# JEE Advanced (2024)

# PAPER 1

***General Instructions***:

**SECTION 1 (Maximum Marks: 12)**

- This section contains **FOUR (04)** questions.
- Each question has **FOUR** options (A), (B), (C) and (D). **ONLY ONE** of these four options is the correct answer.
- For each question, choose the option corresponding to the correct answer.
- Answer to each question will be evaluated according to the following marking scheme:

  *Full Marks* : +3 If **ONLY** the correct option is chosen;
  *Zero Marks* : 0 If none of the options is chosen (i.e., the question is unanswered);
  *Negative Marks* : −1 in all other cases.

**1.** A dimensionless quantity is constructed in terms of electronic charge $e$, permittivity of free space $\varepsilon_0$, Planck's constant $h$, and speed of light $c$. If the dimensionless quantity is written as $e^{\alpha}\,\varepsilon_0^{\beta}\,h^{\gamma}\,c^{\delta}$ and $n$ is a non-zero integer, then $(\alpha, \beta, \gamma, \delta)$ is given by

**(A)** $(2n, -n, -n, -n)$ **(B)** $(n, -n, -2n, -n)$
**(C)** $(n, -n, -n, -2n)$ **(D)** $(2n, -n, -2n, -n)$

**2.** An infinitely long wire, located on the $z$-axis, carries a current $I$ along the $+z$-direction and produces the magnetic field $\vec{B}$. The magnitude of the line integral $\int \vec{B}\cdot\vec{dl}$ along a straight line from the point $\left(-\sqrt{3}a, a, 0\right)$ to $(a, a, 0)$ is given by

[$\mu_0$ is the magnetic permeability of free space.]

**(A)** $7\mu_0 I/24$ **(B)** $7\mu_0 I/12$
**(C)** $\mu_0 I/8$ **(D)** $\mu_0 I/6$

**3.** Two beads, each with charge $q$ and mass $m$, are on a horizontal, frictionless, non-conducting, circular hoop of radius $R$. One of the beads is glued to the hoop at some point, while the other one performs small oscillations about its equilibrium position along the hoop. The square of the angular frequency of the small oscillations is given by

[$\varepsilon_0$ is the permittivity of free space.]

**(A)** $q^2/(4\pi\varepsilon_0 R^3 m)$ **(B)** $q^2/(32\pi\varepsilon_0 R^3 m)$
**(C)** $q^2/(8\pi\varepsilon_0 R^3 m)$ **(D)** $q^2/(16\pi\varepsilon_0 R^3 m)$

**4.** A block of mass 5 kg moves along the $x$-direction subject to the force $F = (-20x + 10)$N, with the value of $x$ in metre. At time $t = 0$ s, it is at rest at position $x = 1$ m. The position and momentum of the block at $t = (\pi/4)$ s are

**(A)** −0.5 m, 5 kg m/s **(B)** 0.5 m, 0 kg m/s
**(C)** 0.5 m, −5 kg m/s **(D)** −1 m, 5 kg m/s

***General Instructions***:

**SECTION 2 (Maximum Marks: 12)**

- This section contains **THREE (03)** questions.
- Each question has **FOUR** options (A), (B), (C) and (D). **ONE OR MORE THAN ONE** of these four option(s) is (are) correct answer(s).
- For each question, choose the option(s) corresponding to (all) the correct answer(s).
- Answer to each question will be evaluated according to the following marking scheme:

  *Full Marks* : +4 ONLY if (all) the correct option(s) is(are) chosen;
  *Partial Marks* : +3 If all the four options are correct but ONLY three options are chosen;
  *Partial Marks* : +2 If three or more options are correct but ONLY two options are chosen, both of which are correct;
  *Partial Marks* : +1 If two or more options are correct but ONLY one option is chosen and it is a correct option;
  *Zero Marks* : 0 If unanswered;
  *Negative Marks* : −2 in all other cases.
- For example, in a question, if (A), (B) and (D) are the ONLY three options corresponding to correct answers, then
  choosing ONLY (A), (B) and (D) will get +4 marks;
  choosing ONLY (A) and (B) will get +2 marks;
  choosing ONLY (A) and (D) will get +2 marks;
  choosing ONLY (B) and (D) will get +2 marks;
  choosing ONLY (A) will get +1 mark;
  choosing ONLY (B) will get +1 mark;
  choosing ONLY (D) will get +1 mark;
  choosing no option(s) (i.e., the question is unanswered) will get 0 marks and
  choosing any other option(s) will get −2 marks.

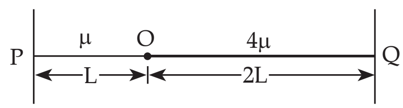
**5.** A particle of mass $m$ is moving in a circular orbit under the influence of the central force $F(r) = -kr$, corresponding to the potential energy $V(r) = kr^2/2$, where $k$ is a positive force constant and $r$ is the radial distance from the origin. According to the Bohr's quantization rule, the angular momentum of the particle is given by $L = n\hbar$, where $\hbar$ =

$h/(2\pi)$, $h$ is the Planck's constant, and $n$ a positive integer. If $v$ and $E$ are the speed and total energy of the particle, respectively, then which of the following expression(s) is(are) correct?

