .



3. Deviation Formula: The angle of deviation  $\delta$  is given by:

$$\delta = i + e - A$$

4. Calculation:

$$\delta = 45^\circ + 45^\circ - 60^\circ = 90^\circ - 60^\circ = 30^\circ$$

The ray undergoes minimum deviation because  $i = e$ .

**Answer: (A)**

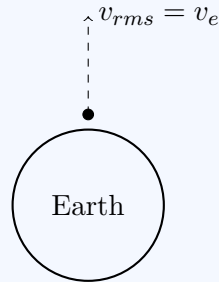


Q17.

### Solution

**Concept:** Kinetic theory of gases and escape velocity.

**Solution:** 1. Formulas: - RMS velocity  $v_{rms} = \sqrt{\frac{3RT}{M}}$  - Escape velocity  $v_e = 11.2 \text{ km/s} = 1.12 \times 10^4 \text{ m/s}$ . 2. Parameters for Hydrogen ( $H_2$ ): - Molar mass  $M = 2 \times 10^{-3} \text{ kg/mol}$ . - Gas constant  $R \approx 8.314 \text{ J/mol} \cdot \text{K}$ .



3. Equating Velocities:

$$\frac{3RT}{M} = v_e^2 \implies T = \frac{Mv_e^2}{3R}$$

4. Calculation:

$$T = \frac{(2 \times 10^{-3}) \times (1.12 \times 10^4)^2}{3 \times 8.314} \approx \frac{2 \times 10^{-3} \times 1.25 \times 10^8}{25}$$

$$T = \frac{2.5 \times 10^5}{25} = 10^4 \text{ K}$$

**Answer: (A)**



Q18.

### Solution

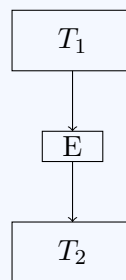
**Concept:** Efficiency of a Carnot Engine  $\eta = 1 - \frac{T_{\text{sink}}}{T_{\text{source}}}$ .

**Solution:** 1. Case 1:  $\eta = 50\% = 0.5$ .

$$0.5 = 1 - \frac{T_2}{T_1} \implies \frac{T_2}{T_1} = 0.5 \implies T_1 = 2T_2$$

2. Case 2: Efficiency increases by 10%, so  $\eta' = 0.5 + 0.1 = 0.6$ . The sink temperature is reduced by 40:  $T_2' = T_2 - 40$ .

$$0.6 = 1 - \frac{T_2 - 40}{T_1} \implies \frac{T_2 - 40}{T_1} = 0.4$$



3. Substitution: Replace  $T_1$  with  $2T_2$ :

$$\frac{T_2 - 40}{2T_2} = 0.4 \implies T_2 - 40 = 0.8T_2$$

$$0.2T_2 = 40 \implies T_2 = 200 \text{ K}$$

4. Find Source Temp:  $T_1 = 2 \times 200 = 400 \text{ K}$ .

**Answer: (A)**

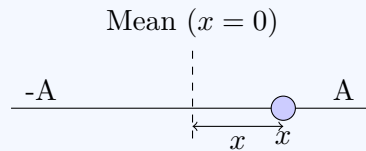


Q19.

### Solution

**Concept:** Energy conservation in Simple Harmonic Motion (SHM).

**Solution:** In SHM, at any displacement  $x$  from the mean position: 1. Potential Energy ( $PE$ ):  $\frac{1}{2}kx^2$  2. Kinetic Energy ( $KE$ ):  $\frac{1}{2}k(A^2 - x^2)$



3. Condition:  $KE = PE$

$$\frac{1}{2}k(A^2 - x^2) = \frac{1}{2}kx^2$$

$$A^2 - x^2 = x^2 \implies A^2 = 2x^2$$

4. Solving for  $x$ :

$$x^2 = \frac{A^2}{2} \implies x = \frac{A}{\sqrt{2}}$$

**Answer: (B)**

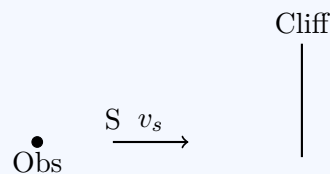
Q20.

### Solution

**Concept:** Doppler effect for sound and reflection from a moving source.

**Solution:** 1. Incident Frequency on Cliff: The cliff acts as a stationary observer. The source  $S$  moves towards the cliff at  $v_s = 15$  m/s.

$$f_{cliff} = f_0 \left( \frac{v}{v - v_s} \right) = 800 \left( \frac{330}{330 - 15} \right) = 800 \left( \frac{330}{315} \right)$$



2. Reflected Frequency: The cliff now acts as a stationary source emitting  $f_{cliff}$ . The observer is stationary relative to the cliff. Thus, the observer hears the same frequency that reached the cliff. 3. Calculation:

$$f_{refl} = 800 \times \frac{330}{315} = 800 \times 1.0476 \approx 838.09 \text{ Hz}$$

The frequency heard by the observer is approximately 838 Hz.

**Answer: (B)**



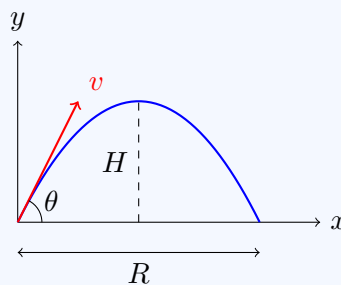
Q21.

