JEE Advanced Paper 2024 with Solutions

Physics

PAPER 1

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.

1. A dimensionless quantity is constructed in terms of electronic charge e, permittivity of free space ε_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) $(2n, -n, -2n, -2n)$

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 $\int \vec{B} \cdot \overrightarrow{dl}$ along a straight line from the point $(-\sqrt{3}\,a, a, 0)$ to $(a, a, 0)$ is given by

[μ_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

[ε_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

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).

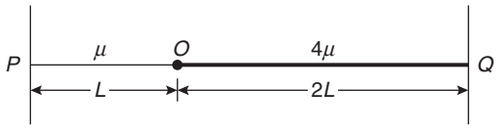
5. A particle of mass m is moving in a circular orbit under the influence of the central force $F(r) = -kr$, corresponding to the potential energy $V(r) = kr^2/2$, where k is a positive force constant and r is the radial distance from the origin. According to the Bohr's quantization rule, the angular momentum of the particle is given by $L = nh$, where $h = h/(2\pi)$, 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) $r^2 = nh\sqrt{\dfrac{1}{mk}}$ **(B)** $v^2 = nh\sqrt{\dfrac{k}{m^3}}$

(C) $\dfrac{L}{mr^2} = \sqrt{\dfrac{k}{m}}$ **(D)** $E = \dfrac{nh}{2}\sqrt{\dfrac{k}{m}}$

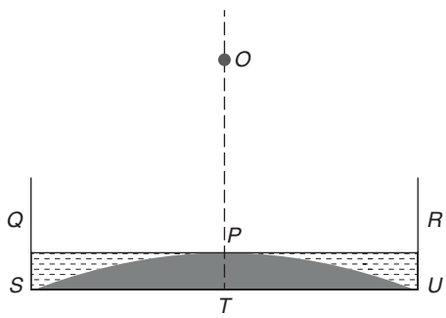
6. Two uniform strings of mass per unit length μ and 4μ, and length L and $2L$, respectively, are joined at point O, and tied at two fixed ends P and Q, as shown in the figure.

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 ν_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?



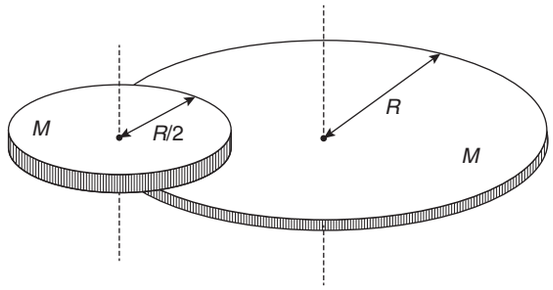
(A) For $n = 1.42$, $h = 50$ cm
(B) For $n = 1.35$, $h = 36$ cm
(C) For $n = 1.45$, $h = 65$ cm
(D) For $n = 1.48$, $h = 85$ cm

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.

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 _____.

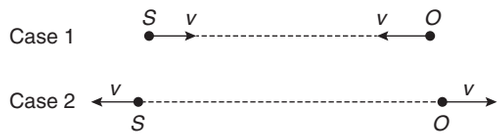
[Given: 0 K = –273° C.]

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 ω/n, then the value of n is _____.



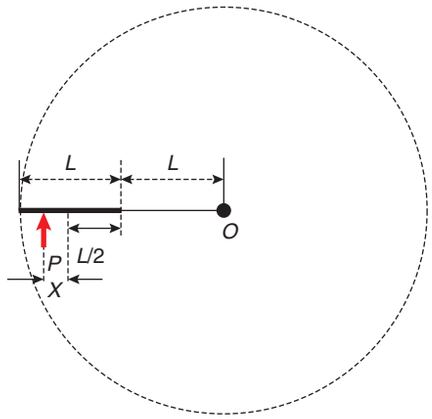
10. A point source S emits unpolarized light uniformly in all directions. At two points A and B, the ratio $r = I_A/I_B$ of the intensities of light is 2. If a set of two polaroids having 45° angle between their pass-axes is placed just before point B, then the new value of r will be _____.

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 _____.



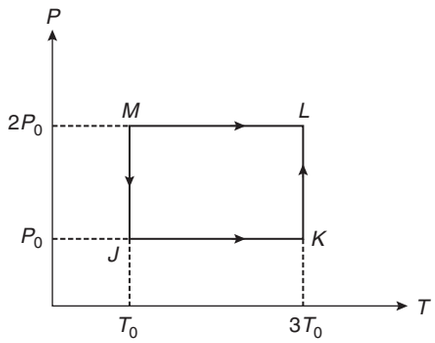
12. Two large, identical water tanks, 1 and 2, kept on the top of a building of height H, are filled with water up to height h in each tank. Both the tanks contain an identical hole of small radius on their sides, close to their bottom. A pipe of the same internal radius as that of the hole is connected to tank 2, and the pipe ends at the ground level. When the water flows 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 _____.



This section contains **FOUR (04)** Matching List Sets. 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.

14. One mole of a monatomic ideal gas undergoes the cyclic process J → K → L→ M → J, as shown in the P-T diagram.



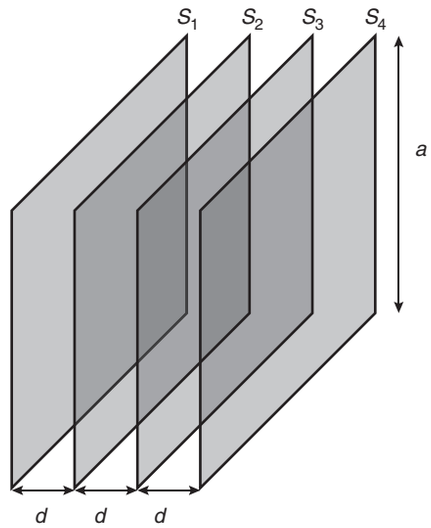
Match the quantities mentioned in List-I with their values in List-II and choose the correct option.

[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 → 1; Q → 3; R → 5; S → 4
(B) P → 4; Q → 3; R → 5; S → 2
(C) P → 4; Q → 1; R → 2; S → 2
(D) P → 2; Q → 5; R → 3; S → 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 ε_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)	$2C_0$

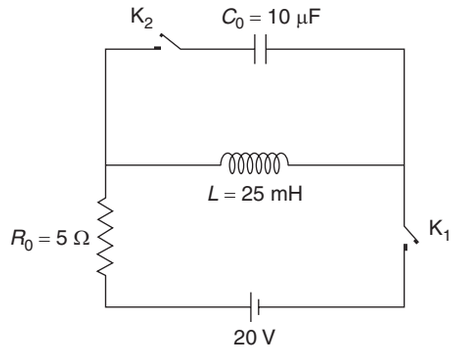
(A) P → 3; Q → 2; R → 4; S → 5
(B) P → 2; Q → 3; R → 2; S → 1
(C) P → 3; Q → 2; R → 4; S → 1
(D) P → 3; Q → 2; R → 2; S → 5

16. A light ray is incident on the surface of a sphere of refractive index n at an angle of incidence θ_0. The ray partially refracts into the sphere with angle of refraction ϕ_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 α. 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 θ_0 will be	(1)	30° and 0°
(Q)	If $n = \sqrt{3}$ and $\alpha = 180°$, then all the possible values of θ_0 will be	(2)	60° and 0°
(R)	If $n = \sqrt{3}$ and $\alpha = 180°$, then all the possible values of ϕ_0 will be	(3)	45° and 0°
(S)	If $n = \sqrt{2}$ and $\theta_0 = 45°$, then all the possible values of α 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 ω_0.



