Date: 01/02/2026

Aakash

Medical | IIT-JEE | Foundations

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Answers & Solutions

Max. Marks: 75 *for* Time: 3 Hrs.

Indian National Physics Olympiad (INPhO) – 2026

Homi Bhabha Centre for Science Education (HBCSE-TIFR)

INSTRUCTIONS TO CANDIDATES

1. This booklet consists of 6 questions. Write roll number at the top wherever asked.
2. Booklet to write the answers is provided separately. Instructions to write the answers are on the Answer Booklet.
3. Non-programmable scientific calculators are allowed. Mobile phones **cannot** be used as calculators.
4. Take as many data points as possible for the analysis.
5. Please submit the Answer Sheet at the end of the examination. You may retain the Question Paper.
6. Except for writing your roll number, no rough work or scribbling is allowed on the question paper.

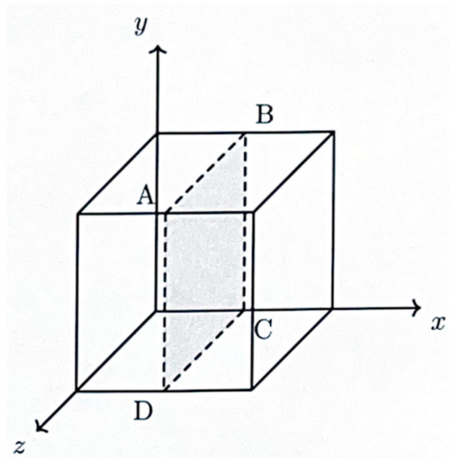
Table of Constants		
Speed of light in vacuum	c	$3.00\times10^{8}\ \text{m}\cdot\text{s}^{-1}$
Magnitude of electron charge	e	$1.60\times10^{-19}\text{C}$
Avogadro's number	N_A	$6.022\times10^{23}\ \text{mol}^{-1}$
Acceleration due to gravity	g	$9.81\ \text{m}\cdot\text{s}^{-2}$
Universal Gas Constant	R	$8.31\ \text{J}\cdot\ \text{K}^{-1}\cdot\text{mol}^{-1}$
	R	$0.0821\ \text{l}\cdot\text{atm}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$
Boltzmann constant	k_B	$1.3806\times10^{-23}\ \text{J}\cdot\text{K}^{-1}$
Permeability constant	μ_0	$4\pi\times10^{-7}\ \text{H}\cdot\text{m}^{-1}$
One Atmospheric pressure	atm	$1.013\times10^{5}\ \text{Pa}$

Question Number	1	2	3	4	5	6	Total
Maximum Marks	12	12	11	10	18	12	75

1. [12 marks] Find the flaw

Consider a non-conducting, charged, thin cubical shell with a uniform surface charge density. Consider the plane ABCD, which vertically and symmetrically divides the cubical shell (see figure). Six students independently solved for the electric field on the plane ABCD and presented six different answers, shown below in Figs. (a) to (f), each approximately depicting the electric field lines in the ABCD plane (the field line arrows are not shown). Consider each of the six answers, and for each, give

- at least one reason (based on a physics argument), explaining why it is incorrect

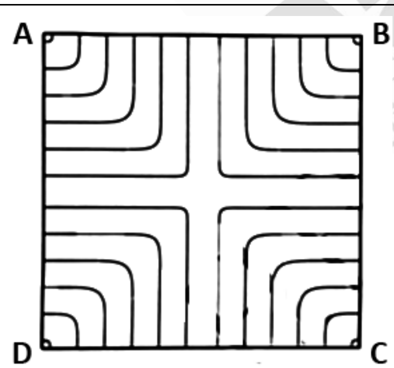
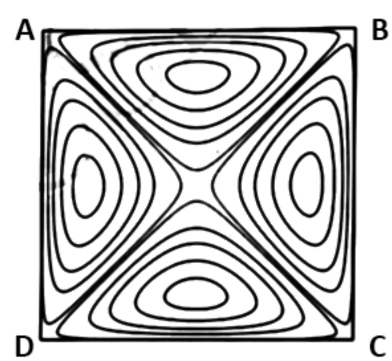
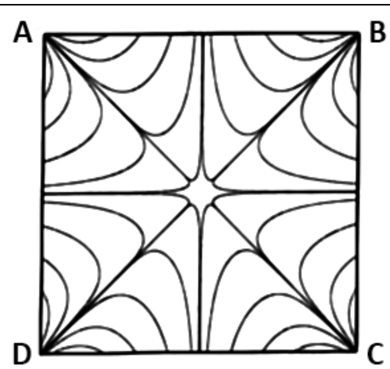
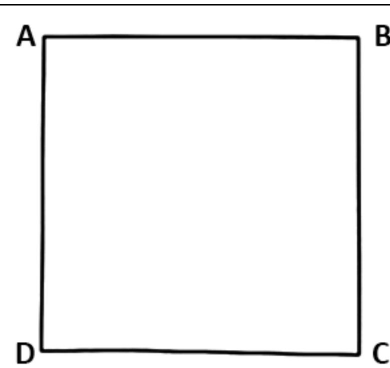


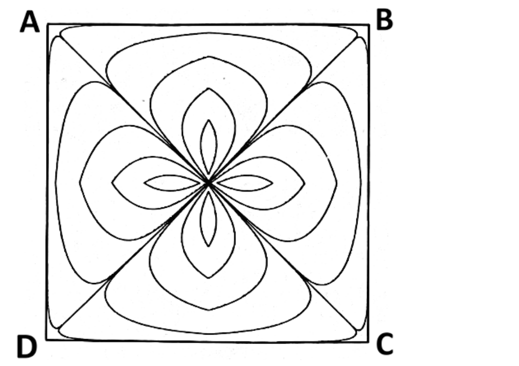
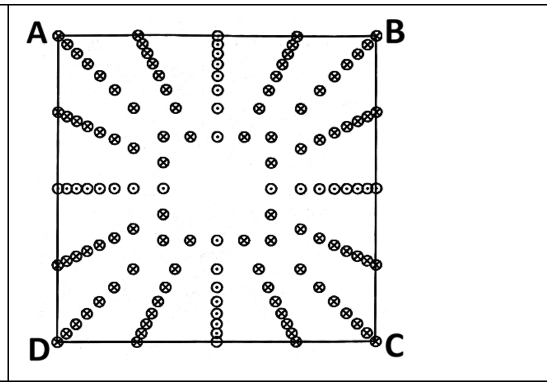
OR

- at least two reasons why it **could be** correct.

