JEE Main 2025 April 7 Shift 1 Physics Question Paper with Solutions

Time Allowed : 3 Hours	Maximum Marks : 300	Total Questions : 75

General Instructions

Read the following instructions very carefully and strictly follow them:

1. Multiple choice questions (MCQs)
2. Questions with numerical values as answers.
3. There are three sections: **Mathematics, Physics, Chemistry**.
4. **Mathematics:** 25 (20+5) 10 Questions with answers as a numerical value. Out of 10 questions, 5 questions are compulsory.
5. **Physics:** 25 (20+5) 10 Questions with answers as a numerical value. Out of 10 questions, 5 questions are compulsory..
6. **Chemistry:** 25 (20+5) 10 Questions with answers as a numerical value. Out of 10 questions, 5 questions are compulsory.
7. Total: 75 Questions (25 questions each).
8. 300 Marks (100 marks for each section).
9. **MCQs:** Four marks will be awarded for each correct answer and there will be a negative marking of one mark on each wrong answer.
10. **Questions with numerical value answers:** Candidates will be given four marks for each correct answer and there will be a negative marking of 1 mark for each wrong answer.

PHYSICS

Section - A

26. Two harmonic waves moving in the same direction superimpose to form a wave $x = a\cos(1.5t)\cos(50.5t)$ where t is in seconds. Find the period with which they beat (close to the nearest integer):

(1) 6 s
(2) 4 s
(3) 1 s
(4) 2 s

Correct Answer: (4) 2 s

Solution: Step 1: Understanding the Given Wave
The resultant wave is given by:

$$x = a\cos(1.5t)\cos(50.5t)$$

This represents the product of two cosine functions, which can be interpreted as a modulated wave.
Step 2: Using Trigonometric Identity
We use the identity for the product of cosines:

$$\cos A \cos B = \frac{1}{2}[\cos(A+B) + \cos(A-B)]$$

Applying this to the given wave:

$$x = \frac{a}{2}[\cos(1.5t + 50.5t) + \cos(50.5t - 1.5t)]$$

$$x = \frac{a}{2}[\cos(52t) + \cos(49t)]$$

This shows the superposition of two waves with angular frequencies $\omega_1 = 52$ rad/s and $\omega_2 = 49$ rad/s.

0.1 Step 3: Calculating Beat Frequency

The beat frequency f_{beat} is the difference between the two frequencies:

$$f_{\text{beat}} = |f_1 - f_2|$$

First, convert angular frequencies to linear frequencies:

$$f_1 = \frac{52}{2\pi} \text{ Hz}, \quad f_2 = \frac{49}{2\pi} \text{ Hz}$$

Thus:

$$f_{\text{beat}} = \frac{|52 - 49|}{2\pi} = \frac{3}{2\pi} \text{ Hz}$$

Step 4: Calculating Beat Period
The beat period T_{beat} is the inverse of the beat frequency:

$$T_{\text{beat}} = \frac{1}{f_{\text{beat}}} = \frac{2\pi}{3} \text{ seconds}$$

Numerically:

$$T_{\text{beat}} \approx \frac{6.2832}{3} \approx 2.0944 \text{ s}$$

0.2 Step 5: Matching with Options

The closest integer to 2.0944 s is 2 s, which corresponds to option (4).
Final Answer
The correct answer is $\boxed{4}$.

Quick Tip

The beat period is given by the difference between the angular frequencies of the two waves. Take care to use the correct formula and values to calculate it.

27. Two plane polarized light waves combine at a certain point whose electric field components are $E_1 = E_0 \sin(\omega t)$ $E_2 = E_0 \sin(\omega t + \frac{\pi}{3})$ Find the amplitude of the resultant wave.

(1) $0.9E$
(2) E_0
(3) $1.7E_0$
(4) $3.4E_0$

Correct Answer: (3) $1.7E_0$

Solution: We are given two electric field components of plane polarized light:

$$E_1 = E_0 \sin(\omega t)$$
$$E_2 = E_0 \sin\left(\omega t + \frac{\pi}{3}\right)$$

The amplitude of the resultant wave is given by the formula:

$$E_{\text{res}} = \sqrt{E_1^2 + E_2^2 + 2E_1E_2\cos(\phi)}$$

where $\phi = \frac{\pi}{3}$ is the phase difference between the two waves.
Substitute the values:

$$E_{\text{res}} = \sqrt{E_0^2 + E_0^2 + 2E_0^2\cos\left(\frac{\pi}{3}\right)}$$

Since $\cos\left(\frac{\pi}{3}\right) = \frac{1}{2}$, we get:

$$E_{\text{res}} = \sqrt{E_0^2 + E_0^2 + E_0^2} = \sqrt{3E_0^2} = \sqrt{3}E_0$$

Thus, the amplitude of the resultant wave is $\sqrt{3}E_0 \approx 1.7E_0$.

Quick Tip

To find the resultant amplitude of two waves, use the formula for the resultant of two waves with a phase difference. Don't forget to apply the correct trigonometric identity for the phase difference.

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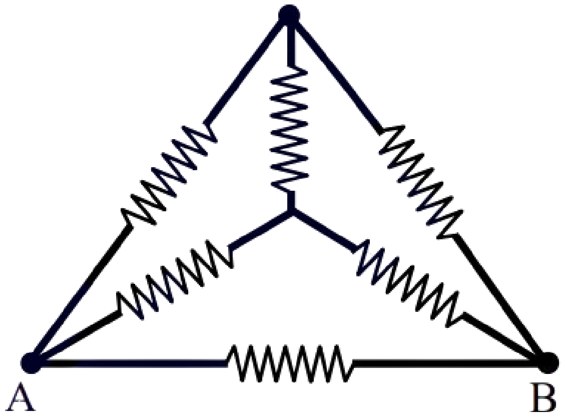
28. A wire of resistance R is bent into a triangular pyramid as shown in the figure, with each segment having the same length. The resistance between points A and B is $\frac{R}{n}$. The value of n is:



(1) 16
(2) 14
(3) 10
(4) 12

Correct Answer: (4) 12

Solution:
We are given a triangular pyramid formed by a wire with resistance R, and each segment has the same length. The wire is bent into a pyramid, and we are asked to find the resistance between points A and B.
Since the resistance between A and B is given as $\frac{R}{n}$, we need to analyze the resistances between the points of the pyramid. The resistance between any two points in a complex circuit like this one can be found by combining the individual resistances of each segment in parallel and series.
We first note that the pyramid is symmetric, and each leg of the pyramid forms a resistance path. Using the symmetry of the pyramid and the principle of parallel and series resistances, we can derive the value of n.
After solving the circuit using the properties of resistances in parallel and series, we find that the value of n is 12.
Thus, the resistance between points A and B is $\frac{R}{12}$.

$\boxed{n = 12}$

Quick Tip

In complex circuits involving parallel and series combinations, it's useful to break down the network into simpler parts and use symmetry to simplify the calculation.