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

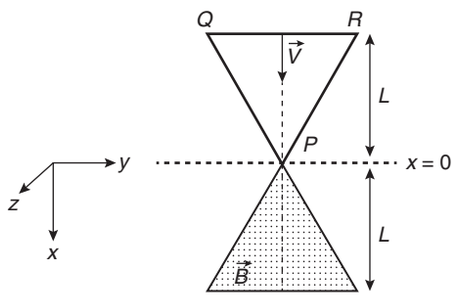
	List-I		List-II
(P)	The value of I_1 in Ampere is	(1)	0
(Q)	The value of I_2 in Ampere is	(2)	2
(R)	The value of ω_0 in kilo-radians/s is	(3)	4
(S)	The value of V_0 in Volt is	(4)	20
		(5)	200

(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

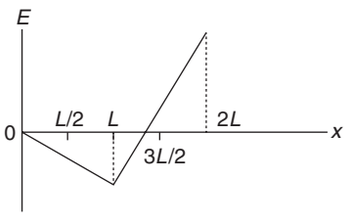
PAPER 2

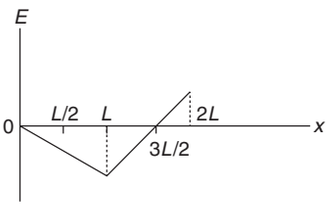
This section contains **FOUR (04)** questions. Each question has **FOUR** options (A), (B), (C) and (D). **ONLY ONE** of these four options is the correct answer. For each question, choose the option corresponding to the correct answer.

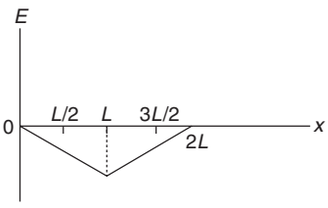
1. A region in the form of an equilateral triangle (in $x - y$ plane) of height L has a uniform magnetic field $\vec{B}$ pointing in the $+z$–direction. A conducting loop PQR, in the form of an equilateral triangle of the same height L, is placed in the $x - y$ plane with its vertex P at $x = 0$ in the orientation shown in the figure. At $t = 0$, the loop starts entering the region of the magnetic field with a uniform velocity $\vec{V}$ along the $+x$–direction. The plane of the loop and its orientation remain unchanged throughout its motion.

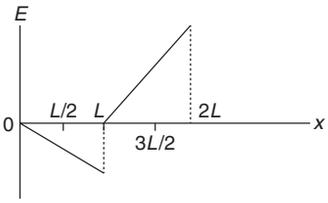


Which of the following graph best depicts the variation of the induced emf (E) in the loop as a function of the distance (x) starting from $x = 0$?

(A)


(B)


(C)


(D)


2. A particle of mass m is under the influence of the gravitational field of a body of mass M ($>> m$). The particle is moving in a circular orbit of radius r_0 with time period T_0 around the mass M. Then, the particle is subjected to an additional central force, corresponding to the potential energy $V_c(r) = m\alpha/r^3$, where α is a positive constant of suitable dimensions and r is the distance from the center of the orbit. If the particle moves in the same circular orbit of radius r_0 in the combined gravitational potential due to M and $V_c(r)$, but with a new time period T_1, then $(T_1^2 - T_0^2)/T_0^2$ is given by

[G is the gravitational constant.]

(A) $\dfrac{3\alpha}{GMr_0^2}$ **(B)** $\dfrac{\alpha}{2GMr_0^2}$

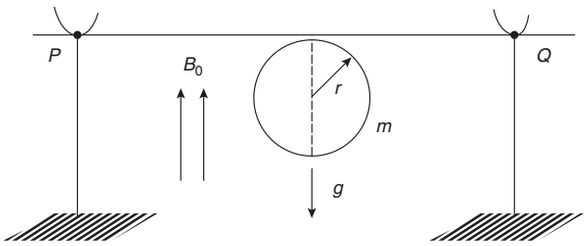
(C) $\dfrac{\alpha}{2GMr_0^2}$ **(D)** $\dfrac{2\alpha}{GMr_0^2}$

3. A metal target with atomic number $Z = 46$ is bombarded with a high energy electron beam. The emission of X–rays from the target is analyzed. The ratio r of the wavelengths of the K_α–line and the cut–off is found to be $r = 2$. If the same electron beam bombards another metal target with $Z = 41$, the value of r will be

(A) 2.53 **(B)** 1.27

(C) 2.24 **(D)** 1.58

4. A thin stiff insulated metal wire is bent into a circular loop with its two ends extending tangentially from the same point of the loop. The wire loop has mass m and radius r and it is in a uniform vertical magnetic field B_0, as shown in the figure. Initially, it hangs vertically downwards, because of acceleration due to gravity g, on two conducting supports at P and Q. When a current I is passed through the loop, the loop turns about the line PQ by an angle θ given by



(A) $\tan\theta = \pi r I B_0/(mg)$

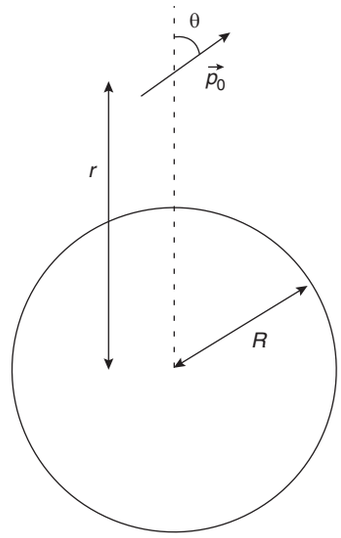
(B) $\tan\theta = 2\pi r I B_0/(mg)$

(C) $\tan\theta = \pi r I B_0/(2mg)$

(D) $\tan\theta = mg/(\pi r I B_0)$

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).

5. A small electric dipole $\vec{p}_0$, having a moment of inertia I about its center, is kept at a distance r from the center of a spherical shell of radius R. The surface charge density σ is uniformly distributed on the spherical shell. The dipole is initially oriented at a small angle θ as shown in the figure. While staying at a distance r, the dipole is free to rotate about its center.



If released from rest, then which of the following statement(s) is (are) correct?

[ε_0 is the permittivity of free space.]

(A) The dipole will undergo small oscillations at any finite value of r.

(B) The dipole will undergo small oscillations at any finite value of $r > R$.