Note that you are not required to obtain the correct depiction of the electric field or to provide a detailed derivation in this question.

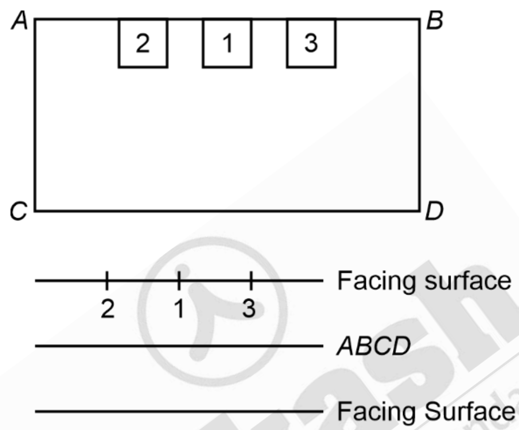
In none of the figures, adjacent field lines touch or intersect each other, although they may appear to do so in Fig. (c) and Fig. (e), where they are very close. In Fig. (d), the diagram indicates that no field is present. In Fig. (f), ⊗ denotes a field directed along the –x axis, and ⊙ denotes a field directed along +x axis.

(a)		(b)	
(c)		(d)	

(e)		(f)	

Sol. (a) Why it is not correct

It is representing uniform field at edges which seems unlikely as they are not symmetric point w.r.t. facing surfaces.



Patches 2 & 3 are symmetric but asymmetric to patch 1 and hence field should not be uniform

(b) Why it is incorrect

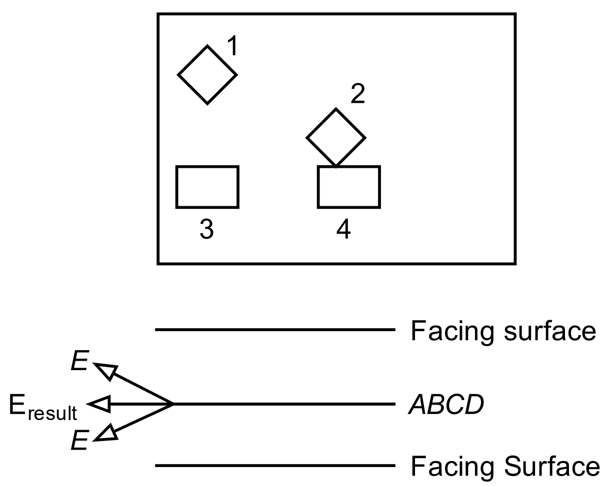
Electric field lines can't form closed loop as it will be representing the non-conservative field contrary to conservative field of charges.

(c) Why it is correct

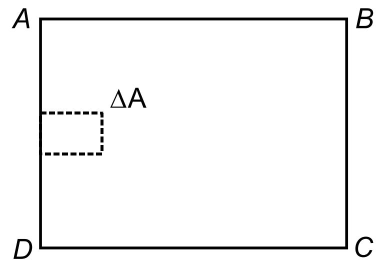
(i) Electric field is symmetric which it should be because of uniform charge.

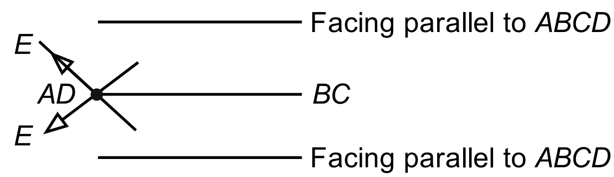
(ii) Field should be along diagonal lines because of symmetricity and also parallel to sides in the middle.

(iii) Field near center of surface *ABCD* should be zero and hence no field lines.



(d) Why it is incorrect.





If we take a small patch then clearly, we can say that field due to two charged surfaces can't cancel each other and hence field can't be zero at edges.

(e) Why it is incorrect

Field lines are not smooth curve as they should be in charge free space and also field lines are forming loops.

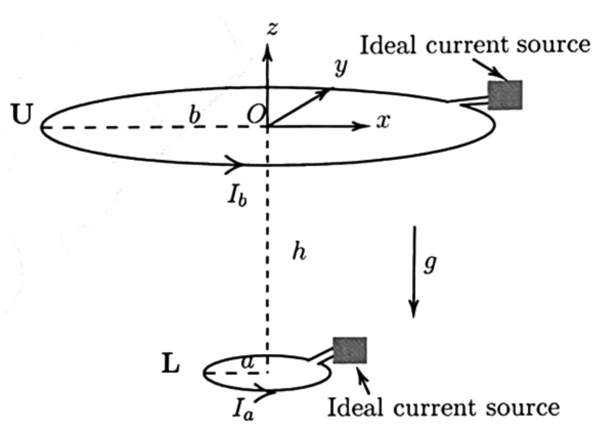
(f) Why it is incorrect

As reasoned in option (d), the field in peripheral of $ABCD$ should be non-zero and directing in same direction. It is representing the resultant field due to facing surface so there shouldn't be field in perpendicular direction. Because resultant would be in plane. Also, field near the faces should be very high and field lines must be in the plane of $ABCD$.

2. [12 marks] Current affairs

Consider two coaxial conducting circular loops: a lower loop L of radius a and an upper loop U of radius b (see figure). The planes of the loops are parallel and separated by a distance h. The loop U is held fixed in the $x-y$ plane, while the loop L is free to move vertically.

Each loop is connected to an ideal current source that maintains a constant current I_a in loop L and I_b in loop U. Assume $a \ll b$, so that the magnetic field produced by the loop U may be treated as uniform over the entire area of the loop L. Let g be the acceleration due to gravity. The system is initially in static equilibrium under gravity.

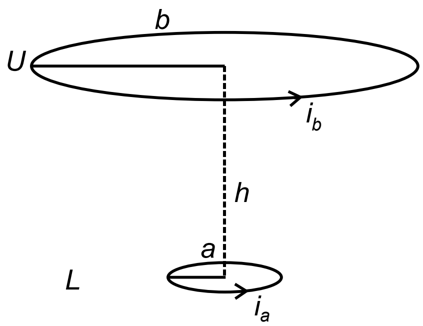


The loop L is then displaced very slowly by an external agent toward the loop U through a distance dh, while the currents in both loops are maintained constant by ideal power supplies.