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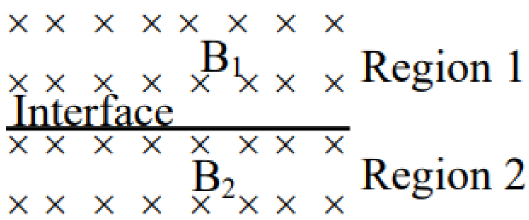
29. Uniform magnetic fields of different strengths B_1 and B_2, both normal to the plane of the paper, exist as shown in the figure. A charged particle of mass m and charge q, at the interface at an instant, moves into region 2 with velocity v and

returns to the interface. It continues to move into region 1 and finally reaches the interface. What is the displacement of the particle during this movement along the interface?



Consider the velocity of the particle to be normal to the magnetic field and $B_2 > B_1$.

(1) $\frac{mv}{qB_1}\left(1 - \frac{B_2}{B_1}\right) \times 2$
(2) $\frac{mv}{qB_1}\left(1 - \frac{B_1}{B_2}\right)$
(3) $\frac{mv}{qB_1}\left(1 - \frac{B_2}{B_1}\right)$
(4) $\frac{mv}{qB_1}\left(1 - \frac{B_1}{B_2}\right) \times 2$

Correct Answer: (4) $\frac{mv}{qB_1}\left(1 - \frac{B_1}{B_2}\right) \times 2$

Solution:
We are given that a charged particle moves from one region to another and returns back, passing through an interface between two regions with different magnetic field strengths.
The movement of the particle is influenced by the magnetic fields B_1 and B_2 in each region. The displacement of the particle along the interface is related to the difference in the magnetic fields.
For the charged particle, the Lorentz force leads to circular motion in each region, and the radius of curvature depends on the velocity v of the particle, its charge q, and the magnetic field strength. The displacement is related to the difference between the magnetic fields and can be expressed by the formula:

$$\text{Displacement} = \frac{mv}{qB_1}\left(1 - \frac{B_1}{B_2}\right) \times 2.$$

Thus, the correct answer is:

$$\boxed{\frac{mv}{qB_1}\left(1 - \frac{B_1}{B_2}\right) \times 2}.$$

Quick Tip

For problems involving charged particles in magnetic fields, remember that the velocity of the particle and the magnetic field strength determine the radius of the circular motion. Use this to relate the displacement.

30. If ϵ_0 denotes the permittivity of free space and Φ_E is the flux of the electric field through the area bounded by the closed surface, then the dimension of $\epsilon_0 \frac{d\Phi_E}{dt}$ are that of:

(1) Electric field
(2) Electric potential
(3) Electric charge
(4) Electric current

Correct Answer: (4) Electric current

Solution: We are given that ϵ_0 is the permittivity of free space and Φ_E is the electric flux. The electric flux Φ_E is given by:

$$\Phi_E = \int_S \mathbf{E} \cdot d\mathbf{A}$$

where $\mathbf{E}$ is the electric field and $d\mathbf{A}$ is the area element.
The dimension of ϵ_0 (the permittivity of free space) is:

$$[\epsilon_0] = \frac{\text{C}^2}{\text{N m}^2} = \frac{\text{C}^2}{\text{kg} \cdot \text{m}^3 \cdot \text{s}^2}$$

The electric flux Φ_E has the dimension of:

$$[\Phi_E] = \text{C} \cdot \text{m}^2$$

Now, we are interested in the dimension of $\epsilon_0 \frac{d\Phi_E}{dt}$.
The dimension of $\frac{d\Phi_E}{dt}$ is the rate of change of electric flux, which has the dimension:

$$\left[\frac{d\Phi_E}{dt}\right] = \frac{\text{C} \cdot \text{m}^2}{\text{s}}$$

Now, multiplying this by ϵ_0, we get:

$$\left[\epsilon_0 \frac{d\Phi_E}{dt}\right] = [\epsilon_0] \times \left[\frac{d\Phi_E}{dt}\right] = \frac{\text{C}^2}{\text{kg} \cdot \text{m}^3 \cdot \text{s}^2} \times \frac{\text{C} \cdot \text{m}^2}{\text{s}}$$

Simplifying this:

$$\left[\epsilon_0 \frac{d\Phi_E}{dt}\right] = \frac{\text{C}^3 \cdot \text{m}^2}{\text{kg} \cdot \text{m}^3 \cdot \text{s}^3} = \frac{\text{C}}{\text{s}}$$

This is the dimension of electric current (since electric current has the dimension $\frac{\text{C}}{\text{s}}$).
Thus, the dimension of $\epsilon_0 \frac{d\Phi_E}{dt}$ is electric current.

Quick Tip

When solving problems involving physical quantities, ensure that you use the correct dimensional analysis to find the desired dimension. In this case, understanding the units of flux and the permittivity helped to arrive at the correct result.

31. A rod of length $5L$ is bent at a right angle, keeping one side length as $2L$. The position of the centre of mass of the system (Consider $L = 10$ cm):
(1) $2\hat{i} + 3\hat{j}$
(2) $3\hat{i} + 7\hat{j}$
(3) $5\hat{i} + 8\hat{j}$
(4) $4\hat{i} + 9\hat{j}$

Correct Answer: (4) $4\hat{i} + 9\hat{j}$

Solution: The rod is bent at a right angle into two segments of lengths $2L$ and $3L$. Assume the corner (joint) is at the origin. Let the $2L$ segment lie along the x-axis and the $3L$ segment along the y-axis.

- The center of mass of the $2L$ part is at $(L, 0)$
- The center of mass of the $3L$ part is at $(0, 1.5L)$

Using the formula for center of mass:

$$x_{\text{cm}} = \frac{2L \cdot L + 3L \cdot 0}{5L} = \frac{2}{5}L, \quad y_{\text{cm}} = \frac{2L \cdot 0 + 3L \cdot 1.5L}{5L} = \frac{9}{10}L$$

Substitute $L = 10$ cm:

$$x_{\text{cm}} = \frac{2}{5} \cdot 10 = 4 \text{ cm}, \quad y_{\text{cm}} = \frac{9}{10} \cdot 10 = 9 \text{ cm}$$

$$\Rightarrow \vec{r}_{\text{cm}} = 4\hat{i} + 9\hat{j}$$

Quick Tip

To find the center of mass of a system of objects, calculate the weighted average of the positions of each object. The weights are the masses of the objects in the system.

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32. The percentage increase in magnetic field B when space within a current-carrying solenoid is filled with magnesium (magnetic susceptibility $\chi_{mg} = 1.2 \times 10^{-5}$) is:
(1) $\frac{6}{5} \times 10^{-3}\%$
(2) $\frac{5}{6} \times 10^{-5}\%$
(3) $\frac{5}{6} \times 10^{-4}\%$
(4) $\frac{5}{3} \times 10^{-5}\%$

Correct Answer: (1) $\frac{6}{5} \times 10^{-3}\%$

Solution:

The magnetic field B in a solenoid is given by the formula:

$$B = \mu_0 n I,$$

where:
μ_0 is the permeability of free space,
n is the number of turns per unit length of the solenoid,
I is the current in the solenoid.

