Exp. No.1.1

Flywheel- Moment of inertia

Aim: To find the moment of inertia of a fly wheel.

Apparatus: The flywheel, weight hanger with slotted weights, stop clock, metre scale etc.

Theory: A flywheel is an inertial energy-storage device. It absorbs mechanical energy and serves as a reservoir, storing energy during the period when the supply of energy is more than the requirement and releases it during the period when the requirement of energy is more than the supply. The main function of a fly wheel is to smoothen out variations in the speed of a shaft caused by torque fluctuations. Many machines have load patterns that cause the torque to vary over the cycle. Internal combustion engines with one or two cylinders, piston compressors, punch presses, rock crushers etc. are the systems that have fly wheel.

A flywheel is a massive wheel fitted with a strong axle projecting on either side of it. The axle is mounted on ball bearings on two fixed supports as shown in fig.b. There is a small peg inserted loosely in a hole on the axle. One end of a string is looped on the peg and the other end carries a weight hanger. A pointer is arranged close to the rim of the flywheel. To do the experiment, the length of the string is adjusted such that when the descending mass just touches the floor, the peg must detach the axle. Now a line is drawn on the rim with a chalk just below the pointer. The string is then attached to the peg and the wheel is rotated for a known number of times 'n' such that the string is wound over 'n' turns on the axle without overlapping. Now the mass m is at a height 'h' from the floor. The mass is then allowed to descend down. It exerts a torque on the axle of the flywheel. Due to this torque the flywheel rotates with an angular acceleration. Let ω be the angular velocity of the wheel when the peg just detaches the axle and W be the work done against friction per one rotation, then by law of conservation of energy,

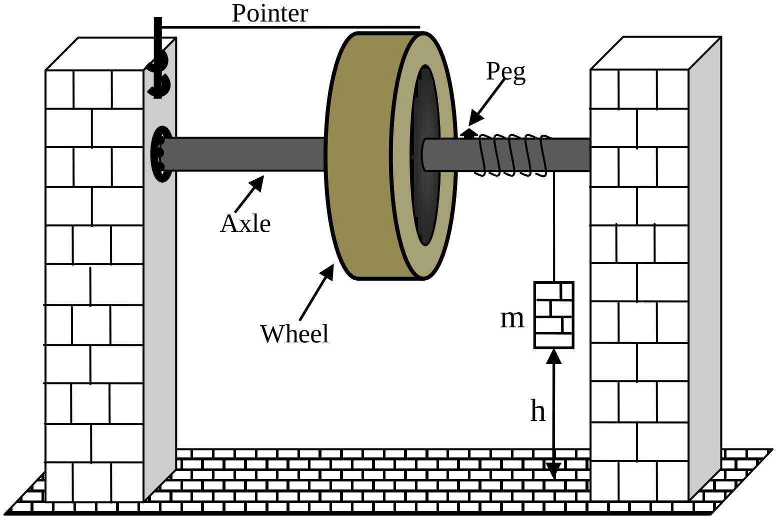


Fig.b

$$mgh = \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2 + nW \qquad (1)$$

Let N be the number of rotations made by the wheel before it stops. Since the kinetic energy of rotation of the flywheel is completely dissipated when it comes to rest, we can write,

$$NW = \frac{1}{2}I\omega^2$$

Or, $$W = \frac{I\omega^2}{2N} \tag{2}$$

Using eqn.2 in eqn.1,

$$mgh = \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2 + n\frac{I\omega^2}{2N} \quad = \frac{1}{2}I\omega^2\left(1+\frac{n}{N}\right)+\frac{1}{2}mr^2\omega^2$$

$$\therefore \quad I = \frac{Nm}{N+n}\left(\frac{2gh}{\omega^2}-r^2\right) \tag{3}$$

where, 'r' is the radius of the axle. To determine 'ω' we assume that the angular retardation of the flywheel is uniform after the mass gets detached from the axle. Then,

$$\text{Average angular velocity} = \frac{\text{Total angular displacement}}{\text{Time taken}}$$

$$\frac{\omega+0}{2} = \frac{2\pi N}{t}$$

$$\therefore \quad \omega = \frac{4\pi N}{t} \tag{4}$$

Procedure: To start with the experiment one end of the string is looped on the peg and a suitable weight is placed in the weight hanger. The fly wheel is rotated 'n' times such that the string is wound over 'n' turns on the axle without overlapping. The flywheel is held stationary at this position. The height 'h' from the floor to the bottom of the weight hanger is measured. The flywheel is then released. The mass descends down and the flywheel rotates. Start a stop watch just when the peg detaches the axle. Count the number of rotations 'N' made by the wheel during the time interval between the peg gets detached from the axle and when the wheel comes to rest. The time interval 't' also is noted. The experiment is repeated for same 'n' and same mass 'm'. The average value of 'N' and 't' are determined. The moment of inertia 'I' is calculated using equations (3) and (4). The entire experiment is repeated for different values of 'n' and 'm' and the average value of I is calculated.

- Ensure that the length of the string is such that when the mass just touches the floor the peg gets detached from the axle.
- In certain wheels the peg is firmly attached to the axle. In such case, one end of the string is loosely looped around the peg such that when the mass just touches the floor the loop gets slipped off from the peg.
- 'm' is the sum of mass of weight hanger and the additional mass placed on it.

Observation and tabulation

To determine the radius of the axle using vernier calipers

Value of one main scale division (1 m s d) = ………. cm

Number of divisions on the vernier scale, x = ……….

Least count, $$\text{L. C} = \frac{\text{Value of one main scale division}}{\text{Number of divisions on the vernier scale}} = \frac{1\text{ m s d}}{x} = \ldots\ldots\text{ cm}$$

Trial No.	M S R cm	V S R	D = M S R + V S R×L C cm	Mean diameter D cm

Diameter of the axle D = …….. cm = ……… m

Radius of the axle $r = \frac{D}{2}$ = …….. m

Determination of moment of inertia

Mass suspended at one end of the string ‘m’ kg	Height from the floor to the bottom of weight hanger ‘h’ m	Number of windings of string on the axle ‘n’	No. of rotations of the wheel after the detachment of the peg from the axle ‘N’			Time interval in between the detachment of the peg and when the wheel comes to stop, ‘t’ sec.			$\omega = \frac{4\pi N}{t}$	I $kg.m^2$
			1	2	Mean N	1	2	Mean t sec		

Result

Moment of inertia of the given flywheel, I = ………. $kg.m^2$

Exp.No.1.2

Compound pendulum- To find 'g' and radius of gyration

Aim: To determine (a) the value of acceleration due to gravity 'g' at the given place by using a compound pendulum, (b) the radius of gyration and hence the moment of inertia of the compound pendulum about an axis passing through its centre of mass.

Apparatus: The compound pendulum, stop watch, etc.

Theory

A compound pendulum, also known as a physical pendulum, is a body of any arbitrary shape pivoted at any point so that it can oscillate in a plane when its centre of mass is slightly displaced on one side and is released.

In the figure *S* is the suspension centre and *G* is the centre of gravity of the body. Let the vertical distance *SG* be l when the body is in its normal position of rest. If the body is oscillated through an angle θ about an axis passing through *S* and perpendicular to the vertical plane of the body, its centre of gravity takes the position *G'*. The torque acting on the body due to its weight *mg* is given by,

$$\Gamma = -Mgl\sin\theta$$

The negative sign indicates that the torque acts opposite to the direction of increase of θ. If I is the moment of inertia of the body about the axis of rotation, then the torque is also given as,

$$\Gamma = I\alpha = I\frac{d^2\theta}{dt^2}$$

i.e. $$I\frac{d^2\theta}{dt^2} = -Mgl\sin\theta$$

If the angular displacement θ is very small, $\sin\theta = \theta$. Then the equation of motion becomes,

$$\frac{d^2\theta}{dt^2} + \frac{Mgl}{I}\theta = 0 \qquad (1)$$

Eqn.1 shows shat the motion of the pendulum is simple harmonic with an angular frequency, $\omega_0 = \sqrt{\frac{Mgl}{I}}$. Its period of oscillation is given by,

$$T = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{I}{Mgl}} \qquad (2)$$

Now we define $$L = \frac{I}{Ml} \qquad (3)$$

Then, $$T = 2\pi\sqrt{\frac{L}{g}} \qquad (4)$$

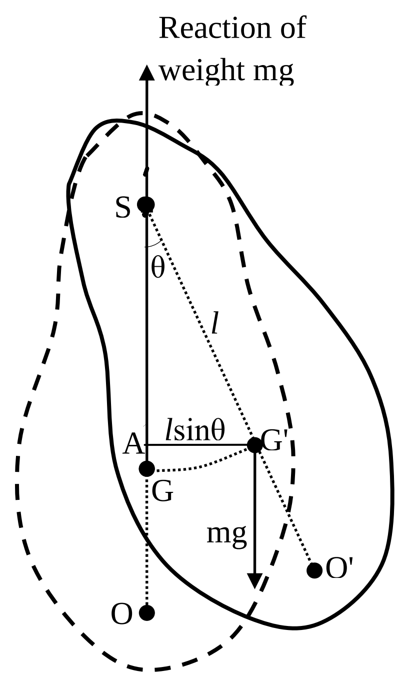


Fig.a

where, L is called the length of an equivalent simple pendulum.

If K is the radius of gyration of the compound pendulum about an axis through the centre of mass, the moment of inertia is,

$$I_{CM} = MK^2 \tag{5}$$

Applying the parallel axes theorem the moment of inertia around the pivot is given by,

$$I = I_{CM} + Ml^2 = MK^2 + Ml^2 = M\left(K^2 + l^2\right) \tag{6}$$

Hence from eqn.2 we get,

$$T = 2\pi\sqrt{\frac{K^2 + l^2}{gl}} = 2\pi\sqrt{\frac{L}{g}} \tag{7}$$

where, $$L = \frac{I}{Ml} = \frac{K^2 + l^2}{l} \tag{8}$$

Thus, if we know the radius of gyration of an irregular body around an axis through the centre of mass, the time period of oscillation of the body for different points of pivoting can be calculated. Fig.b shows the graph between the time period T in the Y axis and the distance of the point of suspension (axis of rotation) from one end of the bar in the X axis.

Centres of suspension and oscillation are mutually interchangeable: In fig.a consider the point O' on the line joining the centre of suspension 'S' and centre of gravity G' at a distance $\left(\frac{K^2}{l} + l\right)$ from 'S' or $\frac{K^2}{l}$ from G'. This point is called the *centre of oscillation*. An axis passing through the centre of oscillation and parallel to the axis of suspension is called *axis of oscillation*.

Let $SG' = l_1$ and $G'O' = l_2 = \frac{K^2}{l_1}$.

Let T_1 be the time period with 'S' as point of suspension. Now we find out the period of oscillation T_2 with O' as point of suspension. Then,

$$T_2 = \sqrt{\frac{4\pi^2}{g}\left(\frac{K^2}{l_2} + l_2\right)}$$

But, $$l_2 = \frac{K^2}{l_1} \tag{9}$$

Then, $$T_2 = \sqrt{\frac{4\pi^2}{g}\left(\frac{K^2}{l_1} + l_1\right)} = T_1$$

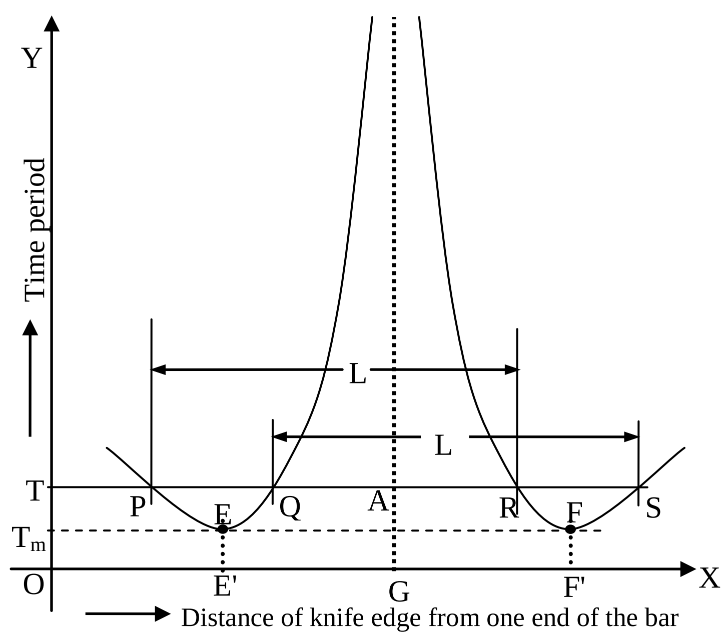


Fig.b

Thus the axes of suspension and oscillation are interchangeable. And if 'L' is the distance between them we can write,

$$L = \frac{K^2}{l_1} + l_1 = \frac{K^2}{l_2} + l_2 \tag{10}$$

And $$T = T_1 = T_2 = 2\pi\sqrt{\frac{L}{g}}$$

Thus by knowing L and T value of acceleration due to gravity g can be obtained as,

$$g = \frac{4\pi^2 L}{T^2} \tag{11}$$

To determine L and K: Draw the graph between the time period T in the X axis and the distance of the point of suspension (axis of rotation) from one end of the bar as shown in fig.b. From the graph, for a given T,

$$L = \frac{PR + QS}{2} \tag{12}$$

By eqn.8, $$K = \sqrt{l_1 l_2} = \sqrt{PA \times AR} = \sqrt{QA \times AS}$$

Thus, $$K = \frac{\sqrt{PA \times AR} + \sqrt{QA \times AS}}{2} \tag{13}$$

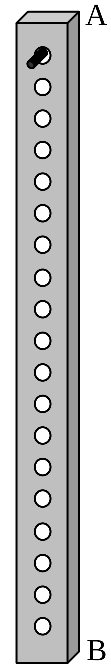


Fig.c

Procedure: In our experiment we use a *symmetric compound pendulum* as shown in fig.c. The compound pendulum is suspended on a knife edge passing through the first hole near one of the ends, say, A. The pendulum is pulled aside slightly and is released so that the pendulum oscillates with small amplitude. The time for 20 oscillations is determined twice and the average is calculated. From this, the period of oscillation T of the symmetric pendulum is found out. Similarly, the time periods of the pendulum by suspending the pendulum in successive holes till the hole near the other end B. (For holes beyond the centre of gravity, the pendulum gets inverted). The distances 'x' from the end A to the edge of the holes at which the knife edge touches are measured by a metre scale.

