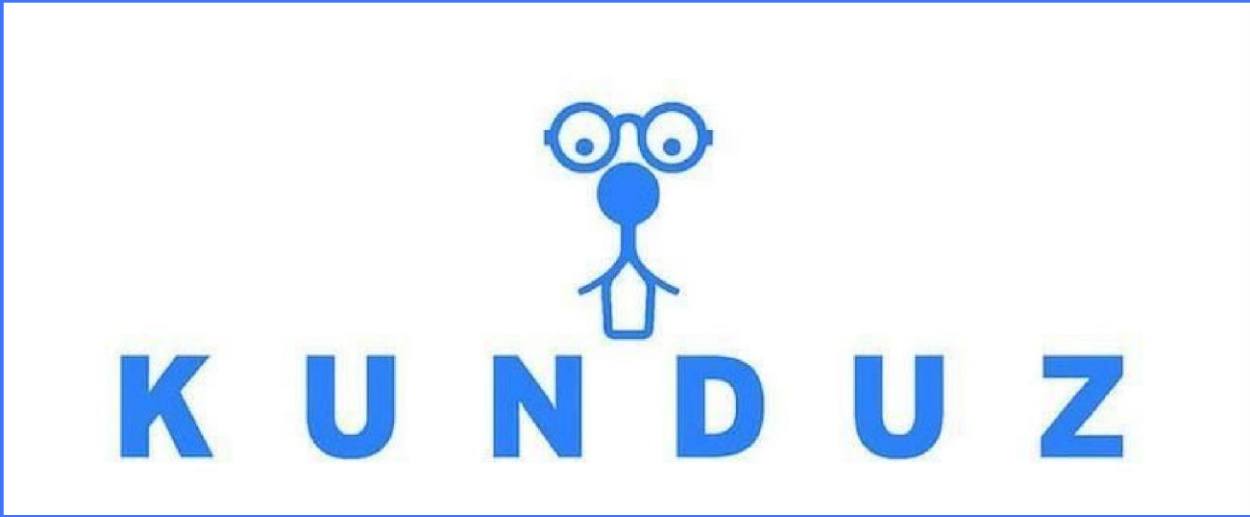

JEE Advanced paper 1 Physics solutions prepared by KUNDUZ tutors

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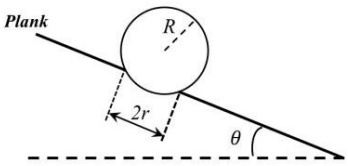
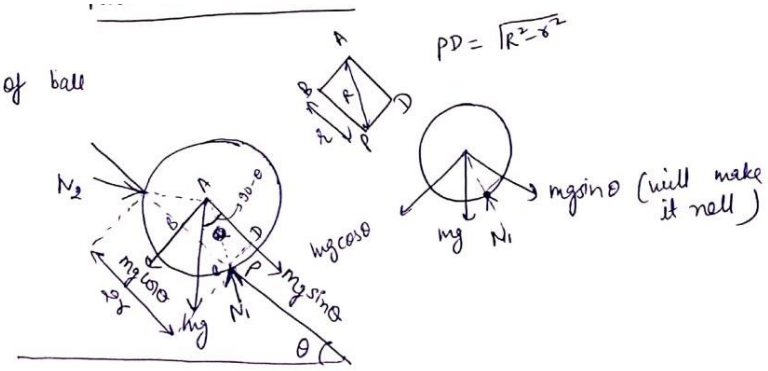
Question number	Question and Answers
1	

Q.1 A football of radius R is kept on a hole of radius r ($r < R$) made on a plank kept horizontally. One end of the plank is now lifted so that it gets tilted making an angle θ from the horizontal as shown in the figure below. The maximum value of θ so that the football does not start rolling down the plank satisfies (figure is schematic and not drawn to scale)



(A) $\sin\theta = \frac{r}{R}$ (B) $\tan\theta = \frac{r}{R}$ (C) $\sin\theta = \frac{r}{2R}$ (D) $\cos\theta = \frac{r}{2R}$

Q.1 FBD of ball



When football is just about to roll, $N_2 = 0$

Balancing Torque at the contact point (P)

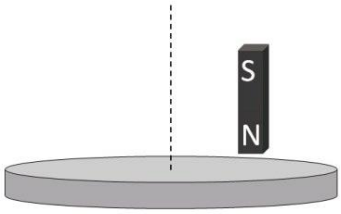
$mg\cos\theta \times r = mg\sin\theta \times \sqrt{R^2 - r^2}$

$\tan\theta = \frac{r}{\sqrt{R^2 - r^2}}$

$\Rightarrow \boxed{\sin\theta = \frac{r}{R}}$ Ans

2

Q.2 A light disc made of aluminium (a nonmagnetic material) is kept horizontally and is free to rotate about its axis as shown in the figure. A strong magnet is held vertically at a point above the disc away from its axis. On revolving the magnet about the axis of the disc, the disc will (figure is schematic and not drawn to scale)



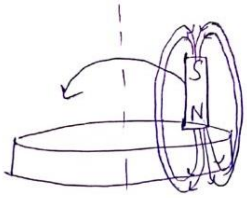
(A) rotate in the direction opposite to the direction of magnet's motion

(B) rotate in the same direction as the direction of magnet's motion

(C) not rotate and its temperature will remain unchanged

(D) not rotate but its temperature will slowly rise

Q.2

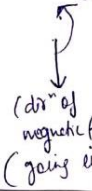


There is magnetic flux between the N pole and the S pole of the magnet. Its magnetic flux crosses through the disk.