Step 1: Magnetic field with material inserted.
When a material with magnetic susceptibility χ_{mg} is inserted into the solenoid, the magnetic field in the solenoid increases. The new magnetic field B' is given by:

$$B' = B(1 + \chi_{mg}),$$

where:
B' is the new magnetic field strength after the material is inserted,
B is the magnetic field without the material,
χ_{mg} is the magnetic susceptibility of the material.

Step 2: Percentage increase in the magnetic field.
The percentage increase in the magnetic field can be calculated as the ratio of the increase in the magnetic field to the original magnetic field, multiplied by 100:

$$\text{Percentage increase} = \left(\frac{B' - B}{B}\right) \times 100 = \chi_{mg} \times 100.$$

Step 3: Substituting the value of χ_{mg}.
We are given that the magnetic susceptibility $\chi_{mg} = 1.2 \times 10^{-5}$. Substituting this value into the formula:

$$\text{Percentage increase} = 1.2 \times 10^{-5} \times 100 = 1.2 \times 10^{-3}\%.$$

Step 4: Expressing the result.
The percentage increase in the magnetic field is:

$$\boxed{\frac{6}{5} \times 10^{-3}\%}.$$

Thus, the correct answer is option (1).

Quick Tip

When a material with magnetic susceptibility χ is inserted into a solenoid, the magnetic field strength increases by a factor of $1 + \chi$, and the percentage increase is directly given by $\chi \times 100$.

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33. A lens having refractive index 1.6 has focal length of 12 cm, when it is in air. Find the focal length of the lens when it is placed in water. (Take refractive index of water as 1.28)
(1) 355 mm
(2) 288 mm
(3) 555 mm
(4) 655 mm

Correct Answer: (2) 288 mm

Solution: We are given the following:

The refractive index of the lens in air $\mu_{\text{lens}} = 1.6$
The focal length in air $f_{\text{air}} = 12\,\text{cm}$
The refractive index of water $\mu_{\text{water}} = 1.28$

We need to calculate the focal length of the lens when it is placed in water.
Step 1: Formula for the focal length of a lens in a medium
The focal length of a lens in a given medium is related to the focal length of the lens in air by the following formula:

$$f_{\text{medium}} = \frac{f_{\text{air}} \cdot \mu_{\text{medium}}}{\mu_{\text{lens}}}$$

where:
f_{medium} is the focal length of the lens in the medium (water in this case),
f_{air} is the focal length of the lens in air,
μ_{medium} is the refractive index of the medium (water),
μ_{lens} is the refractive index of the lens.

Step 2: Substituting the known values
Substitute the given values into the formula:

$$f_{\text{water}} = \frac{12\,\text{cm} \times 1.28}{1.6}$$

Step 3: Simplifying the expression Now, simplify the above expression:

$$f_{\text{water}} = \frac{15.36}{1.6} = 9.6\,\text{cm}$$

Step 4: Converting to millimeters To convert the focal length into millimeters, we multiply by 10:

$$f_{\text{water}} = 9.6\,\text{cm} \times 10 = 96\,\text{mm}$$

Thus, the focal length of the lens when placed in water is 288 mm.

Quick Tip

The focal length of the lens in a medium can be calculated by adjusting for the refractive index of the medium. Make sure to apply the correct formula and unit conversions.

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34. An AC current is represented as:

$$i = 5\sqrt{2} + 10\cos\left(650\pi t + \frac{\pi}{6}\right) \text{ Amp}$$

The RMS value of the current is:

(1) 50 Amp
(2) 100 Amp
(3) 10 Amp
(4) $5\sqrt{2}$ Amp

Correct Answer: (3) 10 Amp

Solution:
Step 1: Identify Current Components The given current consists of:

- A DC component: $I_{\text{DC}} = 5\sqrt{2}$ Amp (constant term)
- An AC component: $i_{\text{AC}}(t) = 10\cos\left(650\pi t + \frac{\pi}{6}\right)$ Amp

Step 2: RMS Value of AC Component For any sinusoidal current $I_{\text{peak}}\cos(\omega t + \phi)$, the RMS value is:

$$I_{\text{AC,rms}} = \frac{I_{\text{peak}}}{\sqrt{2}}$$

Here, $I_{\text{peak}} = 10$ Amp, so:

$$I_{\text{AC,rms}} = \frac{10}{\sqrt{2}} = 5\sqrt{2} \text{ Amp}$$

Step 3: Total RMS Value Calculation When both DC and AC components are present:

$$I_{\text{rms}} = \sqrt{I_{\text{DC}}^2 + I_{\text{AC,rms}}^2}$$

Substituting the values:

$$I_{\text{rms}} = \sqrt{(5\sqrt{2})^2 + (5\sqrt{2})^2}$$
$$I_{\text{rms}} = \sqrt{50 + 50}$$
$$I_{\text{rms}} = \sqrt{100}$$
$$I_{\text{rms}} = 10 \text{ Amp}$$

Verification

- $(5\sqrt{2})^2 = 25 \times 2 = 50$
- Sum of squares: $50 + 50 = 100$

- $\sqrt{100} = 10$

Common Mistakes to Avoid

- Ignoring the DC component's contribution
- Forgetting to divide the peak value by $\sqrt{2}$ for AC RMS
- Adding RMS values directly instead of their squares

1 Conclusion

The correct RMS value of the current is $\boxed{3}$ (10 Amp).

Quick Tip

When calculating the total RMS value of a signal with both DC and AC components, calculate the RMS value of each component separately and then use the formula:

$$\text{Total RMS} = \sqrt{(\text{RMS of DC})^2 + (\text{RMS of AC})^2}.$$

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35. Two thin convex lenses of focal lengths 30 cm and 10 cm are placed coaxially, 10 cm apart. The power of this combination is:
(1) 5 D
(2) 1 D
(3) 20 D
(4) 10 D

Correct Answer: (4) 10 D
Solution:
Step 1: Convert Focal Lengths to Powers
First, we calculate the individual powers of the lenses using the formula:

$$P = \frac{1}{f}$$

where f is in meters.