**(A)** $r^2 = n\hbar\sqrt{\frac{1}{mk}}$ **(B)** $v^2 = n\hbar\sqrt{\frac{k}{m^3}}$

**(C)** $\frac{L}{mr^2} = \sqrt{\frac{k}{m}}$ **(D)** $E = \frac{n\hbar}{2}\sqrt{\frac{k}{m}}$

**6.** Two uniform strings of mass per unit length μ and 4μ, and length $L$ and $2L$, respectively, are joined at point O, and tied at two fixed ends P and Q, as shown in the figure. The strings are under a uniform tension $T$. If we define the frequency $\nu_0 = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$ which of the following statement(s) is(are) correct?



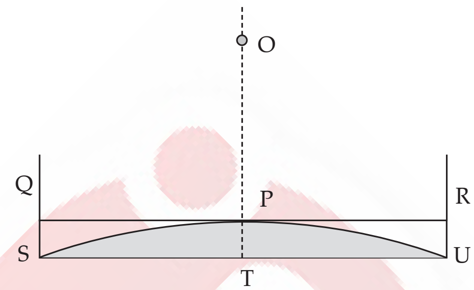

**(A)** With a node at O, the minimum frequency of vibration of the composite string is $\nu_0$.

**(B)** With an antinode at O, the minimum frequency of vibration of the composite string is $2\nu_0$.

**(C)** When the composite string vibrates at the minimum frequency with a node at O, it has 6 nodes, including the end nodes.

**(D)** No vibrational mode with an antinode at O is possible for the composite string.

**7.** A glass beaker has a solid, plano-convex base of refractive index 1.60, as shown in the figure. The radius of curvature of the convex surface (SPU) is 9 cm, while the planar surface (STU) acts as a mirror. This beaker is filled with a liquid of refractive index $n$ up to the level QPR. If the image of a point object O at a height of $h$ (OT in the figure) is formed onto itself, then, which of the following option(s) is(are) correct?




**(A)** For $n$ = 1.42, $h$ = 50 cm.

**(B)** For $n$ = 1.35, $h$ = 36 cm.

**(C)** For $n$ = 1.45, $h$ = 65 cm.

**(D)** For $n$ = 1.48, $h$ = 85 cm.

*General Instructions*:

**SECTION 3 (Maximum Marks: 24)**

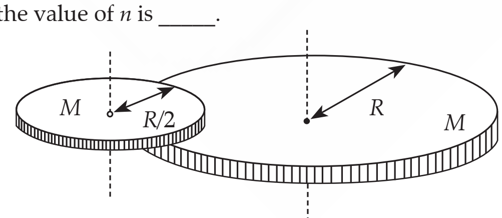
- This section contains **SIX (06)** questions.
- The answer to each question is a **NON-NEGATIVE INTEGER**.
- For each question, enter the correct integer corresponding to the answer using the mouse and the onscreen virtual numeric keypad in the place designated to enter the answer.
- Answer to each question will be evaluated according to the following marking scheme:

*Full Marks* : +4 If **ONLY** the correct integer is entered;
*Zero Marks* : 0 in all other cases.

**8.** The specific heat capacity of a substance is temperature dependent and is given by the formula $C = kT$, where $k$ is a constant of suitable dimensions in SI units, and $T$ is the absolute temperature. If the heat required to raise the temperature of 1 kg of the substance from −73 °C to 27 °C is $nk$, the value of $n$ is _____.

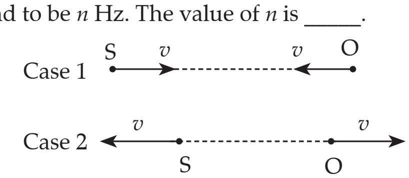
[Given: 0 K = −273 °C.]

**9.** A disc of mass $M$ and radius $R$ is free to rotate about its vertical axis as shown in the figure. A battery operated motor of negligible mass is fixed to this disc at a point on its circumference. Another disc of the same mass $M$ and radius $R/2$ is fixed to the motor's thin shaft. Initially, both the discs are at rest. The motor is switched on so that the smaller disc rotates at a uniform angular speed ω. If the angular speed at which the large disc rotates is $\omega/n$, then the value of $n$ is _____.




**10.** A point source S emits unpolarised light uniformly in all directions. At two points A and B, the ratio $r = I_A/I_B$ of the intensities of light is 2. If a set of two polaroids having 45° angle between their pass-axis is placed just before point B, then the new value of $r$ will be _____.

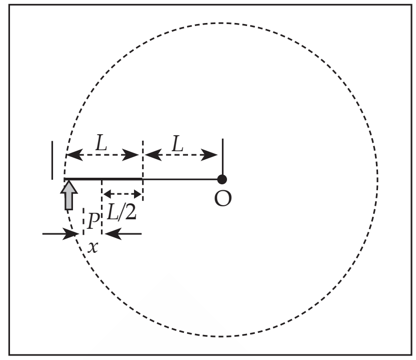
**11.** A source (S) of sound has frequency 240 Hz. When the observer (O) and the source move towards each other at a speed $v$ with respect to the ground (as shown in Case 1 in the figure), the observer measures the frequency of the sound to be 288 Hz. However, when the observer and the source move away from each other at the same speed $v$ with respect to the ground (as shown in Case 2 in the figure), the observer measures the frequency of sound to be $n$ Hz. The value of $n$ is _____.




