

FINAL JEE-MAIN EXAMINATION – JANUARY, 2024

(Held On Thursday 01st February, 2024)

TIME : 9 : 00 AM to 12 : 00 NOON

PHYSICS

SECTION-A

31. With rise in temperature, the Young's modulus of elasticity

- (1) changes erratically
- (2) decreases
- (3) increases
- (4) remains unchanged

Ans. (2)

Sol. Conceptual questions

32. If R is the radius of the earth and the acceleration due to gravity on the surface of earth is $g = \pi^2 \text{ m/s}^2$, then the length of the second's pendulum at a height $h = 2R$ from the surface of earth will be,:

- (1) $\frac{2}{9} \text{ m}$
- (2) $\frac{1}{9} \text{ m}$
- (3) $\frac{4}{9} \text{ m}$
- (4) $\frac{8}{9} \text{ m}$

Ans. (2)

Sol. $g' = \frac{GM_e}{(3R)^2} = \frac{1}{9}g$

$$T = 2\pi \sqrt{\frac{\ell}{g'}}$$

Since the time period of second pendulum is 2 sec.

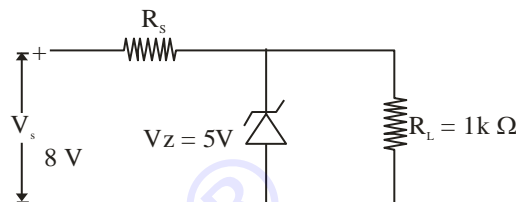
$$T = 2 \text{ sec}$$

$$2 = 2\pi \sqrt{\frac{\ell}{g}}$$

$$\ell = \frac{1}{9} \text{ m}$$

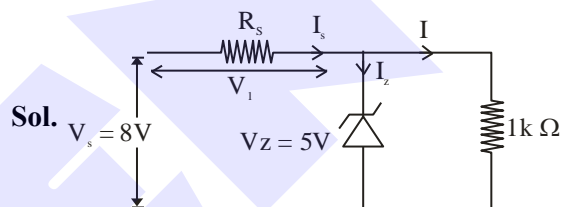
TEST PAPER WITH SOLUTION

33. In the given circuit if the power rating of Zener diode is 10 mW, the value of series resistance R_s to regulate the input unregulated supply is :



- (1) $5\text{k}\Omega$
- (2) 10Ω
- (3) $1\text{k}\Omega$
- (4) $10\text{k}\Omega$

Ans. (BONUS)



Sol.

Pd across R_s

$$V_1 = 8 - 5 = 3\text{V}$$

Current through the load resistor

$$I = \frac{5}{1 \times 10^3} = 5\text{mA}$$

Maximum current through Zener diode

$$I_{Z \text{ max.}} = \frac{10}{5} = 2\text{mA}$$

And minimum current through Zener diode

$$I_{Z \text{ min.}} = 0$$

$$\therefore I_{s \text{ max.}} = 5 + 2 = 7\text{mA}$$

$$\text{And } R_{s \text{ min.}} = \frac{V_1}{I_{s \text{ max.}}} = \frac{3}{7} \text{ k}\Omega$$

Similarly

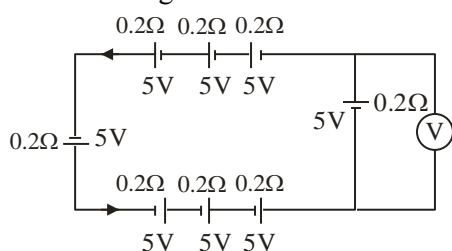
$$I_{s \text{ min.}} = 5\text{mA}$$

$$\text{And } R_{s \text{ max.}} = \frac{V_1}{I_{s \text{ min.}}} = \frac{3}{5} \text{ k}\Omega$$

$$\therefore \frac{3}{7} \text{ k}\Omega < R_s < \frac{3}{5} \text{ k}\Omega$$



34. The reading in the ideal voltmeter (V) shown in the given circuit diagram is :



- (1) 5V (2) 10V
(3) 0 V (4) 3V

Ans. (3)

Sol. $i = \frac{E_{eq}}{r_{eq}} = \frac{8 \times 5}{8 \times 0.2}$

$I = 25A$

$V = E - ir$

$= 5 - 0.2 \times 25$

$= 0$

35. Two identical capacitors have same capacitance C . One of them is charged to the potential V and other to the potential $2V$. The negative ends of both are connected together. When the positive ends are also joined together, the decrease in energy of the combined system is :