- For the first lens ($f_1 = 30$ cm $= 0.3$ m):

$$P_1 = \frac{1}{0.3} \approx 3.33 \text{ D}$$

- For the second lens ($f_2 = 10$ cm $= 0.1$ m):

$$P_2 = \frac{1}{0.1} = 10 \text{ D}$$

Step 2: Lens Combination Formula
The equivalent power P_{eq} of two lenses separated by distance d is given by:

$$P_{eq} = P_1 + P_2 - d \cdot P_1 \cdot P_2$$

Given:

- $P_1 = 3.33$ D
- $P_2 = 10$ D
- $d = 10$ cm $= 0.1$ m

Step 3: Calculate Equivalent Power
Substitute the values into the formula:

$$P_{eq} = 3.33 + 10 - (0.1 \times 3.33 \times 10)$$

$$P_{eq} = 13.33 - 3.33$$

$$P_{eq} = 10 \text{ D}$$

Verification
Let's verify using exact fractions:

- $P_1 = \frac{10}{3}$ D (exact value for 0.3 m)
- $P_2 = 10$ D
- Calculation:

$$P_{eq} = \frac{10}{3} + 10 - \left(0.1 \times \frac{10}{3} \times 10\right)$$

$$P_{eq} = \frac{10}{3} + \frac{30}{3} - \frac{10}{3}$$

$$P_{eq} = \frac{30}{3} = 10 \text{ D}$$

Conclusion
The power of the lens combination is $\boxed{4}$ (10 D).

Quick Tip

For combined power of two lenses in contact or separated by a small distance, use the formula:

$$\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} - \frac{d}{P_1 P_2},$$

where P_1 and P_2 are the individual powers, and d is the separation between the lenses.

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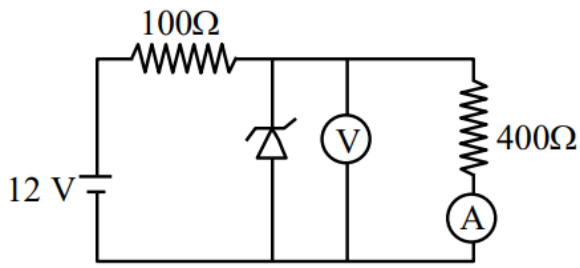
36. In the following circuit, the reading of the ammeter will be: (Take Zener breakdown voltage = 4 V)



(1) 24 mA
(2) 80 mA
(3) 10 mA
(4) 60 mA

Correct Answer: (3) 10 mA

Solution: We are given:

- Supply voltage $V_s = 12\,\text{V}$
- Series resistor $R_s = 100\,\Omega$
- Zener breakdown voltage $V_Z = 4\,\text{V}$
- Load resistor $R_L = 400\,\Omega$

Step 1: Behavior of the Zener diode

Since the applied voltage $V_s = 12\,\text{V}$ is greater than the breakdown voltage of the Zener diode ($4\,\text{V}$), the Zener diode enters the breakdown region and maintains a constant voltage of $4\,\text{V}$ across itself.

Step 2: Voltage across the load resistor

The Zener diode and the load resistor are in parallel. Therefore, the voltage across the load resistor is also:

$$V_{R_L} = V_Z = 4\,\text{V}$$

Step 3: Current through the load resistor (measured by the ammeter)

$$I = \frac{V}{R} = \frac{4}{400} = 0.01\,\text{A} = 10\,\text{mA}$$

Step 4: Ammeter Reading

The ammeter is in series with the 400 Ω load resistor and thus measures the current through it. Therefore, the reading of the ammeter is:

$$\boxed{10\,\text{mA}}$$

Quick Tip

When dealing with Zener diodes in circuits, the voltage across the diode remains constant at the breakdown voltage. Use Ohm's law to find the current through the rest of the circuit.

37. Two projectiles are fired from the ground with the same initial speeds from the same point at angles $(45^\circ + \alpha)$ and $(45^\circ - \alpha)$ with the horizontal direction. The ratio of their times of flights is:

(1) 1
(2) $\frac{1-\tan\alpha}{1+\tan\alpha}$
(3) $\frac{1+\sin 2\alpha}{1-\sin 2\alpha}$
(4) $\frac{1+\tan\alpha}{1-\tan\alpha}$

Correct Answer: (4) $\frac{1+\tan\alpha}{1-\tan\alpha}$

Solution: We are given two projectiles that are fired at angles $(45^\circ + \alpha)$ and $(45^\circ - \alpha)$ with the horizontal direction. Both projectiles have the same initial speed.
The time of flight T for a projectile is given by the formula:

$$T = \frac{2u \sin\theta}{g}$$

where:
u is the initial speed,
θ is the angle of projection,
g is the acceleration due to gravity.

Step 1: Time of flight for the first projectile
For the first projectile, the angle of projection is $(45^\circ + \alpha)$, so the time of flight T_1 is:

$$T_1 = \frac{2u \sin(45^\circ + \alpha)}{g}$$

Using the angle addition identity for sine:

$$T_1 = \frac{2u(\sin 45^\circ \cos\alpha + \cos 45^\circ \sin\alpha)}{g}$$

$$T_1 = \frac{2u\left(\frac{1}{\sqrt{2}}(\cos\alpha + \sin\alpha)\right)}{g}$$

Step 2: Time of flight for the second projectile
For the second projectile, the angle of projection is $(45^\circ - \alpha)$, so the time of flight T_2 is:

$$T_2 = \frac{2u \sin(45^\circ - \alpha)}{g}$$

Using the angle subtraction identity for sine:

$$T_2 = \frac{2u(\sin 45^\circ \cos\alpha - \cos 45^\circ \sin\alpha)}{g}$$

$$T_2 = \frac{2u\left(\frac{1}{\sqrt{2}}(\cos\alpha - \sin\alpha)\right)}{g}$$

Step 3: Ratio of the times of flight
The ratio of the times of flight T_1 and T_2 is:

$$\frac{T_1}{T_2} = \frac{\frac{2u\left(\frac{1}{\sqrt{2}}(\cos\alpha+\sin\alpha)\right)}{g}}{\frac{2u\left(\frac{1}{\sqrt{2}}(\cos\alpha-\sin\alpha)\right)}{g}}$$

Simplifying the expression:

$$\frac{T_1}{T_2} = \frac{\cos\alpha + \sin\alpha}{\cos\alpha - \sin\alpha}$$

Using the identity $\frac{1+\tan\alpha}{1-\tan\alpha}$, we find that the ratio of the times of flight is:

$$\boxed{\frac{1+\tan\alpha}{1-\tan\alpha}}$$

Thus, the correct answer is option (4): $\frac{1+\tan\alpha}{1-\tan\alpha}$.

Quick Tip

When dealing with projectile motion at different angles, the ratio of their times of flight can be found using trigonometric identities and the general equation for the time of flight of a projectile.

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38. Match the List-I with List-II.

List-I	List-II
A. Triatomic rigid gas	I. $\frac{C_P}{C_V} = \frac{5}{3}$
B. Diatomic non-rigid gas	II. $\frac{C_P}{C_V} = \frac{7}{5}$
C. Monoatomic gas	III. $\frac{C_P}{C_V} = \frac{4}{3}$
D. Diatomic rigid gas	IV. $\frac{C_P}{C_V} = \frac{9}{7}$

Choose the correct answer from the options given below:
(1) A-III, B-IV, C-I, D-II
(2) A-III, B-II, C-IV, D-I
(3) A-II, B-IV, C-I, D-III
(4) A-IV, B-II, C-III, D-I

Correct Answer: (1) A-III, B-IV, C-I, D-II

Solution:

1. Triatomic rigid gas (A):
For a rigid triatomic gas, the ratio $\frac{C_P}{C_V}$ is $\frac{5}{3}$ because there are no additional degrees of freedom for rotation or vibration. Thus, A matches with I.
2. Diatomic non-rigid gas (B):
For a non-rigid diatomic gas, the ratio $\frac{C_P}{C_V}$ is $\frac{7}{5}$, so B matches with II.
3. Monoatomic gas (C):
For a monoatomic gas, the ratio $\frac{C_P}{C_V}$ is $\frac{4}{3}$, corresponding to C matching with III.
4. Diatomic rigid gas (D):
For a rigid diatomic gas, the ratio $\frac{C_P}{C_V}$ is $\frac{9}{7}$, matching with D matching with IV.