When magnet revolves, it creates a state where the copper plate moves ~~through~~ through the magnetic flux.

Lets say, magnet is revolving in anti-clockwise direction, then due to Fleming's right hand rule, an electromotive force is generated in disk & an induced current flows.

Top view →



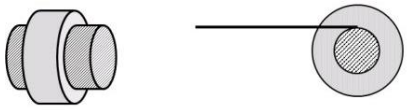
So dirⁿ of ~~force~~ current = radially outwards

Due to this current, force applies on disk in dirⁿ = (magnetic field) X (Current)
= tangential same as dirⁿ of motion of magnet

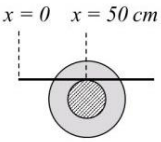
Correct Option = rotate in same dirⁿ as magnet's motion

3

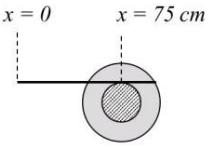
Q.3 A small roller of diameter 20 cm has an axle of diameter 10 cm (see figure below on the left). It is on a horizontal floor and a meter scale is positioned horizontally on its axle with one edge of the scale on top of the axle (see figure on the right). The scale is now pushed slowly on the axle so that it moves without slipping on the axle, and the roller starts rolling without slipping. After the roller has moved 50 cm, the position of the scale will look like (figures are schematic and not drawn to scale)



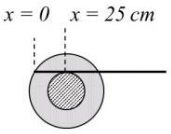
(A)



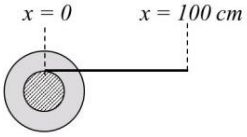
(B)



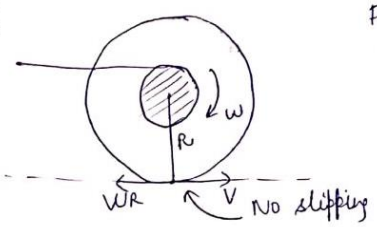
(C)



(D)



Q.3



For no slipping, velocity of point of contact = ωR (R = Radius of roller)

$V = \omega R$ (V = velocity of centre)

$\therefore$ Velocity of scale = $(V_{centre} + \omega r)$

(r = radius of axle).

$V_{scale} = V + \omega r$

Roller moved 50 cm in time t, so $V_{centre} \times t = 50$ cm

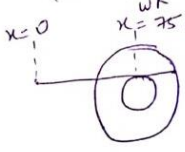
$t = \frac{50}{V_{centre}}$

distance moved by scale = $V_{scale} \times t$

$= (V + \omega r) \times \frac{50}{V}$

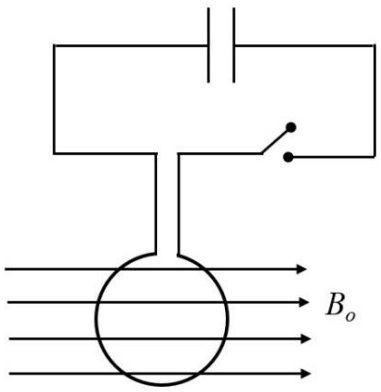
$= (\omega R + \omega r) \times \frac{50}{\omega R} = \left(\frac{R+r}{R}\right) 50 = 50 \times 1.5 = 75$ cm

So correct option =



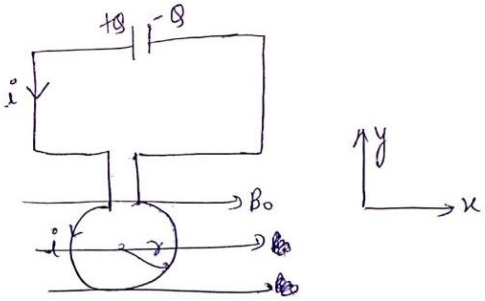
4

Q.4 A circular coil of radius R and N turns has negligible resistance. As shown in the schematic figure, its two ends are connected to two wires and it is hanging by those wires with its plane being vertical. The wires are connected to a capacitor with charge Q through a switch. The coil is in a horizontal uniform magnetic field B_o parallel to the plane of the coil. When the switch is closed, the capacitor gets discharged through the coil in a very short time. By the time the capacitor is discharged fully, magnitude of the angular momentum gained by the coil will be (assume that the discharge time is so short that the coil has hardly rotated during this time)



(A) $\frac{\pi}{2}NQB_oR^2$ (B) πNQB_oR^2 (C) $2\pi NQB_oR^2$ (D) $4\pi NQB_oR^2$

