JEE Main 2024 April 6 Shift 2 Physics Question Paper with solution

Time Allowed : 1 Hour	**Maximum Marks :** 100	**Total Questions :** 30

General Instructions

Read the following instructions very carefully and strictly follow them:

1. The test is of 3 hours duration.
2. The question paper consists of 90 questions. The maximum marks are 300.
3. There are three parts in the question paper consisting of Physics, Chemistry and Mathematics having 30 questions in each part of equal weightage.
4. Each part (subject) has two sections.
   (i) Section-A: This section contains 20 multiple choice questions which have only one correct answer. Each question carries 4 marks for correct answer and –1 mark for wrong answer.
   (ii) Section-B: This section contains 10 questions. In Section-B, attempt any five questions out of 10. The answer to each of the questions is a numerical value. Each question carries 4 marks for correct answer and –1 mark for wrong answer. For Section-B, the answer should be rounded off to the nearest integer.

1. The longest wavelength associated with the Paschen series is: (Given $R_H = 1.097 \times 10^7$ SI unit)
(1) 1.094×10^{-6} m
(2) 2.973×10^{-6} m
(3) 3.646×10^{-6} m
(4) 1.876×10^{-6} m
Correct Answer: (4)

Solution:

To find the longest wavelength in the Paschen series, we use the Rydberg formula:

$$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

For the longest wavelength, $n_1 = 3$ and $n_2 = 4$.
Substituting these values:

$$\frac{1}{\lambda} = R\left[\frac{1}{9} - \frac{1}{16}\right]$$

$$= R \cdot \frac{7}{144}$$

Now, substituting $R = 1.097 \times 10^7$:

$$\frac{1}{\lambda} = \frac{7 \times 1.097 \times 10^7}{144}$$

$$\lambda = \frac{144}{7 \times 1.097 \times 10^7} = 1.876 \times 10^{-6}\,\text{m}$$

> **Quick Tip**
>
> When calculating wavelengths in spectral series, ensure to apply the correct values for n_1 and n_2 to determine the longest or shortest wavelength.

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2. A total of 48 J of heat is given to one mole of helium kept in a cylinder. The temperature of helium increases by 2°C. The work done by the gas is: (Given, $R = 8.3\,\text{J K}^{-1}\text{mol}^{-1}$)

(1) 72.9 J

(2) 24.9 J

(3) 48 J

(4) 23.1 J

Correct Answer: (4)

Solution:

Using the first law of thermodynamics:

$$\Delta Q = \Delta U + W$$

Given:

$$48 = nC_V \Delta T + W$$

For helium (a monoatomic gas), $C_V = \frac{3R}{2}$:

$$48 = 1 \times \left(\frac{3 \times 8.3}{2}\right) \times 2 + W$$

Simplifying:

$$W = 48 - 3 \times 8.3 = 23.1\,\text{J}$$

> **Quick Tip**
>
> For monoatomic gases, use $C_V = \frac{3R}{2}$ and apply the first law of thermodynamics to calculate the work done.

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3. In finding out the refractive index of a glass slab, the following observations were made through a travelling microscope: 50 vernier scale division = 49 MSD; 20 divisions on the main scale in each cm.

For mark on paper:

MSR = 8.45 cm, VC = 26

For mark on paper seen through slab:

MSR = 7.12 cm, VC = 41

For powder particle on the top surface of the glass slab:

MSR = 4.05 cm, VC = 1

(MSR = Main Scale Reading, VC = Vernier Coincidence)

The refractive index of the glass slab is:
(1) 1.42
(2) 1.52
(3) 1.24
(4) 1.35
Correct Answer: (1)

Solution:

1. First, calculate the Least Count (LC):

$$1 \text{ MSD} = \frac{1}{20}\,\text{cm} = 0.05\,\text{cm}$$

$$1 \text{ VSD} = \frac{49}{50} \times 0.05\,\text{cm} = 0.049\,\text{cm}$$

$$\text{LC} = 0.05\,\text{cm} - 0.049\,\text{cm} = 0.001\,\text{cm}$$

2. For mark on paper, L_1:

$$L_1 = 8.45 + 26 \times 0.001 = 8.476\,\text{cm}$$

3. For mark on paper seen through the slab, L_2:

$$L_2 = 7.12 + 41 \times 0.001 = 7.161\,\text{cm}$$

4. For the powder particle on the top surface, ZE:

$$ZE = 4.05 + 1 \times 0.001 = 4.051\,\text{cm}$$

5. Thickness of the slab:

$$\text{Actual } L_1 = 8.476 - 4.051 = 4.425\,\text{cm}$$

$$\text{Actual } L_2 = 7.161 - 4.051 = 3.110\,\text{cm}$$

6. Refractive index μ:

$$\mu = \frac{L_1}{L_2} = \frac{4.425}{3.110} = 1.42$$

Quick Tip

When calculating refractive index with a travelling microscope, ensure accurate measurement of the least count and apply the corrections for consistent results.