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

Ans. (1)

Sol. $V_c = \frac{q_{net}}{C_{net}} = \frac{CV + 2CV}{2C}$

$V_c = \frac{3V}{2}$

Loss of energy

$= \frac{1}{2}CV^2 + \frac{1}{2}C(2V)^2 - \frac{1}{2}2C\left(\frac{3V}{2}\right)^2$

$= \left(\frac{CV^2}{4}\right)$

36. Two moles a monoatomic gas is mixed with six moles of a diatomic gas. The molar specific heat of the mixture at constant volume is :

- (1) $\frac{9}{4}R$ (2) $\frac{7}{4}R$
(3) $\frac{3}{2}R$ (4) $\frac{5}{2}R$

Ans. (1)

Sol. $C_V = \frac{n_1C_{v1} + n_2C_{v2}}{n_1 + n_2}$
 $= \frac{2 \times \frac{3}{2}R + 6 \times \frac{5}{2}R}{2 + 6}$
 $= \frac{9}{4}R$

37. A ball of mass 0.5 kg is attached to a string of length 50 cm. The ball is rotated on a horizontal circular path about its vertical axis. The maximum tension that the string can bear is 400 N. The maximum possible value of angular velocity of the ball in rad/s is,:

- (1) 1600 (2) 40
(3) 1000 (4) 20

Ans. (2)

Sol. $T = m\omega^2\ell$
 $400 = 0.5\omega^2 \times 0.5$
 $\omega = 40 \text{ rad/s.}$

38. A parallel plate capacitor has a capacitance $C = 200 \text{ pF}$. It is connected to 230 V ac supply with an angular frequency 300 rad/s. The rms value of conduction current in the circuit and displacement current in the capacitor respectively are :

- (1) 1.38 μA and 1.38 μA
(2) 14.3 μA and 143 μA
(3) 13.8 μA and 138 μA
(4) 13.8 μA and 13.8 μA

Ans. (4)

Sol. $I = \frac{V}{X_C} = 230 \times 300 \times 200 \times 10^{-12} = 13.8 \mu A$



39. The pressure and volume of an ideal gas are related as $PV^{3/2} = K$ (Constant). The work done when the gas is taken from state A (P_1, V_1, T_1) to state B (P_2, V_2, T_2) is :

- (1) $2(P_1V_1 - P_2V_2)$
- (2) $2(P_2V_2 - P_1V_1)$
- (3) $2(\sqrt{P_1}V_1 - \sqrt{P_2}V_2)$
- (4) $2(P_2\sqrt{V_2} - P_1\sqrt{V_1})$

Ans. (1 or 2)

Sol. For $PV^x = \text{constant}$

If work done by gas is asked then

$$W = \frac{nR\Delta T}{1-x}$$

$$\text{Here } x = \frac{3}{2}$$

$$\therefore W = \frac{P_2V_2 - P_1V_1}{-\frac{1}{2}}$$

$$= 2(P_1V_1 - P_2V_2) \dots \text{Option (1) is correct}$$

If work done by external is asked then

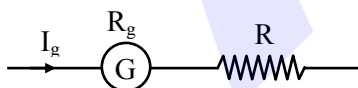
$$W = -2(P_1V_1 - P_2V_2) \dots \text{Option (2) is correct}$$

40. A galvanometer has a resistance of 50Ω and it allows maximum current of 5 mA . It can be converted into voltmeter to measure upto 100 V by connecting in series a resistor of resistance

- (1) 5975Ω
- (2) 20050Ω
- (3) 19950Ω
- (4) 19500Ω

Ans. (3)

Sol.



$$\begin{aligned} R &= \frac{V}{I_g} - R_g = \frac{100}{5 \times 10^{-3}} - 50 \\ &= 20000 - 50 \\ &= 19950 \Omega \end{aligned}$$

41. The de Broglie wavelengths of a proton and an α particle are λ and 2λ respectively. The ratio of the velocities of proton and α particle will be :