Q.4 After closing switch



Magnetic moment's in loop $\vec{M} = NIA$

$= NIA \odot$

$= N\pi I r^2 \odot$

$\vec{B} = B_o \hat{i}$

Torque experienced by loop

$= \vec{M} \times \vec{B}$

$= N\pi I r^2 B_o \hat{j}$

At the instant, $\vec{\tau} dt = d\vec{L} = \pi i r^2 N B_o dt$

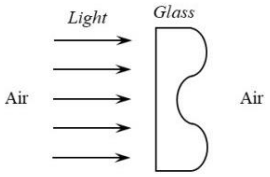
$= (\pi r^2 N B_o)(i dt)$

$= \pi r^2 N B_o Q$

Correct option = $\boxed{\pi N Q B_o R^2}$

5

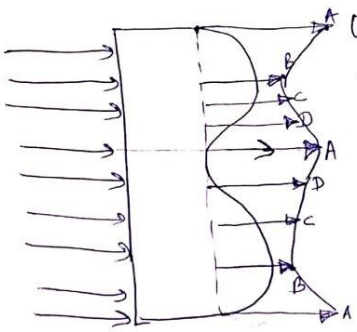
Q.5 A parallel beam of light strikes a piece of transparent glass having cross section as shown in the figure below. Correct shape of the emergent wavefront will be (figures are schematic and not drawn to scale)



(A) (B) (C) (D)



Q.5 Wave front is perpendicular to light



Upto the dotted line, all the light waves will follow same distance in same time.

But light's speed in glass is slower than in air, so at the time when wave in centre will reach at A, other waves which are travelling more distance in glass will cover less distance than A, and let's say reach at B

Similarly others will reach at C, D etc.

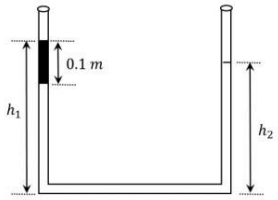
So the wavefront obtained will be.



Ans

6

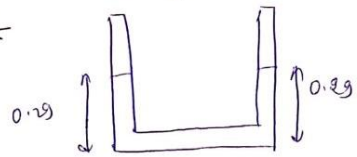
Q.6 An open-ended U-tube of uniform cross-sectional area contains water (density 10^3kg m^{-3}). Initially the water level stands at 0.29 m from the bottom in each arm. Kerosene oil (a water-immiscible liquid) of density 800 kg m^{-3} is added to the left arm until its length is 0.1 m, as shown in the schematic figure below. The ratio $\left(\frac{h_1}{h_2}\right)$ of the heights of the liquid in the two arms is



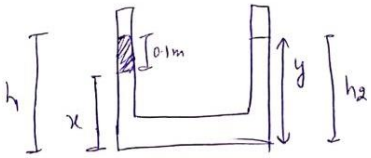
(A) $\frac{15}{14}$ (B) $\frac{35}{33}$ (C) $\frac{7}{6}$ (D) $\frac{5}{4}$

Q.6

Initially



Finally



$x + y = 0.29 + 0.29 = 0.58$ m (as amount of water will remain same)

Now pressure same at bottom on both ends of tube

$0.1 \times 800 \times g + x \times 1000 g = y \times 1000 g$

$80 + 1000x = 1000y$

$80 = 1000(0.58 - 2x - x)$

$\frac{8}{100} = 0.58 - 2x$

$\Rightarrow 2x = 0.5$

$x = 0.25$ m

$\frac{h_1}{h_2} = \frac{x + 0.1}{y} = \frac{0.35}{0.33}$

$\frac{h_1}{h_2} = \frac{35}{33}$

7

Q.7 A particle of mass m moves in circular orbits with potential energy $V(r) = Fr$, where F is a positive constant and r is its distance from the origin. Its energies are calculated using the Bohr model. If the radius of the particle's orbit is denoted by R and its speed and energy are denoted by v and E, respectively, then for the nth orbit (here h is the Planck's constant)

(A) $R \propto n^{1/3}$ and $v \propto n^{2/3}$

(B) $R \propto n^{2/3}$ and $v \propto n^{1/3}$

(C) $E = \frac{3}{2}\left(\frac{n^2h^2F^2}{4\pi^2m}\right)^{1/3}$

(D) $E = 2\left(\frac{n^2h^2F^2}{4\pi^2m}\right)^{1/3}$

Q.7 Potential Energy $U = Fr$

Force $= -\frac{dU}{dr} = -F$

Magnetic of force $= F = \frac{mv^2}{r}$ ① (centripetal force)

According to bohr's model $mvR = \frac{nh}{2\pi}$ ②

$v = \frac{nh}{2\pi mr}$

Putting in ①

$F = \frac{m}{r}\frac{n^2h^2}{(2\pi m)^2 r^2}$

$F = \frac{n^2h^2}{4\pi^2 m r^3}$

$R = \left(\frac{n^2h^2}{4\pi^2 mF}\right)^{1/3}$ $\quad v = \frac{n^{1/3}h^{1/3}(4\pi^2 mF)^{1/3}}{2\pi m}$

$R \propto n^{2/3}$ and $V \propto n^{1/3}$

and $E = \frac{1}{2}mv^2 + U$

$= \frac{1}{2}m\frac{n^2h^2}{4\pi^2 m^2 r^2} + \frac{mn^2h^2}{4\pi^2 m^2 r^2}$

$= \frac{3}{2}\left(\frac{n^2h^2}{4\pi^2 mr^2}\right) = \frac{3}{2}\left(\frac{n^2h^2F^2}{4\pi^2 m}\right)^{1/3}$

8

Q.8 The filament of a light bulb has surface area 64 mm^2. The filament can be considered as a black body at temperature 2500 K emitting radiation like a point source when viewed from far. At night the light bulb is observed from a distance of 100 m. Assume the pupil of the eyes of the observer to be circular with radius 3 mm. Then
(Take Stefan-Boltzmann constant = $5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$, Wien's displacement constant = 2.90×10^{-3} m-K, Planck's constant = 6.63×10^{-34} Js, speed of light in vacuum = $3.00 \times 10^{8}\ ms^{-1}$)