(C) The dipole will undergo small oscillations with an angular frequency of $\sqrt{\dfrac{2\sigma\rho_0}{\varepsilon_0 I}}$ at $r = 2R$

(D) The dipole will undergo small oscillations with an angular frequency of $\sqrt{\dfrac{2\rho_0}{100\,\varepsilon_0 I}}$ at $r = 10R$

6. A table tennis ball has radius $(3/2) \times 10^{-2}$ m and mass $(22/7) \times 10^{-3}$ kg. It is slowly pushed down into a swimming pool to a depth of $d = 0.7$ m below the water surface and then released from rest. It emerges from the water surface at speed v, without getting wet, and rises up to a height H. Which of the following option(s) is (are) correct?

[Given: $\pi = 22/7$, $g = 10$ ms^{-2}, density of water $= 1 \times 10^3$ kg m^{-3}, viscosity of water $= 1 \times 10^{-3}$ Pa–s.]

(A) The work done in pushing the ball to the depth d is 0.077 J.

(B) If we neglect the viscous force in water, then the speed $V = 7$ m/s.

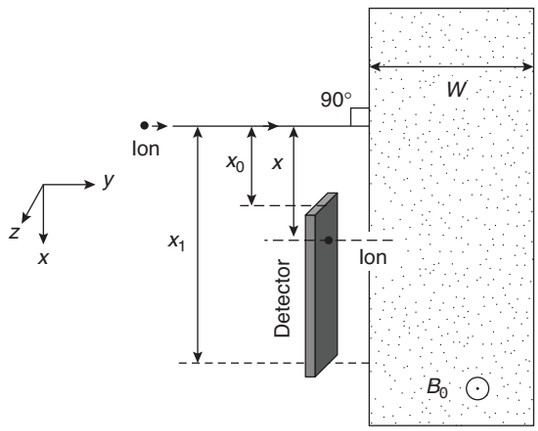
(C) If we neglect the viscous force in water, then the height $H = 1.4$ m.

(D) The ratio of the magnitudes of the net force excluding the viscous force to the maximum viscous force in water is 500/9.

7. A positive, singly ionized atom of mass number A_M is accelerated from rest by the voltage 192 V. Thereafter, it enters a rectangular region of width w with magnetic field $\vec{B}_0 = 0.1\hat{k}$ Tesla, as shown in the figure. The ion

finally hits a detector at the distance x below its starting trajectory.

[Given: Mass of neutron/proton = $(5/3) \times 10^{-27}$ kg, charge of the electron = 1.6×10^{-19} C.]



Which of the following option(s) is (are) correct?

(A) The value of x for H^+ ion is 4 cm.

(B) The value of x for an ion with $A_M = 144$ is 48 cm.

(C) For detecting ions with $1 \le A_M \le 196$, the minimum height $(x_1 - x_0)$ of the detector is 55 cm.

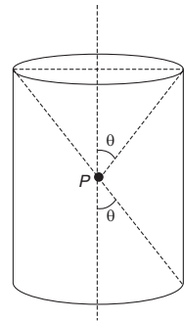
(D) The minimum width w of the region of the magnetic field for detecting ions with $A_M = 196$ is 56 cm.

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.

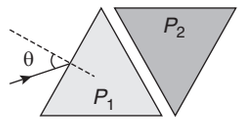
8. The dimensions of a cone are measured using a scale with a least count of 2 mm. The diameter of the base and the height are both measured to be 20.0 cm. The maximum percentage error in the determination of the volume is _____.

9. A ball is thrown from the location $(x_0, y_0) = (0, 0)$ of a horizontal playground with an initial speed v_0 at an angle θ_0 from the $+x$–direction. The ball is to be hit by a stone, which is thrown at the same time from the location $(x_1, y_1) = (L, 0)$. The stone is thrown at an angle $(180 - \theta_1)$ from the $+x$–direction with a suitable initial speed. For a fixed v_0, when $(\theta_0, \theta_1) = (45°, 45°)$, the stone hits the ball after time T_1, and when $(\theta_0, \theta_1) = (60°, 30°)$, it hits the ball after time T_2. In such a case, $(T_1/T_2)^2$ is _____.

10. A charge is kept at the central point P of a cylindrical region. The two edges subtend a half–angle θ at P, as shown in the figure. When $\theta = 30°$, then the electric flux through the curved surface of the cylinder is Φ If $\theta = 60°$, then the electric flux through the curved surface becomes $\Phi/\sqrt{n}$, where the value of n is _____.

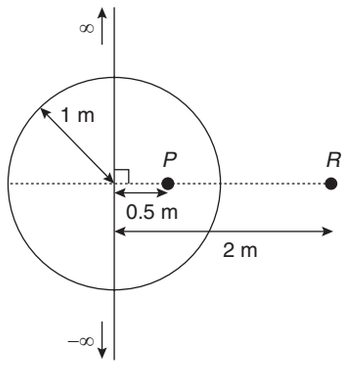


11. Two equilateral–triangular prisms P_1 and P_2 are kept with their sides parallel to each other, in vacuum, as shown in the figure. A light ray enters prism P_1 at an angle of incidence θ such that the outgoing ray undergoes minimum deviation in prism P_2. If the respective refractive indices of P_1 and P_2 are $\sqrt{\frac{3}{2}}$ and $\sqrt{3}$, $\theta = \sin^{-1}\left[\sqrt{\frac{3}{2}}\sin\left(\frac{\pi}{\beta}\right)\right]$, where the value of β is _____.



12. An infinitely long thin wire, having a uniform charge density per unit length of 5 nC/m, is passing through a spherical shell of radius 1 m, as shown in the figure. A 10 nC charge is distributed uniformly over the spherical shell. If the configuration of the charges remains static, the magnitude of the potential difference between points P and R, in Volt, is _____.

[Given: In SI units $\frac{1}{4\pi \epsilon_0} = 9 \times 10^9$, In 2 = 0.7. Ignore the area pierced by the wire.]

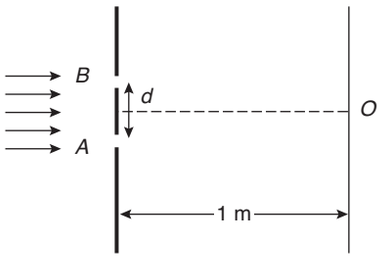


13. A spherical soap bubble inside an air chamber at pressure $P_0 = 10^5$ Pa has a certain radius so that the excess pressure inside the bubble is $\Delta P = 144$ Pa. Now, the chamber pressure is reduced to $\Delta P_0/27$ so that the bubble radius and its excess pressure change. In this process, all the temperatures remain unchanged. Assume air to be an ideal gas and the excess pressure ΔP in both the cases to be much smaller than the chamber pressure. The new excess pressure ΔP in Pa is _____.

This section contains **TWO (02)** paragraphs. Based on each paragraph, there are **TWO (02)** questions. The answer to each question is a **NUMERICAL VALUE**. For each question, enter the correct numerical value of the answer. If the numerical value has more than two decimal places, **truncate/round-off** the value to **TWO** decimal places.