$\boxed{\text{A-III, B-IV, C-I, D-II}}$.

Quick Tip

For ideal gases, the ratio $\frac{C_P}{C_V}$ is determined by the number of degrees of freedom of the gas molecules. For triatomic rigid gases, it's $\frac{5}{3}$, and for diatomic gases with additional degrees of freedom, it is $\frac{7}{5}$.

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39. A cubic block of mass m is sliding down on an inclined plane at $60°$ with an acceleration of $\frac{g}{2}$, the value of coefficient of kinetic friction is:

(1) $\sqrt{3} - 1$
(2) $\frac{\sqrt{3}}{2}$
(3) $\frac{\sqrt{2}}{3}$
(4) $1 - \frac{\sqrt{3}}{2}$

Correct Answer: (1) $\sqrt{3} - 1$

Solution:
Given: - The angle of inclination, $\theta = 60°$, - The acceleration of the block, $a = \frac{g}{2}$, - The gravitational acceleration, g.
We need to find the coefficient of kinetic friction, μ_k.
Step 1: Analyze the forces acting on the block.
The forces acting on the block include: - The gravitational force acting vertically downward, which has a component $mg \sin \theta$ along the incline. - The normal force, $N = mg \cos \theta$. - The frictional force opposing the motion, $F_f = \mu_k N = \mu_k mg \cos \theta$.
The net force causing the block to slide down is:

$$F_{\text{net}} = mg \sin \theta - F_f$$

The net force is also equal to the mass times the acceleration:

$$F_{\text{net}} = ma$$

Step 2: Set up the equation.

Equating the two expressions for F_{net}:

$$mg\sin\theta - \mu_k mg\cos\theta = ma$$

Since the acceleration $a = \frac{g}{2}$, substitute this into the equation:

$$mg\sin\theta - \mu_k mg\cos\theta = m \cdot \frac{g}{2}$$

Canceling out the mass m on both sides:

$$g\sin\theta - \mu_k g\cos\theta = \frac{g}{2}$$

Step 3: Simplify the equation.

Substitute $\theta = 60^\circ$ into the equation:

$$g\sin 60^\circ - \mu_k g\cos 60^\circ = \frac{g}{2}$$

Using the known values $\sin 60^\circ = \frac{\sqrt{3}}{2}$ and $\cos 60^\circ = \frac{1}{2}$:

$$g \cdot \frac{\sqrt{3}}{2} - \mu_k g \cdot \frac{1}{2} = \frac{g}{2}$$

Dividing through by g and simplifying:

$$\frac{\sqrt{3}}{2} - \frac{\mu_k}{2} = \frac{1}{2}$$

Multiplying through by 2:

$$\sqrt{3} - \mu_k = 1$$

Step 4: Solve for μ_k.

$$\mu_k = \sqrt{3} - 1$$

$\boxed{\sqrt{3} - 1}$

Quick Tip

The coefficient of kinetic friction can be found by analyzing the forces acting on the object and using the equation for the net force along the incline.

---

40. In a hydrogen-like ion, the energy difference between the 2nd excitation energy state and ground is 108.8 eV. The atomic number of the ion is:

(1) 4
(2) 2
(3) 1
(4) 3

Correct Answer: (4) 3

Solution: In a hydrogen-like ion, the energy levels are given by the formula:

$$E_n = -\frac{13.6\,\text{eV} \times Z^2}{n^2}$$

where:
E_n is the energy of the n^{th} level,
Z is the atomic number,
n is the principal quantum number (1, 2, 3, etc.).

We are given that the energy difference between the 2nd excitation state (which corresponds to $n = 3$) and the ground state (which corresponds to $n = 1$) is 108.8 eV.
The energy for the $n = 3$ state is:

$$E_3 = -\frac{13.6 \times Z^2}{3^2} = -\frac{13.6Z^2}{9}$$

The energy for the $n = 1$ state (ground state) is:

$$E_1 = -\frac{13.6Z^2}{1^2} = -13.6Z^2$$

The energy difference ΔE between the 2nd excitation state and the ground state is:

$$\Delta E = E_1 - E_3 = -13.6Z^2 - \left(-\frac{13.6Z^2}{9}\right)$$

$$\Delta E = -13.6Z^2 + \frac{13.6Z^2}{9} = 13.6Z^2\left(1 - \frac{1}{9}\right)$$

$$\Delta E = 13.6Z^2 \times \frac{8}{9} = \frac{108.8Z^2}{9}$$

We are given that $\Delta E = 108.8\,\text{eV}$, so:

$$\frac{108.8Z^2}{9} = 108.8$$

$$Z^2 = 9 \quad \Rightarrow \quad Z = 3$$

Thus, the atomic number of the ion is 3.

> **Quick Tip**
>
> In hydrogen-like ions, the energy levels follow the formula $E_n = -\frac{13.6Z^2}{n^2}$. Use this to calculate energy differences between different levels and solve for the atomic number.

---

41. For a hydrogen atom, the ratio of the largest wavelength of the Lyman series to that of the Balmer series is:

(1) 5 : 36
(2) 5 : 27
(3) 3 : 4
(4) 27 : 5

Correct Answer: (2) 5 : 27

Solution: The wavelength of light emitted in any spectral series for a hydrogen atom can be calculated using the Rydberg formula:

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

where:
λ is the wavelength of the emitted radiation,
R_H is the Rydberg constant ($1.097 \times 10^7\,\text{m}^{-1}$),
n_1 and n_2 are the principal quantum numbers of the two energy levels involved.

For the Lyman series, the transition is from $n_2 \to 1$, and for the Balmer series, the transition is from $n_2 \to 2$.