(A) power radiated by the filament is in the range 642 W to 645 W

(B) radiated power entering into one eye of the observer is in the range 3.15×10^{-8} W to 3.25×10^{-8} W

(C) the wavelength corresponding to the maximum intensity of light is 1160 nm

(D) taking the average wavelength of emitted radiation to be 1740 nm, the total number of photons entering per second into one eye of the observer is in the range 2.75×10^{11} to 2.85×10^{11}

Q.8 Power emitted by bulb/ black body : $P = \sigma A e T^4$

$P = 5.64 \times 10^{-8} \times 64 \times 10^{-6} \times 1 \times (2500)^4$ (e = 1 for black body)

$= 141.75$ W

Power reaching to the observer/eye $= \left(\frac{\text{Power emitted by filament}}{\text{Total area}}\right) \times (\text{Area of Pupil})$

$= \frac{141.75 \times (\pi R^2)}{4\pi d^2}$

R = Radius of pupil
d = distance of pupil from filament

$= 3.19 \times 10^{-6}$ W

$\lambda_m T = b$ $\quad T = 2500$.

$\Rightarrow \lambda_m = \frac{2.9 \times 10^{-3}}{2500}$

$\lambda_m = 1160$ nm

Power received by one eye of observer : $\left(\frac{hc}{\lambda}\right)$ (energy of 1 photon) $\times$ No of photons entering into eye per second

No. of photons entering per second $= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1740 \times 10^{-9} \times 3.19 \times 10^{-8}}$

$= \boxed{2.79 \times 10^{11}}$

9

Q.9 Sometimes it is convenient to construct a system of units so that all quantities can be expressed in terms of only one physical quantity. In one such system, dimensions of different quantities are given in terms of a quantity X as follows: [position] = $[X^{\alpha}]$; [speed] = $[X^{\beta}]$; [acceleration] =$[X^{p}]$; [linear momentum] = $[X^{q}]$; [force] = $[X^{r}]$. Then

(A) $\alpha + p = 2\beta$

(B) $p + q - r = \beta$

(C) $p - q + r = \alpha$

(D) $p + q + r = \beta$

Ans:→ Dimension of position = $L = x^{\alpha} \longrightarrow (1)$

" " speed = $LT^{-1} = x^{\beta} \longrightarrow (2)$

" " acc. = $LT^{-2} = x^{p} \longrightarrow (3)$

" " linear momentum = $MLT^{-1} = x^{q} \longrightarrow (4)$

" " Force = $MLT^{-2} = x^{r} \longrightarrow (5)$

$\frac{eq(1)}{eq(2)} \Rightarrow \frac{L}{LT^{-1}} = \frac{x^{\alpha}}{x^{\beta}}$

$\boxed{T = x^{\alpha-\beta}}$

From $\frac{eq(3)}{eq(2)} \Rightarrow \frac{LT^{-2}}{LT^{-1}} = \frac{x^{p}}{x^{\beta}}$

$\frac{1}{T} = \frac{x^{p}}{x^{\beta}} \Rightarrow \boxed{T = x^{\beta-p}}$

since $\because x^{\alpha-\beta} = x^{\beta-p}$

$\alpha - \beta = \beta - p$

$\boxed{\alpha + p = 2\beta}$ option A = correct

$\frac{eq(4)}{eq(5)} \Rightarrow \frac{MLT^{-1}}{MLT^{-2}} = \frac{x^{q}}{x^{r}} = \boxed{T = x^{q-r}}$

$x^{q-r} = x^{\beta-p} = x^{\alpha-\beta}$

$q - r = \alpha - \beta$

$\boxed{\alpha + r = q + \beta}$

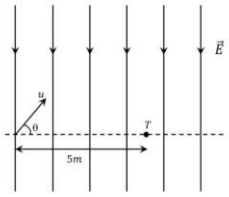
$q - r = \beta - p$

$\boxed{\beta = p + q - r}$ correct option

$\Rightarrow$

10

Q.10 A uniform electric field, $\vec{E} = -400\sqrt{3}\hat{y}\ \text{NC}^{-1}$ is applied in a region. A charged particle of mass m carrying positive charge q is projected in this region with an initial speed of $2\sqrt{10} \times 10^6\ \text{ms}^{-1}$. This particle is aimed to hit a target T, which is 5 m away from its entry point into the field as shown schematically in the figure. Take $\frac{q}{m} = 10^{10}\ \text{Ckg}^{-1}$. Then



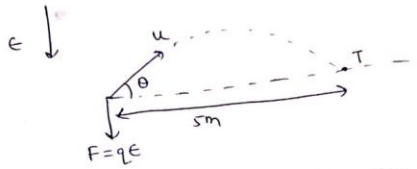
(A) the particle will hit T if projected at an angle 45° from the horizontal

(B) the particle will hit T if projected either at an angle 30° or 60° from the horizontal

(C) time taken by the particle to hit T could be $\sqrt{\frac{5}{6}}\ \mu s$ as well as $\sqrt{\frac{5}{2}}\ \mu s$

