JEE MAIN 2024
Paper with Solution

PHYSICS | 30th January 2024 _ Shift-1

SECTION – A

31. Match **List - I** with **List - II.**

List – I	**List - II**
(A) Coefficient of viscosity	(I) $[M L^2 T^{-2}]$
(B) Surface tension	(II) $[M L^2 T^{-1}]$
(C) Angular momentum	(III) $[M L^{-1} T^{-1}]$
(D) Rotational kinetic energy	(IV) $[M L^0 T^{-2}]$

Choose the correct answer from the options given below :

(1) (A)-(II), (B)-(I), (C)-(IV), (D)-(III) (2) (A)-(I), (B)-(II), (C)-(III), (D)-(IV)

(3) (A)-(III), (B)-(IV), (C)-(II), (D)-(I) (4) (A)-(IV), (B)-(III), (C)-(II), (D)-(I)

Sol. 3

(A) Coefficient of viscosity (η)

$$F = 6\pi\eta rv$$

$[M^1L^1T^{-2}] = [\eta]\,[M^0L^1T^0]\,[M^0L^1T^{-1}]$

$$[\eta] = \frac{[M^1L^1T^{-2}]}{[M^0L^1T^0][M^0L^1T^{-1}]} = [M^1L^{-1}T^{-1}] \quad \rightarrow \quad (III)$$

$$\text{(B) Surface Tension (T)} = \frac{F}{\ell} = \frac{[M^1L^1T^{-2}]}{[M^0L^1T^0]} = [M^1L^0T^{-2}] \rightarrow (IV)$$

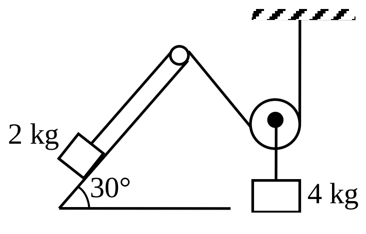
(C) Angular momentum (L) = mvr

$[M^1L^0T^0][M^0L^1T^{-1}]\,[M^0L^1T^0]$

$= [M^1L^2T^{-1}] \quad \rightarrow \quad$ (II)

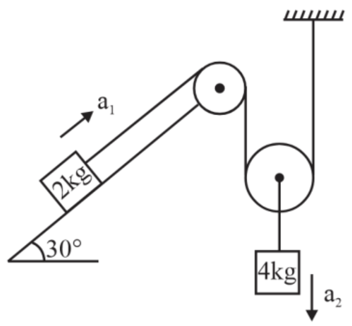
(D) Rotational kinetic energy $[M^1L^2T^{-2}] \rightarrow$ (I)

32. All surfaces shown in figure are assumed to be frictionless and the pulleys and the string are light. The acceleration of the block of mass 2 kg is :



(1) g (2) $\frac{g}{3}$ (3) $\frac{g}{2}$ (4) $\frac{g}{4}$

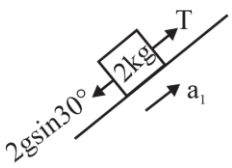
Sol. 2

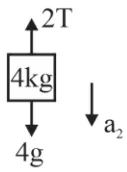


By constrained motion

$-a_1 + a_2 + a_2 = 0$

$a_1 - 2a_2$ or $a_2 = \frac{a_1}{2}$





$T - 2\,g\sin 30° = 2a_1$ $\quad$ $4g - 2T = 4a_2$

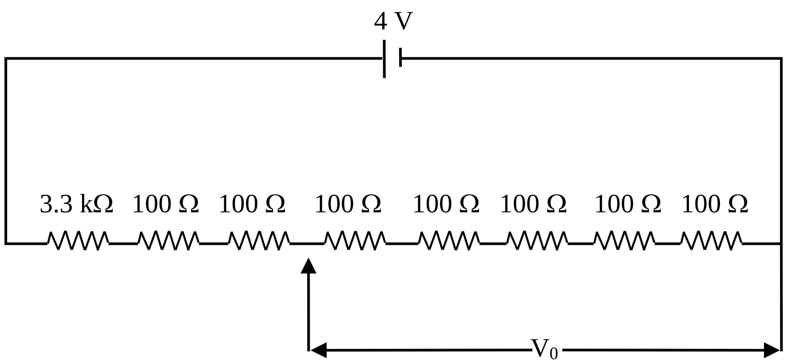
$\Rightarrow T - g = 2a_1$ ....(1) $\quad \Rightarrow 4g - 2T = 4\left[\frac{a_1}{2}\right]$