**12.** Two large, identical water tanks, 1 and 2, kept on the top of a building of height $H$, are filled with water up to height h in each tank. Both the tanks contain an identical hole of small radius on their sides, close to their bottom.

A pipe of the same internal radius as that of the hole is connected to tank 2, and the pipe ends at the ground level. When the water flows from the tanks 1 and 2 through the holes, the times taken to empty the tanks are $t_1$ and $t_2$, respectively. If $H = \left(\frac{16}{9}\right)h$, then the ratio $t_1 / t_2$ is _____.

**13.** A thin uniform rod of length $L$ and certain mass is kept on a frictionless horizontal table with a massless string of length $L$ fixed to one end (top view is shown in the figure). The other end of the string is pivoted to a point O. If a horizontal impulse $P$ is imparted to the rod at a distance $x = L/n$ from the mid-point of the rod (see figure), then the rod and string revolve together around the point O, with the rod remaining aligned with the string. In such a case, the value of $n$ is _____.



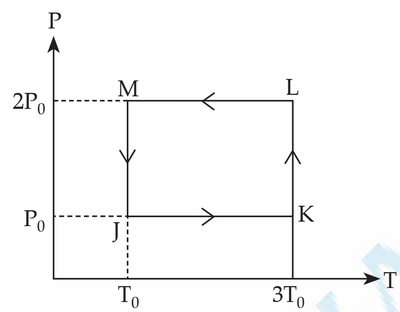

*General Instructions*:

**SECTION 4 (Maximum Marks: 12)**

- This section contains **FOUR (04)** paragraphs.
- Each set has **ONE** Multiple Choice Question.
- Each set has **TWO** lists: **List-I** and **List-II.**
- **List-I** has **Four** entries (P), (Q), (R) and (S) and **List-II** has **FIVE** entries (1), (2), (3), (4) and (5).
- **FOUR** options are given in each Multiple Choice Question based on **List-I** and **List-II** and **ONLY ONE** of these four options satisfies the condition asked in the Multiple Choice Question.
- Answer to each question will be evaluated according to the following marking scheme:

*Full Marks* : +3 **ONLY** if the option corresponding to the correct combination is chosen.
*Zero Marks* : 0 If none of the options is chosen (i.e the question is unanswered);
*Negative Marks* : –1 in all other cases.

**14.** One mole of a monatomic ideal gas undergoes the cyclic process $J \to K \to L \to M \to J$, as shown in the P–T diagram.



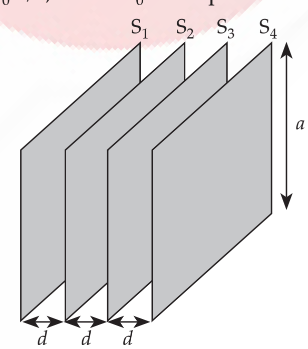

Match the quantities mentioned in List-I with their values in List-II and choose the correct option.

[R is the gas constant].

| List-I | List-II |
|---|---|
| (P) Work done in the complete cyclic process | (1) $RT_0 - 4RT_0 \ln 2$ |
| (Q) Change in the internal energy of the gas in the process JK | (2) 0 |
| (R) Heat given to the gas in the process KL | (3) $3RT_0$ |
| (S) Change in the internal energy of the gas in the process MJ | (4) $-2RT_0 \ln 2$ |
| | (5) $-3RT_0 \ln 2$ |

**(A)** $P \to 1$; $Q \to 3$; $R \to 5$; $S \to 4$
**(B)** $P \to 4$; $Q \to 3$; $R \to 5$; $S \to 2$
**(C)** $P \to 4$; $Q \to 1$; $R \to 2$; $S \to 2$
**(D)** $P \to 2$; $Q \to 5$; $R \to 3$; $S \to 4$

**15.** Four identical thin, square metal sheets, $S_1$, $S_2$, $S_3$ and $S_4$, each of side $a$ are kept parallel to each other with equal distance $d$ ($<< a$) between them, as shown in the figure. Let $C_0 = \varepsilon_0 a^2/d$, where $\varepsilon_0$ is the permittivity of free space.




Match the quantities mentioned in List-I with their values in List-II and choose the correct option.

| List-I | List-II |
|---|---|
| (P) The capacitance between $S_1$ and $S_4$, with $S_2$ and $S_3$ not connected, is | (1) $3C_0$ |
| (Q) The capacitance between $S_1$ and $S_4$, with $S_2$ shorted to $S_3$, is | (2) $C_0/2$ |
| (R) The capacitance between $S_1$ and $S_3$, with $S_2$ shorted to $S_4$, is | (3) $C_0/3$ |
| (S) The capacitance between $S_1$ and $S_2$, with $S_3$ shorted to $S_1$, and $S_2$ shorted to $S_4$, is | (4) $2C_0/3$ |
| | (5) $2C_0$ |