(D) time taken by the particle to hit T is $\sqrt{\frac{5}{3}}\ \mu s$

Ans → 10



F = given as $q\vec{E}$ (since q is positive F is in direction of E)

so it is projectile

Time of flight (T) ⇒

$v = u + at$

$a = \frac{F}{m} = -\frac{qE}{m}$

$0 = u\sin\theta - \frac{qE}{m}t$

$u\sin\theta = \frac{qE}{m}t$

$t = \frac{mu\sin\theta}{qE}$

time of flight (T) = $2t = \frac{2mu\sin\theta}{qE}$

Range = $u\cos\theta \times T$

$= u\cos\theta \times \frac{2mu\sin\theta}{qE}$

For hit the target Range = 5m

$5 = \frac{u\cos\theta \times 2mu\sin\theta}{qE}$

$\frac{5qE}{m} = u^2\sin 2\theta$

$5 \times 10^{10} \times 400\sqrt{3} = 4 \times 10 \times 10^{12}\sin 2\theta$

$\frac{2000\sqrt{3}}{2 \times 400} = \sin 2\theta$

$\sin 2\theta = \frac{\sqrt{3}}{2}$

$2\theta = 60°, 180° - 60°$

$\theta = 30°$ & $\theta = 60°$

Time of flight using $\theta = 60°$

$T = \sqrt{\frac{5}{2}}\ \mu s$

(using $\theta = 30°$)

Time of flight = $\frac{2mu\sin\theta}{qE}$

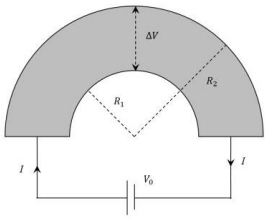
$= \frac{2 \times 2\sqrt{10} \times 10^6 \times \sin 30}{10^{10} \times 400\sqrt{3}}$

$= \frac{4\sqrt{10} \times 10^6}{10^{12} \times 4\sqrt{3} \times 2}$

$= \sqrt{\frac{5}{6}}\ \mu s$

11

Q.11 Shown in the figure is a semicircular metallic strip that has thickness t and resistivity ρ. Its inner radius is R_1 and outer radius is R_2. If a voltage V_0 is applied between its two ends, a current I flows in it. In addition, it is observed that a transverse voltage ΔV develops between its inner and outer surfaces due to purely kinetic effects of moving electrons (ignore any role of the magnetic field due to the current). Then (figure is schematic and not drawn to scale)



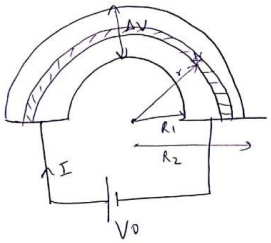
(A) $I = \frac{V_0 t}{\pi \rho} \ln\left(\frac{R_2}{R_1}\right)$

(B) the outer surface is at a higher voltage than the inner surface

(C) the outer surface is at a lower voltage than the inner surface

(D) $\Delta V \propto I^2$

Q.11



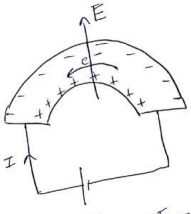
If All such strips are in parallel,

$I = \frac{V_0}{R}$ $\quad R = \frac{\rho l}{A}$

for 1 such strip

$di = \frac{V_0 (dr \times t)}{\rho(\pi r)}$

$di = \frac{V_0 t}{\rho \pi r} dr \Rightarrow \boxed{i = \frac{V_0 t}{\rho \pi} \ln \frac{r_2}{r_1}}$



dirn of Electric field = ↑

force on electron due to this electric field = ↓

This force F will provide centripetal force

$F = eE = \frac{mv^2}{r}$

for 1 strip $\quad i = neAv_d$

$\frac{V_0 t\, dr}{\rho \pi r} = ne(t\,dr)V \Rightarrow V = \frac{V_0}{\rho \pi r ne}$

$E = \frac{mv}{re} = \frac{m}{e r} \frac{V_0^2}{\rho^2 \pi^2 n^2 e^2 r^2}$

$E = \frac{m V_0^2}{\rho^2 \pi^2 n^2 e^3 r^3}$ $\quad E = \frac{k}{r^3}$ lets say

$dV = -E dr = \frac{-k}{r^3} dr$

$V = k \int_{R_1}^{R_2} r^{-3} dr$

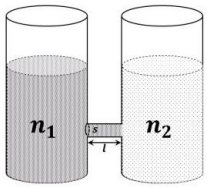
$\Delta V = k\left(\frac{1}{r_1^2} - \frac{1}{r_2^2}\right) = \frac{m V_0^2}{\rho^2 \pi^2 n^2 e^3} \left(\frac{1}{r_1^2} - \frac{1}{r_2^2}\right)$

$\Rightarrow \boxed{\Delta V \propto V_0^2}$

$\boxed{I \propto V_0}$

12

Q.12 As shown schematically in the figure, two vessels contain water solutions (at temperature T) of potassium permanganate ($KMnO_4$) of different concentrations n_1 and n_2 ($n_1 > n_2$) molecules per unit volume with $\Delta n = (n_1 - n_2) \ll n_1$. When they are connected by a tube of small length l and cross-sectional area S, $KMnO_4$ starts to diffuse from the left to the right vessel through the tube. Consider the collection of molecules to behave as dilute ideal gases and the difference in their partial pressure in the two vessels causing the diffusion. The speed v of the molecules is limited by the viscous force $-\beta v$ on each molecule, where β is a constant. Neglecting all terms of the order $(\Delta n)^2$, which of the following is/are correct? (k_B is the Boltzmann constant)



(A) the force causing the molecules to move across the tube is $\Delta n k_B T S$

(B) force balance implies $n_1 \beta v l = \Delta n k_B T$

(C) total number of molecules going across the tube per sec is $\left(\frac{\Delta n}{l}\right)\left(\frac{k_B T}{\beta}\right) S$

(D) rate of molecules getting transferred through the tube does not change with time

Q.12

Considering it as dilute ideal gas.