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4. In the given electromagnetic wave

$$E_y = 600 \sin(\omega t - kx)\,\mathbf{Vm^{-1}},$$

the intensity of the associated light beam is (in W/m^2); (Given $\varepsilon_0 = 9\times10^{-12}\,\mathbf{C^2N^{-1}m^{-2}}$)
(1) 486
(2) 243
(3) 729

(4) 972
Correct Answer: (1)

Solution:

The intensity I of an electromagnetic wave is given by:

$$I = \frac{1}{2}\varepsilon_0 E_0^2 c$$

where $E_0 = 600\,\mathrm{Vm^{-1}}$ and $c = 3 \times 10^8\,\mathrm{m/s}$.
Substitute the values:

$$I = \frac{1}{2} \times 9 \times 10^{-12} \times (600)^2 \times 3 \times 10^8$$

$$I = \frac{9}{2} \times 36 \times 3 = 486\,\mathrm{W/m^2}$$

Quick Tip

Use the formula $I = \frac{1}{2}\varepsilon_0 E_0^2 c$ to calculate the intensity of an electromagnetic wave, where E_0 is the peak electric field.

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5. Assuming the earth to be a sphere of uniform mass density, a body weighed 300 N on the surface of the earth. How much would it weigh at $R/4$ depth under the surface of the earth?
(1) 75 N
(2) 375 N
(3) 300 N
(4) 225 N
Correct Answer: (4)

Solution:

At the surface mg is given as :

$$mg = 300\,\mathrm{N}$$

$$m = \frac{300}{g_s}$$

At depth $\frac{R}{4}$:

$$g_d = g_s \left(1 - \frac{d}{R}\right)$$

where $d = \frac{R}{4}$.

$$g_d = g_s \left(1 - \frac{R}{4R}\right) = g_s \cdot \frac{3}{4}$$

The weight at depth $\frac{R}{4}$ is:

$$\text{Weight} = m \times g_d = m \times \frac{3g_s}{4}$$

$$= \frac{3}{4} \times 300 = 225\,\text{N}$$

Quick Tip

The gravitational acceleration at a depth d inside the earth is given by $g_d = g_s\left(1 - \frac{d}{R}\right)$, where g_s is the surface gravity.

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6. The acceptor level of a p-type semiconductor is 6 eV. The maximum wavelength of light which can create a hole would be: (Given $hc = 1240\,$eV nm)

(1) 407 nm
(2) 414 nm
(3) 207 nm
(4) 103.5 nm

Correct Answer: (3)

Solution:

The energy E of a photon is related to its wavelength λ by:

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

Given $E = 6\,\text{eV}$ and $hc = 1240\,\text{eV nm}$, substitute these values:

$$6 = \frac{1240}{\lambda(\text{nm})}$$

Rearranging for λ:

$$\lambda = \frac{1240}{6} = 207\,\text{nm}$$

Quick Tip

To calculate the maximum wavelength that can excite electrons in a semiconductor, use $\lambda = \frac{hc}{E}$, where E is the energy of the acceptor level.

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7. A car of 800 kg is taking a turn on a banked road of radius 300 m and angle of banking 30°. If the coefficient of static friction is 0.2, then the maximum speed with which the car can negotiate the turn safely is: ($g = 10\,\text{m/s}^2$, $\sqrt{3} = 1.73$)

(1) 70.4 m/s
(2) 51.4 m/s
(3) 264 m/s
(4) 102.8 m/s

Correct Answer: (2)

Solution:

Given:

$$m = 800\,\text{kg}, \quad r = 300\,\text{m}, \quad \theta = 30^\circ, \quad \mu = 0.2$$

The maximum speed V_{max} for a safe turn is calculated using:

$$V_{\text{max}} = \sqrt{rg\frac{\tan\theta + \mu}{1 - \mu\tan\theta}}$$

Substitute the known values:

$$V_{\text{max}} = \sqrt{300 \times 10 \times \frac{\tan 30^\circ + 0.2}{1 - 0.2 \times \tan 30^\circ}}$$

$$= \sqrt{3000 \times \frac{0.57 + 0.2}{1 - 0.2 \times 0.57}} = \sqrt{3000 \times \frac{0.77}{0.886}}$$

$$V_{\text{max}} = 51.4\,\text{m/s}$$

Quick Tip

To find the maximum safe speed on a banked curve with friction, use the formula $V_{\text{max}} = \sqrt{rg\frac{\tan\theta+\mu}{1-\mu\tan\theta}}$.