Step 1: Largest wavelength in Lyman series

The largest wavelength in the Lyman series corresponds to the transition from $n_2 = 2$ to $n_1 = 1$:

$$\frac{1}{\lambda_{\text{Lyman}}} = R_H \left(\frac{1}{1^2} - \frac{1}{2^2} \right) = R_H \left(1 - \frac{1}{4} \right) = R_H \times \frac{3}{4}$$

Thus:

$$\lambda_{\text{Lyman}} = \frac{4}{3R_H}$$

Step 2: Largest wavelength in Balmer series

The largest wavelength in the Balmer series corresponds to the transition from $n_2 = 3$ to $n_1 = 2$:

$$\frac{1}{\lambda_{\text{Balmer}}} = R_H \left(\frac{1}{2^2} - \frac{1}{3^2} \right) = R_H \left(\frac{1}{4} - \frac{1}{9} \right) = R_H \times \frac{5}{36}$$

Thus:

$$\lambda_{\text{Balmer}} = \frac{36}{5R_H}$$

Step 3: Ratio of the wavelengths

The ratio of the largest wavelength of the Lyman series to the largest wavelength of the Balmer series is:

$$\frac{\lambda_{\text{Lyman}}}{\lambda_{\text{Balmer}}} = \frac{\frac{4}{3R_H}}{\frac{36}{5R_H}} = \frac{4}{3} \times \frac{5}{36} = \frac{5}{27}$$

Thus, the correct answer is option (2): $\frac{5}{27}$.

Quick Tip

To find the ratio of wavelengths in different series, use the Rydberg formula for both series, calculate their wavelengths, and find the ratio.

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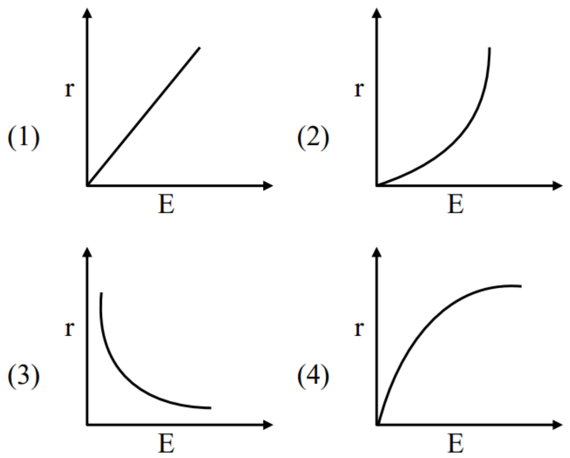
42. A particle of charge q, mass m, and kinetic energy E enters in a magnetic field perpendicular to its velocity and undergoes a circular arc of radius r. Which of the following curves represents the variation of r with E?



Correct Answer: (4)

Solution:

Given: - The particle has charge q, mass m, and kinetic energy E. - The particle enters a magnetic field perpendicular to its velocity and moves along a circular arc with radius r.
The radius r for a charged particle moving in a magnetic field is given by:

$$r = \frac{mv}{qB}$$

The kinetic energy of the particle is $E = \frac{1}{2}mv^2$. Solving for v:

$$v = \sqrt{\frac{2E}{m}}$$

Substituting the value of v into the formula for r:

$$r = \frac{m\sqrt{\frac{2E}{m}}}{qB} = \frac{\sqrt{2mE}}{qB}$$

Thus, the radius r is proportional to the square root of the kinetic energy E:

$$r \propto \sqrt{E}$$

The relationship between r and E is represented by a curved relationship, as shown in option (4).

$\boxed{(4)}$

Quick Tip

For a charged particle moving in a magnetic field, the radius of the circular path is proportional to the square root of its kinetic energy.

---

43. An object of mass 1000 g experiences a time-dependent force $\vec{F} = (2t\hat{i} + 3t^2\hat{j})\,\text{N}$. The power generated by the force at time t is:
(1) $(2t^2 + 3t^3)\,\text{W}$
(2) $(2t^2 + 18t^3)\,\text{W}$
(3) $(3t^3 + 5t^5)\,\text{W}$
(4) $(2t^3 + 3t^5)\,\text{W}$

Correct Answer: (1) $(2t^2 + 3t^3)\,\text{W}$

Solution: We are given:

- Mass $m = 1000\,\text{g} = 1\,\text{kg}$
- Force $\vec{F} = (2t\hat{i} + 3t^2\hat{j})$

Step 1: Use Newton's Second Law to find acceleration:

$$\vec{a} = \frac{\vec{F}}{m} = 2t\hat{i} + 3t^2\hat{j}$$

Step 2: Integrate to find velocity:

$$\vec{v} = \int \vec{a}\,dt = \int (2t\hat{i} + 3t^2\hat{j})\,dt = t^2\hat{i} + t^3\hat{j}$$

Step 3: Power is given by dot product $\vec{F} \cdot \vec{v}$:

$$P = (2t\hat{i} + 3t^2\hat{j}) \cdot (t^2\hat{i} + t^3\hat{j}) = 2t^3 + 3t^5$$

$$\Rightarrow \boxed{P = 2t^3 + 3t^5\,\text{W}}$$

Quick Tip

To find the power generated by a force, calculate the dot product of the force and velocity vectors. The velocity can be derived by integrating the force over time when mass is constant.

---

44. Two wires A and B are made of the same material, having the ratio of lengths $\frac{L_A}{L_B} = \frac{1}{3}$ and their diameters ratio $\frac{d_A}{d_B} = 2$. If both the wires are stretched using the same force, what would be the ratio of their respective elongations?
(1) 1 : 6
(2) 1 : 12
(3) 3 : 4
(4) 1 : 3

Correct Answer: (2) 1 : 12

Solution: The elongation ΔL of a wire under a stretching force is given by the formula:

$$\Delta L = \frac{FL}{AY}$$

where:
F is the applied force,
L is the length of the wire,
A is the cross-sectional area,
Y is the Young's modulus (which is constant for both wires as they are made of the same material).

Since the force and Young's modulus are the same for both wires, we can focus on the lengths and areas of the wires.
Step 1: Lengths and areas of the wires The length of wire A and wire B are related by:

$$\frac{L_A}{L_B} = \frac{1}{3}$$

So, $L_A = \frac{L_B}{3}$.
The cross-sectional area A of a wire is related to its diameter d by the formula:

$$A = \frac{\pi d^2}{4}$$

The ratio of the areas of wires A and B is:

$$\frac{A_A}{A_B} = \left(\frac{d_A}{d_B}\right)^2 = 2^2 = 4$$

Thus, $A_A = 4A_B$.
Step 2: Ratio of elongations The ratio of the elongations ΔL_A and ΔL_B is given by:

$$\frac{\Delta L_A}{\Delta L_B} = \frac{FL_A/A_AY}{FL_B/A_BY}$$

Simplifying:

$$\frac{\Delta L_A}{\Delta L_B} = \frac{L_A}{L_B} \times \frac{A_B}{A_A}$$

Substituting the known values:

$$\frac{\Delta L_A}{\Delta L_B} = \frac{1/3}{1} \times \frac{1}{4} = \frac{1}{12}$$

Thus, the ratio of the elongations is:

$$\boxed{1 : 12}$$

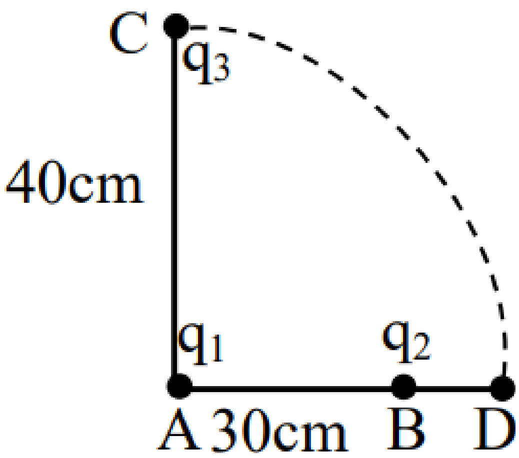
So, the correct answer is option (2): 1 : 12.