$PV = nRT$

or $PV = NKT$

$P = \left(\frac{N}{V}\right)KT$ $\quad \frac{N}{V}$ = molecules per unit volume, lets say n_0

$\boxed{P = n_0 KT}$

for first column $P_1 = n_1 KT$

for second column $P_2 = n_2 KT$

F = due to pressure difference

$= (\Delta P)\, S \rightarrow$ Surface Area

$F = (n_1 - n_2) KTS$

$= \Delta n KTS$ —(1)

viscous force on each molecule $= -\beta V$

net viscous force $= -\beta V \times$ no. of molecules displaced (n_1)

$= n_1 \times S l \beta V$ —(2)

equating (1) & (2)

$\Delta n k_B T S = n_1 S l \beta V$

$\boxed{\Delta n k_B T = n_1 l \beta V} \Rightarrow \boxed{n_1 = \frac{\Delta n k_B T}{\beta V l}}$

Rate of flow of particles = no. of molecules going per sec

$= \frac{dN}{dt} = n_1 (SV)$ where SV = Volume flow rate = area × Velocity

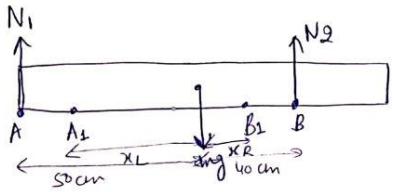
$= n_1 SV = \left(\frac{\Delta n k_B T}{\beta V l}\right) S V$

$\boxed{\frac{dN}{dt} = \left(\frac{\Delta n}{l}\right)\left(\frac{k_B T}{\beta}\right) S}$

13

Q.13 Put a uniform meter scale horizontally on your extended index fingers with the left one at 0.00 cm and the right one at 90.00 cm. When you attempt to move both the fingers slowly towards the center, initially only the left finger slips with respect to the scale and the right finger does not. After some distance, the left finger stops and the right one starts slipping. Then the right finger stops at a distance x_R from the center (50.00 cm) of the scale and the left one starts slipping again. This happens because of the difference in the frictional forces on the two fingers. If the coefficients of static and dynamic friction between the fingers and the scale are 0.40 and 0.32, respectively, the value of x_R (in cm) is _____.

Q.13



Length of whole scale = 100 cm.

Initially left finger is at A & right at B.

let say normal force exerted by left & right fingers are N_1 & N_2 respectively.

Net force = 0 at any time, so $N_1 + N_2 = Mg$ — (1)

Net torque = 0 at centre, so at initial instant $N_1 \times 50 = N_2 \times 40$ — (2)

Solving (1) & (2) $\Rightarrow$ $\boxed{N_1 = \frac{4Mg}{9} \quad \text{and} \quad N_2 = \frac{5Mg}{9}}$

$\Rightarrow$ let say x_L is distance of left finger from centre when right finger starts moving, At this instant also force & torque is zero. So

$N_1 + N_2 = Mg$ and $N_1 x_L = N_2 \times 40$ — (3)

Also, kinetic friction of left finger = static friction of right finger } To balance force in horizontal

$0.32 \times N_1 = 0.40 \times N_2$ — (4)

Solving (3) & (4) $\Rightarrow$ $32N_1 = N_1 x_L \Rightarrow \boxed{x_L = 32 \text{ cm}}$

$\Rightarrow$ x_R is distance of right finger from centre when left finger starts moving again, Balancing force and torque again:

$N_1 x_L = N_2 x_R \Rightarrow 32 N_1 = x_R N_2$ — (5)

Here, kinetic friction of right finger = static friction of left finger

$0.40 N_2 = 0.32 N_1$ — (6)

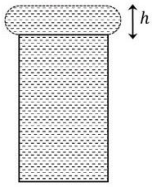
Solving (5) & (6) $\Rightarrow$ $\frac{x_R N_2}{32} = \frac{32 N_2}{40} \Rightarrow x_R = \frac{32 \times 32}{40}$ cm

$= \frac{128}{5}$ cm

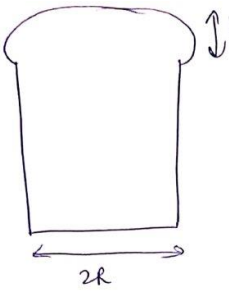
$\boxed{x_R = 25.6 \text{ cm}}$

14

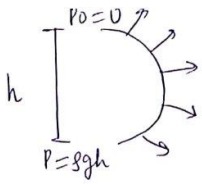
Q.14 When water is filled carefully in a glass, one can fill it to a height h above the rim of the glass due to the surface tension of water. To calculate h just before water starts flowing, model the shape of the water above the rim as a disc of thickness h having semicircular edges, as shown schematically in the figure. When the pressure of water at the bottom of this disc exceeds what can be withstood due to the surface tension, the water surface breaks near the rim and water starts flowing from there. If the density of water, its surface tension and the acceleration due to gravity are 10^3kg m^{-3}, 0.07 Nm^{-1} and 10 ms^{-2}, respectively, the value of h (in mm) is _____.