- (1) $1 : 8$
- (2) $1 : 2$
- (3) $4 : 1$
- (4) $8 : 1$

Ans. (4)

$$\text{Sol. } \lambda = \frac{h}{p} = \frac{h}{mv} \Rightarrow v = \frac{h}{m\lambda}$$

$$\begin{aligned} \frac{v_p}{v_\alpha} &= \frac{m_\alpha}{m_p} \times \frac{\lambda_\alpha}{\lambda_p} \\ &= 4 \times 2 = 8 \end{aligned}$$

42. 10 divisions on the main scale of a Vernier calliper coincide with 11 divisions on the Vernier scale. If each division on the main scale is of 5 units, the least count of the instrument is :

- (1) $\frac{1}{2}$
- (2) $\frac{10}{11}$
- (3) $\frac{50}{11}$
- (4) $\frac{5}{11}$

Ans. (4)

$$\text{Sol. } 10 \text{ MSD} = 11 \text{ VSD}$$

$$1 \text{ VSD} = \frac{10}{11} \text{ MSD}$$

$$\text{LC} = 1 \text{ MSD} - 1 \text{ VSD}$$

$$= 1 \text{ MSD} - \frac{10}{11} \text{ MSD}$$

$$= \frac{1 \text{ MSD}}{11}$$

$$= \frac{5}{11} \text{ units}$$



43. In series LCR circuit, the capacitance is changed from C to $4C$. To keep the resonance frequency unchanged, the new inductance should be :

- (1) reduced by $\frac{1}{4}L$
(2) increased by $2L$
(3) reduced by $\frac{3}{4}L$
(4) increased to $4L$

Ans. (3)

Sol. $\omega' = \omega$

$$\frac{1}{\sqrt{L'C'}} = \frac{1}{\sqrt{LC}}$$

$$\therefore L'C' = LC$$

$$L'(4C) = LC$$

$$L' = \frac{L}{4}$$

\therefore Inductance must be decreased by $\frac{3L}{4}$

44. The radius (r), length (l) and resistance (R) of a metal wire was measured in the laboratory as

$$r = (0.35 \pm 0.05) \text{ cm}$$

$$R = (100 \pm 10) \text{ ohm}$$

$$l = (15 \pm 0.2) \text{ cm}$$

The percentage error in resistivity of the material of the wire is :

- (1) 25.6% (2) 39.9%
(3) 37.3% (4) 35.6%

Ans. (2)

Sol. $\rho = R \frac{\pi r^2}{l}$

$$\frac{\Delta \rho}{\rho} = \frac{\Delta R}{R} + 2 \frac{\Delta r}{r} + \frac{\Delta l}{l}$$

$$= \frac{10}{100} + 2 \times \frac{0.05}{0.35} + \frac{0.2}{15}$$

$$= \frac{1}{10} + \frac{2}{7} + \frac{1}{75}$$

$$\frac{\Delta \rho}{\rho} = 39.9\%$$

45. The dimensional formula of angular impulse is :

- (1) $[M L^{-2} T^{-1}]$ (2) $[M L^2 T^{-2}]$
(3) $[M L T^{-1}]$ (4) $[M L^2 T^{-1}]$

Ans. (4)

Sol. Angular impulse = change in angular momentum.

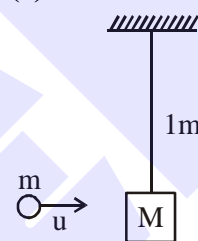
$$[\text{Angular impulse}] = [\text{Angular momentum}] = [mvr] = [M L^2 T^{-1}]$$

46. A simple pendulum of length 1 m has a wooden bob of mass 1 kg. It is struck by a bullet of mass 10^{-2} kg moving with a speed of $2 \times 10^2 \text{ ms}^{-1}$. The bullet gets embedded into the bob. The height to which the bob rises before swinging back is.

(use $g = 10 \text{ m/s}^2$)

- (1) 0.30 m (2) 0.20 m
(3) 0.35 m (4) 0.40 m

Ans. (2)



Sol.

$$mu = (M + m)V$$

$$10^{-2} \times 2 \times 10^2 \cong 1 \times V$$

$$V \cong 2 \text{ m/s}$$

$$h = \frac{V^2}{2g} = 0.2 \text{ m}$$

47. A particle moving in a circle of radius R with uniform speed takes time T to complete one revolution. If this particle is projected with the same speed at an angle θ to the horizontal, the maximum height attained by it is equal to $4R$. The angle of projection θ is then given by :