$\Rightarrow 2g - T = a_1$ .....(2)

adding equation (1) and (2)

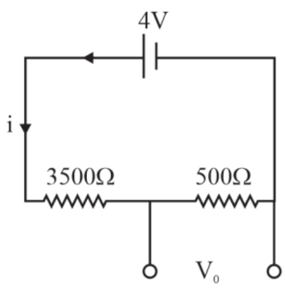
$g = 3a_1 \Rightarrow a_1 = \frac{g}{3}$

33. A potential divider circuit is shown in figure. The output voltage V_0 is :



(1) 4 V (2) 2 mV (3) 0.5 V (4) 12 m V

Sol. **3**



$i = \frac{4V}{4000\Omega} = \frac{1}{1000}$ A

$V_0 = (i)\,(500\Omega)$

$= \frac{1}{1000} \times 500 = 0.5$ volt

34. Young's modules of material of a wire of length ' L ' and cross-sectional area A is Y. If the length of the wire is doubled and cross-sectional area is halved then Young's modules will be:

(1) $\frac{Y}{4}$ (2) 4 Y (3) Y (4) 2Y

Sol. **3**

Young's modules remains same for a given material, it does not depend on the dimensions of the rod.

35. The work function of a substance is 3.0 eV. The longest wavelength of light that can cause the emission of photoelectrons from this substance is approximately;

(1) 215 nm (2) 414 nm (3) 400 nm (4) 200 nm

Sol. **2**

Work function = 3eV

$$\frac{hc}{\lambda_{Th}} = 3eV \text{ or } \lambda_{Th} = \frac{12420}{3} \ (\text{Å})$$

$= 414$ (nm) Approx

36. The ratio of the magnitude of the kinetic energy to the potential energy of an electron in the 5^{th} excited state of a hydrogen atom is :

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

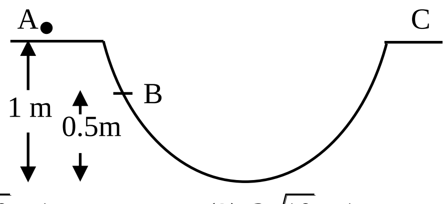
Sol. **3**

In Bohr's model, for a given state or orbit

$$KE = -\frac{PE}{2} \text{ or } |KE| = \frac{|PE|}{2}$$

$$\text{therefore, } \frac{|KE|}{|PE|} = \frac{1}{2}$$

37. A particle is placed at the point A of a frictionless track ABC as shown in figure. It is gently pushed towards right. The speed of the particle when it reaches the point B is : (Take g = 10 m/s^2).



(1) 20 m/s (2) $\sqrt{10}\,m/s$ (3) $2\sqrt{10}\,m/s$ (4) 10 m/s

Sol. **2**

by energy conservation

$|\Delta PE| = |\Delta KE|$

$$mg\,(h_2 - h_1) = \left(\frac{1}{2}mv^2 - 0\right)$$

$$mg\,[0.5] = \frac{1}{2}mv^2$$

$v^2 = 2g\,[0.5]$

$\left(v = \sqrt{10}\,m/s\right)$

38. The electric field of an electromagnetic wave in free space is represented as $\vec{E} = E_0 \cos(\omega t - kz)\hat{i}$. The corresponding magnetic induction vector will be :

(1) $\vec{B} = E_0 C \cos(\omega t - kz)\hat{j}$ (2) $\vec{B} = \frac{E_0}{C}\cos(\omega t - kz)\hat{j}$

(3) $\vec{B} = E_0 C \cos(\omega t + kz)\hat{j}$ (4) $\vec{B} = \frac{E_0}{C}\cos(\omega t + kz)\hat{j}$