During this process, let the change in the gravitational potential energy of the loop L be dU_g, and the change in the energy stored in the magnetic field be dU_m. For the same process, let the extra work done by the power supplies connected to the lower and upper loops be dW_L and dW_U, respectively.

Express each of dU_g, dU_m, dW_U, and dW_L in terms of I_a, I_b, the geometrical parameters (a, b, h, dh), and any relevant constants, if they are non-zero.

Sol.



Flux (ϕ) of magnetic field due to U in loop L

$$\phi = \frac{\mu_0 i_b b^2 \cdot \pi a^2}{2\left(h^2 + b^2\right)^{3/2}}$$

Let mutual inductance of system (M)

$$\phi = M i_b$$

$$M = \frac{\mu_0 \pi a^2 b^2}{2\left(b^2 + h^2\right)^{3/2}}$$

Magnetic energy $U_m = \frac{1}{2} L_1 I_1^2 + \frac{1}{2} L_2 I_2^2 + M I_1 I_2$

$$dU_m = i_a i_b dM$$

$$dU_m = i_a i_b \left(\frac{-3\mu_0}{2} \frac{\pi a^2 b^2 h}{\left(b^2 + h^2\right)^{5/2}} \right)(-dh)$$

$$\boxed{dU_m = \frac{3\mu_0 i_a i_b \pi a^2 b^2 h dh}{2\left(b^2 + h^2\right)^{5/2}}}$$

When h is reduced ϕ increases, so there will be induced emf in each loop, since current is constant in each loop so battery has to do work.

For upper loop

$$\phi = M i_a$$

Induced emf in upper loop $e_u = i_a \cdot \frac{dM}{dt}$

$$d\omega = i_b e_u \cdot dt = i_b i_a dM$$

$$\omega_u = i_a i_b \cdot \frac{3}{2} \frac{\mu_0 \pi a^2 b^2 \cdot h \cdot dh}{\left(b^2 + h^2\right)^{5/2}}$$

For lower loop

$$\phi = Mi_b$$

Induced emf in lower loop $e_L = i_b \frac{dM}{dt}$

$$d\omega = i_a i_b dM$$

$$\omega_L = \frac{3}{2} \frac{\mu_0 \pi a^2 b^2 h dh}{\left(b^2 + h^2\right)^{5/2}} i_a i_b$$

At equilibrium

$$F = mg$$

$$\frac{-\partial U_m}{dh} = mg$$

$$mg = \frac{3}{2} \frac{\mu_0 \pi a^2 b^2 i_a i_b h}{\left(b^2 + h^2\right)^{5/2}}$$

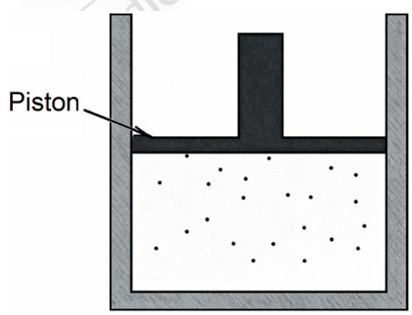
Change in gravitation potential energy

$$dU_g = mgdh$$

$$= \frac{3}{2} \frac{\mu_0 \pi a^2 b^2 i_a i_b h}{\left(b^2 + h^2\right)^{5/2}} dh$$

3. Slow, smooth, and sudden

A vertical insulated cylinder fitted with a frictionless, movable, thermally conducting massless piston contains air at pressure $p_0 = 1$ atm, volume $V_i = 3.0$ L, and temperature $T_0 = 300$ K. Assume the gas is ideal with a ratio of specific heats $\gamma = 1.4$. The system is initially in equilibrium with its surroundings at temperature T_0 and pressure p_0. The piston is then moved so that the gas is compressed to a final volume $V_f = 2.0$ L.



This compression is performed in three different ways:

(a) **[3 marks]** The piston is moved slowly, so that the compression remains quasistatic and the gas stays in thermal equilibrium with the surroundings throughout (isothermal process). Calculate the total heat exchanged Q_a in the process.

(b) **[3 marks]** The piston is moved quickly but smoothly, so that during compression heat exchange with the surroundings is negligible (adiabatic and reversible). After compression, the gas is allowed to exchange heat with the surroundings without any change in volume, and it returns to the equilibrium temperature T_0. Calculate the total heat exchanged Q_b in the process.

(c) **[5 marks]** The piston is moved suddenly, producing a rapid, irreversible adiabatic compression. After compression, the gas reached a temperature T_c. The gas is now left to exchange heat with the surroundings without further change in the volume, and eventually returns to its equilibrium temperature T_0. Calculate T_c and the total heat exchanged Q_c in the process.

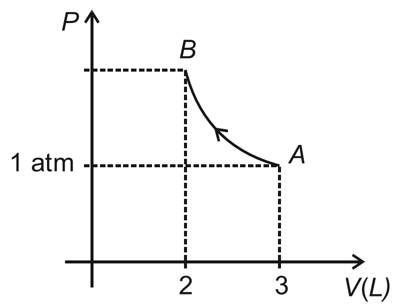
Sol. $P_0 = 1\text{ atm} = 10^5\text{Pa}$

$V_0 = 3L = 3\times10^{-3}\text{ m}^3$

$T_0 = 300\text{ K}$

$\gamma = 1.4$

(a) The process is isothermal.



T = constant

$\Delta U = 0$

$\therefore \quad \Delta Q = W$

$\Rightarrow \quad \Delta Q = nRT_0\log_e\left(\frac{V_2}{V_1}\right)$

$\Rightarrow \quad \Delta Q = P_0V_0\log_e\frac{V_B}{V_A}$

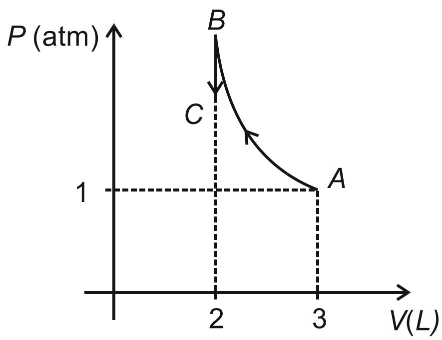
$\Rightarrow \quad \Delta Q = 10^5\times3\times10^{-3}\log_e\left(\frac{2}{3}\right)$

$\Rightarrow \quad \Delta Q = -3\times10^2\log_e\left(\frac{3}{2}\right)$

$\Rightarrow \quad \Delta Q = -300 \times 0.405$

$\Rightarrow \quad \Delta Q = -121.6\text{ J}$

(b) Initially gas is adiabatically compressed and then allowed to exchange heat at constant volume till it reaches to temperature.