PARAGRAPH I

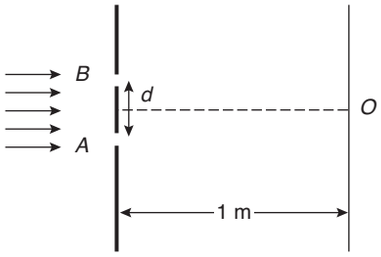
In a Young's double slit experiment, each of the two slits A and B, as shown in the figure, are oscillating about their fixed center and with a mean separation of 0.8 mm. The distance between the slits at time t is given by $d = (0.8 + 0.04 \sin \omega t)$ mm, where $\omega = 0.08$ rad s^{-1}. The distance of the screen from the slits is 1 m and the wavelength of the light used to illuminate the slits is 6000 Å. The interference pattern on the screen changes with time, while the central bright fringe (zeroth fringe) remains fixed at point O.



14. The 8th bright fringe above the point O oscillates with time between two extreme positions. The separation between these two extreme positions, in micrometer (μm), is _____.

PARAGRAPH I

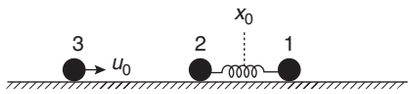
In a Young's double slit experiment, each of the two slits A and B, as shown in the figure, are oscillating about their fixed center and with a mean separation of 0.8 mm. The distance between the slits at time t is given by $d = (0.8 + 0.04 \sin \omega t)$ mm, where $\omega = 0.08$ rad s^{-1}. The distance of the screen from the slits is 1 m and the wavelength of the light used to illuminate the slits is 6000 Å. The interference pattern on the screen changes with time, while the central bright fringe (zeroth fringe) remains fixed at point O.



15. The maximum speed in μ m/s at which the 8th bright fringe will move is _____.

PARAGRAPH II

Two particles, 1 and 2, each of mass m, are connected by a massless spring, and are on a horizontal frictionless plane, as shown in the figure. Initially, the two particles, with their center of mass at x_0, are oscillating with amplitude a and angular frequency ω. Thus, their positions at time t are given by $x_1(t) = (x_0 + d) + a \sin \omega t$ and $x_2(t) = (x_0 - d) - a \sin \omega t$, respectively, where $d > 2a$. Particle 3 of mass m moves towards this system with speed $u_0 = a\omega/2$, and undergoes instantaneous elastic collision with particle 2, at time t_0. Finally, particles 1 and 2 acquire a center of mass speed v_{cm} and oscillate with amplitude b and the same angular frequency ω.



16. If the collision occurs at time $t_0 = 0$, the value of $v_{cm}/(a\omega)$ will be _____.

PARAGRAPH II

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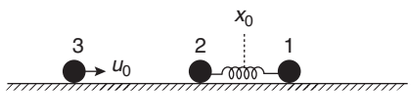


17. If the collision occurs at time $t_0 = \pi/(2\omega)$, then the value of $4b^2/a^2$ will be _____.

ANSWER KEY

Paper 1

1. (A) **2.** (A) **3.** (B) **4.** (C) **5.** (A, B, C) **6.** (A, C, D) **7.** (A, B) **8.** (25000)
9. (12) **10.** (8) **11.** (200) **12.** (3) **13.** (18) **14.** (B) **15.** (C) **16.** (A)
17. (A)

Paper 2

1. (A) **2.** (A) **3.** (A) **4.** (A) **5.** (B, D) **6.** (A, B, D) **7.** (A, B) **8.** (3)
9. (2) **10.** (3) **11.** (12) **12.** (171) **13.** (96) **14.** (601.50) **15.** (24.00) **16.** (00.75)
17. (04.25)

ANSWERS WITH EXPLANATION

PAPER 1

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

$\Rightarrow \alpha+2\beta=0$

$\Rightarrow \alpha=-2\beta$

$\Rightarrow -\beta+\gamma=0$

$\Rightarrow \gamma=\beta$

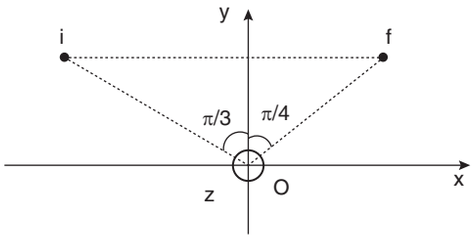
$\Rightarrow -3\beta+2\gamma+\delta=0$

$\Rightarrow \delta=\beta$

$\Rightarrow \alpha+4\beta-\gamma-\delta=0$

$\Rightarrow (-2\beta,\ \beta,\beta,\beta)$

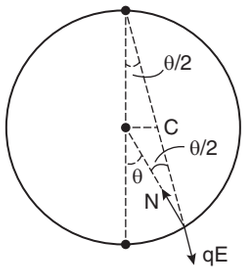
2.



$$\oint \vec{B}\cdot\vec{d\ell}=\int_0^i \vec{B}\cdot\vec{d\ell}+\int_i^f \vec{B}\cdot\vec{d\ell}+\int_f^0 \vec{B}\cdot\vec{d\ell}=\mu_0\frac{I}{2\pi}\frac{7\pi}{12}$$

So, $\int_i^f \vec{B}\cdot\vec{d\ell}=\frac{7\mu_0 I}{24}$

3.



Restoring force $= qE\sin\left(\frac{\theta}{2}\right)$

Therefore, $\tau = qE\sin\left(\frac{\theta}{2}\right)R = I\alpha$

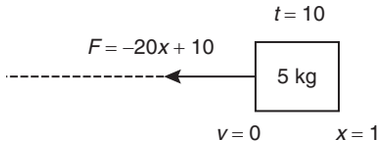
$$E=\frac{Kq}{\left(2R\cos\left(\frac{\theta}{2}\right)\right)^2}=\frac{1}{4\pi\varepsilon_0}\frac{q}{4R^2\cos^2\left(\frac{\theta}{2}\right)}$$

$$\frac{1}{4\pi\varepsilon_0}\frac{qR}{4R^2\cos^2\left(\frac{\theta}{2}\right)}\sin\left(\frac{\theta}{2}\right)q=mR^2\alpha$$

For θ very small, $\frac{-q^2}{32\pi\varepsilon_0 R^3 m}\theta=\alpha$

Therefore, $\omega^2=\frac{-q^2}{32\pi\varepsilon_0 R^3 m}$

4.



Now,

$$a = -\frac{20x+10}{5} = -4x+2$$

$$a = \frac{vdv}{dx} = -4x+2$$

Hence, $\int_0^v vdv = \int_1^x (-4x+2)\,dx \rightarrow \frac{v^2}{2} = [-2x^2+2x]_1^x$

$v = -2\sqrt{x-x^2}$ (as particle starts moving in –ve x-direction)

$$\Rightarrow \frac{dx}{dt} = -2\sqrt{x-x^2} \rightarrow \int_{x=1}^{x=x} \frac{dx}{\sqrt{x-x^2}} = -2\int_0^{\pi/4} dt$$

$$\sin^{-1}[2x-1]_1^x = -\frac{\pi}{2}$$

$$x = \frac{1}{2} = 0.5\,\text{m}$$

Also, momentum $= mV = 5(V)_{x=\frac{1}{2}} = -5$ kg-m/s

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

$v = \sqrt{\frac{k}{m}}r$ and $L = n\hbar = mvr$

So, $r^2 = \frac{n^2\hbar^2}{m^2v^2} = n\hbar\frac{n\hbar}{m^2v^2} = n\hbar\frac{mvr}{m^2v^2}$