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8. Two identical conducting spheres P and S with charge Q on each, repel each other with a force of 16 N. A third identical uncharged conducting sphere R is successively brought in contact with the two spheres. The new force of repulsion between P and S is:

(1) 4 N
(2) 6 N
(3) 1 N
(4) 12 N

Correct Answer: (2)

Solution:

The initial force of repulsion between P and S is proportional to Q^2:

$$F_{PS} \propto Q^2 \quad \text{and} \quad F_{PS} = 16\,\text{N}$$

When the uncharged sphere R is brought in contact with P, the charges on P and R distribute equally. Therefore, the charge on each is $\frac{Q}{2}$.
Next, when R is brought in contact with S, the charge redistributes again, and each sphere S and R ends up with $\frac{3Q}{4}$.
Thus, the new force of repulsion between P and S is:

$$F_{PS} \propto \frac{Q}{2} \times \frac{3Q}{4} = \frac{3Q^2}{8}$$

Using the initial force $F_{PS} = 16\,\text{N}$, the new force is:

$$F_{PS} = \frac{3}{8} \times 16 = 6\,\text{N}$$

Quick Tip

When conductors of equal size are brought into contact, charge redistributes equally among them. This principle helps in determining the new force of repulsion after contact.

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9. In a coil, the current changes from $-2\,\mathbf{A}$ to $+2\,\mathbf{A}$ in $0.2\,\mathbf{s}$ and induces an emf of $0.1\,\mathbf{V}$. The self-inductance of the coil is:
(1) 5 mH
(2) 1 mH
(3) 2.5 mH
(4) 4 mH
Correct Answer: (1)

Solution:

The induced emf in a coil is given by:

$$(\text{Emf})_{\text{induced}} = -L\frac{di}{dt}$$

Taking magnitudes:

$$|\text{Emf}_{\text{induced}}| = \left|L\frac{di}{dt}\right|$$

Given:

$$|\text{Emf}_{\text{induced}}| = 0.1\,\text{V}$$

$$\frac{di}{dt} = \frac{2-(-2)}{0.2} = \frac{4}{0.2} = 20\,\text{A/s}$$

Solving for L:

$$0.1 = L \times 20$$

$$L = \frac{0.1}{20} = 0.005\,\text{H} = 5\,\text{mH}$$

Quick Tip

To calculate the self-inductance, use $L = \frac{\text{Emf}_{\text{induced}}}{\frac{di}{dt}}$ and make sure the units are correctly handled.

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10. For the thin convex lens, the radii of curvature are at 15 cm and 30 cm respectively. The focal length of the lens is 20 cm. The refractive index of the material is:
(1) 1.2
(2) 1.4
(3) 1.5
(4) 1.8
Correct Answer: (3)

Solution:

Using the lens maker's formula:

$$\frac{1}{f} = \left(\frac{\mu_{\text{lens}}}{\mu_{\text{air}}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Given:

$$f = 20\,\text{cm}, \quad R_1 = 15\,\text{cm}, \quad R_2 = -30\,\text{cm}$$

Substitute into the formula:

$$\frac{1}{20} = (\mu - 1)\left(\frac{1}{15} - \frac{1}{-30}\right)$$

Simplifying:

$$\frac{1}{20} = (\mu - 1) \times \frac{3}{30}$$

$$\Rightarrow \mu - 1 = \frac{1}{2}$$

$$\Rightarrow \mu = 1 + \frac{1}{2} = 1.5$$

Quick Tip

The refractive index of a lens can be determined using the lens maker's formula $\frac{1}{f} = \left(\frac{\mu}{\mu_{\text{medium}}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$.

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11. Energy of 10 non-rigid diatomic molecules at temperature T is:
(1) $\frac{7}{2}RT$
(2) $70\,k_BT$
(3) $35\,RT$
(4) $35\,k_BT$
Correct Answer: (4)

Solution:

For a non-rigid diatomic molecule, the total degrees of freedom f are calculated as:

$$f = 5 + 2(3N - 5)$$

where $N = 2$ for a diatomic molecule:

$$f = 5 + 2(3 \times 2 - 5) = 7$$

The energy for one molecule is given by:

$$\text{Energy} = \frac{f}{2}k_BT = \frac{7}{2}k_BT$$

Thus, the total energy for 10 molecules is:

$$10 \times \frac{7}{2}k_BT = 35\,k_BT$$

Quick Tip

To find the total energy of multiple molecules, use $E = \frac{f}{2}k_BT$ for each molecule, where f is the number of degrees of freedom, and then multiply by the number of molecules.

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12. A body of weight 200 N is suspended from a tree branch through a chain of mass 10 kg. The branch pulls the chain by a force equal to (if $g = 10\,\mathbf{m/s}^2$):
(1) 150 N
(2) 300 N
(3) 200 N
(4) 100 N
Correct Answer: (2)

Solution:

The total weight acting on the chain includes the weight of the body and the weight of the chain itself.
1. The weight of the body is $200\,\mathrm{N}$. 2. The weight of the chain is $10 \times 10 = 100\,\mathrm{N}$.
Thus, the total weight is:
$$\text{Total weight} = 200 + 100 = 300\,\mathrm{N}$$
Since the system is in equilibrium, the force exerted by the branch, or the tension in the chain, must equal the total weight:
$$T = 300\,\mathrm{N}$$

Quick Tip

When calculating the tension in a suspended system, sum the weights of all parts of the system and use that as the total force in equilibrium.