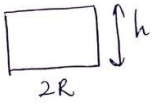


Q.14



$\Rightarrow$



Projected Area = 

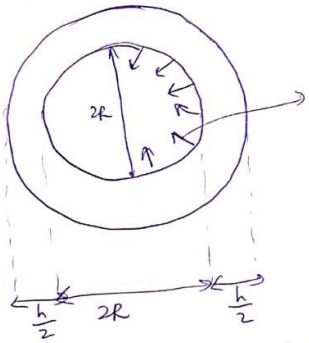
$= 2Rh$

Force due to pressure of water = $(P_{avg}) \times$ Projected area

$= \left(\frac{0+\rho gh}{2}\right) \times 2Rh$

$= \rho g R h^2$ — (1)

Top View



Force due to surface tension.

Projected length = $2R$

Force due to pressure of surface tension

$= S \times$ (projected length)

$= 2RS$ — (2)

∴ When both forces become equal, water starts flowing out.

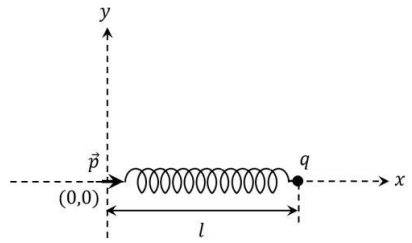
$\rho g R h^2 = 2RS$

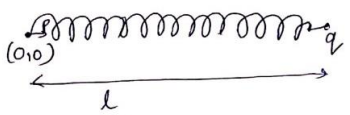
$h^2 = \frac{2S}{\rho g}$

$h = \sqrt{\frac{2 \times 0.07}{10^3 \times 10}} = \sqrt{14 \times 10^{-3}} = 3.74 \text{ mm}$

15

Q.15 One end of a spring of negligible unstretched length and spring constant k is fixed at the origin (0,0). A point particle of mass m carrying a positive charge q is attached at its other end. The entire system is kept on a smooth horizontal surface. When a point dipole $\vec{p}$ pointing towards the charge q is fixed at the origin, the spring gets stretched to a length l and attains a new equilibrium position (see figure below). If the point mass is now displaced slightly by $\Delta l \ll l$ from its equilibrium position and released, it is found to oscillate at frequency $\frac{1}{\delta}\sqrt{\frac{k}{m}}$. The value of δ is _____.





Potential energy at extension x for this system

$$U = \underbrace{\frac{1}{2}kx^2}_{\text{due to spring}} + \underbrace{\frac{Kpq}{x^2}}_{\text{due to dipole}}$$

$$F = \frac{dU}{dx} = Kx - \frac{2Kpq}{x^3}$$

At length l $F_{net} = 0$ So $\quad Kx = \frac{2Kpq}{x^3}$ at $x = l$

$$Kl = \frac{2Kpq}{l^3} \quad \text{—(1)}$$

When stretched further by length x.

$$F_{net} = F_{spring} - F_{dipole}$$

$$= k(l+x) - \frac{q\,2Kp}{(l+x)^3} = Kx + Kl - q\left(\frac{2Kp}{l^3}\right)\left(\frac{1}{\left(1+\frac{x}{l}\right)^3}\right)$$

$$\left(1+\frac{x}{l}\right)^{-3} \approx 1 - \frac{3x}{l} \quad \left(\text{applying binomial theorem as } \frac{3x}{l} << 1\right)$$

$$F_{net} = Kx + Kl - \frac{2Kpq}{l^3} + \frac{2Kpq}{l^3}\frac{3x}{l}$$

$$= Kx + Kl - Kl + Kl\frac{3x}{l} \quad (\text{from } ①)$$

$$= 4Kx$$

Time period $T = 2\pi\sqrt{\frac{m}{4K}} = \pi\sqrt{\frac{m}{K}}$

frequency $f = \frac{1}{\pi}\sqrt{\frac{K}{m}}$

So $\boxed{\delta = \pi = 3.14}$

16

Q.16 Consider one mole of helium gas enclosed in a container at initial pressure P_1 and volume V_1. It expands isothermally to volume $4V_1$. After this, the gas expands adiabatically and its volume becomes $32V_1$. The work done by the gas during isothermal and adiabatic expansion processes are W_{iso} and W_{adia}, respectively. If the ratio $\frac{W_{iso}}{W_{adia}} = f \ln 2$, then f is _____.