**(A)** P → 3; Q → 2; R → 4; S → 5
**(B)** P → 2; Q → 3; R → 2; S → 1
**(C)** P → 3; Q → 2; R → 4; S → 1
**(D)** P → 3; Q → 2; R → 2; S → 5

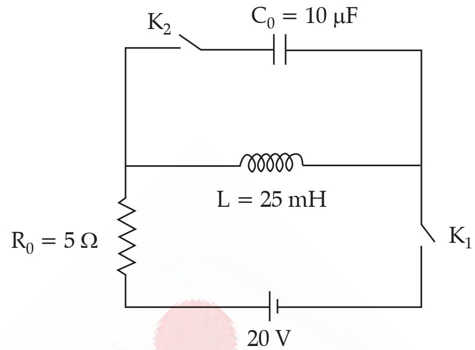
**16.** A light ray is incident on the surface of a sphere of refractive index $n$ at an angle of incidence $\theta_0$. The ray partially refracts into the sphere with angle of refraction $\phi_0$ and then partly reflects from the back surface. The reflected ray then emerges out of the sphere after a partial refraction. The total angle of deviation of the emergent ray with respect to the incident ray is $\alpha$.

Match the quantities mentioned in List-I with their values in List-II and choose the correct option.

| List-I | List-II |
|---|---|
| (P) If $n = 2$ and $\alpha = 180°$, then all the possible values of $\theta_0$ will be | (1) 30° and 0° |
| (Q) If $n = \sqrt{3}$ and $\alpha = 180°$, then all the possible values of $\theta_0$ will be | (2) 60° and 0° |
| (R) If $n = \sqrt{3}$ and $\alpha = 180°$, then all the possible values of $\phi_0$ will be | (3) 45° and 0° |
| (S) If $n = \sqrt{2}$ and $\theta_0 = 45°$, then all the possible values of $\alpha$ will be | (4) 150° |
| | (5) 0° |

**(A)** P → 5; Q → 2; R → 1; S → 4
**(B)** P → 5; Q → 1; R → 2; S → 4
**(C)** P → 3; Q → 2; R → 1; S → 4
**(D)** P → 3; Q → 1; R → 2; S → 5

**17.** The circuit shown in the figure contains an inductor $L$, a capacitor $C_0$, a resistor $R_0$ and an ideal battery. The circuit also contains two keys $K_1$ and $K_2$. Initially, both the keys are open and there is no charge on the capacitor. At an instant, key $K_1$ is closed and immediately after this the current in $R_0$ is found to be $I_1$. After a long time, the current attains a steady state value $I_2$. Thereafter, $K_2$ is closed and simultaneously $K_1$ is opened and the voltage across $C_0$ oscillates with amplitude $V_0$ and angular frequency $\omega_0$.




Match the quantities mentioned in List-I with their values in List-II and choose the correct option.

| List-I | List-II |
|---|---|
| (P) The value of $I_1$ in Ampere is | (1) 0 |
| (Q) The value of $I_2$ in Ampere is | (2) 2 |
| (R) The value of $\omega_0$ in kilo-radians/s is | (3) 4 |
| (S) The value of $V_0$ in Volt is | (4) 20 |
| | (5) 200 |

**(A)** P → 1; Q → 3; R → 2; S → 5
**(B)** P → 1; Q → 2; R → 3; S → 5
**(C)** P → 1; Q → 3; R → 2; S → 4
**(D)** P → 2; Q → 5; R → 3; S → 4

# Answer Key

| Q.No. | Answer key | Topic's name | Chapter's name |
|---|---|---|---|
| 1 | (A) | Unit & Dimensions | General Physics |
| 2 | (A) | Biot-Savart Law and Ampere's Law | Magnetic Effects of Current and Magnetism |
| 3 | (B) | Different SHM, Forced and Damped Oscillations | Oscillation |
| 4 | (C) | Simple Harmonic Motion | Oscillation |
| 5 | (A,B,C) | Bohr's Quantisation Condition | Atomic Physics |
| 6 | (A,C,D) | Standing Waves and Organ Pipe | Wave Motion |
| 7 | (A,B) | Reflection and Refraction of Light and Lens Makers Formula | Geometrical Optics |
| 8 | 25000 | Specific Heat | Thermal Properties of Matter |
| 9 | 12 | Conservation of Angular Momentum | System of Particles and Rotational Motion |
| 10 | 8 | Polarisation and Brewster's Law | Wave Optics |
| 11 | 200 | Beats and Doppler Effect | Wave Motion |
| 12 | 3 | Equation of Continuity | Mechanical Properties of Fluids |
| 13 | 18 | Impulse, Rotational Motion | System of Particles and Rotational Motion |
| 14 | B | Work done in Cyclic Process | Thermodynamics |
| 15 | C | Capacitance, Capacitor and their Combinations, Polarisation and Dielectric | Electrostatic Potential and Capacitors |
| 16 | A | Reflection and Refraction of Light and TIR | Geometrical Optics |
| 17 | A | LCR Series Circuit | Electromagnetic Induction and Alternating Current |