For $A \to B$

$\Delta Q = 0$

$$\Rightarrow \quad P_0 V_0^{\gamma} = P_B (V_B)^{\gamma}$$

$$\Rightarrow \quad P_B = P_0 \left(\frac{V_0}{V_B}\right)^{\gamma}$$

$$\Rightarrow \quad P_B = 10^5 \left(\frac{3}{2}\right)^{1.4}$$

$\Rightarrow \quad P_B = 1.76 \times 10^5$ Pa

For B to C

V = constant

$\therefore \quad W = 0$

$\therefore \quad \Delta Q = \Delta U$

$$\Rightarrow \Delta Q = nC_V \Delta T$$

$$\Rightarrow \Delta Q = \frac{5}{2} nR\Delta T$$

$$\Rightarrow \Delta Q = \frac{5}{2} V\Delta P$$

$$\Rightarrow \Delta Q = \frac{5}{2} \times 2 \times 10^{-3} \times \left(1.5 \times 10^5 - 1.76 \times 10^5\right)$$

$\Rightarrow \Delta Q = -5 \times 10^{-3} \times 10^5 \times 0.26$

$\Rightarrow \Delta Q = -130$ J

$\therefore$ 130 J of total heat is given to surrounding

(c) This process is irreversible adiabatic then isochoric.

For irreversible adiabatic

$\Delta Q = 0$

and $W = P_{ext} (V_2 - V_1)$

$\therefore \quad W + \Delta U = 0$

$$P_{ext} (V_2 - V_1) + nC_V \Delta T = 0$$

$$\Rightarrow \quad P_{ext} (V_1 - V_2) = \frac{5}{2} nR (T_2 - T_1)$$

$$\Rightarrow \quad P_{ext} (V_1 - V_2) = \frac{5}{2} \frac{nRT_2}{T_2} (T_2 - T_1)$$

$$\Rightarrow P_{ext} (V_1 - V_2) = \frac{5}{2} \frac{P_{ext} V_2}{T_2} (T_2 - T_1)$$

$$\Rightarrow \; (V_1 - V_2) \times 2T_2 = 5V_2 (T_2 - T_1)$$

$$\Rightarrow 10^{-3} \times 2 \times T_L = 5 \times 2 \times 10^{-3} (T_L - 300)$$

$$\Rightarrow \; 4T_2 = 1500$$

$\Rightarrow T_2 = \frac{1500}{4}$ K

$\Rightarrow T_2 = 375$ K

For isochoric decrease in pressure

$W = 0$

$\Delta Q = \Delta U$

$\Rightarrow nC_V \Delta T$

$\Rightarrow \frac{5}{2} nR\Delta T$

$\Rightarrow \frac{5}{2} nR(T_1 - T_2)$

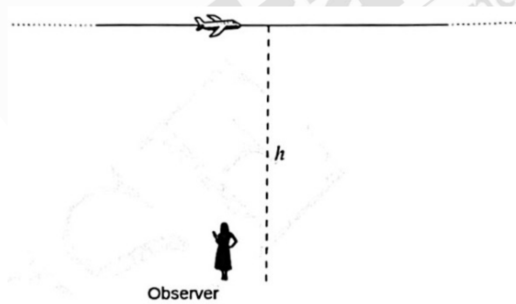
$\Rightarrow \frac{5}{2} \frac{P_0 V_0}{T_1}(T_1 - T_2)$

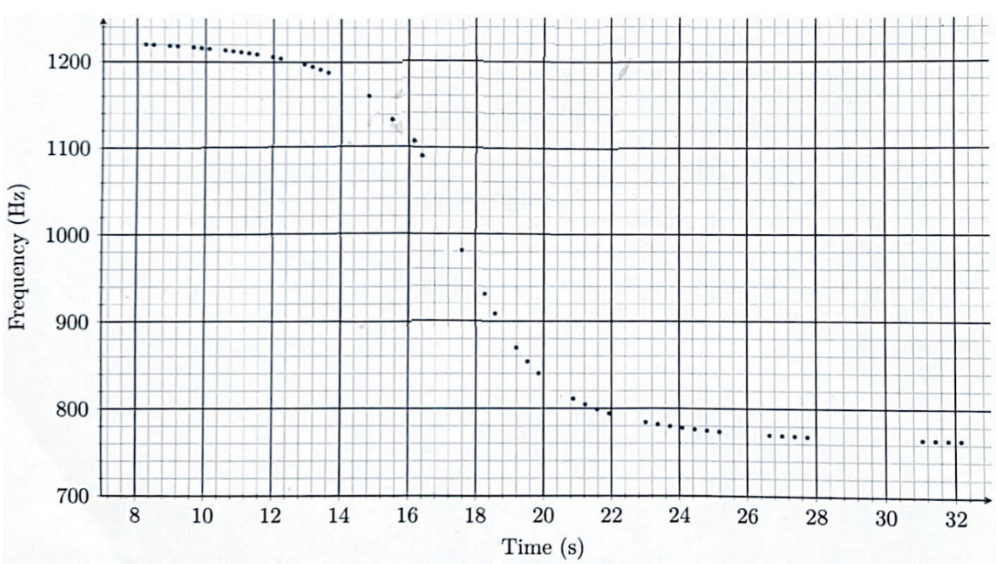
$\Rightarrow \frac{5}{2} \times \frac{10^5 \times 3 \times 10^{-3}}{300}(300 - 375)$

$\Rightarrow -187.5$ J

4. A Curve You Can Hear

An aeroplane flies along a horizontal path, emitting sound at a constant frequency f_0. A stationary observer with a detector on the ground directly beneath the flight path records the sound frequency as the plane passes overhead, which is plotted below. The speed of sound in the medium is $c_s = 340$ m s^{-1}.