Q.16

Initially

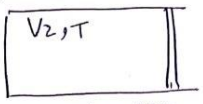


Case #1 (isothermally) $\Rightarrow P_1V_1 = P_2V_2$

$W_{iso} = nRT \ln \frac{V_2}{V_1}$ [n = 1

$= P_1V_1 \ln \frac{V_2}{V_1}$

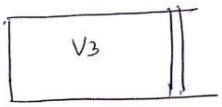
$W_{iso} = 2P_1V_1 \ln 2$



$V_2 = 4V_1$

$\left(P_2 = \frac{P_1V_1}{V_2} = \frac{P_1}{4}\right)$ ← (1)

Case 2 (adiabatically)



$V_3 = 32V_1$

$\gamma = \frac{5}{3}$ for monoatomic gas

also $P_3V_3^{\gamma} = P_2V_2^{\gamma}$

$P_2 = P_3\left(\frac{V_3}{V_2}\right)^{\gamma} = P_3\left(\frac{32V_1}{4V_1}\right)^{5/3} = P_3\left(2^{3\times\frac{5}{3}}\right)$

$P_2 = 32P_3$ $\quad P_3 = \frac{P_2}{32} = \frac{P_1}{128}$ (from (1))

$W_{adi} = \frac{P_3V_3 - P_2V_2}{-(\gamma-1)} = \frac{P_3(32V_1) - 32P_3(4V_1)}{-(2/3)}$

$= \frac{32P_3V_1(3)}{2/3} = 16P_3V_1 \times 9 = \frac{16\times9\times P_1V_1}{128}$

$= \frac{9}{8}P_1V_1$

$\frac{W_{iso}}{W_{adia}} = \frac{2P_1V_1\ln 2}{\frac{9}{8}P_1V_1} = \frac{16\ln 2}{9}$

$f = \frac{16}{9} \Rightarrow f = 1.77$ Ans

17

Q.17 A stationary tuning fork is in resonance with an air column in a pipe. If the tuning fork is moved with a speed of 2 ms^{-1} in front of the open end of the pipe and parallel to it, the length of the pipe should be changed for the resonance to occur with the moving tuning fork. If the speed of sound in air is 320 ms^{-1}, the smallest value of the percentage change required in the length of the pipe is _____.

Q.17 Fundamental frequency for a pipe with one end-closed

$$f = \frac{V}{4l} \quad (l = \text{length of pipe})$$

When fork starts moving, apparent frequency reaching pipe is

$$f' = \left(\frac{V - V_0}{V - V_s}\right) f = \left(\frac{320 - 0}{320 - 2}\right) f$$

$$f' = \left(\frac{320}{318}\right) f \qquad f = \frac{320}{4l_1} = \frac{V}{4l_1} \quad (l_1 = \text{initial length})$$

for smallest value of percentage change in length of pipe, it will resonate with fundamental frequency so

$$f' = \frac{V}{4l_2} \quad (l_2 = \text{increased length})$$

$(V = 320\ m/s)$

$$\frac{320}{4l_2} = \frac{320}{318}\left(\frac{320}{4l_1}\right)$$

$$\frac{l_1}{l_2} = \frac{320}{318}$$

$$\therefore \text{change} = \left|\frac{(l_2 - l_1)}{l_1}\right| = \left|\frac{l_2}{l_1} - 1\right| = \left|1 - \frac{318}{320}\right|$$

$$= \frac{2}{320} \times 100 = 0.62\%$$

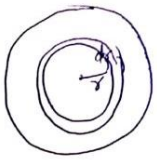
18

Q.18 A circular disc of radius R carries surface charge density $\sigma(r) = \sigma_0\left(1 - \frac{r}{R}\right)$, where σ_0 is a constant and r is the distance from the center of the disc. Electric flux through a large spherical surface that encloses the charged disc completely is ϕ_0. Electric flux through another spherical surface of radius $\frac{R}{4}$ and concentric with the disc is ϕ. Then the ratio $\frac{\phi_0}{\phi}$ is_____.

Q.18

$$\text{flux} = \frac{q_{enclosed}}{\epsilon_0}$$

for disk, $\sigma = \sigma_0\left(1 - \frac{r}{R}\right)$



$$dq = \sigma \times A$$

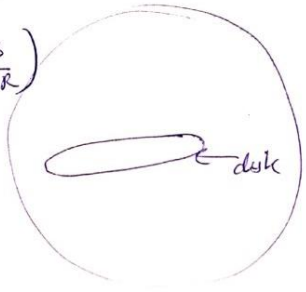
$$= \sigma_0\left(1 - \frac{r}{R}\right) 2\pi r\, dr$$

$$dq = \sigma_0 2\pi \left(r - \frac{r^2}{R}\right) dr$$

For any r, charge enclosed :

$$\int_0^q dq = \sigma_0 2\pi \int_0^r \left(r - \frac{r^2}{R}\right) dr$$

$$q = 2\pi\sigma_0\left(\frac{r^2}{2} - \frac{r^3}{3R}\right)$$

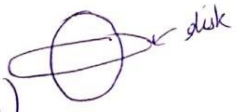


For large spherical surface

q_{en} = total charge of disk

$$\text{flux} = \phi_s = \frac{2\pi\sigma_0\left(\frac{R^2}{2} - \frac{R^2}{3}\right)}{\epsilon_0}$$

$$= \frac{2\pi\sigma_0 R^2}{\epsilon_0 6}$$



For small sphere $\left(r = \frac{R}{4}\right)$

$$\text{flux } \phi_{ss} = 2\pi\sigma_0\left(\frac{R^2}{32} - \frac{R^2}{64 \times 3}\right)$$

$$= \frac{2\pi\sigma_0 \times R^2 \times 5}{64 \times 3} = \frac{5\pi\sigma_0 R^2}{96}$$

$$\frac{\phi_0}{\phi} = \frac{\frac{2\pi\sigma_0 R^2}{\epsilon_0 6}}{\frac{5\pi\sigma_0 R^2}{96}} = \frac{96}{15} = 6.40$$

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