❑❑

# ANSWERS WITH EXPLANATIONS

**1. Correct option is (A).**

Dimensionless quantity $= e^{\alpha}\,\varepsilon_0^{\beta}\,h^{\gamma}\,c^{\delta}$

$$[AT]^{\alpha}\,[M^{-1}L^{-3}T^{4}A^{2}]^{\beta}\,[ML^{2}T^{-1}]^{\gamma}\,[LT^{-1}]^{\delta} = [M^0L^0T^0]$$

$$[A]^{\alpha+2\beta}\,[M]^{-\beta+\gamma}\,[L]^{-3\beta+2\gamma+\delta}\,[T]^{\alpha+4\beta-\gamma-\delta} = [M^0L^0T^0]$$

So,

$$\alpha + 2\beta = 0 \qquad ...(i)$$

$$-\beta + \gamma = 0 \qquad ...(ii)$$

$$-3\beta + 2\gamma + \delta = 0 \qquad ...(iii)$$

$$\alpha + 4\beta - \gamma - \delta = 0 \qquad ...(iv)$$

On solving above equations

$$\alpha = -2\beta$$

$$\gamma = \beta$$

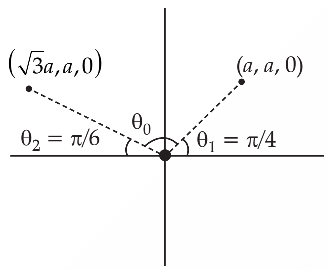
$$\delta = \beta$$

Hence, $(\alpha, \beta, \gamma, \delta) = (-2\beta, \beta, \beta, \beta) \approx (2n, -n, -n, -n)$

**2. Correct option is (A).**

$$\theta_0 = \pi - \frac{\pi}{6} - \frac{\pi}{4}$$

$$= \frac{7\pi}{12}$$

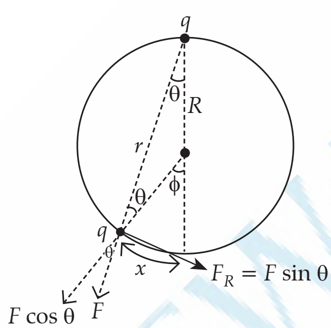



Now,

$$\int \vec{B}\cdot\vec{dl} = \frac{\mu_0 I}{2\pi}[\theta]_{\theta_1}^{\theta_0+\theta_1}$$

$$= \frac{\mu_0 I}{2\pi}\theta_0 = \frac{7\mu_0 I}{24}$$

**3. Correct option is (B).**




$$F = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}$$

Restoring force $= F\sin\theta$

$$F_R = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}\sin\theta$$

$$F_R = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{4R^2\cos^2\theta}\sin\theta \quad (r = 2R\cos\theta)$$

$$F_R = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{4R^2\cos^2\left(\frac{\phi}{2}\right)}\sin\left(\frac{\phi}{2}\right)$$

$$\because (\phi = 2\theta)$$

For small $\phi$,

$$m\omega^2 x = \frac{q^2}{16\pi R^2\varepsilon_0}\left(\frac{\phi}{2}\right)$$

$$\omega^2 = \frac{q^2}{16\pi R^2\varepsilon_0}\left(\frac{\phi}{2}\right)\times\frac{1}{mR\phi} \qquad \because (x = R\phi)$$

$$\omega^2 = \frac{q^2}{32\pi\varepsilon_0 mR^3}$$

**4. Correct option is (C).**

Given, $F = (-20x + 10)\,N$

$\Rightarrow a = -4x + 2$

In SHM $a = \omega^2 x + c$,

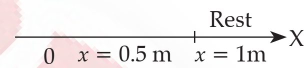
At extreme position, $a = 0$ then $x_0 = \dfrac{c}{\omega^2} = \dfrac{2}{4} = 0.5$ m

This is the near position of the particle performing SHM.

Now $\omega^2 = 4$

$\Rightarrow \omega = 2$

So $T = \dfrac{2\pi}{\omega}$




$\Rightarrow T = \pi\, s$

At $t = \dfrac{\pi}{4}$, the particle is at the mean position and is moving with the fastest speed, i.e.,

$v = A\omega$

$\Rightarrow v = -0.5 \times 2 = -1\ \text{ms}^{-1}$

So, Linear momentum $p = mv$

$= -5\ \text{kg ms}^{-1}$

**5. Correct options are (A, B, C).**

According to Bohr's quantization rule,

$$L = n\hbar$$

$$mvr = n\hbar$$

$$v = \frac{n\hbar}{mr} \qquad ...(1)$$

and

$$\frac{mv^2}{r} = kr$$

$$r^2 = \frac{mv^2}{k} = \frac{m}{k}\frac{n^2\hbar^2}{m^2r^2}$$

$$r^2 = \frac{n\hbar}{\sqrt{mk}} \qquad \text{(option A is correct)}$$

From equation (1)

$$v^2 = \left(\frac{n\hbar}{m}\right)^2 \times \frac{1}{r^2} = \frac{(n\hbar)^2}{m^2}\times\frac{\sqrt{mk}}{n\hbar}$$

$$v^2 = n\hbar\sqrt{\frac{k}{m^3}} \qquad \text{(option B is correct)}$$

Now

$$v^2 = L\sqrt{\frac{k}{m^3}}$$

Putting $v$ from equation (1)