- (1) $\sin^{-1} \left[\frac{2gT^2}{\pi^2 R} \right]^{\frac{1}{2}}$ (2) $\sin^{-1} \left[\frac{\pi^2 R}{2gT^2} \right]^{\frac{1}{2}}$
(3) $\cos^{-1} \left[\frac{2gT^2}{\pi^2 R} \right]^{\frac{1}{2}}$ (4) $\cos^{-1} \left[\frac{\pi R}{2gT^2} \right]^{\frac{1}{2}}$

Ans. (1)



Sol. $\frac{2\pi R}{T} = V$

Maximum height $H = \frac{v^2 \sin^2 \theta}{2g}$

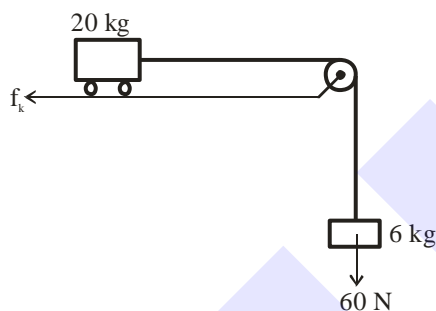
$4R = \frac{4\pi^2 R^2}{T^2 2g} \sin^2 \theta$

$\sin \theta = \sqrt{\frac{2gT^2}{\pi^2 R}}$

$\theta = \sin^{-1} \left(\frac{2gT^2}{\pi^2 R} \right)^{\frac{1}{2}}$

- 48.** Consider a block and trolley system as shown in figure. If the coefficient of kinetic friction between the trolley and the surface is 0.04, the acceleration of the system in ms^{-2} is :

(Consider that the string is massless and unstretchable and the pulley is also massless and frictionless) :



- (1) 3
(2) 4
(3) 2
(4) 1.2

Ans. (3)

Sol. $f_k = \mu N = 0.04 \times 20g = 8 \text{ Newton}$

$a = \frac{60 - 8}{26} = 2 \text{ m/s}^2$

- 49.** The minimum energy required by a hydrogen atom in ground state to emit radiation in Balmer series is nearly :

- (1) 1.5 eV
(2) 13.6 eV
(3) 1.9 eV
(4) 12.1 eV

Ans. (4)

Sol. Transition from $n = 1$ to $n = 3$

$\Delta E = 12.1 \text{ eV}$

- 50.** A monochromatic light of wavelength 6000 \AA is incident on the single slit of width 0.01 mm . If the diffraction pattern is formed at the focus of the convex lens of focal length 20 cm , the linear width of the central maximum is :

- (1) 60 mm
(2) 24 mm
(3) 120 mm
(4) 12 mm

Ans. (2)

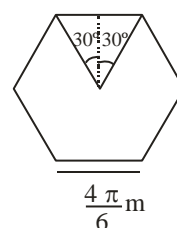
Sol. Linear width

$$W = \frac{2\lambda d}{a} = \frac{2 \times 6 \times 10^{-7} \times 0.2}{1 \times 10^{-5}} = 2.4 \times 10^{-2} = 24 \text{ mm}$$

SECTION-B

- 51.** A regular polygon of 6 sides is formed by bending a wire of length 4π meter. If an electric current of $4\pi\sqrt{3} \text{ A}$ is flowing through the sides of the polygon, the magnetic field at the centre of the polygon would be $x \times 10^{-7} \text{ T}$. The value of x is _____.

Ans. (72)



Sol.

$$B = 6 \left(\frac{\mu_0 I}{4\pi r} \right) (\sin 30^\circ + \sin 30^\circ)$$

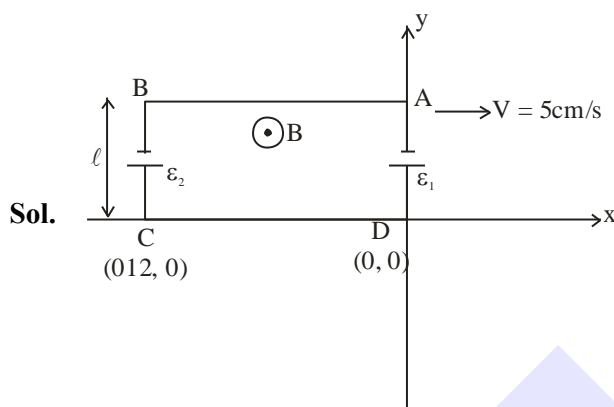
$$= 6 \frac{10^{-7} \times 4\pi\sqrt{3}}{\left(\frac{\sqrt{3} \times 4\pi}{2 \times 6} \right)}$$