**Solution****Concept:** Horizontal range and maximum height of a projectile.**Solution:** For a projectile fired with speed  $v$  at an angle  $\theta$ : 1. Maximum Height ( $H$ ): The vertical component of velocity becomes zero at the peak.

$$H = \frac{v^2 \sin^2 \theta}{2g}$$

2. Horizontal Range ( $R$ ): The total distance traveled horizontally.

$$R = \frac{v^2 \sin 2\theta}{g} = \frac{2v^2 \sin \theta \cos \theta}{g}$$

3. Condition:  $H = R$ .

$$\begin{aligned} \frac{v^2 \sin^2 \theta}{2g} &= \frac{2v^2 \sin \theta \cos \theta}{g} \\ \frac{\sin \theta}{2} &= 2 \cos \theta \implies \frac{\sin \theta}{\cos \theta} = 4 \\ \tan \theta &= 4 \end{aligned}$$

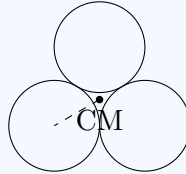
**Answer:** (4)

Q22.

### Solution

**Concept:** Moment of Inertia and Parallel Axis Theorem.

**Solution:** 1. System Geometry: Three spheres touch, forming an equilateral triangle of centers with side  $a = 2R$ . The distance from the centroid (CM) of the system to each sphere's center is  $r = \frac{a}{\sqrt{3}} = \frac{2R}{\sqrt{3}}$ .



2. Individual Moment of Inertia: For one solid sphere about its own center,  $I_{cm} = \frac{2}{5}MR^2$ .

3. Parallel Axis Theorem:  $I_{axis} = I_{cm} + Mr^2$ .

$$I_{one} = \frac{2}{5}MR^2 + M \left( \frac{2R}{\sqrt{3}} \right)^2 = \frac{2}{5}MR^2 + \frac{4}{3}MR^2 = \left( \frac{6 + 20}{15} \right) MR^2 = \frac{26}{15}MR^2$$

4. Total System:  $I_{total} = 3 \times I_{one}$ .

$$I_{total} = 3 \times \frac{26}{15}MR^2 = \frac{26}{5}MR^2$$

Comparing with  $\frac{X}{5}MR^2$ , we find  $X = 26$ .

**Answer: (26)**



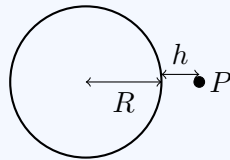
Q23.

## Solution

**Concept:** Variation of acceleration due to gravity with height.

**Solution:** 1. Surface Weight:  $W = mg_0 = 72 \text{ N}$ . 2. Gravity at Height ( $h$ ): The formula for  $g$  at a height  $h$  from the surface is:

$$g_h = g_0 \left( \frac{R}{R+h} \right)^2$$



3. Calculation: Given  $h = R/2$ :

$$g_h = g_0 \left( \frac{R}{R+R/2} \right)^2 = g_0 \left( \frac{R}{3R/2} \right)^2 = g_0 \left( \frac{2}{3} \right)^2 = \frac{4}{9}g_0$$

4. New Weight:

$$W_h = mg_h = m \left( \frac{4}{9}g_0 \right) = \frac{4}{9} \times (mg_0)$$

$$W_h = \frac{4}{9} \times 72 = 4 \times 8 = 32 \text{ N}$$

**Answer: (32)**

Q24.

## Solution

**Concept:** Young's Modulus and longitudinal strain.

**Solution:** The Young's Modulus  $Y$  is defined as  $Y = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{l/L}$ . 1. Extension for Wire 1:

$$l = \frac{FL}{AY} = \frac{FL}{\pi r^2 Y}$$

2. Parameters for Wire 2: - Length  $L' = 2L$ , Radius  $r' = 2r$ , Force  $F' = 2F$ . - Since the material is the same,  $Y$  remains constant. 3. Extension for Wire 2 ( $l'$ ):

$$l' = \frac{F'L'}{A'Y} = \frac{(2F)(2L)}{\pi(2r)^2 Y}$$

$$l' = \frac{4FL}{4\pi r^2 Y} = \frac{FL}{\pi r^2 Y}$$

4. Comparison: Comparing  $l'$  to  $l$ , we see  $l' = 1 \times l$ . The extension will be **1** times  $l$ .

**Answer: (1)**



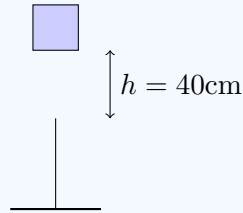
Q25.

### Solution

**Concept:** Conservation of Mechanical Energy involving gravitation and springs.

**Solution:** 1. Energy Conservation: Let  $x$  be the maximum compression. Total potential energy lost by the block equals the elastic potential energy gained by the spring. 2. Total height drop:  $H = h + x$ , where  $h = 40 \text{ cm} = 0.4 \text{ m}$ .

$$mg(h + x) = \frac{1}{2}kx^2$$



3. Calculation:  $m = 2 \text{ kg}$ ,  $g = 9.8 \text{ m/s}^2$ ,  $k = 1960 \text{ N/m}$ .

$$2 \times 9.8 \times (0.4 + x) = \frac{1}{2} \times 1960 \times x^2$$

$$19.6(0.4 + x) = 980x^2 \implies 0.4 + x = 50x^2$$

$$50x^2 - x - 0.4 = 0$$

4. Quadratic Formula:  $x = \frac{1 \pm \sqrt{1 - 4(50)(-0.4)}}{100} = \frac{1 \pm \sqrt{81}}{100} = \frac{1+9}{100} = 0.1 \text{ m}$ . Compression  $x = 10 \text{ cm}$ .

**Answer: (10)**



## Answer Key — Section A

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	B	2	C	3	B	4	A	5	C
6	B	7	B	8	B	9	A	10	B
11	A	12	A	13	C	14	A	15	A
16	A	17	A	18	A	19	B	20	B

## Answer Key — Section B

Q	Ans	Q	Ans
21	4	22	26
23	32	24	1
25	10		