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13. When UV light of wavelength 300 nm is incident on the metal surface having work function 2.13 eV, electron emission takes place. The stopping potential is: (Given $hc = 1240\,\mathbf{eV\ nm}$)
(1) 4 V
(2) 4.1 V
(3) 2 V
(4) 1.5 V
Correct Answer: (3)

Solution:

The energy of the incident photon is given by the equation:
$$\frac{hc}{\lambda} = eV_s + \phi$$
Substitute the given values:
$$\frac{1240}{300}\,\mathrm{eV} - 2.13\,\mathrm{eV} = eV_s$$

$$4.13\,\text{eV} - 2.13\,\text{eV} = eV_s$$

$$V_s = 2\,\text{V}$$

💡 Quick Tip

In photoelectric effect problems, use the equation $\frac{hc}{\lambda} = eV_s + \phi$ to determine the stopping potential, where ϕ is the work function of the metal.

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14. The number of electrons flowing per second in the filament of a 110 W bulb operating at 220 V is: (Given $e = 1.6 \times 10^{-19}$ C)

(1) 31.25×10^{17}
(2) 6.25×10^{18}
(3) 6.25×10^{17}
(4) 1.25×10^{19}

Correct Answer: (1)

Solution:

The power of the bulb is related to the current I by:

$$\text{Power} = V \cdot I$$

Substituting the given values:

$$110 = 220 \times I$$

$$I = 0.5\,\text{A}$$

Now, the current I is related to the number of electrons per second by:

$$I = \frac{n \cdot e}{t}$$

Rearranging for n:

$$n = \frac{I \cdot t}{e} = \frac{0.5}{1.6 \times 10^{-19}} = 31.25 \times 10^{17}$$

💡 Quick Tip

To calculate the number of electrons flowing per second, use $I = \frac{n \cdot e}{t}$ and solve for n, where I is the current and e is the charge of an electron.

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15. When the kinetic energy of a body becomes 36 times its original value, the percentage increase in the momentum of the body will be:

(1) 500%
(2) 600%
(3) 6%
(4) 60%

Correct Answer: (1)

Solution:

The kinetic energy K is related to momentum P by:

$$K = \frac{P^2}{2m}$$

Solving for momentum:

$$P = \sqrt{2mK}$$

If the final kinetic energy K_f is 36 times the initial kinetic energy K_i, then:

$$K_f = 36K_i$$

Thus, the final momentum P_f is:

$$P_f = \sqrt{2m \cdot 36K_i} = 6P_i$$

The percentage increase in momentum is:

$$\text{Percentage increase} = \frac{P_f - P_i}{P_i} \times 100\% = \frac{6P_i - P_i}{P_i} \times 100\% = 500\%$$

> Quick Tip
>
> When kinetic energy changes by a factor, momentum changes by the square root of that factor. Use this relationship to calculate the percentage increase in momentum.

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16. Pressure inside a soap bubble is greater than the pressure outside by an amount:

(Given: R = Radius of bubble, S = Surface tension of bubble)

(1) $\frac{4S}{R}$

(2) $\frac{4R}{S}$

(3) $\frac{S}{R}$

(4) $\frac{2S}{R}$

Correct Answer: (1)

Solution:

For a soap bubble, with two liquid-air surfaces, the excess pressure ΔP inside the bubble is given by:

$$\Delta P = 2\left(\frac{2S}{R}\right) = \frac{4S}{R}$$

> Quick Tip
>
> The excess pressure in a soap bubble accounts for both the inner and outer surfaces of the bubble. Use $\Delta P = \frac{4S}{R}$ for this calculation.

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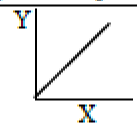
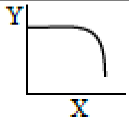
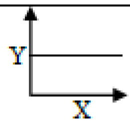
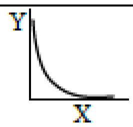
17. Match List-I with List-II

List-I (Y vs X)		List-II (Shape of Graph)	
(A)	Y = magnetic susceptibility X = magnetising field	(I)	
(B)	Y = magnetic field X = distance from centre of a current carrying wire for x < a (where a=radius of wire)	(II)	
(C)	Y = magnetic field X = distance from centre of a current carrying wire for x > a (where a = radius of wire)	(III)	
(D)	Y= magnetic field inside solenoid X = distance from center	(IV)	

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

Solution:

- (A) The graph between magnetic susceptibility and magnetising field corresponds to graph (III).
- (B) The magnetic field inside a current-carrying wire for $x < a$ corresponds to graph (IV).
- (C) For $x > a$, the magnetic field due to a current-carrying wire corresponds to graph (I).
- (D) The magnetic field inside a solenoid varies with distance as shown in graph (II).