$$= 72 \times 10^{-7} \text{ T}$$



52. A rectangular loop of sides 12 cm and 5 cm, with its sides parallel to the x-axis and y-axis respectively moves with a velocity of 5 cm/s in the positive x axis direction, in a space containing a variable magnetic field in the positive z direction. The field has a gradient of 10^{-3} T/cm along the negative x direction and it is decreasing with time at the rate of 10^{-3} T/s. If the resistance of the loop is $6 \text{ m}\Omega$, the power dissipated by the loop as heat is _____ $\times 10^{-9} \text{ W}$.

Ans. (216)



B_0 is the magnetic field at origin

$$\frac{dB}{dx} = -\frac{10^{-3}}{10^{-2}}$$

$$\int_{B_0}^B dB = -\int_0^x 10^{-1} dx$$

$$B - B_0 = -10^{-1}x$$

$$B = \left(B_0 - \frac{x}{10} \right)$$

Motional emf in AB = 0

Motional emf in CD = 0

Motional emf in AD = $\epsilon_1 = B_0 \ell v$

Magnetic field on rod BC B

$$= \left(B_0 - \frac{(-12 \times 10^{-2})}{10} \right)$$

$$\text{Motional emf in BC} = \epsilon_2 = \left(B_0 + \frac{12 \times 10^{-2}}{10} \right) \ell \times v$$

$$\epsilon_{eq} = \epsilon_2 - \epsilon_1 = 300 \times 10^{-7} \text{ V}$$

For time variation

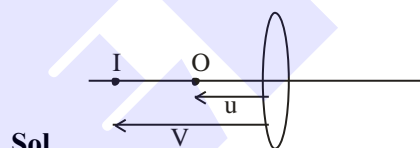
$$(\epsilon_{eq})' = A \frac{dB}{dt} = 60 \times 10^{-7} \text{ V}$$

$$(\epsilon_{eq})_{net} = \epsilon_{eq} + (\epsilon_{eq})' = 360 \times 10^{-7} \text{ V}$$

$$\text{Power} = \frac{(\epsilon_{eq})_{net}^2}{R} = 216 \times 10^{-9} \text{ W}$$

53. The distance between object and its 3 times magnified virtual image as produced by a convex lens is 20 cm. The focal length of the lens used is _____ cm.

Ans. (15)



$$v = 3u$$

$$v - u = 20 \text{ cm}$$

$$2u = 20 \text{ cm}$$

$$u = 10 \text{ cm}$$

$$\frac{1}{(-30)} - \frac{1}{(-10)} = \frac{1}{f}$$

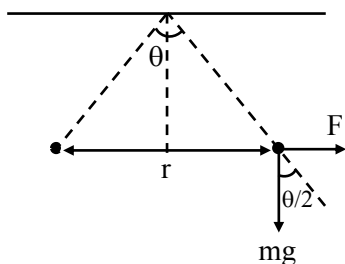
$$f = 15 \text{ cm}$$

54. Two identical charged spheres are suspended by strings of equal lengths. The strings make an angle θ with each other. When suspended in water the angle remains the same. If density of the material of the sphere is 1.5 g/cc, the dielectric constant of water will be _____
(Take density of water = 1 g/cc)

Ans. (3)



Sol.



$$\text{In air } \tan \frac{\theta}{2} = \frac{F}{mg} = \frac{q^2}{4\pi\epsilon_0 r^2 mg}$$

$$\text{In water } \tan \frac{\theta}{2} = \frac{F'}{mg'} = \frac{q^2}{4\pi\epsilon_0 \epsilon_r r^2 mg_{\text{eff}}}$$

Equate both equations

$$\epsilon_0 g = \epsilon_0 \epsilon_r g \left[1 - \frac{1}{1.5} \right]$$

$$\epsilon_r = 3$$

55. The radius of a nucleus of mass number 64 is 4.8 fermi. Then the mass number of another nucleus having radius of 4 fermi is $\frac{1000}{x}$, where x is _____.