$$\left(\frac{n\hbar}{mr}\right)^2 = L\sqrt{\frac{k}{m^3}}$$

$$\frac{L}{m^2r^2} = \sqrt{\frac{k}{m^3}}$$

$$\frac{L}{mr^2} = \sqrt{\frac{k}{m}} \qquad \text{(option C is correct)}$$

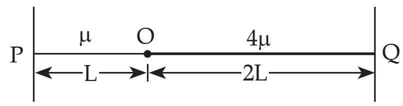
and,

$$T = \text{K.E.} + \text{P.E} = \frac{1}{2}mv^2 + \frac{1}{2}kr^2$$

$$= \frac{1}{2}m\left(n\hbar\sqrt{\frac{k}{m^3}}\right) + \frac{1}{2}k\left(\frac{n\hbar}{\sqrt{mk}}\right)$$

$$= n\hbar\sqrt{\frac{k}{m}}$$ (option D is incorrect)

**6. Correct options are (A, C, D).**




$$v = \sqrt{\frac{T}{\mu}} \qquad v' = \sqrt{\frac{T}{4\mu}} = \frac{1}{2}v$$

With a node at O

$$m\frac{1}{2L}\sqrt{\frac{T}{\mu}} = n\frac{1}{2(2L)}\sqrt{\frac{T}{4\mu}}$$

$$\frac{m}{n} = \frac{1}{4}$$

$$f_{min} = 1\times\frac{1}{2L}\sqrt{\frac{T}{\mu}} = \nu_0$$ (option A is correct)

With an antinode at O

$$(2m+1)\frac{1}{4L}\sqrt{\frac{T}{\mu}} = (2n+1)\frac{1}{4(2L)}\sqrt{\frac{T}{4\mu}}$$

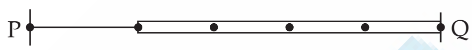
$$\frac{2n+1}{2m+1} = 4$$

$$\frac{\text{odd}}{\text{odd}} = \text{even}$$

Not possible (option D is correct)

(option B is incorrect)

With node at O




Total node = 6 (option C is correct)

For antinode at O.

**7. Correct options are (A, B).**

$$\frac{1}{f_{liq}} = (n-1)\left(\frac{1}{\infty}-\frac{1}{9}\right) = -\left(\frac{n-1}{9}\right)$$

$$\frac{1}{f_{lens}} = (1.6-1)\left(\frac{1}{9}-\frac{1}{\infty}\right) = \frac{0.6}{9}$$

$$\frac{1}{f_{mirror}} = \frac{1}{\infty}$$

Now, Net focal length is

$$-\frac{1}{f_{net}} = 2\left(\frac{1}{f_{liq}}\right)+2\left(\frac{1}{f_{lens}}\right)+\left(-\frac{1}{f_{mirror}}\right)$$

For image to coincide with object

$$-h = 2f_{net}$$

$$\frac{2}{h} = -2\left(\frac{n-1}{9}\right)+2\left(\frac{0.6}{9}\right)+\left(-\frac{1}{\infty}\right)$$

$$h = \frac{9}{1.6-n}$$

Now,

$n = 1.42$, $h = \frac{9}{1.6-1.42} = 50$ cm (option A is correct)

$n = 1.35$, $h = \frac{9}{1.6-1.35} = 36$ cm (option B is correct)

$n = 1.45$, $h = \frac{9}{1.6-1.45} = 60$ cm (option C is incorrect)

$n = 1.48$, $h = \frac{9}{1.6-1.48} = 75$ cm (option D is incorrect)

**8. Correct answer is [25000].**

$$T_1 = 273 + (-73) = 200K$$

$$T_2 = 273 + (27) = 300K$$

Now

$$\frac{dQ}{dT} = mC = mkT$$

$$\int_0^Q dQ = mk\int_{200k}^{300k} TdT$$

$$Q = mk\frac{T^2}{2} = \frac{mk}{2}[300^2 - 200^2]$$

$$Q = 1\times\frac{k}{2}\times 5\times 10^4 = 25000k = nk$$

$$n = 25000$$

**9. Correct answer is [12].**

Applying conservation of angular momentum

$$\left(\frac{MR^2}{2}+MR^2\right)\omega' + \frac{M\left(\frac{R}{2}\right)^2}{2}\omega = 0$$

$$\frac{3}{2}MR^2\omega' = -\frac{MR^2}{8}\omega$$

$$\omega' = -\frac{\omega}{12}$$

$$|\omega'| = \frac{\omega}{n} = \frac{\omega}{12}$$

$$n = 12$$

**10. Correct answer is [8].**

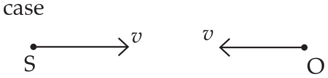
$$I'_A = I_A$$

$$I'_B = \frac{I_B}{2}\cos^2 45° = \frac{I_B}{4}$$

$$r_{new} = \frac{I'_A}{I'_B} = \frac{I_A\times 4}{I_B} = 2\times 4 = 8$$

**11. Correct answer is [200].**

For First case



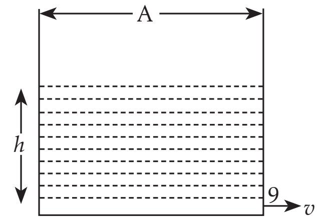

$$f' = f\left(\frac{v_0+v}{v_0-v}\right)$$

$$288 = 240\left(\frac{v_0+v}{v_0-v}\right) \qquad ...(1)$$

For Second case

$$f'' = f\left(\frac{v_0 - v}{v_0 + v}\right) = 240\left(\frac{240}{288}\right)$$
$$= 200 \text{ Hz}$$