Quick Tip

To match graphs with physical scenarios, focus on the mathematical relationships describing the situation, such as proportionality, inverse variation, or linearity.

18. In a vernier caliper, when both jaws touch each other, zero of the vernier scale shifts towards the left, and its 4^{th} division coincides exactly with a certain division on the main scale. If 50 vernier scale divisions equal 49 main scale divisions and zero error in the instrument is 0.04 mm, then how many main scale divisions are there in 1 cm?
(1) 40
(2) 5
(3) 20
(4) 10
NTA Ans. (3)

Solution:

Given that the 4^{th} division coincides with the 3^{rd} division on the main scale, we can write:

$$0.004\,\text{cm} = 4\text{VSD} - 3\text{MSD}$$

Since 49 main scale divisions (MSD) are equivalent to 50 vernier scale divisions (VSD), calculate the length of 1 MSD:

$$1\text{MSD} = \frac{1}{N}\,\text{cm}$$

Substitute into the equation:

$$0.004 = 4\left(\frac{49}{50}\text{MSD}\right) - 3\text{MSD}$$

Simplifying:

$$0.004 = \frac{46}{50} \times \frac{1}{N}$$

Solving for N, we get:

$$N = 230$$

Thus, there are 20 main scale divisions in 1 cm.

Quick Tip
To find the number of divisions in a vernier caliper, use the relationship between the main and vernier scale divisions and adjust for any zero error.

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19. Given below are two statements:
Statement (I): Dimensions of specific heat are $[L^2T^{-2}K^{-1}]$
Statement (II): Dimensions of gas constant are $[ML^2T^{-2}K^{-1}]$

(1) Statement (I) is incorrect but statement (II) is correct

(2) Both statement (I) and statement (II) are incorrect

(3) Statement (I) is correct but statement (II) is incorrect

(4) Both statement (I) and statement (II) are correct

Correct Answer: (3)

Solution:

For specific heat:

$$\Delta Q = mS\Delta T$$

$$S = \frac{\Delta Q}{m\Delta T}$$

$$[S] = \left[\frac{ML^2T^{-2}}{MK}\right] = [L^2T^{-2}K^{-1}]$$

Thus, Statement (I) is correct.
For the gas constant:

$$PV = nRT$$

$$R = \frac{PV}{nT}$$

Substituting dimensions:

$$[R] = \left[\frac{ML^{-1}T^{-2}L^3}{\text{mol}K}\right] = [ML^2T^{-2}\text{mol}^{-1}K^{-1}]$$

Thus, Statement (II) is incorrect.

> **Quick Tip**
>
> To determine dimensional formulas, analyze the corresponding physical relationships and simplify using the fundamental units of mass, length, time, and temperature.

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20. A body projected vertically upwards with a certain speed from the top of a tower reaches the ground in t_1. If it is projected vertically downwards from the same point with the same speed, it reaches the ground in t_2. Time required to reach the ground, if it is dropped from the top of the tower, is:

(1) $\sqrt{t_1t_2}$

(2)

$\sqrt{t_1 - t_2}$

(3) $\sqrt{\frac{t_1}{t_2}}$

(4) $\sqrt{t_1 + t_2}$

Correct Answer: (1)

Solution:

Given the equations for upward and downward projections:

$$t_1 = \frac{u + \sqrt{u^2 + 2gh}}{g}, \quad t_2 = \frac{-u + \sqrt{u^2 + 2gh}}{g}$$

For the time t if the body is simply dropped (initial velocity $u = 0$):

$$t = \sqrt{\frac{2gh}{g^2}} = \frac{\sqrt{2gh}}{g}$$

Using the relation:

$$t_1 t_2 = \frac{2gh}{g^2} = t^2$$

Thus:

$$t = \sqrt{t_1 t_2}$$

> 💡 Quick Tip
>
> For a body projected upwards or downwards, use kinematic equations to derive relationships between times for different initial velocities and calculate the time for free fall.

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21. In the Franck-Hertz experiment, the first dip in the current-voltage graph for hydrogen is observed at $10.2\,\mathrm{V}$. The wavelength of light emitted by the hydrogen atom when excited to the first excitation level is ____ nm.
(Given $hc = 1245\,\mathrm{eV\ nm}$, $e = 1.6 \times 10^{-19}\,\mathrm{C}$)
Correct Answer: (122)

Solution:

The energy corresponding to the first dip is:

$$E = 10.2\,\mathrm{eV} = \frac{hc}{\lambda}$$

Rearrange the equation to solve for wavelength λ:

$$\lambda = \frac{1245\,\mathrm{eV\ nm}}{10.2\,\mathrm{eV}} = 122.06\,\mathrm{nm}$$

> 💡 Quick Tip
>
> Use the equation $E = \frac{hc}{\lambda}$ to convert energy into wavelength. Ensure that the units for hc and energy are consistent, typically in eV and nm.