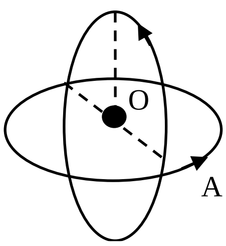
Sol. **2**

$E_0 = B_0 c, \Rightarrow \left(B_0 = \frac{E_0}{c}\right)$

therefore $\vec{B} = \frac{E_0}{c}\cos(\omega t - kz)\hat{j}$

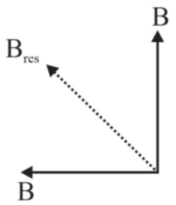
as $\vec{E}$ and $\vec{B}$ are in same phase.

39. Two insulated circular loop A and B of radius 'a' carrying a current of 'I' in the anti clockwise direction as shown in the figure. The magnitude of the magnetic induction at the centre will be:



(1) $\frac{\sqrt{2}\mu_0 I}{a}$ (2) $\frac{\mu_0 I}{2a}$ (3) $\frac{\mu_0 I}{\sqrt{2}a}$ (4) $\frac{2\mu_0 I}{a}$

Sol. **3**



$B = \frac{\mu_0 I}{2a}$;

$B_{res} = \sqrt{2}B$ (resultant)

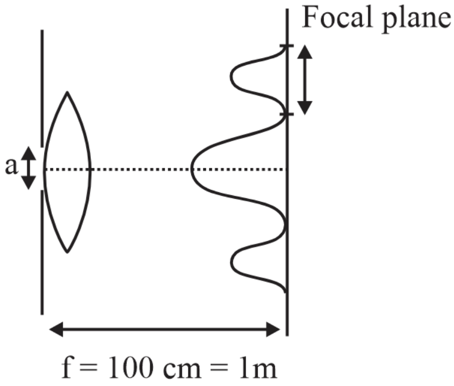
$= \sqrt{2}.\frac{\mu_0 I}{2a}$

$= \frac{\mu_0 I}{\sqrt{2}a}$

40. The diffraction pattern of a light of wavelength 400 nm diffracting from a slit of width 0.2 mm is focused on the focal plane of a convex lens of focal length 100 cm. The width of the 1st secondary maxima will be :

(1) 2 mm (2) 2 cm (3) 0.02 mm (4) 0.2 mm

Sol. 1



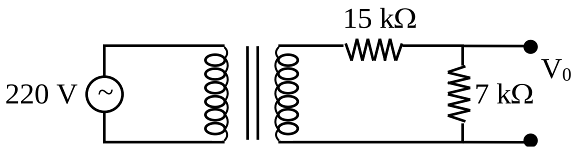
width of secondary maxima = $\frac{\lambda f}{a}$

$= \frac{400 \times 10^{-9} \times 1}{0.2 \times 10^{-3}} = \frac{2 \times 10^{-7}}{10^{-4}}$

$= 2 \times 10^{-3}$ m

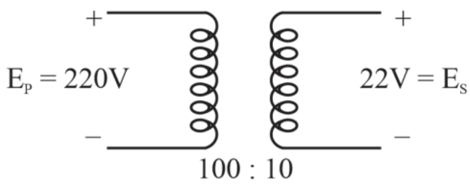
= 2 mm

41. Primary coil of a transformer is connected to 220 V ac. Primary and secondary turns of the transforms are 100 and 10 respectively. Secondary coil of transformer is connected to two series resistances shown in figure. The output voltage (V_0) is :



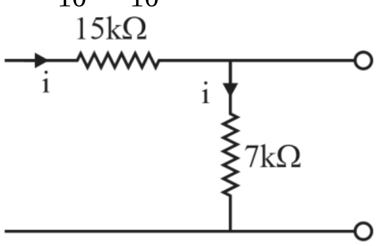
(1) 7 V (2) 15 V (3) 44 V (4) 22 V

Sol. 1



$\frac{E_P}{E_S} = \frac{N_P}{N_S} = \frac{100}{10} = 10$

$E_S = \frac{E_P}{10} = \frac{220}{10} = 22\,V$



$V_0 = (i)(7k\Omega)$

$= \frac{22}{(15+7)k\Omega} \times 7\ k\Omega$

$V_0 = 7V$

42. The gravitational potential at a point above the surface of earth is -5.12×10^7 J/kg and the acceleration due to gravity at that point is 6.4 m/s^2. Assume that the mean radius of earth to be 6400 km. The height of this point above the earth's surface is :