(a) **[5 marks]** Your task is to measure the speed of the aeroplane, v, from the graph. Express v in terms of quantities measurable from the graph, and define/mark these quantities on the graph reproduced in the Summary Answer sheet. Calculate the value of v.

(b) **[5 marks]** Find the height h of the plane's flight path.

Sol. (a) Max frequency is recorded when plane is far-off and approaching whereas minimum frequency is recorded when plane is far-off and going away.

Thus,

$$f_{max} = \frac{c}{c-v} f_0 \quad f_{min} = \frac{c}{c+v} f_0$$

from graph $f_{max} = 1220$ Hz and $f_{min} = 760$ Hz

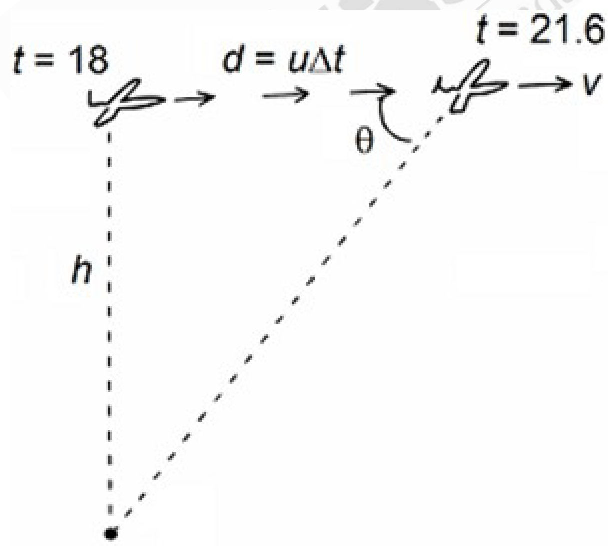
$$\therefore \frac{f_{max}}{f_{min}} = \frac{c+v}{c-v} \Rightarrow \frac{v}{c} = \frac{f_{max} - f_{min}}{f_{max} + f_{min}}$$

$$\Rightarrow v = \frac{460}{1980} \times 340 \Rightarrow v = 79.06 \text{ m/s}$$

whereas $f_0 = 1220 \frac{(340-79)}{340} = 936.5$ Hz

Since, the error of measurement in frequency is ± 10 Hz we may assume $v = 80$ m/s and $f_0 = 940$ Hz for further calculations.

(b) From graph it is confirmed that it recorded actual frequency (with flight just overhead) at $t = 18$ s and at $t = 21.6$ s the recorded frequency was 800 Hz.



Thus,

$$f = \frac{340}{340 + 80\cos\theta} 940 = 800$$

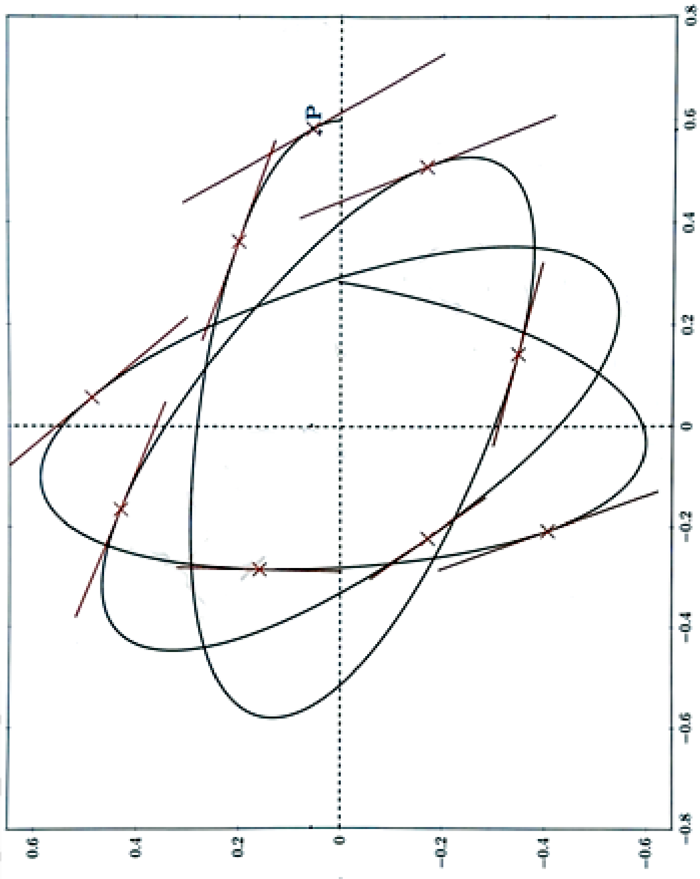
$$\cos\theta = \frac{340}{80}\left(\frac{940}{800} - 1\right) \approx \frac{6}{8} \approx \frac{3}{4}$$

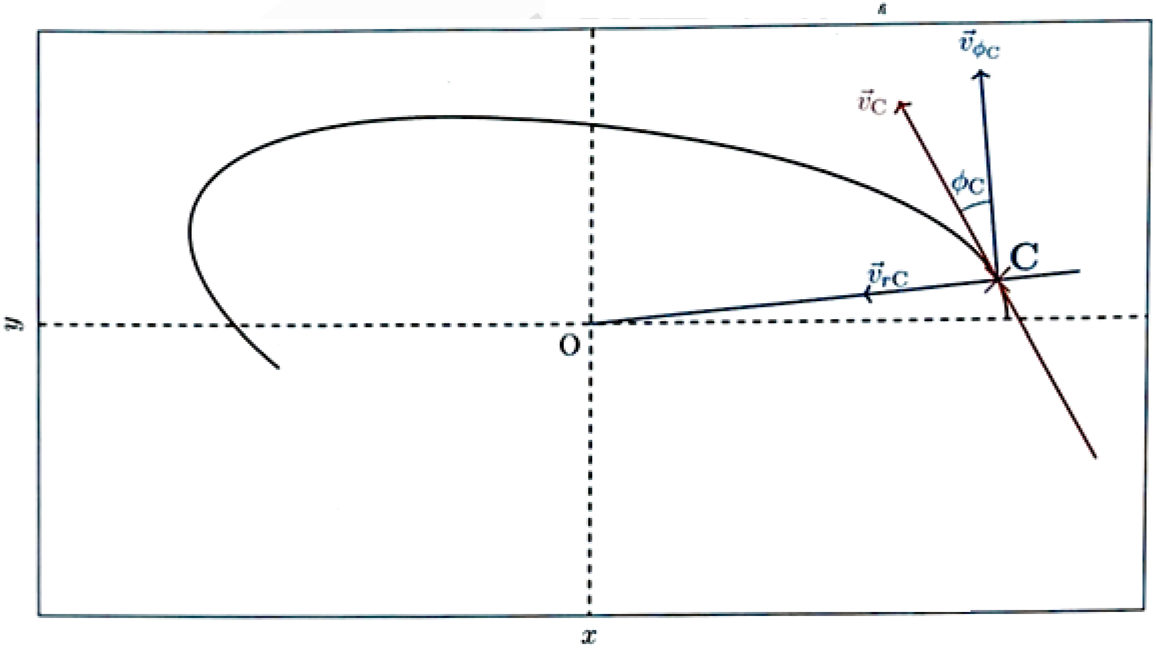
$$\tan\theta = \frac{h}{d} = \frac{h}{v\Delta t} = \frac{h}{288} \approx 259 \text{ m}$$