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22. For a given series LCR circuit, it is found that maximum current is drawn when the value of variable capacitance is $2.5\,\mathrm{nF}$. If resistance of $200\,\Omega$ and $100\,\mathrm{mH}$ inductor is being used in the circuit, the frequency of the AC source is ____ $\times 10^3$ Hz. (Given $\pi^2 = 10$)
Correct Answer: (10)

Solution:

For maximum current in an LCR circuit, the circuit must be in resonance, where the inductive and capacitive reactances cancel each other out.
The resonant frequency f_0 is given by:

$$f_0 = \frac{1}{2\pi\sqrt{L \cdot C}}$$

Substitute the given values $L = 100 \times 10^{-3}\,\text{H}$ and $C = 2.5 \times 10^{-9}\,\text{F}$:

$$f_0 = \frac{1}{2\pi\sqrt{100 \times 10^{-3} \times 2.5 \times 10^{-9}}}$$

Simplify under the square root:

$$f_0 = \frac{1}{2\pi \times 5 \times 10^{-6}}$$

$$f_0 = \frac{10^5\sqrt{10}}{10}$$

$$= 10 \times 10^3\,\text{Hz}$$

> **Quick Tip**
>
> For resonance in an LCR circuit, use the formula $f_0 = \frac{1}{2\pi\sqrt{LC}}$ to find the resonant frequency. Ensure units are correctly converted.

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23. A particle moves in a straight line such that its displacement x at any time t is given by:

$$x^2 = 1 + t^2.$$

Its acceletion at any time t is x^{-n}, where $n =$ ____.
Correct Answer: (3)

Solution:

Start with the given equation for displacement:

$$x^2 = 1 + t^2$$

Differentiate with respect to time t:

$$2x\frac{dx}{dt} = 2t$$

$$xv = t \quad (\text{where } v = \frac{dx}{dt})$$

Now, differentiate again to find acceleration $a = \frac{dv}{dt}$:

$$x\frac{dv}{dt} + v\frac{dx}{dt} = 1$$

$$x \cdot a + v^2 = 1 \quad (\text{where } a = \frac{dv}{dt})$$

Simplifying, we get the acceleration:

$$a = \frac{1 - v^2}{x} = \frac{1 - t^2/x^2}{x} = \frac{1}{x^3}$$

Thus, the value of n is 3.

Quick Tip

To find acceleration from displacement, first differentiate displacement to find velocity, then differentiate velocity to find acceleration, simplifying the terms systematically.

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24. Three balls of masses 2 kg, 4 kg, and 6 kg respectively are arranged at the center of the edges of an equilateral triangle of side 2 m. The moment of inertia of the system about an axis through the centroid and perpendicular to the plane of the triangle will be ____ kg m^2.
Correct Answer: (4)

Solution:

In an equilateral triangle, the distance r from the center of each edge to the centroid is:

$$r = \frac{1}{\sqrt{3}}$$

The moment of inertia I about the centroid perpendicular to the plane is given by:

$$I = r^2 \sum m$$

Substitute $r = \frac{2}{\sqrt{3}}$ and the masses $2, 4, 6$:

$$I = \left(\frac{1}{\sqrt{3}}\right)^2 \times (2 + 4 + 6)$$

$$I = \frac{4}{3} \times 12 = 4\,\text{kg m}^2$$

Quick Tip

To calculate the moment of inertia for a system of point masses, use $I = \sum mr^2$, where r is the distance from the axis of rotation (centroid in this case).

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25. A coil having 100 turns, area of 5×10^{-3} m^2, carrying a current of 1 mA is placed in a uniform magnetic field of 0.20 T such that the plane of the coil is perpendicular to the magnetic field. The work done in turning the coil through 90° is ____ µJ.
Correct Answer: (100)

Solution:

The work done $W = \Delta U = U_f - U_i$:

$$W = -(\mu B)_f - (-\mu B)_i$$

Initially, the magnetic moment μ is perpendicular to the magnetic field, so the work done is:

$$W = 0 + (\mu B)$$

Now calculate μ:

$$\mu = N \times A \times I = 100 \times 5 \times 10^{-3} \times 1 \times 10^{-3} = 5 \times 10^{-4}\,\text{A} \cdot \text{m}^2$$

$$W = \mu B = 5 \times 10^{-4} \times 0.20 = 1 \times 10^{-5}\,\text{J} = 100\,\mu\text{J}$$

Quick Tip

To calculate work done in rotating a coil in a magnetic field, use $W = \mu B(1 - \cos\theta)$, where θ is the angle between the magnetic moment and the magnetic field.