(1) 1600 km (2) 540 km (3) 1200 km (4) 1000 km

Sol. **1**

$$V_g = \frac{-GM}{(R+h)} = -5.12 \times 10^7 \text{ J/kg}$$

$$g = \frac{GM}{(R+h)^2} = 6.4 \text{ m/s}^2$$

$$\frac{V_g}{g} = -(R+h)$$

$$\Rightarrow \frac{-5.12 \times 10^7}{6.4} = -(R+h)$$

$R + h = 0.8 \times 10^7$

6400 km + h = 8000 km

h = 1600 km

43. An electric toaster has resistance of 60 Ω at room temperature (27°C). The toaster is connected to a 220 V supply. If the current flowing through it reaches 2.75 A, the temperature attained by toaster is around :

(if $\alpha = 2 \times 10^{-4}$/°C)

(1) 694 °C (2) 1235 °C (3) 1694 °C (4) 1667 °C

Sol. **3**

i = 2.75 A. V = 220 V

$$R_{new} = \frac{V}{i} = \frac{220}{2.75}\Omega = 80\Omega$$

$R_{old} = 60\ \Omega$

$R_{new} = R_{old}[1 + \alpha\Delta T]$

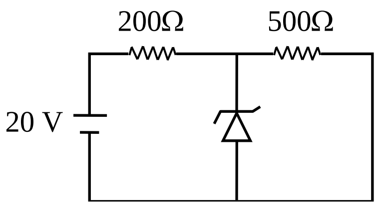
$80 = 60[1 + 2 \times 10^{-4}\ \Delta T]$

$\Delta T = 1666.67$

T – 27 = 1666.67

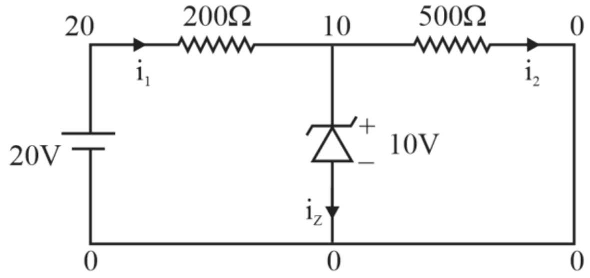
T = 1693.66 = 1694° C

44. A Zener diode of breakdown voltage 10 V is used as a voltage regulator as shown in the figure. The current through the Zener diode is:



(1) 50 mA (2) 0 (3) 30 mA (4) 20 mA

Sol. **3**



$i_1 = \frac{20-10}{200} = \frac{1}{20}$

$i_2 = \frac{10-0}{500} = \frac{1}{50}$

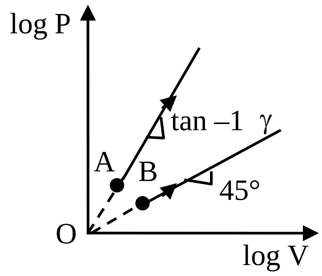
$i_z = i_1 - i_2$

$= \frac{1}{20} - \frac{1}{50}$

$= \frac{5-2}{100}$

$= \frac{3}{100} A = 30 mA$

45. Two thermodynamical processes are shown in the figure. The molar heat capacity for process A and B are C_A and C_B. The molar heat capacity at constant pressure and constant volume are represented by C_P and C_V, respectively. Choose the correct statement.