So, $r^2 = n\hbar\frac{r}{mv} = n\hbar\frac{1}{mv}v\sqrt{\frac{m}{k}}$

So, $r^2 = n\hbar\sqrt{\frac{1}{mk}}$ Option (A)

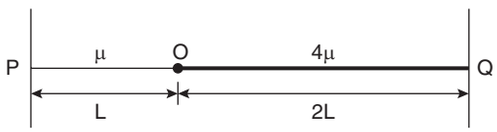
$v^2 = \frac{k}{m}r^2 = \frac{k}{m}n\hbar\frac{1}{\sqrt{mk}} = \sqrt{\frac{k}{m^3}}$ Option (B)

$\frac{L}{mr^2} = \frac{v}{r} = \sqrt{\frac{k}{m}}$ Option (C)

$$E = U + K = \frac{kr^2}{2} + \frac{kr^2}{2} = kr^2$$

$$E = kn\hbar\sqrt{\frac{1}{mk}} = n\hbar\sqrt{\frac{k}{m}}$$

6.



$$C_1 = \sqrt{\frac{T}{\mu}},\ C_2 = \sqrt{\frac{T}{4\mu}} = \frac{C_1}{2}$$

For node at O:

$$L = \frac{n\lambda_1}{2},\ 2L = \frac{m\lambda_2}{2}\ (n,\ m \text{ are integers})$$

$$\lambda_1 = \frac{2L}{n},\ \lambda_2 = \frac{4L}{m}$$

$$\frac{C_1}{\lambda_1} = \frac{C_2}{\lambda_2}$$

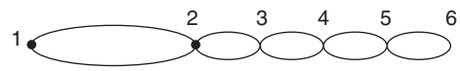
$$\frac{C_1}{\frac{2L}{n}} = \frac{\frac{C_1}{2}}{\frac{4L}{m}}$$

$$4n = m$$

For a minimum frequency, $n = 1, m = 4$

$$\therefore v_{min} = \frac{C_1 \times 1}{2L} = \frac{1}{2L}\sqrt{\frac{T}{\mu}} = v_0$$

The string will look like



Total number of nodes = 6, including the end nodes.

For antinode at O:

$$L = (2n+1)\frac{\lambda_1}{4};\ 2L = (2n+1)\frac{\lambda_2}{4}\ (n, m \text{ are integers})$$

$$\lambda_1 = \frac{4L}{(2n+1)};\ \lambda_2 = \frac{8L}{(2m+1)}$$

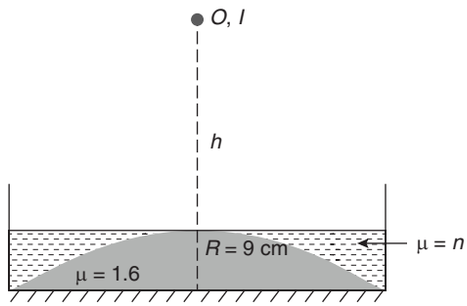
$$\frac{C_1}{\lambda_1} = \frac{C_2}{\lambda_2}$$

$$\frac{C_1}{C_2} = \frac{\lambda_1}{\lambda_2}$$

$$2 = \frac{\frac{4L}{(2n+1)}}{\frac{8L}{(2m+1)}}$$

$4 = \frac{(2m+1)}{(2n+1)} = >$ even $= \frac{\text{odd}}{\text{odd}} = >$ This node is not possible.

7.



For image to coincide with object

$-h = 2(f_{\text{net}})$

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

$$=> -\frac{1}{f_{net}} = 2\left(\frac{n-1}{-9}\right) + 2\left(\frac{0.6}{9}\right) + \left(-\frac{1}{\infty}\right) \quad \text{(ii)}$$

From Eq. (i) and (ii)

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

For $n = 1.42, h = 50$ cm (A is correct)

For $n = 1.35, h = 36$ cm (B is correct)

For $n = 1.45, h = 60$ cm (C is incorrect)

For $n = 1.48, h = 75$ cm (D is incorrect)

8. $dQ = mSdT$

$$\int dQ = \int 1 \cdot KT\, dT$$

$$\Delta Q = K\int_{200}^{300} T\, dT$$

$$\Delta Q = \frac{K}{2}[T^2]_{200}^{300}$$

$$\Delta Q = \frac{K}{2} \times (9-4) \times 10^4$$

$$\Delta Q = 25000\, K$$

$$n = 25000$$

9. Conserving angular momentum of the system (bigger disc + smaller disc) about the symmetric axis of bigger disc:

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

where ω' is the required angular speed.

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

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

$$\Rightarrow n = 12$$

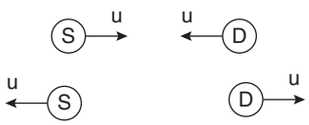
10. New intensity at B

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

New value of $\alpha = \dfrac{I_A}{\frac{I_B}{4}} = \dfrac{4I_A}{I_B}$

$$= 4 \times 2;\ \alpha = 8$$

11.



$$f_0 = 240\,\text{Hz}$$

$$f_1 = \left(\frac{v+u}{v-u}\right)f_0$$

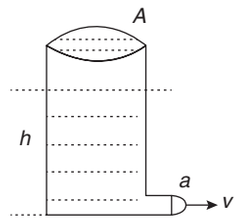
$$288 = \left(\frac{v+u}{v-u}\right)240 \Rightarrow \frac{v+u}{v-u} = \frac{6}{5}$$

$$v = 11u \quad \text{(i)}$$

$$f_2 = \left(\frac{v-u}{v+u}\right)f_0$$

$$f_2 = \frac{5}{6} \times 240 = 200\,\text{Hz}$$

12. In general case



$$a\sqrt{2gh} = -A\frac{dh}{dt}$$

$$dt = -\frac{A}{a}\frac{dh}{\sqrt{2gh}}$$

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

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

For tank 1:

$$h_i = h_f = 0$$

$$T_1 = \frac{2A}{a\sqrt{2g}}\left(\sqrt{h}\right)$$

For tank 2:

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

$$T_2 = \frac{2A\sqrt{h}}{a\sqrt{2g}}\left(\frac{5}{3} - \frac{4}{3}\right) = \frac{2A\sqrt{h}}{a\sqrt{2g}} \times \frac{1}{3}$$

$$\frac{T_1}{T_2} = 3$$

13. Linear impulse $\int F\, dt = \Delta$ momentum

$$= m(V_{cm} - 0)$$

$$P = m(\omega r_{cm})$$

$$= m\omega\left(L + \frac{L}{2}\right)$$

$$P = m\omega\left(\frac{3L}{2}\right) \quad \text{(i)}$$

Angular impulse $\int \tau\, dt = \Delta$ angular momentum

$$\int r \times F dt = \Delta L$$

$r \times \int F\, dt = I(\omega - 0)$, and I is moment of inertia about axis of rotation.

$$\left(L + \frac{L}{2} + x\right) \times P = (I_{cm} + md^2)\omega$$

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

$$\left(\frac{3L}{2} + x\right)P = mL^2\left(\frac{1}{12} + \left(\frac{3}{2}\right)^2\right)\omega$$

$$\left(\frac{3L}{2} + x\right)P = mL^2\left(\frac{7}{3}\right)\omega \qquad \text{(ii)}$$