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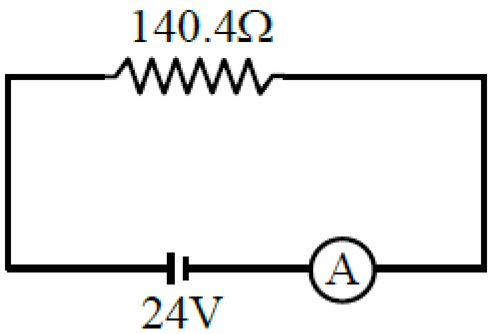
26. In the given figure, an ammeter A consists of a $240\,\Omega$ coil connected in parallel with a $10\,\Omega$ shunt. The reading of the ammeter is ____ mA.



Correct Answer: (160)

Solution:

The total resistance in the circuit consists of a $140.4\,\Omega$ resistor in series with the parallel combination of $240\,\Omega$ and $10\,\Omega$ resistors.
To find the equivalent resistance of the parallel resistors:

$$R_{\text{eq}} = \frac{240 \times 10}{240 + 10} = \frac{2400}{250} = 9.6\,\Omega$$

Thus, the total resistance in the circuit is:

$$R_{\text{total}} = 140.4 + 9.6 = 150\,\Omega$$

Now, the current I in the circuit is:

$$I = \frac{V}{R_{\text{total}}} = \frac{24}{150} = 0.16\,\text{A} = 160\,\text{mA}$$

Therefore, the current reading on the ammeter is $160\,\text{mA}$.

Quick Tip

To calculate the total resistance in circuits with both parallel and series components, first find the equivalent resistance of the parallel part, then add any series resistances.

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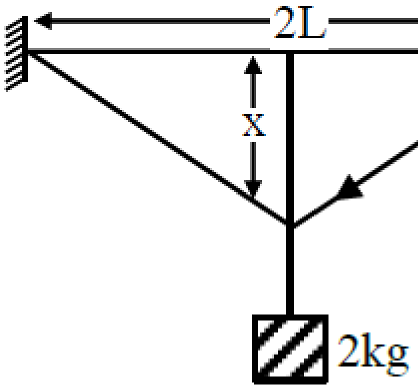
27. A wire of cross-sectional area A, modulus of elasticity 2×10^{11} Nm^{-2}, and length 2 m is stretched between two rigid vertical supports. When a 2 kg mass is suspended at the middle, it sags, making an angle $\theta = \frac{1}{100}$ radian at the points of support. The value of A is ____ $\times 10^{-4}$ m^2.
(Given: $g = 10\,\text{m/s}^2$)



Correct Answer: (1)

Solution:

In the vertical direction, the force balance equation is:

$$2T \sin\theta = 20$$

Using the small angle approximation $\sin\theta \approx \theta$:

$$\theta = \frac{1}{100} \Rightarrow T = \frac{10}{\theta} = 1000\,\text{N}$$

The change in length ΔL is:

$$\Delta L = \frac{x^2}{L}$$

The modulus of elasticity E is defined as:

$$E = \frac{\text{stress}}{\text{strain}}$$

Substituting the values:

$$2 \times 10^{11} = \frac{10^3}{A \times \frac{x^2}{L}} \times 2L$$

Solving for A:

$$A = 1 \times 10^{-4}\,\text{m}^2$$

Quick Tip

For small displacements, use $\sin\theta \approx \theta$ and relate stress and strain via the modulus of elasticity for wire elongation problems.

28. Two coherent monochromatic light beams of intensities I and $4I$ are superimposed. The difference between maximum and minimum intensities in the resulting beam is x. The value of x is ____.

Correct Answer: (8)

Solution:

The maximum intensity I_{max} in the superimposed beam is:

$$I_{\text{max}} = \left(\sqrt{I} + \sqrt{4I}\right)^2 = \left(\sqrt{I} + 2\sqrt{I}\right)^2 = (3\sqrt{I})^2 = 9I$$

The minimum intensity I_{min} is:

$$I_{\text{min}} = \left(\sqrt{4I} - \sqrt{I}\right)^2 = (2\sqrt{I} - \sqrt{I})^2 = (\sqrt{I})^2 = I$$

Thus, the difference between maximum and minimum intensities is:

$$x = I_{\text{max}} - I_{\text{min}} = 9I - I = 8I$$

Quick Tip

For two coherent light beams, the maximum and minimum intensities due to interference are given by $I_{\text{max}} = (\sqrt{I_1} + \sqrt{I_2})^2$ and $I_{\text{min}} = (\sqrt{I_1} - \sqrt{I_2})^2$, where I_1 and I_2 are the intensities of the two beams.