(1) $C_B = \infty$, $C_A = 0$ (2) $C_A = 0$ and $C_B = \infty$ (3) $C_P > C_V > C_A = C_B$ (4) $C_A > C_P > C_V$

Sol. **Bonus**

46. The electrostatic potential due to an electric dipole at a distance 'r' varies as :

(1) r (2) $\frac{1}{r^2}$ (3) $\frac{1}{r^3}$ (4) $\frac{1}{r}$

Sol. **2**

Electric potential due to an electric dipole

$V = \frac{1}{4\pi\varepsilon_0} \frac{P\cos\theta}{r^2}$

$V \propto \frac{1}{r^2}$

47. A spherical body of mass 100 g is dropped from a height of 10 m from the ground. After hitting the ground, the body rebounds to a height of 5 m. The impulse of force imparted by the ground to the body is given by : (given, $g = 9.8\ m/s^2$)

(1) $4.32\ kg\ ms^{-1}$ (2) $43.2\ kg\ ms^{-1}$ (3) $23.9\ kg\ ms^{-1}$ (4) $2.39\ kg\ ms^{-1}$

Sol. **4**

$m = 100\ g = 0.1\ kg,\ h_1 = 10m,\ h_2 = 5\ m$

$u = \sqrt{2gh_1} = \sqrt{20g} = \sqrt{2\times 98}\ m/s$

$v = \sqrt{2gh_2} = \sqrt{10g} = \sqrt{98}\ m/s$

Impuse = $\Delta\vec{P} = \vec{P_f} - \vec{p_i}$

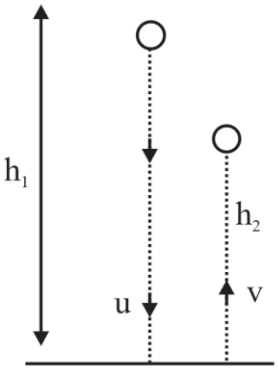
$= mv - (-mu)$

$= m (v + u)$

$= 0.1\left[\sqrt{98} + \sqrt{2\times 98}\right]$

$= 0.1\sqrt{98}\left[1+\sqrt{2}\right]$

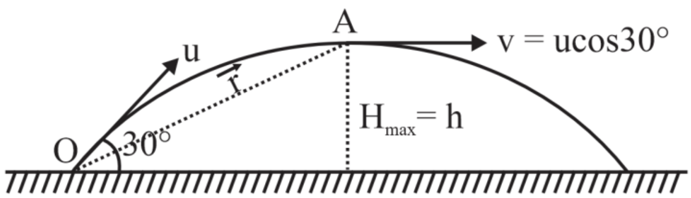
$\approx 2.39\ kg\ m/s$



48. A particle of mass m is projected with a velocity ' u ' making an angle of 30° with the horizontal. The magnitude of angular momentum of the projectile about the point of projection when the particle is at its maximum height h is :

(1) $\frac{\sqrt{3}}{16}\frac{mu^3}{g}$ (2) $\frac{\sqrt{3}}{2}\frac{mu^2}{g}$ (3) $\frac{mu^3}{\sqrt{2}g}$ (4) Zero

Sol. **1**



velocity of particle at maximum height

$v = u\cos 30° = \frac{u\sqrt{3}}{2}$

maximum height

$h = \frac{u^2\sin^2 30°}{2g} = \frac{u^2}{8g}$

magnitude of angular momentum

$|\vec{L}| = hmv$

$= \left(\frac{u^2}{8g}\right) m \left(\frac{u\sqrt{3}}{2}\right)$

$= \frac{\sqrt{3}mu^3}{16g}$

49. At which temperature the r.m.s. velocity of a hydrogen molecule equal to that of an oxygen molecule at 47°C ?

(1) 80 K (2) –73 K (3) 4 K (4) 20 K

Sol. **4**

$V_{rms} = \sqrt{\frac{3RT}{M}}$

$\Rightarrow (V_{rms})_{H_2} = (V_{rms})_{O_2}$

$\Rightarrow \sqrt{\frac{3RT_1}{M_1}} = \sqrt{\frac{3RT_2}{M_2}}$

$\Rightarrow \frac{T_1}{M_1} = \frac{T_2}{M_2}$

$\Rightarrow T_1 = \frac{M_1}{M_2} T_2$

$= \frac{2}{32}(273 + 47)$

$= \frac{2}{32} \times 320 = 20$ K

50. A series L.R circuit connected with an ac source E = (25 sin 1000 t) V has a power factor of $\frac{1}{\sqrt{2}}$. If the source of emf is changed to E = (20 sin 2000 t) V, the new power factor of the circuit will be :