After dividing Eq. (i) and (ii)

$$\left(\frac{3L}{2} + x\right) = \frac{L\left(\frac{7}{3}\right)}{\left(\frac{3}{2}\right)}$$

$$\frac{3L}{2} + x = L\left(\frac{14}{9}\right)$$

$$x = \frac{L}{18}$$

14. (P) JK $\Rightarrow \Delta W_{JK} = P\Delta V = nR\Delta T = 1 \cdot R(3T_0 - T_0) = 2RT_0$

LM $\Rightarrow \Delta W_{LM} = P\Delta V = nR\Delta T = 1 \cdot R(T_0 - 3T_0) = -2RT_0$

KL $\Rightarrow \Delta W_{KL} = nR\ell n\left(\frac{P_i}{P_f}\right) = R3T_0\ell n\left(\frac{P_0}{2P_0}\right) = -3RT_0\ell n2$

MJ $\Rightarrow \Delta W_{MJ} = nRT\ell n\left(\frac{P_i}{P_f}\right) = RT_0\ell n\left(\frac{2P_0}{P_0}\right) = RT_0\ell n2$

Total work done

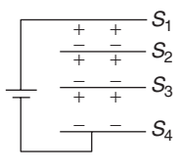
$$\Delta W = -2RT_0\ell n2$$

(Q) $\Delta U_{JK} = nC_v\Delta T = 1 \cdot \frac{3}{2}R(3T_0 - T_0) = 3RT_0$

(R) $\Delta Q_{KL} = \Delta W_{KL} + \Delta U_{KL} = \Delta W_{KL} + 0 = -3RT_0\ell n2$

(S) $\Delta U_{MJ} = nC_v\Delta T = 0$

15. For P

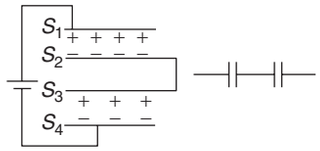


All are in series

$$C_{eq} = \frac{C_0}{3}$$

$$P \to (3)$$

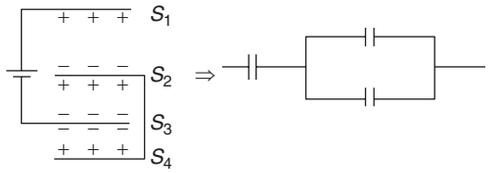
For Q



$$C_{eq} = \frac{C_0}{2}$$

$$Q \to (2)$$

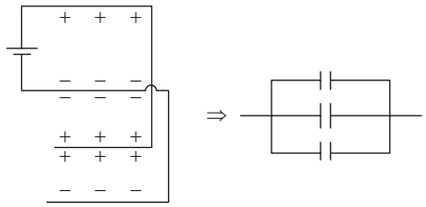
For R



$$C_{eq} = \frac{2C_0}{3}$$

$$R \to (4)$$

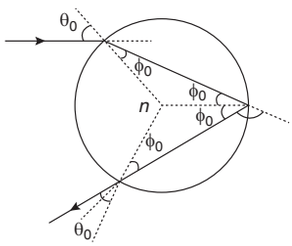
For S



$$\Rightarrow C_{eq} = 3C_0$$

$$S \to (1)$$

16.



$$\alpha = (\theta_0 - \phi_0) + (\pi - 2\phi_0) + (\theta_0 - \phi_0)$$

$$\alpha = \pi + 2\theta_0 - 4\phi_0 \qquad \text{(i)}$$

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

For (P)

$$n = 2, \alpha = 180$$

If $\alpha = \pi, 2\theta_0 - 4\theta_0 = 0$

$$\theta_0 = 2\theta_0$$

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

$$\text{P} \to (5)$$

For Q, $n = \sqrt{3}, \alpha = 180$

$$\theta_0 = 2\phi_0$$

$$Q \to (2)$$

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

$$\theta_0 = 60.0°$$

17. (P) At $t = 0$, $l_1 = 0$

(Q) At $t \to \infty$, $l_2 = \frac{20}{5} = 4\,\text{amp}$

(R) $\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{25\times10^{-3}\times10\times10^{-6}}}$

$= \frac{1}{5\times10^{-4}} = 2\times10^3 = 2\,\text{kilo-rad/sec}$

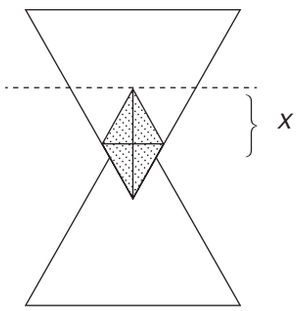
(S) $\frac{1}{2}LI_2^2 = \frac{1}{2}CV_0^2$

$V_0 = \left(\sqrt{\frac{L}{C}}\right)l_2 = \left(\sqrt{\frac{25\times10^{-3}}{10\times10^{-6}}}\right)4 = 5\times10\times4$

$V_0 = 200\,\text{volts}$

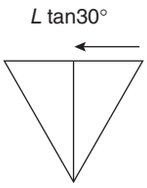
PAPER 2

1. For $x < L$

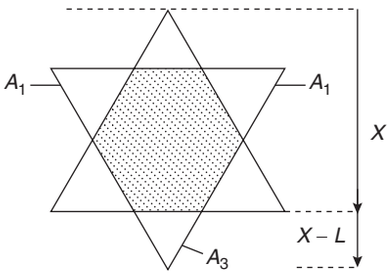


$\text{Area} = \frac{x}{2}\frac{x}{2}\tan 30\times4\times\frac{1}{2} = \frac{1}{2}x^2\tan 30$

$\phi' = B_0 x\tan 30V \quad \varepsilon \propto x$



$X \geq L$



$\text{Area} = A_0 - A_1 - A_2 - A_3$

$= A_0 - 2A_1 - (x-L)(x-L)\tan 30$

$= A_0 - (x-L)^2\tan 30 - \{L\tan 30 - (x-L)\tan 30\}^2$

$\frac{1}{2}\times\frac{1}{2}\tan 60\times 2$

$= A_0 - (x-L)^2\tan 30 - \tan 30\{2L - x\}^2\frac{1}{2}$

$\varepsilon' = -2(x-L)\tan 30V - \tan 30\ 2(2L-x)(-)V$

$= (4L - x - 2x + 2)\tan 30V$

$= (4L - 3x)V$

$= 0\ at\ x = \frac{4L}{3}$

For 1 and 2

1.33 < 1.5

2. $\frac{GMm}{r_0^2} = m\omega^2 r_0$

$\omega = \sqrt{\frac{GM}{r_0^3}}$

$T_0^2 = 4\pi^2\left(\frac{r_0^3}{GM}\right)$ (i)