Ans. (27)

Sol. $R = R_0 A^{1/3}$

$$R^3 \propto A$$

$$\left(\frac{4.8}{4} \right)^3 = \frac{64}{A}$$

$$= \frac{64}{A} = (1.2)^3$$

$$\frac{64}{A} = 1.44 \times 1.2$$

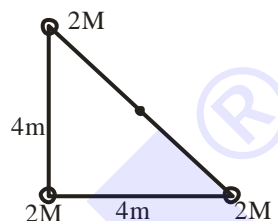
$$A = \frac{64}{1.44 \times 1.2} = \frac{1000}{x}$$

$$x = \frac{144 \times 12}{64} = 27$$

56. The identical spheres each of mass $2M$ are placed at the corners of a right angled triangle with mutually perpendicular sides equal to 4 m each. Taking point of intersection of these two sides as origin, the magnitude of position vector of the centre of mass of the system is $\frac{4\sqrt{2}}{x}$, where the value of x is _____

Ans. (3)

Sol.



$$\text{Position vector } \vec{r}_{\text{COM}} = \frac{m_1 \vec{r}_1 + m_2 \vec{r}_2 + m_3 \vec{r}_3}{m_1 + m_2 + m_3}$$

$$\vec{r}_{\text{COM}} = \frac{2M \times 0 + 2M \times 4\hat{i} + 2M \times 4\hat{j}}{6M}$$

$$\vec{r} = \frac{4}{3}\hat{i} + \frac{4}{3}\hat{j}$$

$$|\vec{r}| = \frac{4\sqrt{2}}{3}$$

$$x = 3$$

57. A tuning fork resonates with a sonometer wire of length 1 m stretched with a tension of 6 N. When the tension in the wire is changed to 54 N, the same tuning fork produces 12 beats per second with it. The frequency of the tuning fork is _____ Hz.

Ans. (6)

Sol. $f = \frac{1}{2L} \sqrt{\frac{T}{\mu}}$

$$f_1 = \frac{1}{2} \sqrt{\frac{6}{\mu}}$$

$$f_2 = \frac{1}{2} \sqrt{\frac{54}{\mu}}$$

$$\frac{f_1}{f_2} = \frac{1}{3}$$

$$f_2 - f_1 = 12$$

$$f_1 = 6\text{HZ}$$



58. A plane is in level flight at constant speed and each of its two wings has an area of 40 m^2 . If the speed of the air is 180 km/h over the lower wing surface and 252 km/h over the upper wing surface, the mass of the plane is _____ kg. (Take air density to be 1 kg m^{-3} and $g = 10 \text{ ms}^{-2}$)

Ans. (9600)

Sol. $A = 80 \text{ m}^2$

Using Bernonlli equation

$$A(P_2 - P_1) = \frac{1}{2}\rho(V_1^2 - V_2^2)A$$

$$mg = \frac{1}{2} \times 1 (70^2 - 50^2) \times 80$$

$$mg = 40 \times 2400$$

$$m = 9600 \text{ kg}$$

59. The current in a conductor is expressed as $I = 3t^2 + 4t^3$, where I is in Ampere and t is in second. The amount of electric charge that flows through a section of the conductor during $t = 1 \text{ s}$ to $t = 2 \text{ s}$ is _____ C.

Ans. (22)

Sol. $q = \int_1^2 i \, dt = \int_1^2 (3t^2 + 4t^3) dt$

$$q = \left(t^3 + t^4 \right) \Big|_1^2$$

$$q = 22 \text{ C}$$

60. A particle is moving in one dimension (along x axis) under the action of a variable force. It's initial position was 16 m right of origin. The variation of its position (x) with time (t) is given as $x = -3t^3 + 18t^2 + 16t$, where x is in m and t is in s . The velocity of the particle when its acceleration becomes zero is _____ m/s .

Ans. (52)

Sol. $x = 3t^3 + 18t^2 + 16t$

$$v = -9t^2 + 36t + 16$$

$$a = -18t + 36$$

$$a = 0 \text{ at } t = 2 \text{ s}$$

$$v = -9(2)^2 + 36 \times 2 + 16$$

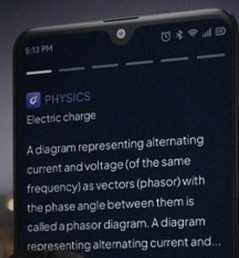
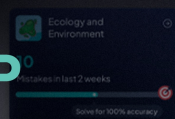
$$v = 52 \text{ m/s}$$

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