The centre of gravity of the bar is determined by balancing it on a knife edge. The position of centre of gravity from the end A is also measured. The mass of the bar (including the knife edge if it is attached to the bar) is measured using a balance.

A graph is drawn taking the distances 'x' of the holes from the end A along the X-axis and the time periods T along the Y-axis as shown in fig.b.

To determine the length of the equivalent simple pendulum and the radius of gyration K about the axis passing through the centre of gravity from the graph, draw lines parallel to the X-axis for particular values of T. Determine PR and QS and from these L is calculated. Also determine PA, AR, QA and AS and from these K is calculated. Finally, using eqn.11 the value of acceleration due to gravity 'g' is calculated and the moment of inertia of the bar about an axis through the centre of mass (centre of gravity) using eqn.5. We can also calculate the moment of inertia of the bar about an axis at a distance 'a' from the end A and perpendicular to the bar by applying the parallel axes theorem, $I = MK^2 + Ma^2$.

- Distances 'x' from the end A depends on how the knife edge is fixed in the holes. It may be the top end, bottom end or centre of the hole. The inversion of the bar also is taken into account in this case.

Observation and tabulation

Mass of the bar, M = …….. kg.

Position of centre of gravity G from the end A = ……. m

Distance 'x' from the end A in metre	Time for 20 oscillations in sec.			Period T sec
	1	2	Mean	

To determine acceleration due to gravity (Observations from graph)

Sl.No.	T sec	PR m	QS m	$L = \frac{PR + QS}{2}$ m	$\frac{L}{T^2}$ ms^{-2}	Mean $\frac{L}{T^2}$ ms^{-2}	$g = 4\pi^2\left(\frac{L}{T^2}\right)$ ms^{-2}

To find radius of gyration and moment of inertia (Observations from graph)

Sl.No.	T sec	PA m	AR m	QA m	AS m	$K = \frac{\sqrt{PA \times AR} + \sqrt{QA \times AS}}{2}$ m	Mean K m	$I_{CM} = MK^2$ kg.m^2

Result

Acceleration due to gravity at the place, 'g' = ……… ms^{-2}

Radius of gyration about an axis through the centre of mass, K = ………. m

Moment of inertia about an axis through the centre of mass, I_{CM} = ………. kg.m^2

Exp.No.1.3

Surface Tension by capillary rise method

Aim: To determine the surface tension of the given liquid by capillary rise method.
Apparatus: Beaker with the given liquid, capillary tube, travelling microscope, etc.
Theory

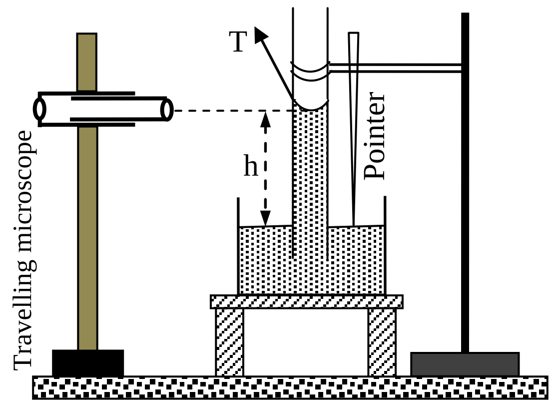


Fig.a

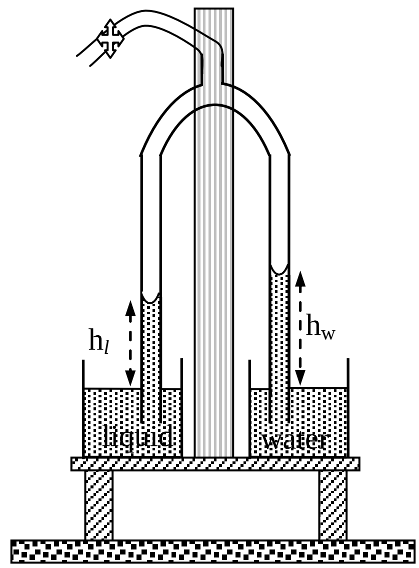


Fig.b

When a capillary tube of inner radius 'r' is dipped in a liquid of surface tension 'T' the liquid rises through the tube to a certain height. This is known as capillary rise. If θ is the angle of contact of the liquid with the capillary tube, the height of the capillary rise is such that the upward surface tension force is equal to the weight of the liquid column in the tube. Let 'h' be the height from the liquid surface in the beaker to the liquid meniscus in the capillary tube. Then,

$$2\pi rT\cos\theta = \pi r^2 h\rho g + \frac{1}{3}\pi r^3\rho g \qquad (1)$$

The second term in the R H S is the weight of the liquid in the meniscus portion, which is negligibly small.

$$T = \frac{\left(h + \frac{r}{3}\right)r\rho g}{2\cos\theta} \qquad (2)$$

We usually use the capillary rise method to find out the surface tension of liquid that wets the glass and have negligibly small angle of contact. Thus,

$$T = \frac{\left(h + \frac{r}{3}\right)r\rho g}{2} \qquad (3)$$

The density of the liquid can be determined by Hare's apparatus as shown in the fig.b. Let h_w is the height of the water column and h_l is the height of the liquid column, then,

Atmospheric pressure, $H = P + h_w\rho_w g = P + h_l\rho g$

i.e. $h_w\rho_w = h_l\rho$

$$\rho = \frac{h_w}{h_l}\rho_w = \frac{\text{Height of water column}}{\text{Height of liquid column}}\times 1000 \text{ kgm}^{-3} \qquad (4)$$

Procedure: The capillary tube and the pointer are arranged as shown in the fig.a. Raise and lower the beaker and check that the meniscus also raises or lowers correspondingly. Otherwise, clean the tube and is again checked that the tube is completely wet with the liquid. The pointer is arranged such that its tip just touches the liquid surface in the beaker. Then the travelling microscope is focused to see the liquid meniscus. (It is better to place the microscope close to the tube and is then pulled back till the tube is seen clearly and then it is raised or lowered to see the meniscus). The horizontal wire of the microscope is made to coincide with the meniscus and the readings on the vertical scale are noted. Now the beaker is removed and the microscope is adjusted to see the tip of the pointer. By adjusting the vertical tangential screw the tip of the pointer is made to coincide with the horizontal cross wire. The reading on the vertical scale is noted. The difference between the two vertical scale readings gives the capillary rise. The experiment is repeated after the beaker is placed in another level.

To find the diameter of the bore of the capillary tube it is arranged horizontally. The travelling microscope is adjusted to see the bore clearly. The horizontal tangential screw of the microscope is adjusted such that the vertical cross wire is tangential to the left side of the bore. The reading on the horizontal scale is noted. The vertical wire is then made to coincide with the right side of the bore and the reading on the horizontal scale is again noted. The difference between the readings gives the diameter in the horizontal direction. Similarly by adjusting the vertical tangential screw the horizontal cross wire is made to coincide with the top and bottom and the corresponding readings on the vertical scale are noted. The difference between the readings gives the vertical diameter. The average diameter and hence the radius of the bore is calculated.

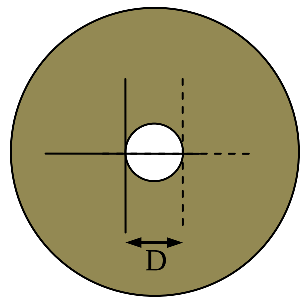


Fig.c

The density of the given liquid is determined by Hare's apparatus. The beakers containing the given liquid and water are arranged as shown in fig.b. The height of the liquid column and the height of the water column are determined and the density is calculated using eqn.4.

Finally, the surface tension of the liquid is calculated using eqn.3.

- The interior of the tube must be clean. It is free from any surface contamination. When the beaker is raised or lowered the liquid meniscus also is raised or lowered correspondingly. Otherwise clean the tube.
- Ensure that there are no air bubbles inside the capillary tube.
- Ensure that the pointer just touches the water surface before taking the meniscus reading.
- Ensure that while using Hare's apparatus h_w is the height from the water surface in the beaker to the meniscus and not the scale reading against the meniscus. Also h_l is the height from the liquid surface to the meniscus.

Observation and tabulation

Value of one main scale division (1 m s d) = …….. cm

Number of divisions on the vernier scale, n = ……..

$$\text{Least count (LC)} = \frac{\text{Value of one main scale division}}{\text{Number of divisions on the vernier}} = \frac{1\text{ m s d}}{n} = \ldots\ldots \text{ cm}$$

Determination of capillary rise

Trial No.	Reading against the liquid meniscus			Reading against the tip of the pointer			Capillary rise h = a–b cm
	M S R cm	V S R	Total reading ‘a’ cm	M S R cm	V S R	Total reading ‘b’ cm	
1							
2							
3							
4							

Mean ‘h’ = ……. cm

Determination of radius of the capillary tube

Mode	Reading corresponding to Left/top			Reading corresponding to Right/bottom			Diameter ‘D’ cm
	M S R cm	V S R	Total reading cm	M S R cm	V S R	Total reading cm	
Horizontal							
Vertical							

Mean ‘D’ = ……. cm

Determination of density of liquid using Hare’s apparatus

Density of water, ρ_w = 1000 kg/m^3

Trial No.	Height of liquid column, h_l cm	Height of water column, h_w cm	$\rho = \frac{h_w}{h_l}\rho_w$ kg/m^3
1			
2			
3			
4			
5			

Mean ρ = …………… kg/m^3

Surface tension of the given liquid, T $= \dfrac{\left(h + \frac{r}{3}\right) r\rho g}{2}$ = …………

= ……… N/m

Result

The surface tension of the given liquid = …….. N/m

Exp.No.1.4
Young's modulus of the material of bar-Non-uniform bending
(using pin & microscope)

Aim: To determine the Young's modulus of the material of a bar by subjecting it to non-uniform bending and measuring the depression at centre of the bar by using pin and microscope.

Apparatus: A long uniform bar, two knife edges, a travelling microscope, pin, weight hanger and slotted weights, etc.

Theory: Let a beam AB be supported by two knife-edges K_1 and K_2 and loaded at the middle C with a weight W = Mg as shown in Fig.(a). The length of the beam between the knife-edges is l and the reaction at each knife-edge is W/2, acting upwards. The depression is maximum at the middle. Let this maximum depression be δ. Since the middle of the beam is almost horizontal, the beam may be considered to be equivalent to two inverted cantilevers CA and CB, each of length $l/2$ and carrying an upward load W/2. Therefore, the maximum depression δ of C below the knife-edges is equivalent to the elevation of A and B from the lowest position C.

Now, consider a vertical section P, distant x from C. Then, the moment of the deflecting couple on the section PB is

$$\frac{W}{2}.PB = \frac{W}{2}\left(\frac{l}{2} - x\right)$$

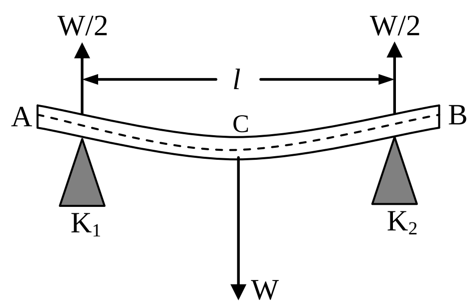


Fig.a

In the equilibrium condition, this deflecting couple is balanced by the bending moment.

$$\frac{YI}{R} = \frac{W}{2}\left(\frac{l}{2} - x\right) \qquad (1)$$

where, Y is the Young's modulus, R is the radius of curvature at any point on the bent beam and I is the geometrical moment of inertia. For a beam with rectangular cross-section, the geometrical moment of inertia I = $\frac{bd^3}{12}$, where b is the breadth and d is the thickness of the bar. For a circular beam of radius r, it is,

$$I = \frac{\pi r^4}{4}$$

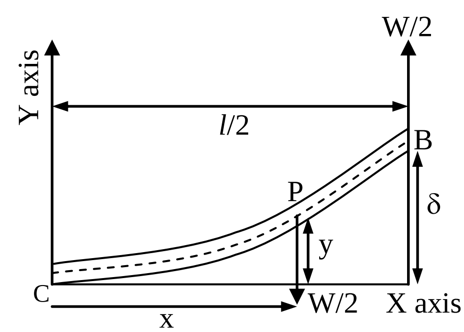


Fig.b

If y is the elevation of the section P above C, the radius of curvature of the neutral axis at this section is given by,

$$\frac{1}{R} = \frac{d^2y}{dx^2}$$

Substituting this value of 1/R in eqn.1,

$$YI\frac{d^2y}{dx^2} = \frac{W}{2}\left(\frac{l}{2} - x\right)$$

Or, $$\frac{d^2y}{dx^2} = \frac{W}{2YI}\left(\frac{l}{2} - x\right) \qquad (2)$$

On integration we get, $$\frac{dy}{dx} = \frac{W}{2YI}\left(\frac{l}{2}x - \frac{x^2}{2}\right) + C_1$$

where C_1 is the constant of integration. Since x = 0 and $\frac{dy}{dx} = 0$ at C (i.e. at $l = 0$), $C_1 = 0$.

Therefore, $$\frac{dy}{dx} = \frac{W}{2YI}\left(\frac{l}{2}x - \frac{x^2}{2}\right)$$

Integrating the expression again, we get

$$y = \frac{W}{2YI}\left(\frac{l}{2}\frac{x^2}{2} - \frac{x^3}{6}\right) + C_2$$

where, C_2 is a constant of integration. Since y = 0 at x = 0, $C_2 = 0$.