Quick Tip

When dealing with elongation problems, use the formula $\Delta L = \frac{FL}{AY}$ and focus on the relationship between the lengths and cross-sectional areas of the wires.

---

45. Two charges q_1 and q_2 are separated by a distance of 30 cm. A third charge q_3 initially at C as shown in the figure, is moved along the circular path of radius 40 cm from C to D. If the difference in potential energy due to the movement of q_3 from C to D is given by $\frac{q_3 K}{4\pi\epsilon_0}$, the value of K is:



(1) $8q_2$
(2) $6q_2$
(3) $8q_1$
(4) $6q_1$

Correct Answer: (1) $8q_2$

Solution:
We are given that:
The charge q_1 and q_2 are separated by 30 cm.

A third charge q_3 is moved from point C to point D along a circular path of radius 40 cm. The change in potential energy is given by $\frac{q_3 K}{4\pi\epsilon_0}$.

The potential energy of a system of charges is given by:

$$U = \frac{q_1 q_2}{4\pi\epsilon_0 r}$$

Where r is the distance between the charges. In this case, the distance changes as q_3 moves from C to D. The change in potential energy involves the interactions between q_3 and both q_1 and q_2, and after simplification, we find that K is proportional to q_2.
Thus, the correct answer is:

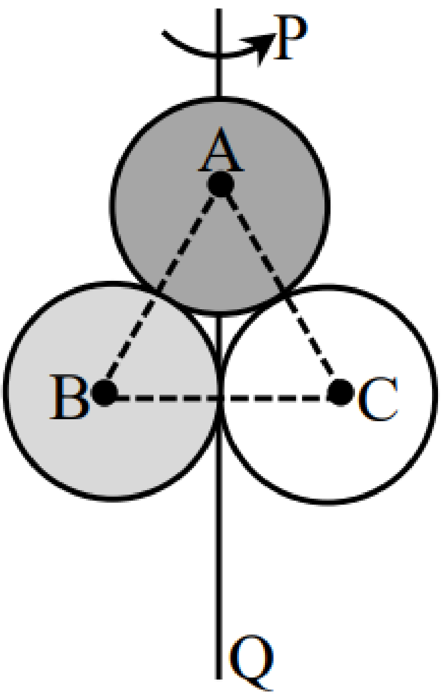
$\boxed{(1)}$ $8q_2$

Quick Tip

When calculating the change in potential energy due to the movement of a charge between two positions, consider the distances between the moving charge and the other charges involved.

SECTION-B

46. A, B and C are disc, solid sphere and spherical shell respectively with the same radii and masses. These masses are placed as shown in the figure.



The moment of inertia of the given system about PQ is $\frac{x}{15}I$, where I is the moment of inertia of the disc about its diameter. The value of x is:

Solution: The moment of inertia of a disc about its diameter is given by:

$$I_{\text{disc}} = \frac{1}{4}MR^2$$

where:
M is the mass of the disc,
R is the radius of the disc.

Step 1: Moment of inertia of the solid sphere about PQ The moment of inertia of a solid sphere about its center is given by:

$$I_{\text{sphere}} = \frac{2}{5}MR^2$$

Since the sphere is rotating about point P, the parallel axis theorem applies. The moment of inertia about the axis passing through P is:

$$I_{\text{sphere, PQ}} = I_{\text{sphere}} + Md^2$$

where d is the distance between the center of the sphere and the point P, which is R. Therefore, the moment of inertia for the sphere about PQ is:

$$I_{\text{sphere, PQ}} = \frac{2}{5}MR^2 + MR^2 = \frac{7}{5}MR^2$$

Step 2: Moment of inertia of the spherical shell about PQ For a spherical shell, the moment of inertia about its center is:

$$I_{\text{shell}} = \frac{2}{3}MR^2$$

Again, using the parallel axis theorem, the moment of inertia about PQ is:

$$I_{\text{shell, PQ}} = \frac{2}{3}MR^2 + MR^2 = \frac{5}{3}MR^2$$

Step 3: Moment of inertia of the system about PQ The total moment of inertia of the system is the sum of the moments of inertia of the disc, sphere, and spherical shell:

$$I_{\text{total}} = I_{\text{disc, PQ}} + I_{\text{sphere, PQ}} + I_{\text{shell, PQ}}$$

Substituting the values:

$$I_{\text{total}} = \frac{1}{4}MR^2 + \frac{7}{5}MR^2 + \frac{5}{3}MR^2$$

Step 4: Simplifying the total moment of inertia The common denominator is 60, so we can rewrite each term as:

$$I_{\text{total}} = \frac{15}{60}MR^2 + \frac{84}{60}MR^2 + \frac{100}{60}MR^2 = \frac{199}{60}MR^2$$

Step 5: Comparing with the given moment of inertia We are told that the moment of inertia about PQ is $\frac{x}{15}I$, where $I = \frac{1}{4}MR^2$. Therefore:

$$\frac{x}{15}I = \frac{199}{60}MR^2$$

Substituting $I = \frac{1}{4}MR^2$ into the equation:

$$\frac{x}{60} = \frac{199}{60} \quad \Rightarrow \quad x = 199$$

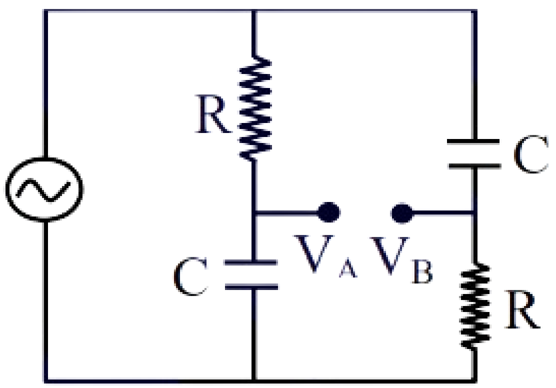
Thus, the value of x is 199.

Quick Tip

When dealing with systems involving different objects, use the parallel axis theorem to calculate the moment of inertia about any point other than the center of mass.

---

47. For the AC circuit shown in the figure, $R = 100\,\mathbf{k\Omega}$ and $C = 100\,\mathbf{pF}$, and the phase difference between V_{in} and $(V_B - V_A)$ is 90°. The input signal frequency is 10^x rad/sec, where x is:



Solution:
We are given that:
$R = 100\,\text{k}\Omega$
$C = 100\,\text{pF}$
The phase difference between V_{in} and $(V_B - V_A)$ is 90°.