5. From Kepler's archive

A short note found in Kepler's archive describes a curious central-force problem. The note states that the radial potential has the form $U(r) = kr^n$, where $k > 0$ is a dimensional constant, n is a positive integer, and r is the distance from a fixed origin. Kepler also recorded the particle's precise trajectory by listing its $x - y$ coordinates in its plane of motion (see the figure below). His sketch includes several short tangent segments drawn at selected points, marked by X .

The coordinates x and y are given in arbitrary units. Kepler's notes indicate that at point P, the kinetic energy is exactly one quarter of the total mechanical energy. He further noted that the exponent n could be determined by performing calculations based on the graph and by constructing a linear plot. Unfortunately, the remainder of the manuscript explaining this method has been lost. To understand what Kepler did, we define a few variables below. The figure below shows the trajectory of a particle moving under a central force.





Consider a fixed point C on the trajectory (shown by X), located at a distance r_C from the origin O. At point C, let the speed of the particle be v_C , and let the radial and tangential components of its velocity be v_{rC} and $v_{\phi C}$, respectively ($\vec{v}_{\phi C}$ is $\perp$ to $\vec{v}_{rC}$).

The angle between $\vec{v}_{\phi C}$ and the velocity vector $\vec{v}_C$ is denoted by ϕ_C .

At an arbitrary point on the trajectory, the particle is at a distance r from the origin, its speed is v, and the corresponding angle between $\vec{v}$ and its tangential component $\vec{v}_\phi$ is ϕ.

(a) **[5 marks]** The speed v at an arbitrary point can be written in terms of the speed at point C as $v = \alpha v_C$. Express α in terms of r_C, r, ϕ_C, and ϕ.

(b) **[13 marks]** Two versions of Kepler's diagram are given in the answer sheet: one with tangents drawn and one without. You may use either or both figures as needed.

Use these to devise a method to find the value of n. Perform all relevant analyses using the figures provided on the answer sheet. Finally, use the graph paper at the end of the answer sheet for plotting a linear graph to determine n, and report any necessary data tables in the detailed answer sheet.

Sol. (a) In central force motion the net torque is zero. So, angular momentum will remain conserved.

For the two reference point given,

$$m \cdot |\vec{r}_c| \cdot (\vec{v}_{\phi c}) = m|\vec{r}||\vec{v}|\cos\phi$$

$\Rightarrow$ given $v = \alpha|v_c|$.

So, $r_c \cdot v_{\phi_c} = r \cdot v_c \alpha \cdot \cos\phi$

$$\Rightarrow v_{\phi_c} = v_c \cos\phi_c$$

$$\Rightarrow \alpha = \frac{r_c \cdot v_c \cos\phi_c}{r v_c \cos\phi} = \frac{r_c \cos\phi_c}{r\cos\phi}.$$

(b) Since the force is conservative so the mechanical energy will remain conserved.

Total energy $= KE + PE$.

So, $TE = \frac{1}{2}mv^2 + k(r)^n$.

For the given point 'P'

$$\frac{1}{2}m(v_P)^2 = \frac{TE}{4} \quad \text{so,} \quad k(r_P)^n = \frac{3}{4}TE = 3(KE)$$

$$\text{So } TE = v^2\left[\frac{TE}{4v_P^2}\right] + (r)^n \cdot \left[\frac{3}{4}\frac{TE}{r_P^n}\right]$$

$$\Rightarrow TE = TE\left[\frac{1}{4v_P^2}v^2\right] + TE\left[\frac{3r^n}{4r_P^n}\right]$$

$$\Rightarrow 4 = \frac{v^2}{v_P^2} + \frac{3r_n^2}{r_P^2} \quad \ldots (1)$$

Now we know $vr\cos\phi = v_P \cdot r_P \cos\phi_P$.

$$\text{So } \left(\frac{v}{v_P}\right)^2 = \left(\frac{r_P \cos\phi_P}{r\cos\phi}\right)^2$$

So, eq. (1) will become

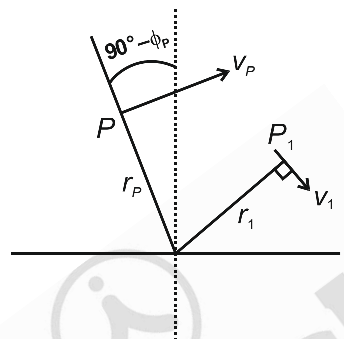
$$4 = \left(\frac{r_P}{r}\right)^2 \cdot \left(\frac{\cos\phi_P}{\cos\phi}\right)^2 + 3\left(\frac{r}{r_P}\right)^4$$

Considering the ratio $\frac{r}{r_P} = a$.