At the free end, $x = \frac{l}{2}$ and if the corresponding elevation $y = \delta$, we can write,

$$\delta = \frac{W}{2YI}\left(\frac{l}{2}\times\frac{l^2}{8} - \frac{l^3}{48}\right)$$

Or, $$\delta = \frac{Wl^3}{48YI} = \frac{Mgl^3}{48YI} \qquad (3)$$

For a beam of rectangular cross-section, $I = \frac{bd^3}{12}$

Then, $$\delta = \frac{Wl^3}{4bd^3Y} = \frac{Mgl^3}{4bd^3Y} \qquad (4)$$

Or, $$Y = \frac{Mg}{4bd^3}\left(\frac{l^3}{\delta}\right) \qquad (5)$$

For a beam of circular cross-section, $I = \frac{\pi r^4}{4}$ and hence,

$$\delta = \frac{Wl^3}{12Y\pi r^4} = \frac{Mgl^3}{12Y\pi r^4} \qquad (6)$$

Or, $$Y = \frac{Mg}{12\pi r^4}\left(\frac{l^3}{\delta}\right) \qquad (7)$$

Procedure: The given bar is supported symmetrically on two knife edges, such that the length of the bar in between the knife edges is *l*, say 40 cm, as shown in fig.c. (If a metre scale is used as the bar, we can place the bar on the knife edges such that they are at 30 cm and 70 cm marks). The weight hanger is suspended at the midpoint of the bar (in between the knife edges). A pin is fixed vertically at the midpoint of the bar. A travelling microscope is focused such that the horizontal wire is at the tip of the pin.

Now the bar is brought into an elastic mood by loading and unloading it step by step several times. A sufficient dead load is placed in the weight hanger. Let ‘w_0’ be the mass of weight hanger and the additional dead load placed in it. The microscope is focused such that the tip of the pointer is at the horizontal wire. (The microscope is initially placed very close to the pin. It is then pulled back till the pin is seen clearly. Then the rack and pinion arrangement is adjusted to see the pin very clearly. The microscope is raised or lowered by adjusting the main screw and tangential screws to make the horizontal wire to coincide with the tip of the pin). The reading on the vertical scale is taken. Now the slotted weights are added to the weight hanger in steps of mass ‘m’. In each case the microscope is made to coincide with the tip of the pin and the readings are taken. Then the mass in the weight hanger is unloaded in steps and again the readings are noted. From these readings the average depression δ is found out for a particular mass M, say M = 4m =200 gm, and $\frac{l^3}{\delta}$ is calculated. The experiment is repeated for different values of ‘l’ and the mean value of $\frac{l^3}{\delta}$ is determined.

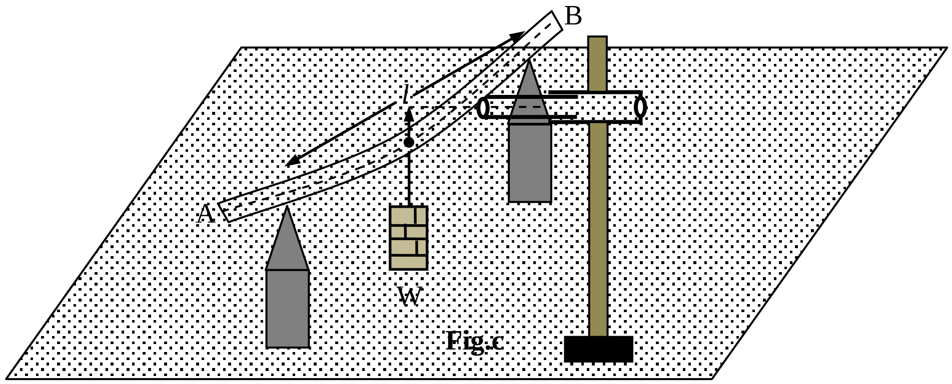


Fig.c

The breadth ‘b’ of the bar is determined with a vernier calipers and the thickness ‘d’ by a screw gauge. The Young’s modulus of the bar is calculated using eqn.5.

Observation and tabulation

To find breadth of the bar using vernier calipers

Value of one main scale reading of the vernier calipers (1 m s d) = …….. cm

Number of divisions on the vernier scale n_1 = ……..

Least count (LC) of the vernier calipers = $\frac{1\text{ m s d}}{n_1}$ = …… cm

Trial No.	M S R cm	V S R	b = M S R + V S R×L C cm	Mean breadth b cm

To find the thickness of the bar using screw gauge

Distance moved by the screw tip for 5 rotations of the head = ……… mm

Pitch of the screw, P $= \dfrac{\text{Distance moved by the screw tip}}{\text{Number of rotations of the head}}$ = ……… mm

Number of divisions on the head scale = ………

Least count (L C) $= \dfrac{\text{Pitch}}{\text{Number of divisions on the head scale}}$ = ……. mm

Zero coincidence = …….. ; Zero error = …….

Zero correction = ……..

Trial No.	P S R ‘x’ mm	Observed H S R	Corrected H S R ‘y’	Thickness $d = x + y \times LC$ mm	Mean d mm
1					
2					
3					
4					
5					

To find $\dfrac{l^3}{\delta}$

Value of one main scale reading of the microscope (1 m s d) = …….. cm

Number of divisions on the vernier scale n = ……..

Least count (LC) of the travelling microscope $= \dfrac{1\text{ m s d}}{n}$ = …… cm

Mass for which depression is calculated, M = 4m = 0.2 kg.

Length ‘l’ in m	Suspended Load in kg.	Microscope readings						Mean reading cm	Depression for the mass M=4m ‘δ’ in cm	Mean δ cm	$\left(\dfrac{l^3}{\delta}\right)$ m^2
		loading			Unloading						
		M S R cm	V S R	Total cm	M S R cm	V S R	Total cm				
	W_0										
	$W_0 + m$										
	$W_0 + 2m$										
	$W_0 + 3m$										
	$W_0 + 4m$										
	$W_0 + 5m$										
	$W_0 + 6m$										
	$W_0 + 7m$										

	W_0										
	$W_0 + m$										
	$W_0 + 2m$										
	$W_0 + 3m$										
	$W_0 + 4m$										
	$W_0 + 5m$										
	$W_0 + 6m$										
	$W_0 + 7m$										
	W_0										
	$W_0 + m$										
	$W_0 + 2m$										
	$W_0 + 3m$										
	$W_0 + 4m$										
	$W_0 + 5m$										
	$W_0 + 6m$										
	$W_0 + 7m$										

Mean $\frac{l^3}{\delta}$ = …….m^2

Young’s modulus of the material of the bar, $Y = \frac{Mg}{4bd^3}\left(\frac{l^3}{\delta}\right) = \ldots\ldots$

$= \ldots\ldots\ Nm^{-2}$

Result

Young’s modulus of the material of the bar, $Y = \ldots\ldots\ Nm^{-2}$

Exp.No.1.5

Young's modulus of the material of a bar -Uniform Bending
(Using optic lever, telescope and scale)

Aim: To determine the Young's modulus of the material of the given bar by subjecting it to uniform bending and by measuring the elevation using an optic lever, scale and telescope arrangement.

Apparatus: A long uniform bar, two knife edges, an optic lever, scale and telescope arrangement, weight hanger and slotted weights, etc.

Theory

Consider a beam supported symmetrically on two knife edges A and B and with a length l between the knife edges. The beam is loaded with equal weights W = Mg at the ends at equal distances p from the knife edges, as shown in Fig.(a). The bar is bent uniformly since it is loaded symmetrically at both ends. Let δ be the elevation of the midpoint O of the bar when it is loaded.

Consider the equilibrium of one half of the bar, say OC. The only external forces acting on this section of the beam are the load W acting vertically downwards at C and its reaction W acting vertically upwards at the knife edge A. The distance between these two forces is p. These two forces constitute a couple, whose moment is given by W.p. In the equilibrium condition, this moment is balanced by the bending moment $\frac{YI}{R}$.

$$\therefore \quad W.p = \frac{YI}{R} \qquad (1)$$

The bar bends into the arc of a circle as shown in Fig. (b). If R is the radius of curvature of the neutral surface and δ is the elevation,

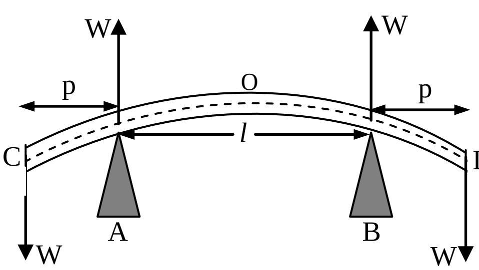


Fig.a

$$(2R-\delta)\delta = \frac{l}{2}.\frac{l}{2} \quad \text{or} \quad 2R\delta-\delta^2 = \frac{l^2}{4}$$

Since δ^2 is negligibly small compared to 2Rδ, we can write

$$2R\delta = \frac{l^2}{4} \quad \text{or} \quad R = \frac{l^2}{8\delta}$$

Substituting for R in eqn.1,

$$W.p = \frac{YI}{l^2/8\delta} = \frac{8YI}{l^2}\delta$$

$$\therefore \quad \delta = \frac{Wpl^2}{8YI}$$

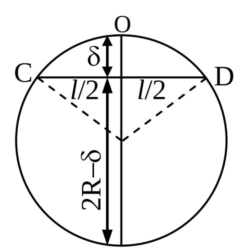


Fig.b

For a bar of rectangular cross section, since $I = \frac{bd^3}{12}$

$$\delta = \frac{Wpl^2}{8Y\frac{bd^3}{12}} = \frac{12Wpl^2}{8Ybd^3} = \frac{3Wpl^2}{2bd^3Y}$$

Or, $$Y = \frac{3Wpl^2}{2bd^3\delta} = \frac{3Mgpl^2}{2bd^3\delta} \quad (3)$$

Similarly, for a bar of circular cross section, $I = \frac{\pi r^4}{4}$

$$= \frac{Wpl^2}{8Y\frac{\pi r^4}{4}} = \frac{Wpl^2}{2\pi r^4 Y}$$

Or, $$Y = \frac{Wpl^2}{2\pi r^4\delta} = \frac{Mgpl^2}{2\pi r^4\delta} \quad (4)$$

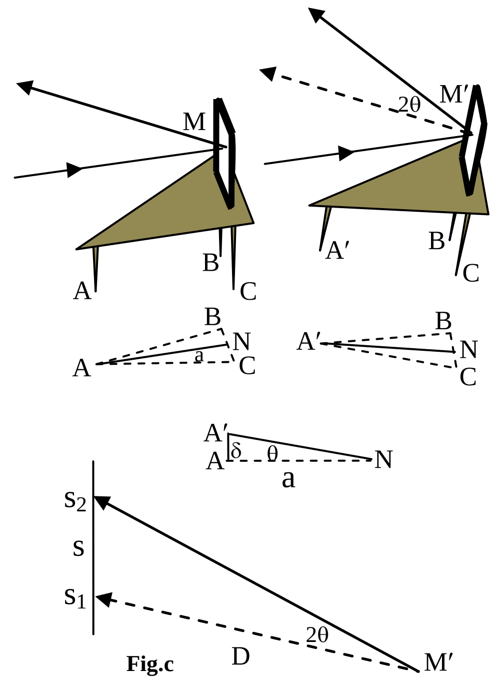


Fig.c

Principle of optic lever: In this experiment we determine the elevation ‘δ’ by using an optic lever, scale and telescope arrangement. The principle behind it is that, if the mirror turns through an angle θ the reflected ray turns through an angle 2θ. The optic lever consists of a triangular frame with three legs and a mirror strip is fixed perpendicularly on it as shown in fig.c. The optic lever is placed with its front leg ‘A’ at the midpoint of the experimental bar arranged on the knife edges. The back legs B and C rest on another bar placed behind the experimental bar. A scale and telescope is arranged at a distance D, say 1 m, from the mirror of the optic lever such that the image of the scale is obtained on the cross wire of the telescope. Let s_1 be the scale reading that coincides with the horizontal wire. Then the bar is loaded symmetrically. Due to the elevation δ of the bar, the optic lever and hence its mirror turns through an angle ‘θ’. Since the reflected ray turns through an angle 2θ, we get another scale reading s_2 that coincides with the horizontal wire of the telescope. Then,

Shift in scale reading when the bar is loaded, $s = s_2 \sim s_1$

Let ‘a’ be the length of the line joining the front leg and the midpoint of the line joining the back legs of the optic lever.

Angle turned by the optic lever due to the elevation δ of the bar, $\theta = \frac{\delta}{a}$

Angle turned by the reflected ray from the mirror of the optic lever, $2\theta = \frac{s}{D}$

i.e. $$\frac{\delta}{a} = \frac{s}{2D}$$

$$\delta = \frac{as}{2D} \quad (5)$$

Using eqn.5, eqns.3 and 4 become,

For rectangular bar, $$Y = \frac{3MgD}{abd^3}\left(\frac{pl^2}{s}\right) \quad (3a)$$

For cylindrical bar, $$Y = \frac{MgD}{\pi r^4 a}\left(\frac{pl^2}{s}\right) \quad (4a)$$

Procedure: The given bar is supported symmetrically on two knife edges with length of the bar in between the knife edges is ‘*l*’. For uniform bending of the bar, equal weights are suspended at equal distances, ‘p’ from the knife edges. An optic lever is arranged behind the bar such that its front leg is at the midpoint of the bar and the two back legs are on another bar arranged as shown in the fig.d. (Ensure that the two bars do not touch each other). The scale and telescope arrangement is placed in front of the bar with the distance in between the scale and the mirror D is greater than or equal to 1 m. The telescope can be focused as follows.