$F = -\frac{dv_c(r)}{dr}$

$F = \frac{3m\alpha}{r^4}$

Net force

$\frac{GMm}{r_0^2} - \frac{3m\alpha}{r_0^4} = m\omega^2 r_0$

$\omega^2 = \frac{GM}{r_0^3} - \frac{3\alpha}{r_0^5}$

We know $\omega = \frac{2\pi}{T_1}$

$\frac{4\pi^2}{T_1^2} = \frac{GM}{r_0^3} - \frac{3\alpha}{r_0^5}$

$T_1^2 = \frac{4\pi^2}{\frac{GM}{r_0^3} - \frac{3\alpha}{r_0^5}}$ (ii)

From equations (1) and (2)

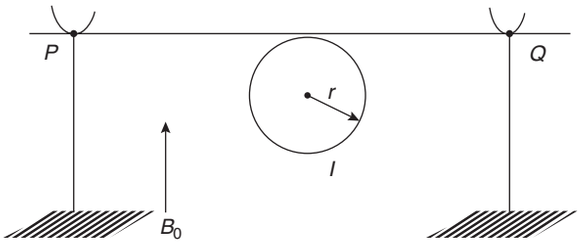
$\frac{T_1^2 - T_0^2}{T_1^2} = \frac{3\alpha}{GMr_0^2}$

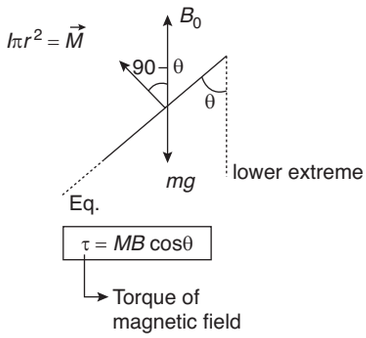
3. $r = \frac{\lambda_{k\alpha}}{\lambda_0} \propto \frac{1}{(z-1)^2}$

$\frac{r_2}{r_1} = \frac{(z_1-1)^2}{(z_2-1)^2} = \frac{(45)^2}{(40)^2}$

$r_2 = 1.265\times r_1 = 2.53$

4.





Now, $\dfrac{\text{For equilibrium}}{\tau = mg\, r \sin\theta}$

$$I\pi r^2 B_0 \cos\theta = mgr \sin\theta$$

$$\tan\theta = \frac{I\pi r B_0}{mg}$$

5. $\sigma = \dfrac{Q}{4\pi R^2}$

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{r^2} = \frac{\sigma R^2}{\varepsilon_0 r^2}$$

Now $\vec{\tau} = \vec{p}_0 \times \vec{E}$

$$I\alpha = \frac{\sigma R^2}{\varepsilon_0 r^2} p_0\theta \quad [\theta \to \text{small}]$$

$$\alpha = \frac{\sigma R^2}{\varepsilon_0 r^2} p_0\theta$$

So, $\omega = \sqrt{\dfrac{\sigma R^2}{\varepsilon_0 r^2}}$

6. (A) $W_{ext} + W_g + W_B = \Delta K$ ($\because WD$ by viscous force $= 0$)

$$W_{ext} + mgh - \rho vgh = 0$$

$$W_{ext} = \rho_\ell vgh - mgh = gh(\rho_g v - m)$$

$$= 10 \times 0.7\left[10^3 \times \frac{4}{3}\pi(1.5\times10^{-2})^3 - \pi\times10^{-3}\right] = 0.77\,\text{J}$$

(B) $W_g + W_B = \dfrac{1}{2}mv^2 - 0$

$$0.77 = \frac{1}{2}\left(\frac{22}{7}\times10^{-3}\right)v^2 \Rightarrow v = 7\,\text{m/s}$$

(C) $H = \dfrac{v^2}{2g} = \dfrac{(7)^2}{2\times10} = 2.45\,\text{m}$

(D) Ratio $= \left|\dfrac{\rho_\ell Vg - Mg}{6\pi\eta rv}\right| = \dfrac{500}{9}\,\text{J}$

7. $x = 2R$

$$= 2\frac{mv}{qB}$$

$$2\frac{\sqrt{2m(e\Delta V)}}{qB}$$

For H^+ ion

$x = 3.91$ cm

$\simeq 4$ cm (A is correct)

For $m = 144\ (m_p)$

$= 12(X_{H^+})$

$= 48$ cm (B is correct)

For $1 \le A_M \le 196$

$= (x_1 - x_0)_{\min} = 2R_{196} - 2R_1$

$= (14\times4) - 4$

$= 52$ cm (C is incorrect)

For $A_M = 196$

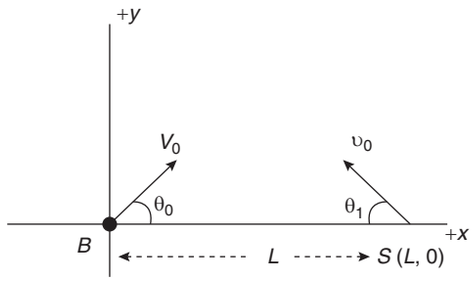
$W_{\min} = R_{196} = 28$ cm (D is incorrect)

8. Percentage error in volume:

$$\frac{\Delta V}{V}\times100 = 2\frac{\Delta d}{d}\times100 + \frac{\Delta h}{h}\times100 \quad \left(\frac{\Delta d}{d} = \frac{\Delta h}{h} = \frac{1}{100}\right)$$

$$\Rightarrow \frac{\Delta V}{V}\times100 = 3\%$$

9.



Let

Let B : Ball

S : Stone

υ_0 : Initial speed of stone

Since relative acceleration = zero

$\Rightarrow$ Path seen would be straight line

$\Rightarrow$ To meet, $v_0 \sin\theta_0 = v_0 \sin\theta_1$

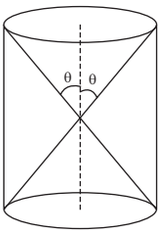
And $\Delta t = \dfrac{L}{\upsilon_0 \cos\theta_1 + v_0 \cos\theta_0}$

Case I: $\upsilon_0 = v_0 => \Delta t_1 = T_1 = \dfrac{L}{v_0\left[\dfrac{1}{\sqrt{2}} + \dfrac{1}{\sqrt{2}}\right]} = \dfrac{L}{\sqrt{2}v_0}$

Case II: $\sqrt{3}v_0 = \upsilon_0 => \Delta t_2 = T_2 = \dfrac{L}{\sqrt{3}v_0\Delta\dfrac{\sqrt{3}}{2} + \dfrac{v_0}{2}} = \dfrac{L}{2v_0}$

$$\Rightarrow \left(\frac{T_1}{T_2}\right)^2 = \left(\sqrt{2}\right)^2 = 2$$

10.



Solid angle made by plane surfaces $\Omega = 2\times 2\pi(1-\cos\theta)$

$\Rightarrow \Omega = 4\times 4\pi\cos\theta$

So solid angle made by curved surface = $4\pi - \Omega$

$= 4\pi - (4\pi\times 4\pi\cos\theta) = 4\pi\cos\theta$

$$\phi_{30} = \phi = \frac{4\pi\cos 30}{4\pi}\frac{Q}{\epsilon_0} = \cos 30\frac{Q}{\epsilon_0}$$

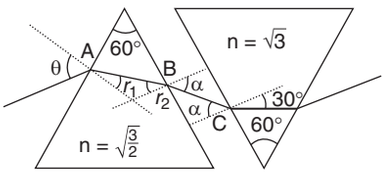
$$\phi_{60} = \frac{4\pi\cos 60}{4\pi}\frac{Q}{\epsilon_0} = \cos 60\frac{Q}{\epsilon_0}$$

$$\frac{\phi_{30}}{\phi_{60}} = \frac{\cos 30}{\cos 60} = \sqrt{3}$$

$$\frac{\phi}{\phi_{60}} = \sqrt{3}$$

$$\frac{\phi}{\phi_{60}} = \frac{\phi}{\sqrt{3}} => n = 3$$

11.