**12. Correct answer is [3].**




$$v = \sqrt{2gh}$$

Applying equation of continuity

$$-A\left(\frac{dh}{dt}\right) = a\sqrt{2gh}$$

$$\int_0^t dt = \int_{h_i}^{h_f} \frac{-A}{a\sqrt{2g}} \frac{dh}{\sqrt{h}}$$

$$t = \frac{2A}{a\sqrt{2g}}\left(\sqrt{h_i} - \sqrt{h_f}\right)$$

For tank 2

$$h_i = h + H = h + \frac{16h}{9} = \frac{25h}{9}$$

$$h_f = H = \frac{16h}{9}$$

$$t_2 = \frac{2A}{a\sqrt{2g}}\left(\sqrt{\frac{25h}{9}} - \sqrt{\frac{16h}{9}}\right) = \frac{2A\sqrt{h}}{3a\sqrt{2g}}$$

For tank 1

$$h_i = h, \text{ and } h_f = 0$$

$$t_1 = \frac{2A}{a\sqrt{2g}}\left(\sqrt{h} - 0\right) = \frac{2A\sqrt{h}}{a\sqrt{2g}}$$

$$\frac{t_1}{t_2} = 3$$

**13. Correct answer is [18].**

Moment of inertia of rod about centre (O)

$$I = \frac{mL^2}{12} + m\left(L + \frac{L}{2}\right)^2$$

Now, $$I = \frac{7mL^2}{3}$$

Ang. Mom. $$J = p\left(L + \frac{L}{2} + \frac{L}{n}\right)$$

$$I\omega_0 = p\left(\frac{3L}{2} + \frac{L}{n}\right) \quad ...(1)$$

$$p = mv_c = m\omega_0\left(L + \frac{L}{2}\right) = m\omega_0\left(\frac{3L}{2}\right) \quad ...(2)$$

So,

$$\frac{7mL^2}{3}\omega_0 = m\omega_0\left(\frac{3L}{2}\right)\left(\frac{3L}{2} + \frac{L}{n}\right)$$

$$\frac{7}{3} = \frac{3}{2}\left(\frac{3}{2} + \frac{1}{n}\right)$$

$$\frac{3}{2n} = \frac{1}{12} \Rightarrow n = 18$$

**14. Correct option is (B).**

Work done ($W_1$) in process ($J \to K$)

$$W_1 = nR(\Delta T) = nR(3T_0 - T_0) = 2nRT_0$$

Work done ($W_2$) in process ($K \to L$)

$$W_2 = nR(3T_0)\ln\left(\frac{P_0}{2P_0}\right) = -3RT_0 \ln(2)$$

Work done ($W_3$) in process ($L \to M$)

$$W_3 = nR(T_0 - 3T_0) = -2nRT_0$$

Work done ($W_4$) in process ($M \to L$)

$$W_4 = nRT_0\left(\frac{2P_0}{P_0}\right) = nRT_0 \ln 2$$

Total work done $= 2nRT_0 - 3RT_0 \ln(2) - 2nRT_0 + nRT_0 \ln(2)$
$= -2nRT_0 \ln(2)$

$P \to 4$

In process $J \to K$

$$\Delta U = nC_V\Delta T = 1 \times \frac{3R}{2} \times (3T_0 - T_0) = 3RT_0$$

$Q \to 3$

In process $K \to L$

$\Delta Q = \Delta W = -3RT_0 \ln(2)$

$R \to 5$

In process $M \to J$

$\Delta U = nC_V\Delta T = 0$

$S \to 2$

**15. Correct option is (C).**

For P

$$\frac{1}{C_{eq}} = \frac{1}{C_0} + \frac{1}{C_0} + \frac{1}{C_0} \Rightarrow C_{eq} = \frac{C_0}{3}$$

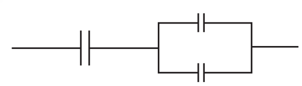
$P \to 3$

For Q

$$\frac{1}{C_{eq}} = \frac{1}{C_0} + \frac{1}{C_0} \Rightarrow C_{eq} = \frac{C_0}{2}$$

$Q \to 2$

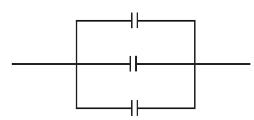
For R



$$\frac{1}{C_{eq}} = \frac{1}{C_0} + \frac{1}{2C_0} \Rightarrow C_{eq} = \frac{2C_0}{3}$$