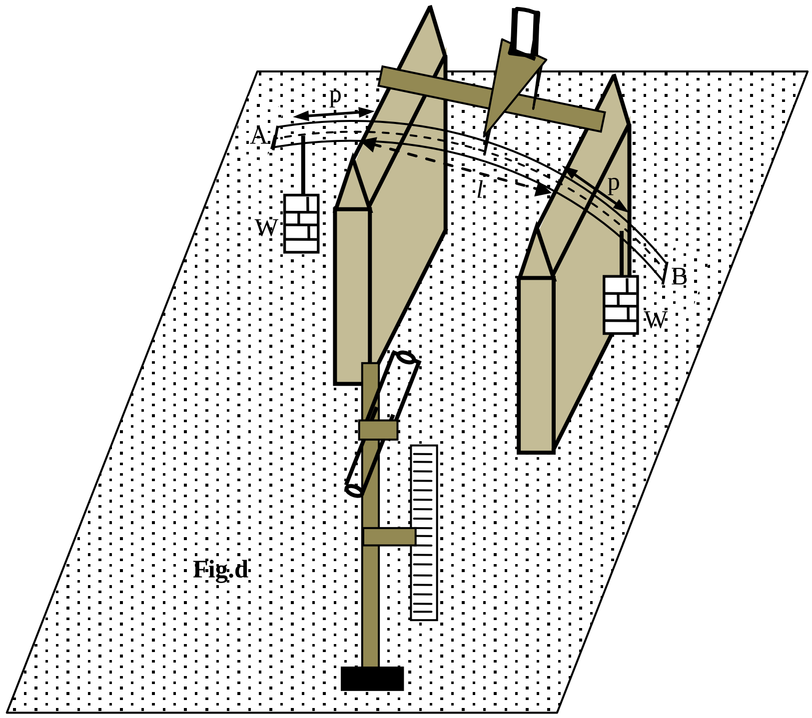


Fig.d

- Looking above the edges of the telescope with one eye (other eye closed) the stand on which the telescope fixed is moved sideways till the image of the scale is seen clearly on the mirror of the optic lever.
- Looking through the edges in the right side of the telescope with one eye, adjust the leveling screws (vertical and sidewise) till the telescope is exactly towards the mirror strip of the optic lever.
- Now looking through the eyepiece, the telescope is focused by adjusting the rack and pinion arrangement till the clear image of the scale is seen exactly on the cross wires of the telescope.
- Before starting to take reading, ensure that it is possible to get scale readings for the minimum and maximum loads. The scale is raised or lowered if needed.

Now the bar is brought to elastic mood by loading and unloading in steps for several times. Now suitable dead loads are placed in the weight hangers. The scale reading that coincides with the horizontal cross wire is noted. Increase the slotted weights in the weight hangers in steps of mass ‘m’ and in each case the scale reading is noted. The scale readings are also taken during the unloading of the slotted weights. The average shift in scale reading for particular loads, say M = 4m in each weight hanger, is determined. The entire experiment is repeated for different values of *l*.

The breadth of the bar is determined by a vernier calipers and its thickness by a screw gauge. The length ‘a’ between the front leg and the midpoint of the line joining the back legs is determined as follows. The optic lever is pressed on a paper so that the impressions of the three legs are obtained on the paper. Construct the triangle with these impressions. Find out the midpoint N of the line joining the back legs (refer fig.c). Then measure the distance ‘a’ between this point and the point corresponding to the front leg.

Observation and tabulation

Mass used to increase the load in steps, m = …….. kg.

Mass for which the elevation is calculated, M = 4m = …….. kg.

Length l in m	P m	D m	Suspended load in kg	Telescope reading in cm			Shift in scale reading 's' for a mass M=4m cm	Mean 's' in m	$\left(\frac{Dpl^2}{s}\right)$ m^3
				loading	Unloading	Mean			
			W_0						
			$W_0 + m$						
			$W_0 + 2m$						
			$W_0 + 3m$						
			$W_0 + 4m$						
			$W_0 + 5m$						
			$W_0 + 6m$						
			$W_0 + 7m$						
			W_0						
			$W_0 + m$						
			$W_0 + 2m$						
			$W_0 + 3m$						
			$W_0 + 4m$						
			$W_0 + 5m$						
			$W_0 + 6m$						
			$W_0 + 7m$						
			W_0						
			$W_0 + m$						
			$W_0 + 2m$						
			$W_0 + 3m$						
			$W_0 + 4m$						
			$W_0 + 5m$						
			$W_0 + 6m$						
			$W_0 + 7m$						

Mean …….

To find breadth of the bar using vernier calipers

Value of one main scale reading of the vernier calipers (1 m s d) = …….. cm

Number of divisions on the vernier scale n = ……..

Least count (LC) of the vernier calipers $= \frac{1 \text{ m s d}}{n}$ = …… cm

Trial No.	M S R cm	V S R	b = M S R + V S R×L C cm	Mean breadth b cm

To find the thickness of the bar using screw gauge

Distance moved by the screw tip for 5 rotations of the head = ……… mm

Pitch of the screw, P $= \dfrac{\text{Distance moved by the screw tip}}{\text{Number of rotations of the head}}$ = ……… mm

Number of divisions on the head scale = ………

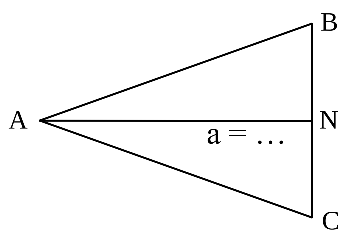
Least count (L C) $= \dfrac{\text{Pitch}}{\text{Number of divisions on the head scale}}$ = ……. mm

Zero coincidence = …….. ; Zero error = …….

Zero correction = ……..

Trial No.	P S R ‘x’ mm	Observed H S R	Corrected H S R ‘y’	Thickness $d = x + y \times LC$ mm	Mean d mm
1					
2					
3					
4					
5					

To determine ‘a’



Distance between the front leg and the midpoint of the line joining the back legs,

a = …….. m

Young’s modulus of the material of the bar, $Y = \dfrac{3Mg}{abd^3}\left(\dfrac{Dpl^2}{s}\right)$ = …………

= ……… Nm^{-2}

Result

Young’s modulus of the material of the bar, Y = ……… Nm^{-2}

Exp.No.1.6
Torsion pendulum
(Moment of inertia of a disc and rigidity modulus)

Aim: To determine the moment of inertia of a given disc and the rigidity modulus of the material of the wire used to suspend the disc by the method of torsional oscillations.

Apparatus: The torsion pendulum consisting of the suspension wire and the heavy disc, two identical masses, stop watch etc.

Theory: A heavy body, say a disc, having a moment of inertia I is suspended by a metallic wire whose one end is fixed on a rigid support. The body is twisted slightly by applying a torque and is released. Then the body executes torsional oscillations. This arrangement is called a **torsion pendulum**. Using the law of conservation of energy we can show that the torsional oscillations are simple harmonic and find out the period of oscillations.

The total energy of the system is equal to the sum of the kinetic energy of rotation of the body and the work done in twisting the wire.

i.e. $$E = \frac{1}{2}I\omega^2 + \frac{1}{2}C\theta^2 = \frac{1}{2}I\left(\frac{d\theta}{dt}\right)^2 + \frac{1}{2}C\theta^2$$

Since the total energy is conserved $$\frac{dE}{dt} = 0$$

Thus, $$0 = \frac{1}{2}2I\left(\frac{d\theta}{dt}\right)\left(\frac{d^2\theta}{dt^2}\right) + \frac{1}{2}2C\theta\left(\frac{d\theta}{dt}\right)$$

Dividing throughout by $\left(\frac{d\theta}{dt}\right)$ we get,

$$I\frac{d^2\theta}{dt^2} + C\theta = 0$$

i.e. $$\frac{d^2\theta}{dt^2} + \frac{C}{I}\theta = 0$$

Or, $$\frac{d^2\theta}{dt^2} = -\frac{C}{I}\theta$$

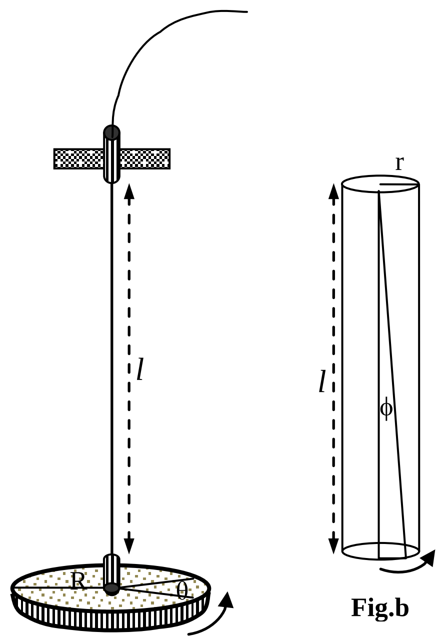


Fig.a Fig.b

That is, the angular acceleration is proportional to angular displacement from the equilibrium position and is opposite to it. Hence the oscillations of the torsion pendulum are simple harmonic. Comparing with the standard equation for a simple harmonic motion $\frac{d^2y}{dt^2} + \omega^2 y = 0$ we get, $\omega^2 = \frac{C}{I}$

Thus the period of oscillation , $$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\frac{C}{I}}} = 2\pi\sqrt{\frac{I}{C}}$$

where, $C = \frac{\pi nr^4}{2l}$ is the couple per unit twist of the suspension wire and I the moment of inertia of the suspended body.

Determination of rigidity modulus of a wire

Method (1): To determine the rigidity modulus of the material of a wire a torsion pendulum is arranged. It consists of a heavy disc suspended by a thin uniform wire whose rigidity modulus is to be determined. Length between the chucks is adjusted to a suitable value as shown in the fig.a. Now the disc is rotated through a small angle and is released. The period of oscillation T_0 is determined. The radius of the wire 'r', mass of the disc 'M' and the radius of the disc 'R' are also determined. The rigidity modulus of the material of the wire is calculated as follows.

The period of oscillation $T_0 = 2\pi\sqrt{\frac{I}{C}}$

Squaring and rearranging we get, $C = 4\pi^2 \frac{I}{T_0^2}$

Substituting for couple per unit twist C we get,

$$\frac{\pi n r^4}{2l} = 4\pi^2 \frac{I}{T_0^2}$$

$$\therefore \quad \text{Rigidity modulus} \quad n = \frac{8\pi I}{r^4}\left(\frac{l}{T_0^2}\right) \qquad (1)$$

where, I is the moment of inertia of the disc that can be calculated using $I = \frac{MR^2}{2}$ (2)

Method (2) - using identical masses: In this method two identical masses (say, cylindrical in shape) of mass 'm' and moment of inertia I_0 about its own axis, are placed at equal distances d_1 from the suspension wire as shown in fig.c. Let I be the moment of inertia of the disc and I_1 be the moment of inertia of the system. Applying parallel axes theorem, the moment of inertia of the identical masses about the axis through the suspension wire is $2I_0 + 2md_1^2$. Hence the moment of inertia of the system,

$$I_1 = I + 2I_0 + 2md_1^2 \qquad (3)$$

If the identical masses are placed at distances d_2 from the wire, the moment of inertia of the system is given by,

$$I_2 = I + 2I_0 + 2md_2^2 \qquad (4)$$

$$I_2 - I_1 = 2m\left(d_2^2 - d_1^2\right) \qquad (5)$$

Let T_0 be the period of oscillations of the torsion pendulum without the identical mass and T_1 and T_2 be the corresponding periods with identical masses at distances d_1 and d_2, respectively. Then,

$$T_0^2 = 4\pi^2 \frac{I}{C} \qquad (6)$$

$$T_1^2 = 4\pi^2 \frac{I_1}{C}$$

Or, $$I_1 = \frac{CT_1^2}{4\pi^2} \qquad (7)$$

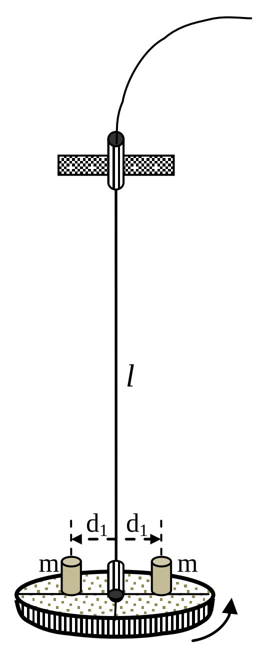


Fig.c

And, $$I_2 = \frac{CT_2^2}{4\pi^2} \quad (8)$$

$$I_2 - I_1 = \frac{C}{4\pi^2}\left(T_2^2 - T_1^2\right) \quad (9)$$

From eqns. 5 and 9,

$$\frac{C}{4\pi^2} = \frac{2m\left(d_2^2 - d_1^2\right)}{\left(T_2^2 - T_1^2\right)} \quad (10)$$

Using eqn.10 in eqn.6, we get,

$$I = 2m\left(d_2^2 - d_1^2\right)\frac{T_0^2}{\left(T_2^2 - T_1^2\right)} \quad (11)$$

By eqn.6, $$C = 4\pi^2\frac{I}{T_0^2} = \frac{8\pi^2 m\left(d_2^2 - d_1^2\right)}{\left(T_2^2 - T_1^2\right)}$$

i.e. $$\frac{\pi nr^4}{2l} = \frac{8\pi^2 m\left(d_2^2 - d_1^2\right)}{\left(T_2^2 - T_1^2\right)}$$

$$\therefore \quad n = \frac{16\pi m\left(d_2^2 - d_1^2\right)}{r^4}\left(\frac{l}{T_2^2 - T_1^2}\right) \quad (12)$$

Procedure: A reference line is drawn on the disc along its diameter. The torsion pendulum is set for a desired length '*l*' in between the two chucks, one on the clamp and the other on the disc. A pointer is arranged close to the disc. This helps to count the oscillations. The disc is twisted slightly and is released. The pendulum executes torsional oscillations. The time for 20 oscillations is noted. This is done once again and the average time for 20 oscillations is calculated. From this the average time period T_0 is determined.

The two identical masses are now placed (on a diametrical line of the disc) at equal distance d_1 each from the centre of the disc (from the wire) and the time period T_1 of the new oscillations is determined as above. Then the distance of the identical mass is changed to d_2 and the corresponding time period T_2 is determined.

The entire experiment is repeated for different lengths *l*. The mass of the identical masses 'm' and the mass of the disc 'M' are measured with a balance. Radius R of the disc is determined by measuring its diameter by a scale. The radius 'r' of the suspension wire is determined accurately using a screw gauge.