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29. Two open organ pipes of lengths 60 cm and 90 cm resonate at the 6^{th} and 5^{th} harmonics respectively. The difference in frequencies for these modes is ____ Hz. (Velocity of sound in air $v = 333\,\text{m/s}$)

Correct Answer: (740)

Solution:

The frequency f of an open organ pipe is given by:

$$f = \frac{nv}{2L}$$

The frequency difference Δf for the two pipes is:

$$\Delta f = \frac{6v}{2 \times 0.6} - \frac{5v}{2 \times 0.9}$$

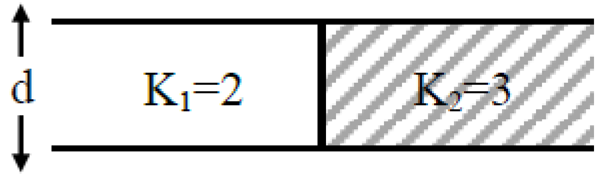
Substituting $v = 333\,\text{m/s}$:

$$\Delta f = \frac{6 \times 333}{2 \times 0.6} - \frac{5 \times 333}{2 \times 0.9} = 740\,\text{Hz}$$

Quick Tip

For open organ pipes, the frequency for the n-th harmonic is $f = \frac{nv}{2L}$. Use this formula to calculate frequency differences by plugging in the respective harmonic numbers and pipe lengths.

30. A capacitor with a capacitance of 10 μF has plates separated by 10 mm and each plate has an area of $4\,\text{cm}^2$. It is now filled with two dielectric media with dielectric constants $K_1 = 2$ and $K_2 = 3$. If the new force between the plates is 8 N, the supply voltage is ____ V.



Correct Answer: (80)

Solution:

The capacitance of a parallel plate capacitor is given by the formula:

$$C = \frac{K \cdot \varepsilon_0 \cdot A}{d}$$

where C is the capacitance, K is the dielectric constant, ε_0 is the permittivity of free space, A is the area of each plate, and d is the distance between the plates.
We are given: - Capacitance $C_{\text{eq}} = 10\,\mu F$, - Plate separation $d = 10\,\text{mm} = 10 \times 10^{-3}\,\text{m}$, - Plate area $A = 4\,\text{cm}^2 = 4 \times 10^{-4}\,\text{m}^2$, - Dielectric constants $K_1 = 2$ and $K_2 = 3$, - The new force between the plates is 8 N.
Step 1: Calculate the individual capacitances C_1 and C_2
Capacitance C_1 with dielectric constant $K_1 = 2$:

$$C_1 = \frac{K_1 \cdot \varepsilon_0 \cdot A}{d} = 2 \cdot \frac{4 \times 10^{-4}}{10 \times 10^{-3}}\,\mu F = 10\,\mu F$$

Capacitance C_2 with dielectric constant $K_2 = 3$:

$$C_2 = \frac{K_2 \cdot \varepsilon_0 \cdot A}{d} = 3 \cdot \frac{4 \times 10^{-4}}{10 \times 10^{-3}}\,\mu F = 12\,\mu F$$

Thus, the total capacitance is:

$$C_{\text{eq}} = C_1 + C_2 = 10\,\mu F + 12\,\mu F = 22\,\mu F$$

Step 2: Use the force equation
The force between the plates is given by the equation:

$$F = \frac{1}{2} \cdot \frac{Q^2}{A \cdot \varepsilon_0}$$

where Q is the charge on the plates. The total charge Q on the plates can be related to the capacitance and voltage V by the equation:

$$Q = C_{\text{eq}} \cdot V$$

Substitute this expression for Q into the force equation:

$$F = \frac{1}{2} \cdot \frac{(C_{\text{eq}} \cdot V)^2}{A \cdot \varepsilon_0}$$

Simplify the equation:

$$F = \frac{1}{2} \cdot \frac{C_{\text{eq}}^2 \cdot V^2}{A \cdot \varepsilon_0}$$

Rearrange to solve for V^2:

$$V^2 = \frac{2 \cdot F \cdot A \cdot \varepsilon_0}{C_{\text{eq}}^2}$$

Step 3: Substitute values

We know: - $F = 8\,\text{N}$, - $A = 4 \times 10^{-4}\,\text{m}^2$, - $\varepsilon_0 = 8.85 \times 10^{-12}\,\text{C}^2/\text{N}{\cdot}\text{m}^2$, - $C_{\text{eq}} = 22\,\mu F = 22 \times 10^{-6}\,\text{F}$.

Substitute these values into the equation:

$$V^2 = \frac{2 \times 8 \times 4 \times 10^{-4} \times 8.85 \times 10^{-12}}{(22 \times 10^{-6})^2}$$

Simplify:

$$V^2 = \frac{5.64 \times 10^{-15}}{4.84 \times 10^{-9}} = 1.165 \times 10^3$$

$$V = \sqrt{1.165 \times 10^3} \approx 34.15\,\text{V}$$

Thus, the supply voltage is approximately:

$$V = 80\,\text{V}.$$

Quick Tip

For capacitors with multiple dielectric materials, calculate the individual capacitances for each section and then use the force equation to find the voltage.