(1) $\frac{1}{\sqrt{2}}$ (2) $\frac{1}{\sqrt{3}}$ (3) $\frac{1}{\sqrt{5}}$ (4) $\frac{1}{\sqrt{7}}$

Sol. **3**

For first source power factor

$\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + \omega^2 L^2}}$

$\Rightarrow \frac{1}{\sqrt{2}} = \frac{R}{\sqrt{R^2 + \omega^2 L^2}}$

$\Rightarrow R^2 + \omega^2 L^2 = 2R^2$

$\Rightarrow R = \omega L$

for second source

$\omega' = 2000 = 2\omega$

Power Factor $= \frac{R}{\sqrt{R^2 + \omega'^2 L^2}}$

$= \frac{\omega L}{\sqrt{\omega^2 L^2 + 4\omega^2 L^2}}$

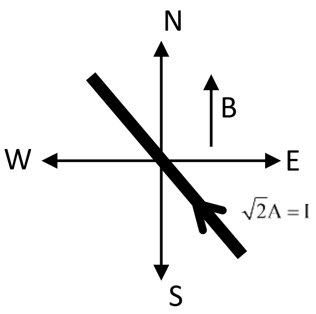
$= \frac{\omega L}{\sqrt{5\omega^2 L^2}}$

$= \frac{1}{\sqrt{5}}$

SECTION – B

51. The horizontal component of earth's magnetic field at a place is 3.5×10^{-5} T. A very long straight conductor carrying current of $\sqrt{2}A$ in the direction from South east to North West is placed. The force per unit length experienced by the conductor is ________10^{-6} N/m.

Sol. **35**



$F = I \ell B \sin\theta$

$\frac{F}{\ell} = IB\sin\theta$

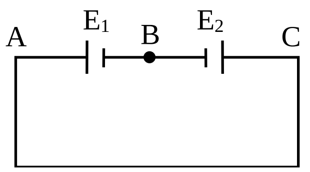
$= \sqrt{2} \times 3.5 \times 10^{-5} \times \sin 45^{o}$

$= \sqrt{2} \times 3.5 \times 10^{-5} \times \frac{1}{\sqrt{2}}$

$= 3.5 \times 10^{-5}$

$= 35 \times 10^{-6}$ N/m

52. Two cells are connected in opposition as shown. Cell E_1 is of 8 V emf and 2Ω internal resistance; the cell E_2 is of 2V emf and 4 Ω internal resistance. The terminal potential difference of cell E_2 is _______ V.



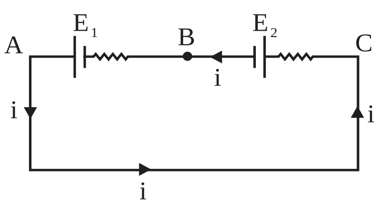
Sol. **6**

$\varepsilon_{eq} = E_1 - E_2 = (8 - 2)V = 6V$

$r_{eq} = r_1 + r_2 = (2 + 4)\Omega = 6\Omega$

Current in the loop,

$i = \frac{\varepsilon_{eq}}{r_{eq}} = \frac{6V}{6\Omega} = 1A$



Terminal potential difference of cell $E_2 \Rightarrow E_2 + ir_2$

$\Rightarrow [2 + (1)(4)]V$

$\Rightarrow 6V$

53. A electron of hydrogen atom on an excited state is having energy $E_n = -0.85eV$. The maximum number of allowed transitions to lower energy level is _______.