In method (1), the moment of inertia of the disc is calculated using eqn.2 and the rigidity modulus of the material of the suspension wire by eqn.1.

In the method (2), the moment of inertia of the disc is calculated by eqn.11 and the rigidity modulus by eqn.12.

Observation and tabulation

Mass of the disc, M = …….. kg

Mass of identical masses, m = …….. kg

Radius of the disc, R = …….. m

To determine 'I' and 'n' (d_1 and d_2 fixed)

l m	Distance of the mass 'm' from the axis in m	Time for 20 oscillations 't' sec			$T = \frac{t}{20}$ sec	$\left(\frac{l}{T_0^2}\right)$ ms^{-2}	$\frac{T_0^2}{\left(T_2^2 - T_1^2\right)}$	$\left(\frac{l}{T_2^2 - T_1^2}\right)$ ms^{-2}
		1	2	Mean				
	Disc alone				$T_0 =$			
	$d_1 =$				$T_1 =$			
	$d_2 =$				$T_2 =$			
	Disc alone				$T_0 =$			
	$d_1 =$				$T_1 =$			
	$d_2 =$				$T_2 =$			
	Disc alone				$T_0 =$			
	$d_1 =$				$T_1 =$			
	$d_2 =$				$T_2 =$			
	Disc alone				$T_0 =$			
	$d_1 =$				$T_1 =$			
	$d_2 =$				$T_2 =$			
	Disc alone				$T_0 =$			
	$d_1 =$				$T_1 =$			
	$d_2 =$				$T_2 =$			
	Disc alone				$T_0 =$			
	$d_1 =$				$T_1 =$			
	$d_2 =$				$T_2 =$			
					Mean			

To measure the radius 'r' of the wire using screw gauge

Distance moved by the screw tip for 5 rotations of the head = ……… mm

Pitch of the screw, P $= \frac{\text{Distance moved by the screw tip}}{\text{Number of rotations of the head}}$ = ……… mm

Number of divisions on the head scale = ………

Least count (L C) $= \frac{\text{Pitch}}{\text{Number of divisions on the head scale}}$ = ……. mm

Zero coincidence = …….. ; Zero error = ……. ; Zero correction = ……..

Trial No.	P S R 'x' mm	Observed H S R	Corrected H S R 'y'	Thickness $d = x + y \times LC$ mm	Mean d mm
1					
2					
3					
4					
5					

Radius of the wire, r = d/2 = …….. mm

Calculations

Method 1

Moment of inertia of the disc, $I = \dfrac{MR^2}{2}$ = ………….. = ……… $kg.m^2$

Rigidity modulus of the material of the wire, $n = \dfrac{8\pi I}{r^4}\left(\dfrac{l}{T_0^2}\right)$ = ………..

= ………. Nm^{-2}

Method 2

Moment of inertia of the disc, $I = 2m\left(d_2^2 - d_1^2\right)\dfrac{T_0^2}{\left(T_2^2 - T_1^2\right)}$

=

= ………. $kg.m^2$

Rigidity modulus, $n = \dfrac{16\pi m\left(d_2^2 - d_1^2\right)}{r^4}\left(\dfrac{l}{T_2^2 - T_1^2}\right)$ =

= ………. Nm^{-2}

Result

Moment of inertia of the disc, I = ………. $kg.m^2$

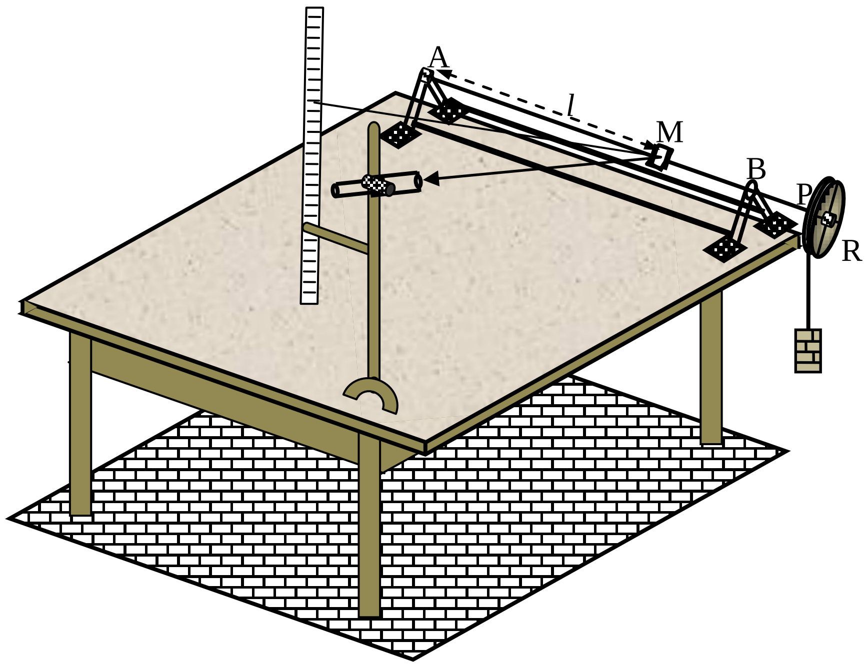
Rigidity modulus of the material of the wire, n = ………. Nm^{-2}

Exp.No.1.7

Rigidity modulus of a material-Static torsion

Aim: To find out the rigidity modulus of the material of a rod using static torsion apparatus.

Apparatus: The static torsion apparatus, mirror strip, scale and telescope arrangement, slotted weights etc.



Theory: The static torsion apparatus consists of a heavy metallic frame that can be fixed on a table. The experimental rod is passed through the hole in the frame B. One end of the experimental rod is rigidly clamped at the frame A. The other end P of the rod is held tightly by the chucks on a metallic wheel having radius R. One end of a metal wire is fixed on a small peg on the wheel. The wire can be wound clockwise or anti-clockwise over the wheel in the groove provided on it. The free end of the wire carries a weight hanger. When a mass M is suspended on the wheel, the wheel and hence the rod get twisted through an angle θ. If C is the couple per unit twist of the rod, we can write,

$$MgR = C\theta = \frac{\pi n r^4 \theta}{2l}$$

where, n is the rigidity modulus of the material of the rod, ‘r’ its radius and ‘*l*’ is the length of the rod from the fixed end of the rod to the point at which the mirror is fixed. Then,

$$\text{Rigidity modulus,} \quad n = \frac{2MgR}{\pi r^4}\left(\frac{l}{\theta}\right) \qquad (1)$$

The angle ‘θ’ is measured by an indirect method by using a scale and telescope, which employs the principle that when the mirror turns through an angle θ, the reflected ray turns through an angle 2θ. If ‘s’ be the shift in scale reading for a mass ‘M’,

$$2\theta = \frac{s}{D} \qquad (2)$$

where, D is the distance between the mirror and the scale. Then,

$$n = \frac{4MgR}{\pi r^4}\left(\frac{lD}{s}\right) \qquad (3)$$

Procedure: The given rod is clamped in the static torsion apparatus. The mirror strip M is fixed at a distance '*l*', say 20 cm, from the end A. The weight hanger carrying the dead load is suspended at the free end of the metal wire wound clockwise on the wheel. The scale and telescope arrangement is placed at a distance D, say 1 m, from the mirror. The telescope is adjusted as mentioned in exp.No.5 so that the scale is seen clearly in the telescope. Then the weight hanger is loaded and unloaded in steps several times so as to bring the rod in elastic mood. Before starting to take the reading, check that we get the scale readings for the minimum and maximum weight in the weight hanger.

To start to take reading, the weight hanger is loaded with the minimum weight W_0. The scale reading that coincides with the horizontal wire of the telescope is noted. Then the load is increased in steps and in each case the coinciding scale reading is noted. After taking the reading for maximum load, the load is decreased in steps and again the corresponding scale readings are noted. Now the experiment is repeated after the metal wire is wound over the wheel anticlockwise. The entire experiment is repeated for different values of '*l*'.

Using a piece of twine wound over the wheel, its circumference can be measured and from it the radius R can be calculated. The radius 'r' of the rod is measured using a screw gauge. Finally, the rigidity modulus is calculated using eqn.3.

Observation and tabulation

To find the radius of the wheel

Circumference of the wheel, L = ……. cm

Radius of the wheel, $R = \dfrac{L}{2\pi}$ = …….. m

To find the radius of the rod using screw gauge

Distance moved by the screw tip for 5 rotations of the head = ……… mm

Pitch of the screw, $P = \dfrac{\text{Distance moved by the screw tip}}{\text{Number of rotations of the head}}$ = ……… mm

Number of divisions on the head scale = ………

Least count (L C) $= \dfrac{\text{Pitch}}{\text{Number of divisions on the head scale}}$ = ……. mm

Zero coincidence = …….. ; Zero error = …….

Zero correction = ……..

Trial No.	P S R 'x' mm	Observed H S R	Corrected H S R 'y'	Thickness $d = x + y \times LC$ mm	Mean d mm
1					
2					
3					
4					
5					

Radius of the rod, r = d/2 = …….. mm

To find out $\left(\frac{l\mathrm{D}}{\mathrm{s}}\right)$

Mass used to increase the load in steps, $m = \ldots\ldots$ kg.

Mass for which the elevation is calculated, $M = 4m = \ldots\ldots$ kg.

			Telescope reading in cm									
			Clockwise				Anticlockwise					
l m	D m	Suspended load in kg.	Loading	Unloading	Mean	Shift for a mass M = 4m	loading	unloading	Mean	Shift for a mass M = 4m	Mean shift 's' for the mass M = 4m metre	$\left(\frac{l\mathrm{D}}{\mathrm{s}}\right)$ m
		W_0										
		$W_0 + m$										
		$W_0 + 2m$										
		$W_0 + 3m$										
		$W_0 + 4m$										
		$W_0 + 5m$										
		$W_0 + 6m$										
		$W_0 + 7m$										
		W_0										
		$W_0 + m$										
		$W_0 + 2m$										
		$W_0 + 3m$										
		$W_0 + 4m$										
		$W_0 + 5m$										
		$W_0 + 6m$										
		$W_0 + 7m$										
		W_0										
		$W_0 + m$										
		$W_0 + 2m$										
		$W_0 + 3m$										
		$W_0 + 4m$										
		$W_0 + 5m$										
		$W_0 + 6m$										
		$W_0 + 7m$										

Mean ……..

Rigidity modulus of the material of the rod, $n = \frac{4MgR}{\pi r^4}\left(\frac{l\mathrm{D}}{\mathrm{s}}\right) = \ldots\ldots\ldots$

$= \ldots\ldots\ \mathrm{Nm^{-2}}$

Result

Rigidity modulus of the material of the rod, $n = \ldots\ldots\ \mathrm{Nm^{-2}}$

Exp.No.1.8

Melde's String- Frequency of a tuning fork

Aim: To determine the frequency of a tuning fork by Melde's string arrangement set for (a) transverse mode of vibration and (b) longitudinal mode of vibration.

Apparatus: An electrically maintained tuning fork, sufficient length of string, a light scale pan, smooth pulley, weight box, common balance, etc.

Theory: When the entire string vibrates with one loop, the corresponding frequency of the string is called its fundamental frequency. The theory of vibrations of a stretched string shows that the fundamental frequency of transverse vibrations in a stretched string of length 'l' is

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} \tag{1}$$

where, T is the tension on the string and 'm' is its linear density (mass per unit length).

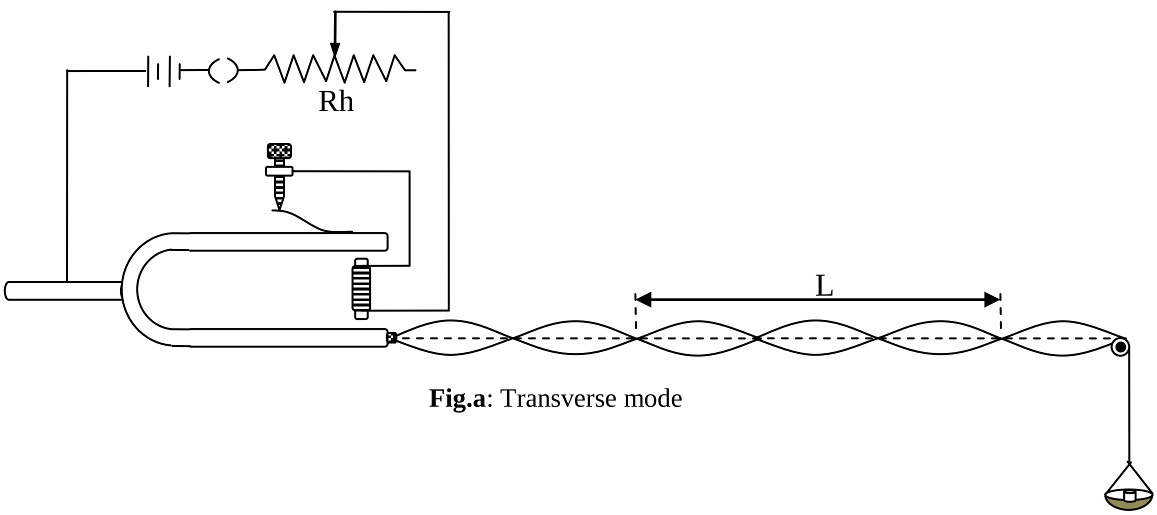


Fig.a: Transverse mode

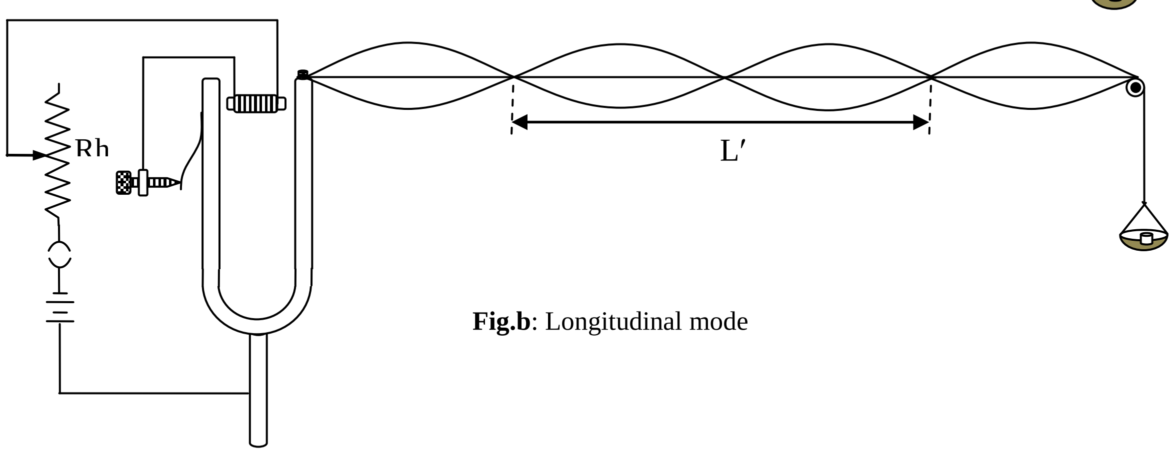


Fig.b: Longitudinal mode

In the longitudinal mode of vibration, the fundamental frequency of vibration is given by,