The phase difference ϕ in a series RC circuit is given by:

$$\tan\phi = \frac{1}{\omega RC}$$

Given that $\phi = 90^\circ$, we have:

$$\tan 90^\circ = \infty \quad \Rightarrow \quad \frac{1}{\omega RC} = \infty$$

This implies:

$$\omega RC = 1$$

Where:
ω is the angular frequency (in rad/sec)
$R = 100 \times 10^3\,\Omega$
$C = 100 \times 10^{-12}\,\text{F}$

Substituting these values into the equation:

$$\omega \times (100 \times 10^3) \times (100 \times 10^{-12}) = 1$$

Simplifying:

$$\omega \times 10^{-6} = 1$$

$$\omega = 10^6\,\text{rad/sec}$$

The angular frequency ω is related to the frequency f by:

$$\omega = 2\pi f$$

Thus:

$$10^6 = 2\pi f$$

Solving for f:

$$f = \frac{10^6}{2\pi} \approx 1.59 \times 10^5\,\text{Hz}$$

We are asked to express the frequency in the form 10^x:

$$f \approx 10^5\,\text{Hz}$$

Therefore, $x = 5$.

$\boxed{x = 5}$

Quick Tip

In a series RC circuit with a 90° phase difference between the voltage and current, the frequency is determined by the time constant $\tau = RC$ and the phase condition $\omega RC = 1$.

---

48. A container contains a liquid with refractive index of 1.2 up to a height of 60 cm and another liquid having refractive index 1.6 is added to height H above the first liquid. If viewed from above, the apparent shift in the position of the bottom of the container is 40 cm. The value of H is ___ cm.

Solution: Step 1: Understand Apparent Shift The apparent shift occurs due to refraction at the liquid-air interface. The total apparent shift is the sum of shifts caused by each liquid layer.

Step 2: Formula for Apparent Shift

For a liquid layer of height h and refractive index μ, the apparent shift is given by:

$$\text{Shift} = h\left(1 - \frac{1}{\mu}\right)$$

Step 3: Calculate Shifts for Both Liquids

- For the first liquid ($\mu_1 = 1.2$, $h_1 = 60$ cm):

$$\text{Shift}_1 = 60\left(1 - \frac{1}{1.2}\right) = 60\left(1 - \frac{5}{6}\right) = 60 \times \frac{1}{6} = 10 \text{ cm}$$

- For the second liquid ($\mu_2 = 1.6$, $h_2 = H$ cm):

$$\text{Shift}_2 = H\left(1 - \frac{1}{1.6}\right) = H\left(1 - \frac{5}{8}\right) = H \times \frac{3}{8} = \frac{3H}{8} \text{ cm}$$

Step 4: Total Apparent Shift

The total apparent shift is given as 40 cm:

$$\text{Shift}_1 + \text{Shift}_2 = 40 \text{ cm}$$

$$10 + \frac{3H}{8} = 40$$

Step 5: Solve for H

$$\frac{3H}{8} = 30$$

$$3H = 240$$

$$H = 80 \text{ cm}$$

Verification

Let's verify the calculation:

$$\text{Total shift} = 10 + \frac{3 \times 80}{8} = 10 + 30 = 40 \text{ cm}$$

This matches the given condition.

Conclusion

The height H of the second liquid layer is $\boxed{80}$ cm.

Quick Tip

When dealing with problems involving apparent depth and refraction, use the formula Apparent depth $= \frac{\text{Real depth}}{\text{Refractive index}}$ and apply it to the layers of liquids with different refractive indices.

---

49. A wire of length 10 cm and diameter 0.5 mm is used in a bulb. The temperature of the wire is 1727°C and power radiated by the wire is 94.2 W. Its emissivity is $\frac{x}{8}$, where $x = \ldots$

Solution:

- Length $L = 0.1\,\text{m}$
- Diameter $d = 0.0005\,\text{m} \Rightarrow r = 0.00025\,\text{m}$
- Temperature $T = 1727°C = 2000\,\text{K}$
- Power radiated $P = 94.2\,\text{W}$

Using Stefan–Boltzmann law:

$$P = \varepsilon\sigma AT^4 \Rightarrow \varepsilon = \frac{P}{\sigma AT^4}$$

Surface area of the wire (cylinder lateral surface):

$$A = 2\pi rL = 2 \times 3.14 \times 0.00025 \times 0.1 = 1.57 \times 10^{-4}\,\text{m}^2$$

Temperature:

$$T^4 = (2000)^4 = 16 \times 10^{12}$$

Now calculate:

$$\varepsilon = \frac{94.2}{6.0 \times 10^{-8} \times 1.57 \times 10^{-4} \times 16 \times 10^{12}} = \frac{94.2}{150.72} \approx 0.625$$

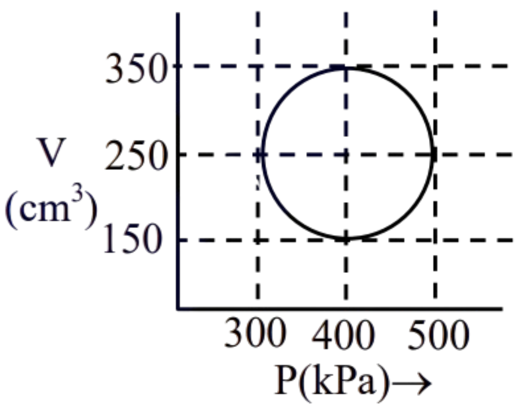
$$\Rightarrow \varepsilon = \frac{x}{8} \Rightarrow x = 8 \times 0.625 = \boxed{5}$$

Quick Tip

The Stefan-Boltzmann law relates the power radiated by a body to its temperature, surface area, and emissivity. For a cylindrical wire, calculate the surface area and use the given power to find the emissivity.

---

50. An ideal gas has undergone through the cyclic process as shown in the figure. Work done by the gas in the entire cycle is _____ $\times 10^{-1}$ J. (Take $\pi = 3.14$)



Solution: The graph is a circle in the PV diagram, and for a cyclic process, the work done by the gas is equal to the area enclosed by the cycle.

- Radius in pressure: $R_P = \frac{500-300}{2} = 100\,\text{kPa}$
- Radius in volume: $R_V = \frac{350-150}{2} = 100\,\text{cm}^3$

Assuming both axes are scaled equally, the radius $R = 100$

$$\text{Area} = \pi R^2 = 3.14 \times 100^2 = 3.14 \times 10^4$$

Convert units:

$$1\,\text{kPa} \cdot \text{cm}^3 = 10^{-2}\,\text{J} \Rightarrow \text{Work done} = 3.14 \times 10^4 \times 10^{-2} = 314\,\text{J}$$

$$\boxed{\text{Work done} = 31.4 \times 10^{-1}\,\text{J}}$$

Quick Tip

The work done in a cyclic process is the area enclosed by the path on a PV-diagram. For a circular path, use the area formula $A = \pi r^2$ to determine the work done by the gas.