Sol. **6**

$$-0.85 = \frac{-13.6}{n^2}$$

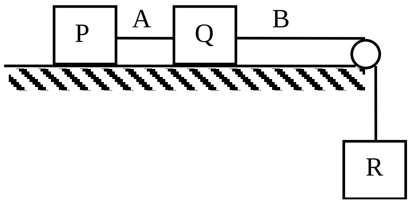
$$\Rightarrow n^2 = \frac{-13.6}{0.85} = 16$$

$n = 4$

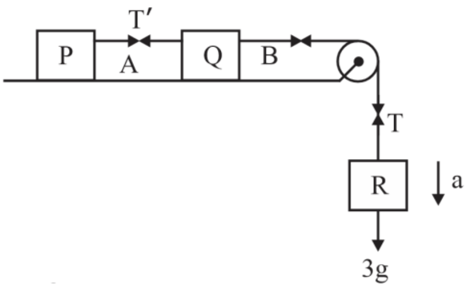
maximum number of transitions

$$= \frac{4 \times 3}{2} = 6$$

54. Each of three blocks P, Q and R shown in figure has a mass of 3 kg. Each of the wires A and B has cross-sectional area 0.005 cm^2 and Young's modulus 2×10^{11} N m^{-2}. Neglecting friction, the longitudinal strain on wire B is ______ $\times 10^{-4}$. (Take $g = 10\ m/s^2$)



Sol. **2**



$3g = (3 + 3 + 3)\ a$

$$\Rightarrow a = \frac{3}{9}g = \frac{1}{3}g$$

Now, $3g - T = 3a$

$$\Rightarrow T = 3(g - a) = 3\left(g - \frac{g}{3}\right) = 2g = 20\ N$$

$$Y = \frac{\text{longitudinal stress}}{\text{longitudinal strain}}$$

$$\text{longitudinal strain} = \frac{\text{longitudinal stress}}{Y}$$

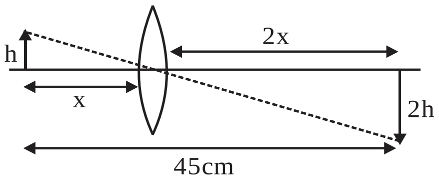
$$= \frac{T}{AY}$$

$$= \frac{20}{5 \times 10^{-7} \times 2 \times 10^{11}}$$

$= 2 \times 10^{-4}$

55. The distance between object and its two times magnified real image as produced by a convex lens is 45 cm. The focal length of the lens used is ______ cm.

Sol. **10**



3x = 45 cm   u = –15 cm

x = 15 cm   v = +30 cm

By lens formula

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

$$\frac{1}{30}-\frac{1}{-15}=\frac{1}{f}$$

$$\frac{1+2}{30}=\frac{1}{f}$$

$$\boxed{f=10\,\text{cm}}$$

56. The displacement and the increase in the velocity of a moving particle in the time interval of t to (t + 1) s are 125 m and 50 m/s, respectively. The distance travelled by the particle in $(t+2)^{th}$ s is ______ m.

Sol. **175**

$a=\frac{\Delta V}{\Delta t}=\frac{50}{1}=50\ m/s^2$

displacement in $(t+1)^{th}$ second

$S_1 = 125$ m

$\Rightarrow 125 = u + \frac{50}{2}[2(t+1)-1]$

$\Rightarrow u = 125 - 25[2t+1]$ …..(1)

displacement in $(t+2)^{th}$ second

$S_2 = u + \frac{50}{2}[2(t+2)-1]$

$= u + 25[2t+3]$ ….(2)

using equation (1) in equation (2)

$S_2 = 125 - 25(2t+1) + 25(2t+3)$

$= 125 - 25 + 75$

$= 175$ m

57. A capacitor of capacitance C and potential V has energy E. It is connected to another capacitor of capacitance 2 C and potential 2 V. Then the loss of energy is $\frac{x}{3}E$, where x is _______.

Sol. **2**

Initial potential energy of system

$$\Rightarrow \frac{1}{2}CV^2 + \frac{1}{2}(2C)(2V)^2$$

$U_i = E + 8E = 9E$

Common potential difference across capacitors, finally

$$\Rightarrow V_0 = \frac{C_1V_1 + C_2V_2}{C_1 + C_2} = \frac{CV + 4CV}{C + 2C} = \frac{5V}{3}$$