$$n' = \frac{1}{l'}\sqrt{\frac{T'}{m}} \tag{2}$$

When the stretched string vibrates in unison with the tuning fork, the frequency of the tuning fork N is same as the fundamental frequency of the stretched string. Thus for transverse vibrations, if 'l' is the length of one loop, the frequency of the tuning fork,

$$N = n = \frac{1}{2l}\sqrt{\frac{T}{m}} = \frac{1}{2l}\sqrt{\frac{Mg}{m}} = \sqrt{\frac{g}{4m}\left(\frac{M}{l^2}\right)} \qquad (3)$$

where, M is the sum of the mass of scale pan and the mass placed in it.
And for longitudinal mode of vibration, the frequency of the tuning fork,

$$N = n' = \frac{1}{l'}\sqrt{\frac{T'}{m}} = \frac{1}{l'}\sqrt{\frac{M'g}{m}} = \sqrt{\frac{g}{m}\left(\frac{M'}{l'^2}\right)} \qquad (4)$$

where, M′ is the sum of the mass of scale pan and the mass placed in it.
If L is the length of 'p' loops in transverse mode, the length of one loop is given by,

$$l = \frac{L}{p} \qquad (5)$$

And, if L′ is the length of 'q' loops in longitudinal mode, the length of one loop is given by,

$$l' = \frac{L'}{q} \qquad (6)$$

Procedure

(a) Transverse mode: The apparatus is arranged and the connections are made as shown in the fig.a. A suitable weight, say 1 or 2 gm, is placed in the scale pan. By adjusting the screw the tuning fork is set into vibration. Place one of the two pointers at a well defined node and the other pointer at another node. Count the number of loops 'n' in between the two pointers and measure the length 'L' of the string in between the pointers.

(b) Longitudinal mode: In this case the arrangements are done as shown in the fig.b. Suitable weights (500 mg or 600 mg) are placed in the scale pan and the tuning fork is set into vibration. The number of loops and the length of the string in between the two pointers are measured.

- Adjust the total length between the tuning fork and the pulley by moving the tuning fork back or forth so that the nodes and hence the loops are well defined. This adjustment is needed since the string in between the two fixed ends (one at the tuning fork and the other at the pulley) must contain integral number of loops.
- The mass M is the mass of the scale pan plus the mass placed in it.
- Use masses of the order of a few grams in the transverse mode and masses of the order of milligrams in the case of longitudinal mode.
- Instead of the apparatus shown in the figure we may use an electromagnet with alternating current and a strip of magnetic material to vibrate with the frequency of the alternating current used. In this case the length of the strip is to be adjusted to get oscillations.

Measurement of the mass of the scale pan and the linear density of the string: The mass of the scale pan is determined by a common balance in the sensibility method. To find the linear density (mass per unit length) 'm' of the string, take 10 metre length of the same string and find out the mass of it using a common balance in the sensibility method.

Observations and tabulations

To find mass of the scale pan M_0 and the linear density 'm'

Load in the pans of the balance		Turning points		Resting point	Sensibility	Correct weight
left	Right (gm)	Left (3)	Right (2)		$S = \frac{0.01}{R_1 \sim R_2}$	$M=W+S(R_1-R_0)$ gm
Nil	Nil			$R_0 = \ldots$		
Scale pan	W			$R_1 = \ldots$		
	W + 0.01			$R_2 = \ldots$		
Known length (L_1) of string	W			$R_1 = \ldots$		
	W + 0.01			$R_2 = \ldots$		

Mass of the scale pan, M_0 = ………. gm = ………. kg

Mass of known length (L_1 = …. metre) of the string, M_1 = …….. kg

Linear density, $m = \frac{M_1}{L_1}$ = ……. kg/metre

To find frequency-Transverse mode

Trial No.	Mass in the scale pan x gm	Total mass suspended $M = (M_0+x)$ gm	Number of loops 'p'	Length of p loops in cm	Length of one loop l in cm	$\frac{M}{l^2}$ kg.m^{-2}
1						
2						
3						
4						
5						

Mean …………

Frequency of the tuning fork, $N = \sqrt{\frac{g}{4m}\left(\frac{M}{l^2}\right)}$ = ……….. = ……… Hz

To find frequency-Longitudinal mode

Trial No.	Mass in the scale pan x' gm	Total mass suspended $M' = (M_0+x')$ gm	Number of loops 'q'	Length of q loops in cm	Length of one loop l' in cm	$\frac{M'}{l'^2}$ kg.m^{-2}
1						
2						
3						
4						
5						

Mean …………

Frequency of the tuning fork, $N = \sqrt{\frac{g}{m}\left(\frac{M'}{l'^2}\right)}$ = ……….. = ……… Hz

Result

Frequency of the tuning fork, N = …….. Hz

Exp.No.1.9

Lee's disc- Thermal conductivity of a bad conductor

Aim: To determine the thermal conductivity of a bad conductor by Lee's disc method.

Apparatus: The Lee's disc apparatus, bad conductor in the form of disc, two thermometers, steam boiler, etc.

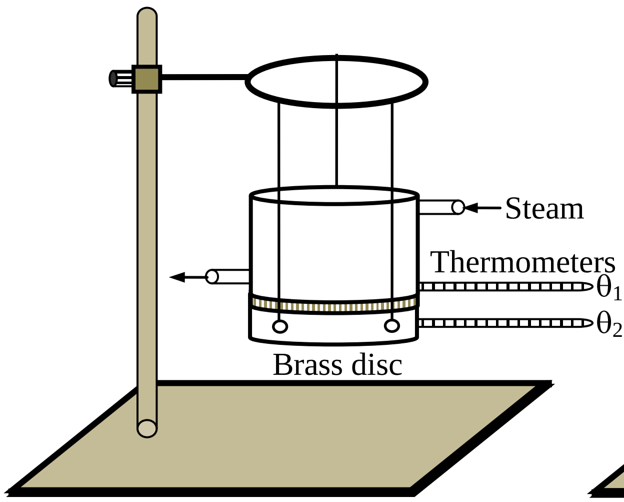


Fig.a

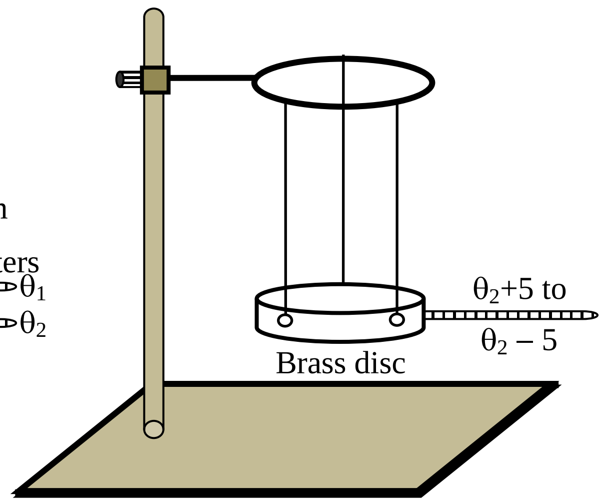


Fig.b

The Lee's disc apparatus consists of a circular brass disc of about 8 to 12 cm diameter and thickness about 1 to 2 cm. It is suspended on a stand as shown in the fig.a. A steam chamber of the same diameter is used to heat the disc. The bad conductor whose thermal conductivity is to be determined is taken in the form of a disc of the same diameter of the brass disc. It is kept in between the brass disc and the steam chamber. There are holes provided on the steam chamber and the disc to insert the thermometers.

Theory: The quantity of heat conducted per second through a conductor is proportional to the area through which heat conducts and the temperature gradient. That is,

$$Q \propto A\left(\frac{\theta_1 - \theta_2}{d}\right)$$

$$= \lambda A\left(\frac{\theta_1 - \theta_2}{d}\right) \qquad (1)$$

where, λ is a constant for a particular material. The constant λ is called the thermal conductivity of the material. θ_1 and θ_2 are the temperatures on both sides of the bad conducting disc and 'd' is its thickness. These temperatures, respectively, are the temperature of the steam chamber and the brass disc near the bad conductor. At the steady state condition, the quantity of heat conducted through the experimental disc is completely radiated from the brass disc.

The quantity of heat radiated by the brass disc is calculated as follows. The brass disc alone is heated (after removing the bad conducting disc) to a temperature greater than the steady state temperature θ_2 and is allowed to cool by radiation. Let $\left(\frac{d\theta}{dt}\right)_{\theta_2}$ is the rate of cooling of the Lees disc at a temperature θ_2. Then the rate of loss of heat by the brass disc is proportional to the area of its exposed region. When the disc is completely exposed for radiation we can write, the rate of loss of heat per unit area

$$\frac{Q_{total}}{\text{Total area of the Lee's disc}} = \frac{Mc\left(\frac{d\theta}{dt}\right)_{\theta_2}}{2\pi r^2 + 2\pi rh}$$

where, M is the mass, c is the specific heat capacity, r is the radius and h is the height of the brass disc. At the steady state condition during the experiment, the exposed area of the brass disc does not contain the upper face. Therefore, the rate of loss of heat from the disc during the experiment is given by,

$$Q' = \text{Rate of loss of heat through unit area} \times \text{exposed area of the disc}$$

$$= \frac{Mc\left(\frac{d\theta}{dt}\right)_{\theta_2}}{2\pi r^2 + 2\pi rh} \times \left(\pi r^2 + 2\pi rh\right) = Mc\left(\frac{d\theta}{dt}\right)_{\theta_2}\left(\frac{r+2h}{2r+2h}\right) \qquad (2)$$

At the steady state condition, since the quantity of heat conducted through the experimental disc is completely radiated from the brass disc, Q = Q′. Thus from eqns.1 and 2,

$$\lambda A\left(\frac{\theta_1 - \theta_2}{d}\right) = Mc\left(\frac{d\theta}{dt}\right)_{\theta_2}\left(\frac{r+2h}{2r+2h}\right)$$

$$\therefore \qquad \lambda = \frac{Mc}{A}\left(\frac{d}{\theta_1 - \theta_2}\right)\left(\frac{d\theta}{dt}\right)_{\theta_2}\left(\frac{r+2h}{2r+2h}\right)$$

$$= \frac{Mc}{\pi r^2}\left(\frac{d}{\theta_1 - \theta_2}\right)\left(\frac{d\theta}{dt}\right)_{\theta_2}\left(\frac{r+2h}{2r+2h}\right) \qquad (3)$$

$\left(\frac{d\theta}{dt}\right)_{\theta_2}$ is the rate of cooling of the brass disc at the temperature θ_2. This can be determined by finding the slope of the time-temperature graph at the temperature θ_2.

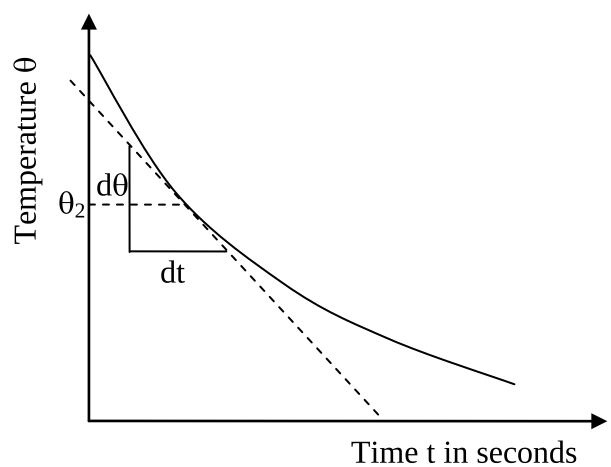


Fig.c

Procedure: The diameter and the thickness of the brass disc are measured by a vernier calipers. Its mass M is measured by a balance. The thickness ‘d’ of the experimental disc is determined by a screw gauge.

The experimental arrangements are set up as shown in the fig.a. The brass disc is suspended by a heavy retort stand. The experimental disc and the steam chamber are placed on it. Thermometers are inserted in the holes provided for that. Steam from a boiler is allowed to pass through the steam chamber till the two thermometers show steady temperatures. Note the steady temperatures θ_1 of the steam chamber and θ_2 of the brass disc. Then the experimental disc is removed and the steam chamber is kept in contact with the brass disc. When the temperature of the brass disc is raised by about 8 or 10 degree, the steam chamber is removed and the brass disc is allowed to cool (as shown in fig.b).

When the temperature of the brass disc reaches θ_2+5, a stop watch is started. The time is noted at regular intervals of temperature, say 0.5°C (or 0.2°C) till the temperature falls to θ_2–5. A graph is plotted with time along the X axis and the temperature along the Y axis as shown in fig.c. To find out $\left(\frac{d\theta}{dt}\right)_{\theta_2}$, draw a line parallel to the X axis at the temperature θ_2. At the point of intersection of this line with the curve, draw the tangent of the curve. Now construct a triangle as shown in fig.c and the slope of the curve at θ_2 is determined.