$R \to 4$

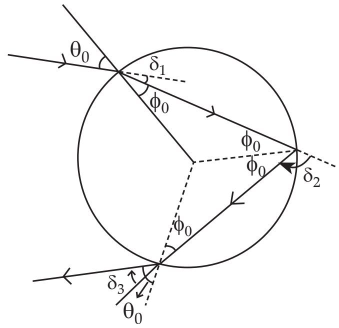
For S



$C_{eq} = C_0 + C_0 + C_0 = 3C_0$

$S \to 1$

**16. Correct option is (A).**




$$\sin\theta_0 = n\sin\phi_0 \qquad \text{...(i)}$$

$$\delta_1 = \theta_0 - \phi_0$$

$$\delta_2 = 180° - (2\phi_0)$$

$$\delta_3 = \theta_0 - \phi_0$$

$$\alpha = \delta_1 + \delta_2 + \delta_3$$

$$\alpha = 180° + 2\theta_0 - 4\phi_0$$

Now for P

$$n = 2 \text{ and } \alpha = 180°$$

$$2\theta_0 = 4\phi_0 = \theta_0 = 2\phi_0$$

$$\sin\theta_0 = n\sin\phi_0 = 2\sin\left(\frac{\theta_0}{2}\right)$$

$$\cos\left(\frac{\theta_0}{2}\right) = 1 \Rightarrow \theta_0 = 0°$$

$P \rightarrow 5$

For Q $\theta_0 = 2\phi_0$

$$\sin\theta_0 = \sqrt{3}\sin\phi_0 = \sqrt{3}\sin\left(\frac{\theta_0}{2}\right)$$

$$\cos\left(\frac{\theta_0}{2}\right) = \frac{\sqrt{3}}{2}$$

$$\theta_0 = 60°$$

$Q \rightarrow 2$

For R $\sin 2\phi_0 = \sqrt{3}\sin\phi_0$

$$\phi_0 = 0°$$

$$\cos\phi_0 = \frac{\sqrt{3}}{2}$$

$$\phi_0 = 30°$$

$R \rightarrow 1$

For S

Given $\theta_0 = 45°$ $n = \sqrt{2}$ , $\alpha = ?$

$\Rightarrow \alpha = 180° + 2\theta_0 - 4\phi_0$

$\alpha = 180° + 2 \times 45° - 4\phi_0$

$\alpha = (90° - 4\phi_0)$

$4\phi_0 = (90° - \alpha)$

$$\phi_0 = \frac{(90° - \alpha)}{4}$$

From equation (1)

$$\sin 45° = \sqrt{2}\sin\frac{(90° - \alpha)}{4}$$

$$\frac{1}{\sqrt{2}} = \sqrt{2}\sin\left(\frac{90° - \alpha}{4}\right)$$

$$\frac{1}{2} = \sin\frac{(90° - \alpha)}{4}$$

$$\sin 30° = \sin\frac{(90° - \alpha)}{4}$$

$$30° = \frac{90° - \alpha}{4}$$

$$120° = 90° - \alpha$$

$$\alpha = 90° - 120°$$

$$\boxed{\alpha = -30°}$$

In anticlockwise direction,

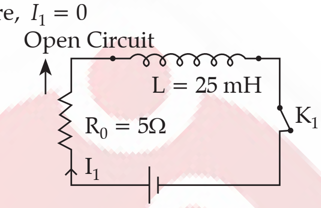
angle, $\alpha = 180° - 30°$

$$\boxed{\alpha = 150°}$$

**17. Correct option is (A).**

**For P:** When key $k_1$ is closed, then current is $I_1$ in $R_0$.

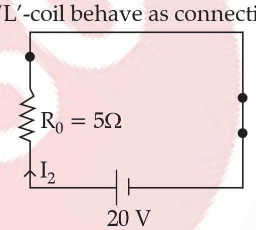
At instant ($t = 0$), $L$-coil act as high-resistive in nature. Therefore, $I_1 = 0$




$P \rightarrow 1$

**For Q:** For long time, 'L'-coil behave as connecting wire.

$$I_2 = \frac{20}{5} = 4A$$




$Q \rightarrow 3$

**For R:** When $k_1$ is open and $k_2$ is closed.

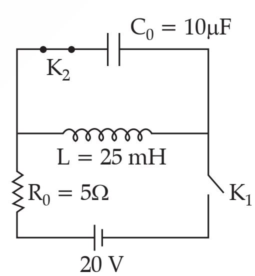
$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$\omega_0 = \frac{1}{\sqrt{25\times 10^{-3}\times 10\times 10^{-6}}}$$

$\omega_0 = 2 \times 10^3$ rad/s or $\omega_0 = 2\,k$ rad/s

$R \rightarrow 2$

**For S:** Voltage across $C_0$ is $V_0$, while $K_1$ is open and $K_2$ is closed.




Energe in capacitor = Energy in inductor coil

$$\frac{1}{2}CV_0^2 = \frac{1}{2}LI_2^2$$

$$\frac{1}{2}\times 10\times 10^{-6}\times V_0^2 = \frac{1}{2}\times 25\times 10^{-3}\times 4^2$$

$$V_0^2 = 2500\times 16$$

$$V_0 = 50\times 4$$

$$V_0 = 200 \text{ V}$$

$S \rightarrow 5$