Then $4 = \left(\frac{\cos\phi_P}{\cos\phi}\right)^2 \cdot \frac{1}{a^2} + 3a^n$

$$\Rightarrow 4 - \left(\frac{\cos\phi_P}{\cos\phi}\right)^2 \cdot \frac{1}{a^2} = 3a^n$$

$$\Rightarrow \log\left[\frac{4 - \left(\frac{\cos\phi_P}{\cos\phi}\right)^2 \cdot \frac{1}{a^2}}{3}\right] = n\log a$$



If we take at least two reference point at P and P_1 such the at P_1, $\phi_{P_1} = 0$ then

$r_1 \approx 0.598$; $\phi_{P_1} = 0^\circ$ at P_1

$\cos\phi_{P_1} = 1$

$\Rightarrow r_P = 0.5914$; $\cos\phi_P = 0.985$

$$\text{So, } \log\left[\frac{4 - \left(\frac{0.985}{1}\right)^2\left(\frac{0.5914}{0.598}\right)^2}{3}\right] = n\log\left(\frac{0.598}{0.5914}\right)$$

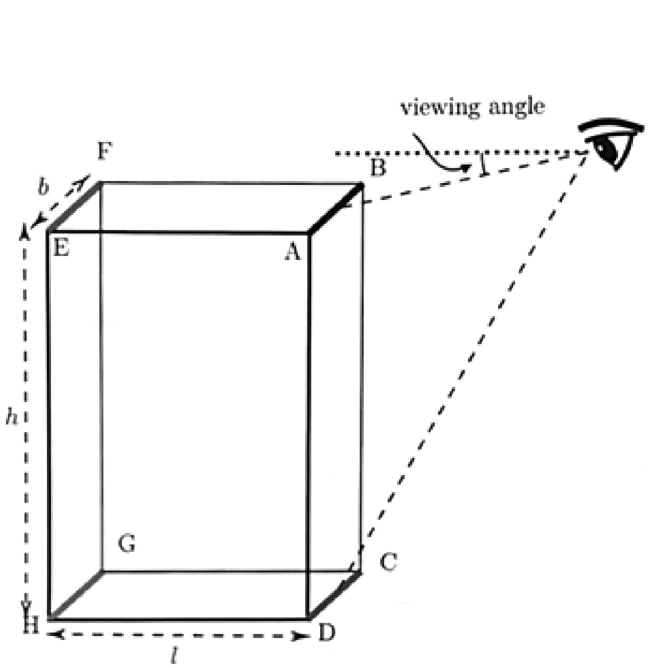
$$\log(1.01702) = n\log(1.0112)$$

$$\Rightarrow n = \frac{\log(1.01702)}{\log(1.0112)}$$

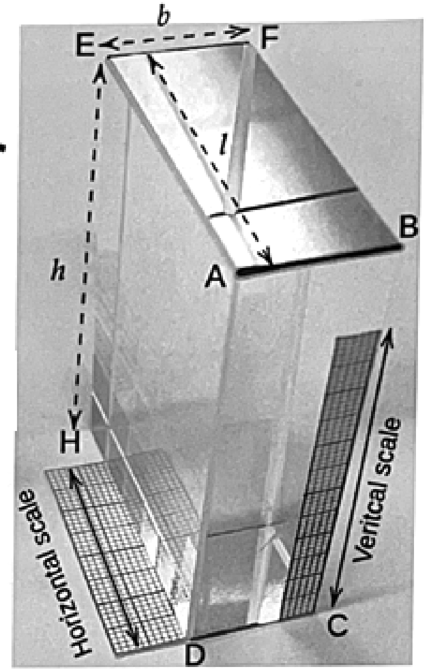
$$\Rightarrow n = 1.515 \approx \frac{3}{2}$$

6. Perspective matters

Consider a glass slab (ABCDHGFE) of dimensions ($l \times b \times h$). The slab is placed on its base (CDHG), and viewed at different viewing angles with the vertical face (ABCD) facing the observer (see Fig. (a)). The edges of the glass slab are coloured as shown in Fig. (a). A piece of graph paper is placed next to the base (CDHG). Another piece of graph paper is pasted on the vertical face (ABCD) of the slab (see Fig. (b)). The least count of both the pasted graph papers is 1 mm .

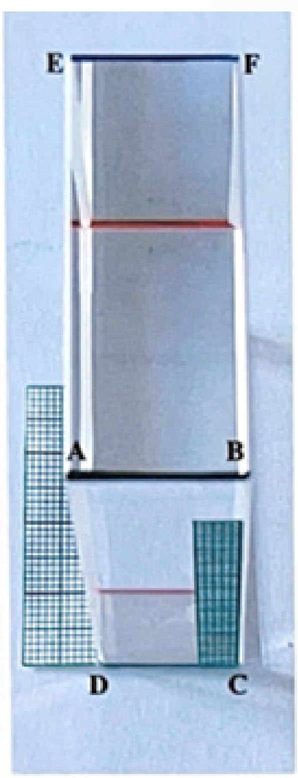


(a)

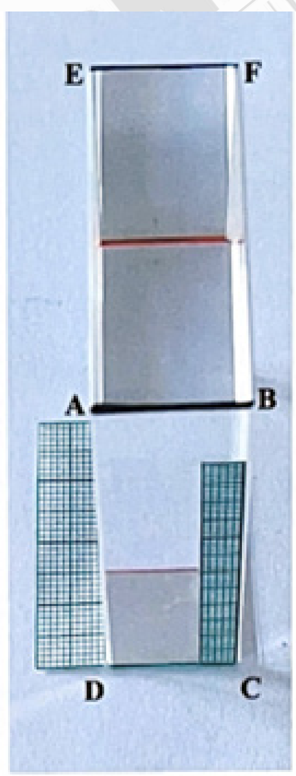


(b)

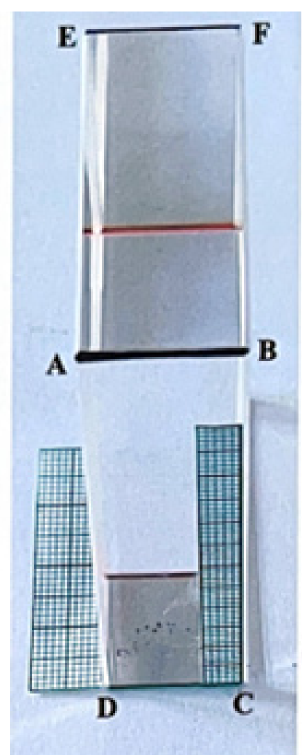
The task is to determine the refractive index μ_g of the glass slab from a series of photographs of the slab taken from different viewing angles (by lowering the eye position) shown in Figs. (i) to (vi). The viewing angle decreases progressively from Figs. (i) to (vi). Take the refractive index of air μ_a to be 1.00 . In this exercise, focus your attention on the red line visible through the vertical face (ABCD) only.