At C, $1\sin\alpha = \sqrt{3}\sin 30° \Rightarrow \alpha = 60°$

At B, $\sqrt{\frac{3}{2}}\sin r_2 = 1\sin\alpha\, r_2 = 45°$

At A, $1\sin\theta = \sqrt{\frac{3}{2}}\sin 15°$

$$\Rightarrow \theta = \sin^{-1}\left[\sqrt{\frac{3}{2}}\sin\left(\frac{\pi}{12}\right)\right]$$

12.

$$E_{\text{Line charge}} = \frac{\lambda}{2\pi\epsilon_0 r}$$

$$\Rightarrow \Delta V_{\text{Line charge}} = \int_{0.5}^{2}\frac{\lambda}{2\pi\epsilon_0 r}dr = \frac{\lambda}{2\pi\epsilon_0}$$

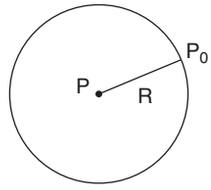
$$\Delta V_{\text{Sphere}} = \frac{1}{4\pi\epsilon_0}\frac{Q}{R} - \frac{1}{4\pi\epsilon_0}\frac{Q}{2R}$$

$$= \frac{1}{4\pi\epsilon_0}\frac{Q}{2}$$

$$\Rightarrow \Delta V_{\text{Net}} = \frac{\lambda}{2\pi\epsilon_0}\text{In}4 + \frac{1}{4\pi\epsilon_0}\frac{Q}{2}$$

$$= 171\,\text{Volts}$$

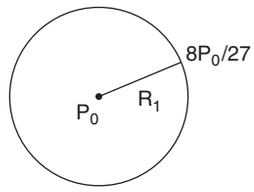
13. Case 1



$$P - P_0 = \Delta P = \frac{4T}{R}$$

$$P = \left(P_0 + \frac{4T}{R}\right)$$

Case 2



$$P_1 - \frac{8P_0}{27} = \Delta P_1 = \frac{4T}{R_1}$$

$$P_1 = \frac{4T}{R_1} + \frac{8P_0}{27}$$

Constant temperature process

$$PV = P_1V_1$$

$$\left(P_0 + \frac{4T}{R}\right)\frac{4}{3}\pi R^3 = \left(\frac{4T}{R_1} + \frac{8P_0}{27}\right)\frac{4}{3}\pi R_1^3; \left(\frac{4T}{R}\right), \left(\frac{4T}{R_1}\right) \rightarrow \text{Neglected}$$

$$R = \frac{2}{3}R_1 => R_1 = \frac{3}{2}R$$

$$\Delta P_1 = \frac{4T}{R_1} = \frac{4T}{3}\times 2 = \frac{2}{3}\times 144 = 96\text{ Pa}$$

14. As central bright fringe position is not changing, the two slits are oscillating with a phase diff of π.

For 8th bright fringe

$$y = \frac{8\lambda D}{(0.8 + 0.04\sin\omega t)}\times 10^3$$

$$= \frac{8\times 6000\times 10^{-10}\times 10^3}{(0.8 + 0.04\sin\omega t)}$$

$$y = \frac{48\times 10^{-4}}{(0.8 + 0.04\sin\omega t)}$$

d varies from 0.84 mm to 0.76 mm

$$\Delta y = 6.015\times 10^{-4}$$

$$= 601.50\ \mu\text{m}$$

15. $$y = \frac{8 \times 6000 \times 10^{-10} \times 1}{(0.8 + 0.04 \sin \omega t) \times 10^{-3}}$$

$$y = \frac{48 \times 10^{-4}}{(0.8 + 0.04 \sin \omega t)}$$

$$\left|\frac{dy}{dt}\right| = +\frac{48 \times 10^{-4}}{(0.8 + 0.04 \sin \omega t)^2}(0.04\,\omega \cos \omega t)$$

$$t = 0,\ v = v_{max}$$

$$v_{max} = \frac{48 \times 10^{-4} \times 0.04 \times 0.08}{(0.8)^2} = 24 \times 10^{-6}\ \text{m/s} = 24\mu\ \text{m/s}$$

16. $\therefore u_2 = a\omega$ towards left after collision, velocity will exchange

$\therefore v_2 = \frac{a\omega}{2}$ towards right

$\therefore u_1 = a\omega$ towards right

$$\therefore v_{cm} = \frac{3a\omega}{4}$$

$$\frac{v_{cm}}{a\omega} = \frac{3}{4} = 0.75$$

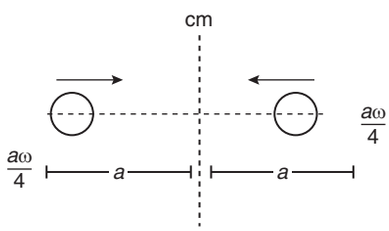
At $t = \frac{\pi}{2\omega}$, $u_2 = 0$

After collision, $v_2 = \frac{a\omega}{2}$ towards right

$u_1 = 0$

$\therefore v_{cm} = \frac{a\omega}{4}$ towards right

w.r.t center of mass



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

$$\frac{a\omega}{4} = \omega\sqrt{A^2 - a^2}$$

$$\frac{a^2}{16} + a^2 = A^2$$

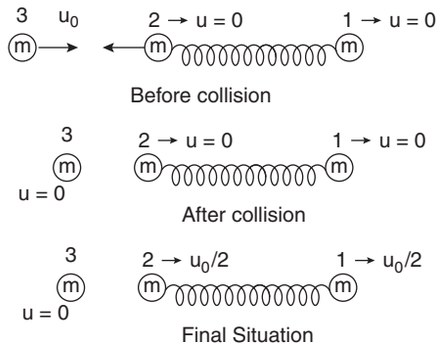
$$\frac{17}{16}a^2 = A^2 = b^2$$

$$\therefore b^2 = \frac{17}{16}a^2$$

$$\frac{4b^2}{a^2} = \frac{17}{4}$$

$$= 4.25$$

17. If collision occurs at $t_0 = \frac{\pi}{2\omega}$



From conservation of mechanical energy

$$\frac{1}{2}K(2a)^2 + \frac{1}{2}mu_0^2 = \frac{1}{2}K(2b)^2 + \frac{1}{2}(2m)\left(\frac{u_0}{2}\right)^2$$

Here, $K = \frac{m\omega^2}{2}$ and $u_0 = \frac{a\omega}{2}$

Solving, we get $\frac{4b^2}{a^2} = \frac{17}{4} = 4.25$