- Do not stop the stop watch while taking the temperature-time observation. Count the time in minutes and seconds.
- It should be remembered that the slope of the curve is determined at the steady state temperature θ_2 of the brass disc.

Observation and tabulation

To find the thickness ‘d’ of the experimental disc using screw gauge

Distance moved by the screw tip for 5 rotations of the head = ……… mm

Pitch of the screw, P = $\frac{\text{Distance moved by the screw tip}}{\text{Number of rotations of the head}}$ = ……… mm

Number of divisions on the head scale = ………

Least count (L C) = $\frac{\text{Pitch}}{\text{Number of divisions on the head scale}}$ = ……. mm

Zero coincidence = …….. ; Zero error = ……. ; Zero correction = ……..

Trial No.	P S R ‘x’ mm	Observed H S R	Corrected H S R ‘y’	Thickness $d = x + y \times LC$ mm	Mean d mm
1					
2					
3					
4					
5					

To find the radius ‘r’ and thickness ‘h’ of the brass disc using vernier calipers

Value of one main scale reading of the vernier calipers (1 m s d) = …….. cm

Number of divisions on the vernier scale n = ……..

Least count (LC) of the vernier calipers = $\frac{1\text{ m s d}}{n}$ = …… cm

Radius ‘r’

Trial No.	M S R cm	V S R	D = M S R + V S R×L C cm	Mean diameter ‘D’ cm	Mean radius r = D/2 cm

Thickness ‘h’

Trial No.	M S R cm	V S R	h = M S R + V S R×L C cm	Mean thickness ‘h’ cm

Mass of the brass disc, M = ………. kg

Specific heat capacity, c = ……….. J/kg.K

Steady temperature of the steam chamber, θ_1= ………°C

Steady temperature of the brass disc, θ_2 = ………°C

To find $\left(\dfrac{d\theta}{dt}\right)_{\theta_2}$

Temperature																				
Time																				
Temperature																				
Time																				
Temperature																				
Time																				

Calculation

Rate of cooling of brass disc at the temperature θ_2, = $\left(\dfrac{d\theta}{dt}\right)_{\theta_2}$ = ……… K/s

Thermal conductivity,

$$\lambda = \frac{Mc}{\pi r^2}\left(\frac{d}{\theta_1 - \theta_2}\right)\left(\frac{d\theta}{dt}\right)_{\theta_2}\left(\frac{r+2h}{2r+2h}\right)$$

= ……………………………….

= ………. $Wm^{-1}K^{-1}$

Result

Thermal conductivity of the given ………… disc = ………. $Wm^{-1}K^{-1}$

Physical constants and data

Specific heat capacity of brass = 370 J/(kg.K)

Exp.No.1.10

Newton's law of cooling- Specific heat of a liquid

Aim: To determine the specific heat capacity of a liquid by the method using Newton's law of cooling.

Apparatus: A spherical calorimeter, a thermometer, stop clock, given liquid, water, etc.

Theory: Newton's law of cooling states that the rate of cooling of a body is proportional to the mean difference of temperature between the body and its surroundings. If θ_1 is the initial temperature of the body, θ_2 is the temperature after a time 't' seconds and θ_0 be the temperature of the surroundings we can write,

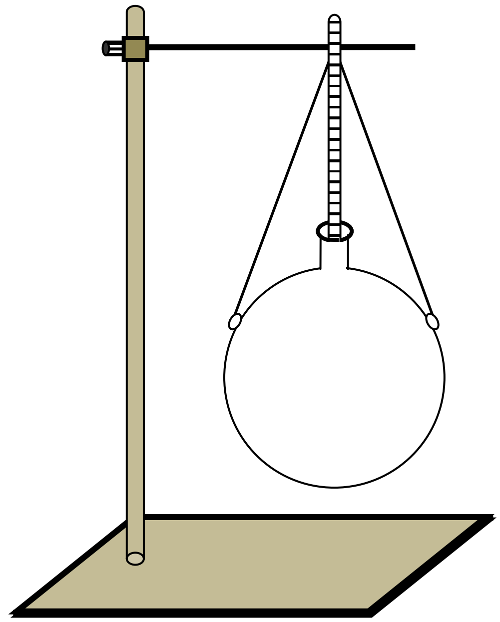


Fig.a

$$\text{Rate of cooling, } \frac{\theta_1-\theta_2}{t} \propto \frac{\theta_1+\theta_2}{2}-\theta_0 \qquad (1)$$

Since the rate of cooling of the body is proportional to its rate of loss of heat,

$$\frac{Mc(\theta_1-\theta_2)}{t} = K\left(\frac{\theta_1+\theta_2}{2}-\theta_0\right) \qquad (2)$$

where, M is the mass of the body, 'c' is its specific heat capacity and K is a constant.

Let the calorimeter is first filled with hot water. If 't_w' is the time taken by the calorimeter and water to cool from θ_1 to θ_2,

$$\frac{m_c c_c(\theta_1-\theta_2)+m_w c_w(\theta_1-\theta_2)}{t_w} = K\left(\frac{\theta_1+\theta_2}{2}-\theta_0\right) \qquad (3)$$

where, m_c is the mass of calorimeter, c_c is the specific heat capacity of the calorimeter, m_w mass of water and c_w is specific heat capacity of water.

If the calorimeter is filled with the given hot liquid and is allowed to cool from the same range of temperature and 't_l' be the corresponding time taken, we can write,

$$\frac{m_c c_c(\theta_1-\theta_2)+m_l c_l(\theta_1-\theta_2)}{t_l} = K\left(\frac{\theta_1+\theta_2}{2}-\theta_0\right) \qquad (4)$$

where, m_l is mass of liquid and c_l is its specific heat capacity. From eqns.3 and 4,

$$\frac{m_c c_c(\theta_1-\theta_2)+m_l c_l(\theta_1-\theta_2)}{t_l} = \frac{m_c c_c(\theta_1-\theta_2)+m_w c_w(\theta_1-\theta_2)}{t_w}$$

$$\therefore \qquad c_l = \frac{\{m_c c_c+m_w c_w\}\left(\frac{t_l}{t_w}\right)-m_c c_c}{m_l} \qquad (5)$$

Usually $\frac{t_l}{t_w}$ is determined by plotting the cooling curves for water filled calorimeter and liquid filled calorimeter as shown in the fig.b.

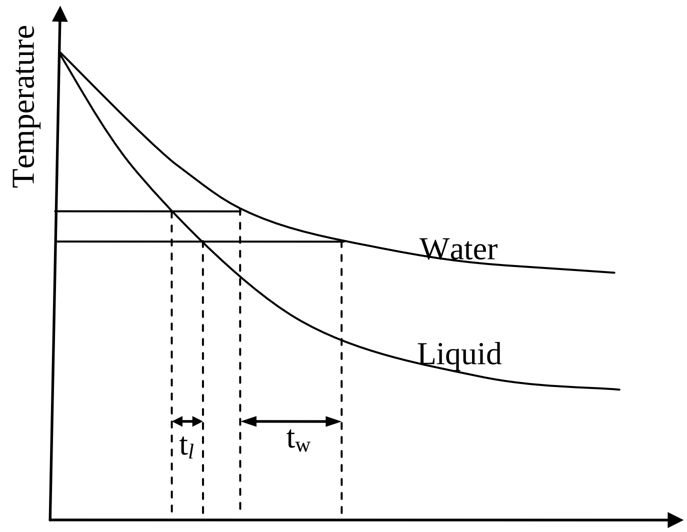


Fig.b

Procedure: The mass m_c of a clean dry spherical calorimeter is determined by a common balance. It is then almost filled with hot water of temperature nearly 90°C. It is then suspended in air as shown in fig.a. A sensitive thermometer is inserted in the calorimeter. When the temperature falls to 80°C, start a stop watch and the time temperature observations are made at regular intervals of temperature or time. (The time may be noted at a regular fall of temperature of 1°C till the temperature falls to about 60°C or the temperature may be noted at a regular interval of half a minute till the temperature falls to 60°C. The first method is advised since the time measurement is more sensitive than the temperature measurement). Let the calorimeter is cooled to room temperature. Then the mass of the calorimeter and water is determined. Let it be m_2.

The water is poured out and the calorimeter is dried. It is then filled with the hot liquid and the time-temperature observations are made for the same temperature range (80°C to 60°C) as in the case of water. The calorimeter is again cooled to room temperature and the mass of calorimeter plus liquid, m_3, is determined.

The time-temperature observations are plotted on the same graph paper as shown in fig.b. Find out $\frac{t_l}{t_w}$ for different temperature ranges and its average is calculated. Finally, the specific heat capacity of the given liquid is calculated using eqn.5.

Observation and tabulation

Temperature		80	79	78	77	76	75	74	73	72	71	70
Time in minutes and seconds	water											
	Liquid											
Temperature		69	68	67	66	65	64	63	62	61	60	
Time in minutes and seconds	water											
	Liquid											

Temperature		80	79	78	77	76	75	74	73	72	71	70
Time in seconds	water											
	Liquid											
Temperature		69	68	67	66	65	64	63	62	61	60	
Time in seconds	water											
	Liquid											

To find $\frac{t_l}{t_w}$

Sl.No	Range of temperature	Time of cooling in seconds		$\frac{t_l}{t_w}$
		Water	Liquid	

Mean ………

To find masses of calorimeter, water and liquid

Load in the pans of the balance		Turning points		Resting point	Sensibility $S = \frac{0.01}{R_0 \sim R_1}$	Correct weight $m = W+S(R-R_0)$ gm
left	Right W (gm)	Left (3)	Right (2)			
Nil	Nil			$R_0 = \ldots$		
Nil	0.01			$R_1 = \ldots$		
Empty calorimeter				$R = \ldots$		$m_1 = \ldots\ldots$
Calorimeter + water				$R = \ldots$		$m_2 = \ldots\ldots$
Calorimeter + liquid				$R = \ldots$		$m_3 = \ldots\ldots$

Mass of calorimeter, $m_c = m_1$ = …….. gm = ………. kg.

Mass of water, $m_w = m_2 - m_1$ = …….. gm = ………. kg.

Mass of liquid, $m_l = m_3 - m_1$ = …….. gm = ………. kg.

Specific heat capacity of (copper) calorimeter, c_c = ………. $Jkg^{-1}K^{-1}$

Specific heat capacity of water, c_w = ………. $Jkg^{-1}K^{-1}$

Specific heat capacity of liquid, $$c_l = \frac{\{m_c c_c + m_w c_w\}\left(\frac{t_l}{t_w}\right) - m_c c_c}{m_l}$$

= ………………………..

= ……… $Jkg^{-1}K^{-1}$

Result

Specific heat capacity of liquid, c_l = …….. $Jkg^{-1}K^{-1}$

*Standard data

Specific heat capacity of water = 4190 $Jkg^{-1}K^{-1}$

Specific heat capacity of copper = 385 $Jkg^{-1}K^{-1}$

Exp.No.1.11

Spectrometer - Refractive index of the material of a prism

Aim: To determine the refractive index of the material of the prism by finding out the angle of minimum deviation.

Apparatus: Spectrometer, sodium vapor lamp, prism, reading lens etc.

Theory: For a given prism, corresponding to a given angle of deviation there are two possible angles of incidence i_1 and i_2. These two angles are such that if one of the angles is the angle of incidence, the other angle will be the angle of emergence.

Let i_1 and i_2 be the two angles of incidence and r_1 and r_2 be the corresponding angles of refraction for the given angle of deviation d. Then,

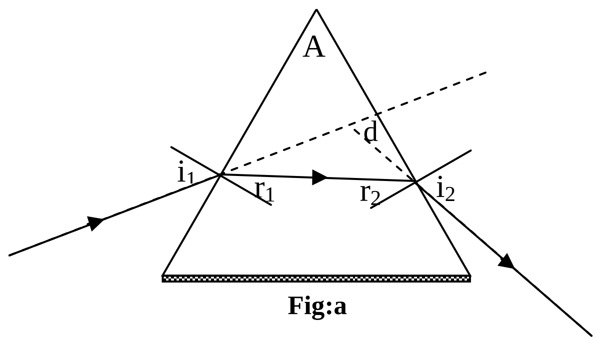


Fig:a

$$i_1 + i_2 = A + d \qquad (1)$$

$$r_1 + r_2 = A \qquad (2)$$

Fig.b gives the variation of angle of deviation d with angle of incidence i. When the angle of deviation is minimum, $i_1 = i_2 = i$, $r_1 = r_2 = r$ and $d = D$. Then, from eqn.1 we get,

$$2i = A + D \qquad (3)$$

$$i = \frac{A+D}{2} \qquad (4)$$

From eqn.2,

$$r = \frac{A}{2} \qquad (5)$$

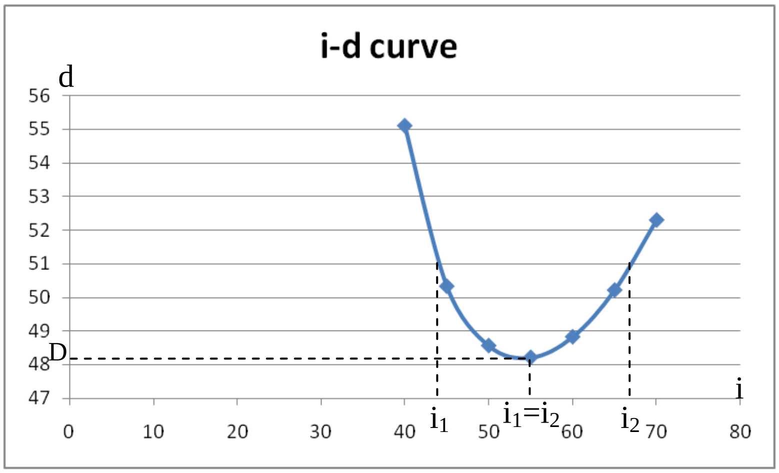


Fig.b : i-d curve for an equilateral prism of $\mu = 1.62$

Refractive index of the material of the prism, $$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)} \qquad (6)$$

Procedure: The following **preliminary adjustments** of the spectrometer are to be made.