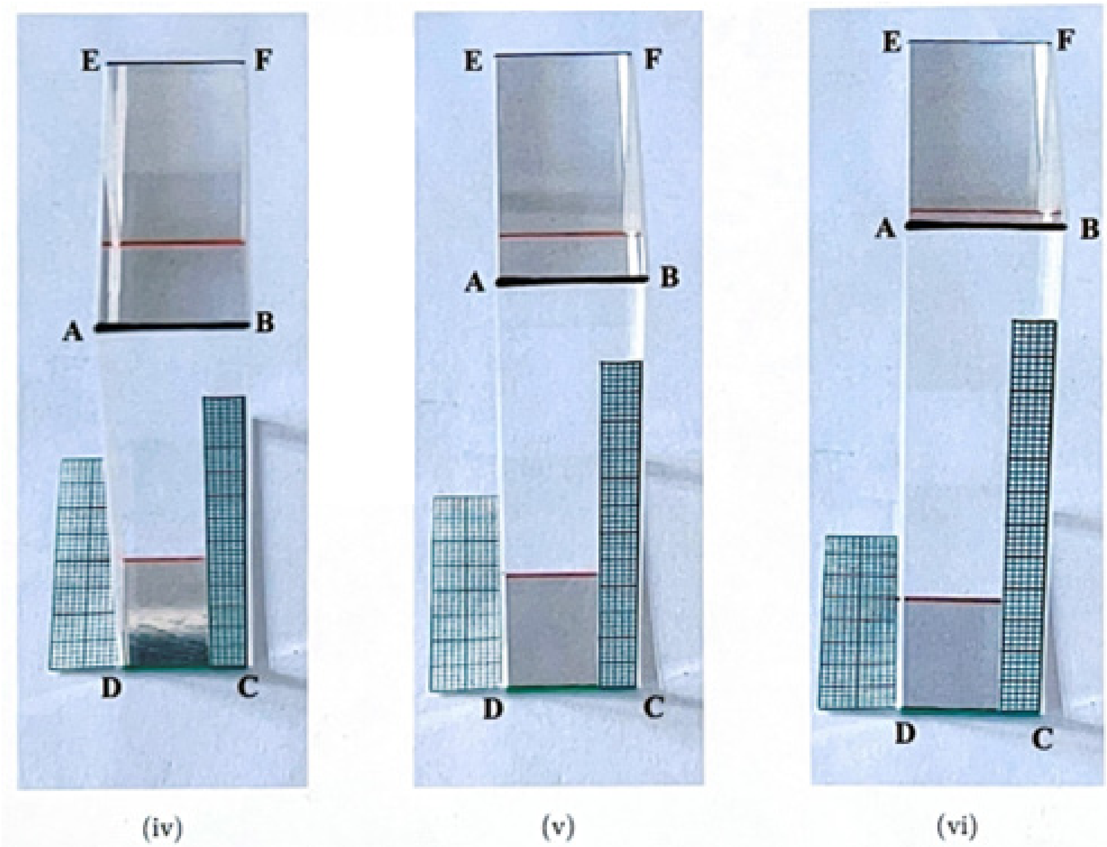
(i)



(ii)



(iii)

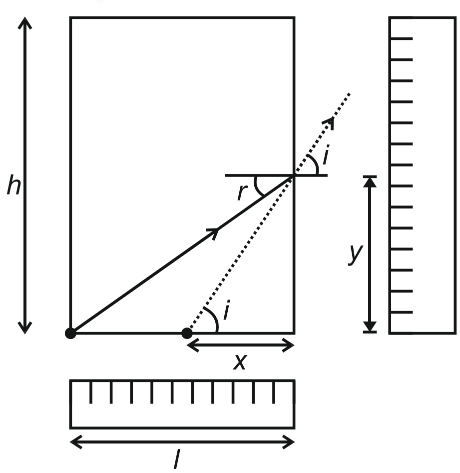


(a) **[2 marks]** Mark and state the measurable quantities in the photo given in the summary answer sheet, that can be used in subsequent parts for measuring the refractive index of the slab.

(b) **[4 marks]** Draw a ray diagram showing these measured quantities, and the relevant given dimensions of the slab. Derive an expression for the refractive index μ_g of the glass slab in terms of the measured quantities that you have decided to use.

(c) **[6 marks]** Calculate the value of μ_g, by plotting a linear graph. Report your data table in the detailed answer sheet.

Sol. We can see the red spots on two scales as shown.



By Snell's law

$\sin i = \mu \sin r$

From geometry

$$\frac{y}{\sqrt{y^2+x^2}}=\frac{\mu y}{\sqrt{y^2+l^2}}$$

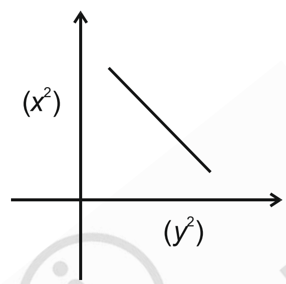
$$\mu^2=\frac{y^2+l^2}{y^2+x^2}$$

Let's make graph between x and y as they are measured quantity

$$\mu^2 y^2+\mu^2 x^2=y^2+l^2$$

$$\mu^2 x^2=y^2(1-\mu^2)+l^2$$

$$x^2=\frac{-(\mu^2-1)}{\mu^2}y^2+\frac{l^2}{\mu^2}$$



Given 6 reading

x	y	x^2	y^2	Slope w.r.t. 1
10	34	100	1156	
15	31	225	961	0.64
18	28	324	784	0.60
20	26	400	676	0.63
23	22	529	484	0.64
25	18	625	324	0.63

Average slope $=\frac{3.14}{5}=0.628$

Therefore $\frac{\mu^2-1}{\mu^2}=$ slope

$$\mu^2-1=\text{slope } \mu^2$$

$$\mu^2=\frac{1}{1-\text{ slope}}$$

$$\mu=\frac{1}{\sqrt{1-\text{ slope}}}=1.639$$

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