Final potential energy of system

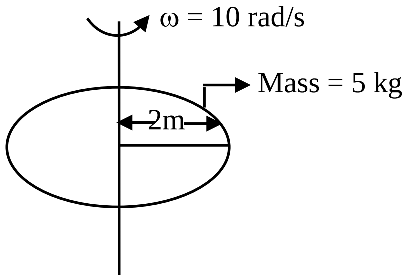
$$\frac{1}{2}CV_0^2 + \frac{1}{2}(2C)V_0^2$$

$$U_f = \frac{3C}{2}V_0^2 = \frac{3C}{2}\left(\frac{5V}{3}\right)^2 = \frac{1}{2}CV^2\left(\frac{25}{3}\right) = \frac{25}{3}E$$

Loss of energy

$$\Rightarrow U_i - U_f = 9E - \frac{25E}{3} = \frac{(27-25)E}{3} = \frac{2E}{3}$$

58.



Consider a Disc of mass 5 kg, radius 2 m, rotating with angular velocity of 10 rad /s about an axis perpendicular to the plane of rotation. An identical disc is kept gently over the rotating disc along the same axis. The energy dissipated so that both the discs continue to rotate together without slipping is _____ J.

Sol. **250**

Net torque about axis of rotation is zero

$\Rightarrow L_i = L_f$

$\Rightarrow I_i \omega_i = I_f \omega_f$

$$\Rightarrow \left(\frac{5 \times 2^2}{2}\right) \times 10 = \left(\frac{10 \times 2^2}{2}\right)\omega_f$$

$5 = \omega_f$

$\Rightarrow \omega_f = 5$

$\Delta E = E_i - E_f$

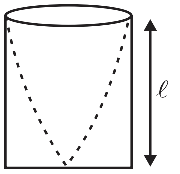
$$= \frac{1}{2}I_i\omega_i^2 - \frac{1}{2}I_f\omega_f^2$$

$$= \frac{1}{2}\left(\frac{5 \times 2^2}{2}\right) \times 10^2 - \frac{1}{2}\left(\frac{10 \times 2^2}{2}\right)5^2$$

$= 500 - 250 = 250$ J

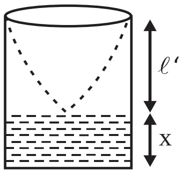
59. In a closed organ pipe, the frequency of fundamental note is 30 Hz. A certain amount of water is now poured in the organ pipe so that the fundamental frequency is increased to 110 Hz. If the organ pipe has a cross-sectional area of 2 cm^2, the amount of water poured in the organ tube is _____ g. (Take speed of sound in air is 330 m/s)

Sol. **400**



Fundamental frequency = $\frac{v}{4\ell} = 30\text{Hz}$

$\frac{330}{4\ell} = 30 \Rightarrow \ell = \frac{11}{4}\text{m}$



New fundamental frequency = $\frac{v}{4\ell'} = 110\text{Hz}$

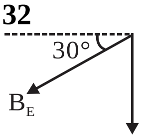
$\frac{330}{4(\ell')} = 110 \Rightarrow \ell' = \frac{3}{4}\text{m}$

$x = \ell - \ell' = \left(\frac{11}{4} - \frac{3}{4}\right) \times 100\,\text{cm} \Rightarrow 200\,\text{cm};$

mass of water = $\rho \times V$
= 1 g/cm^3 × (2 cm^2 × 200 cm)
= 400 g

60. A ceiling fan having 3 blades of length 80 cm each is rotating with an angular velocity of 1200 rpm. The magnetic field of earth in that region is 0.5 G and angle of dip is 30°. The emf induced across the blades is N $\pi \times 10^{-5}$ V. The value of N is ______.

Sol. **32**



$B_V = B_E \sin 30°$

$= \left[(0.5 \times 10^{-4}) \times \frac{1}{2}\right]\text{T}$

B = 0.25 × 10^{-4} T

ω = 1200 rpm = $1200 \times \frac{2\pi\,\text{rad}}{60\,\text{sec}}$

40π rad/s

emf induced in rotating blades = $\frac{1}{2}B\omega\ell^2$

$= \frac{1}{2}.(0.25 \times 10^{-4}).(40\pi).(0.8)^2\,\text{V}$

= 3.2π × 10^{-4} V = 32π × 10^{-5} V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