1. Turn the telescope to the white wall. Hold the telescope with left hand firmly. By looking through the eye piece, it alone is pushed in or pulled out with right hand till the cross wire is seen clearly.
2. The telescope is then turned towards the distant object and the rack and pinion arrangement is adjusted till the image of the distant object is formed clearly on the cross wire.

3. The telescope is brought in a line with the collimator and sees the image of the slit. If there is no image, check whether the slit is opened.
4. Looking through the telescope, the rack and pinion arrangement of the collimator is adjusted till the image of the slit is seen clearly on the cross wire. (Usually the image is blurred and spread. Focus the collimator till the image is not blurred and its width is minimum).
5. Now adjust the width of the slit, if needed, to a minimum by rotating the slit width adjusting screw.

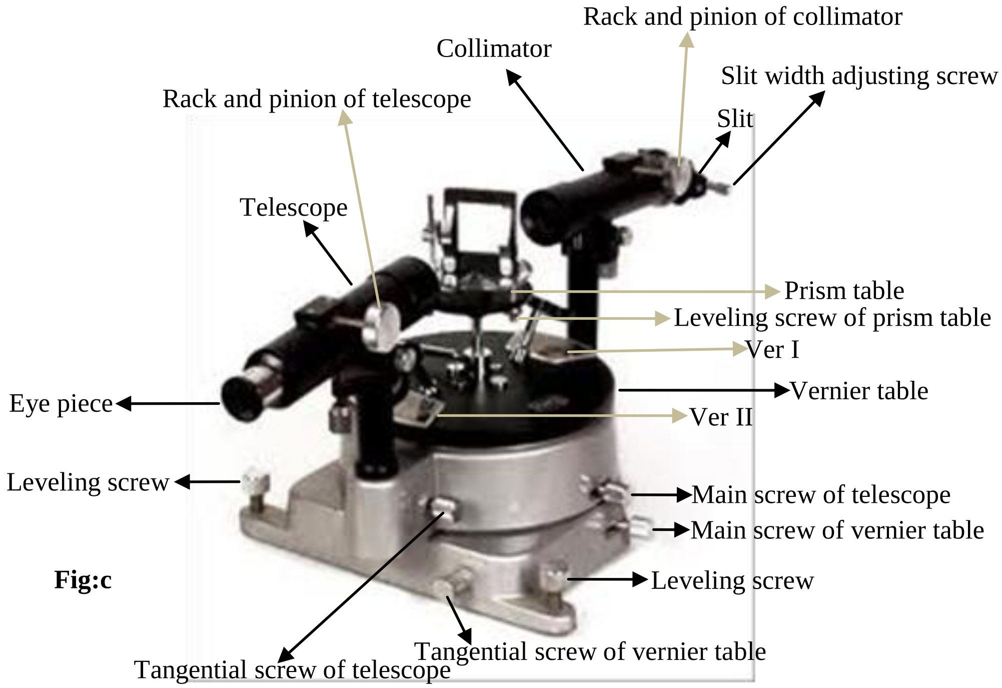


Fig:c

6. The prism table is leveled either by observing the reflected images from both the sides of the prism or by using a spirit level. In the former method, the prism is mounted on the prism table with its base is parallel and close to the clamp. The prism table (or vernier table) is rotated till the refracting edge of the prism is towards the collimator. Turn the telescope and the reflected image from one of the faces of the prism is observed. The two leveling screws on that side of the prism table are adjusted so that the image is bisected by the horizontal cross-wire. Now the telescope is turned to the other side of the prism and the reflected image from the other face is viewed through the telescope. Then the leveling screw on that side of the prism table is adjusted till the image is bisected by the horizontal wire. This process may be repeated once again.

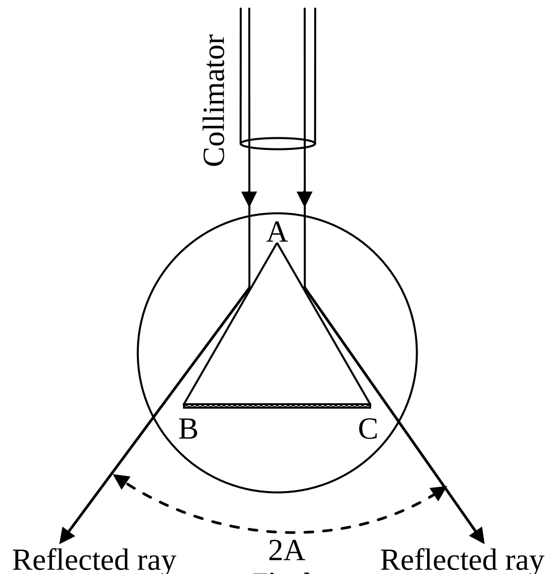


Fig:d

To determine the angle of the prism A: After doing the preliminary adjustments, the telescope is turned towards one side of the prism and the reflected image from that face is viewed through the telescope (refer fig.d). The vernier table and the telescope are clamped by tightening their main screws. The tangential screw of the telescope is adjusted till the reflected ray coincides with the vertical cross-wire. The readings on both the verniers are noted. Now release the telescope and is turned to the other side of the prism till the reflected image from that face is obtained in the telescope. Clamp the telescope there. By adjusting its tangential screw, the reflected image is made to coincide with the vertical cross-wire. The readings on both the verniers are again noted. The difference between the corresponding vernier readings gives the angle of the prism.

To determine the angle of minimum deviation: The vernier table is released and is rotated such that one of the refracting faces is towards the collimator (See fig.e and also fig.c in the next experiment). Looking through the other face with one eye (other eye closed) the vernier table is rotated till the refracted image is seen. Find approximately the position at which the image turns back. Now bring the telescope in the line of the refracted ray and view the refracted image. Looking through the telescope the vernier table is slightly turned to and fro and finds the exact position at which the refracted image just turns back. Now the prism is set for its minimum deviation position. The vernier table and the telescope are clamped at this position by tightening their main screws. Now adjust the tangential screw of the telescope so that the refracted image coincides with the vertical cross wire. The readings on both the verniers corresponding to this position are taken. The prism is now removed and the telescope is brought in the line of the direct ray. After clamping the telescope, its tangential screw is adjusted such that the direct image coincides with the vertical wire. The readings on both the verniers are again taken. The difference between the minimum deviation position reading and the direct reading gives the angle of minimum deviation.

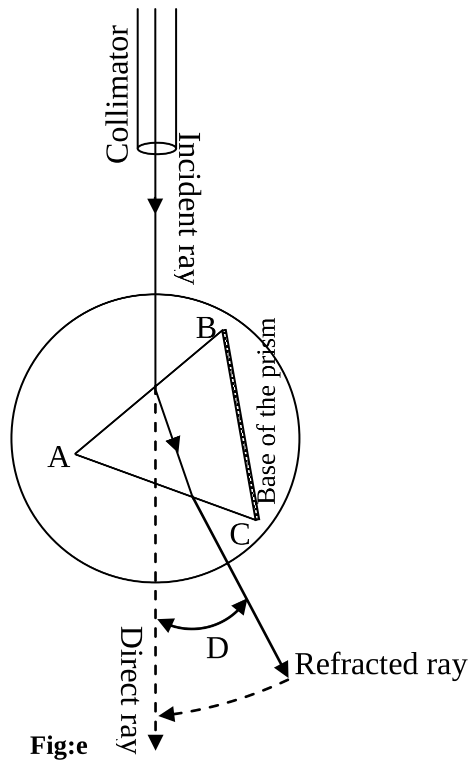


Fig:e

- If the prism table is not properly leveled one may not get the image in the field of view of the telescope. In such a case the reflected images are seen directly with naked eye without using telescope and the approximate leveling is to be done.
- The vernier table and the prism table are initially adjusted at the proper positions (both the verniers are in a line perpendicular to collimator) so that the readings on both the verniers are conveniently taken.
- Reading lens must be used to observe the vernier readings.
- Don’t forget to clamp the vernier table and the telescope after each adjustment. For taking the direct reading, the prism must be removed carefully without any change in the vernier table.
- The removal of the prism to take the direct reading can be avoided if initially the prism table is adjusted to a height such that upper half the light from the slit passes above the

prism and the lower half of light passes through the prism so that we can simultaneously see the direct image and the image formed by the prism.

Observation and Tabulation of data:

Value of one main scale division (1 m s d) = ……………

Number of divisions on the vernier n = ……………

$$\text{Least count (L C)} = \frac{\text{Value of 1 m s d}}{n} = \ldots\ldots\ldots\ldots$$

[One degree = 60 minute, (1° = 60′)]

To determine the angle of the prism A

Reading of the	Ver I			Ver II			Mean	
	M S R	V S R	Total	M S R	V S R	Total	2A	A
Reflected image from first face ‘a’								
Reflected image from second face ‘b’								
Difference between the above readings 2A = a~b				2A = a~b				

To determine the angle of minimum deviation D

Reading of the	Ver I			Ver II			Mean
	M S R	V S R	Total	M S R	V S R	Total	D
Refracted image corresponding to minimum deviation ‘x’							
Direct image ‘y’							
Difference between the above readings D = x~y				D = x~y			

Calculation

Refractive index of the material of the prism,

$$\mu = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \ldots\ldots\ldots$$

$$= \ldots\ldots\ldots$$

Result

Angle of the prism A = ………….

Refractive index of the material of the prism, μ = ………….

Standard data*

Refractive index against air for mean sodium line (589.3 nm)

Crown glass 1.48 ~ 1.61

Flint glass 1.53 ~ 1.96

Exp.No.1.12

Spectrometer-Dispersive power of a prism

Aim: To determine the dispersive power of the material of the prism for different pairs of spectral lines.

Apparatus: Spectrometer, mercury vapor lamp, prism, reading lens etc.

Theory: For a given prism, corresponding to a given angle of deviation there are two possible angles of incidence i_1 and i_2. These two angles are such that if one of the angles is the angle of incidence, the other angle will be the angle of emergence.

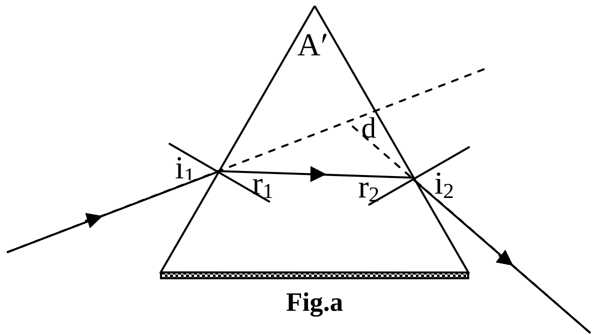


Fig.a

Let i_1 and i_2 be the two angles of incidence and r_1 and r_2 be the corresponding angles of refraction for the given angle of deviation d. Then,

$$i_1 + i_2 = A' + d \qquad (1)$$

$$r_1 + r_2 = A' \qquad (2)$$

Fig.b gives the variation of angle of deviation d with angle of incidence i. When the angle of deviation is minimum, $i_1 = i_2 = i$, $r_1 = r_2 = r$ and $d = D$. Then, from eqn.1 we get,

$$2i = A' + D \qquad (3)$$

$$i = \frac{A'+D}{2} \qquad (4)$$

From eqn.2,

$$r = \frac{A'}{2} \qquad (5)$$

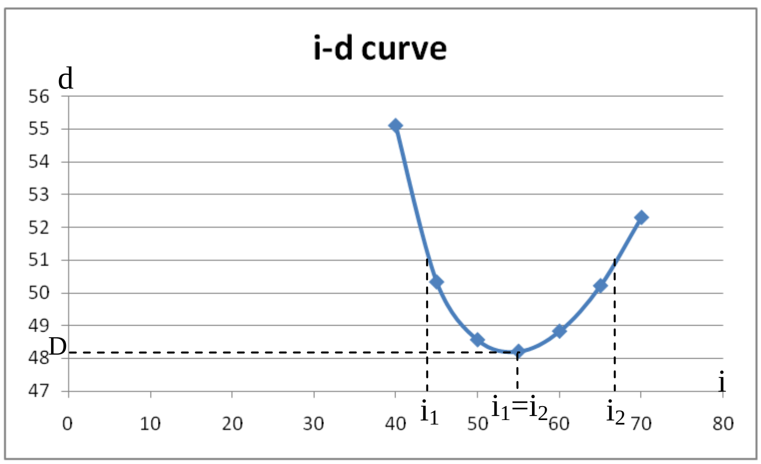


Fig.b : i-d curve for an equilateral prism of $\mu = 1.62$

Refractive index of the material of the prism,

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A'+D}{2}\right)}{\sin\left(\frac{A'}{2}\right)} \qquad (6)$$

The refractive index μ of a material depends on the wavelength of the light. Hence it is a function of wavelength λ. The dispersive power of the material is defined as $\frac{d\mu}{d\lambda}$. By Cauchy's relation,

$$\text{Refractive index,} \quad \mu = A + \frac{B}{\lambda^2} \qquad (7)$$

where, A and B are constants.

$$\text{Dispersive power, } \omega = \frac{d\mu}{d\lambda} = -\frac{2B}{\lambda^3} \tag{8}$$

Since the dispersive power varies inversely with cube of the wavelength, it is different at different wavelength region. If μ_1 and μ_2 are the refractive indices for the wavelengths λ_1 and λ_2, it can be shown that the dispersive power of the material in that wavelength range as,

$$\omega_{12} = \frac{\mu_2 - \mu_1}{\mu - 1}, \text{ where, } \mu = \frac{\mu_2 + \mu_1}{2} \tag{9}$$

Procedure: All the procedures are same as that for the previous experiment. Instead of a sodium lamp we use a mercury lamp in this case. The refracted spectrum consists of a number of spectral lines of different colours (wavelengths). The prism is adjusted to be in the minimum deviation position for each line and the corresponding angle of minimum deviation is determined as described in the previous experiment. Using eqn.9 the dispersive powers for different pairs of wavelengths (refractive indices) are calculated.

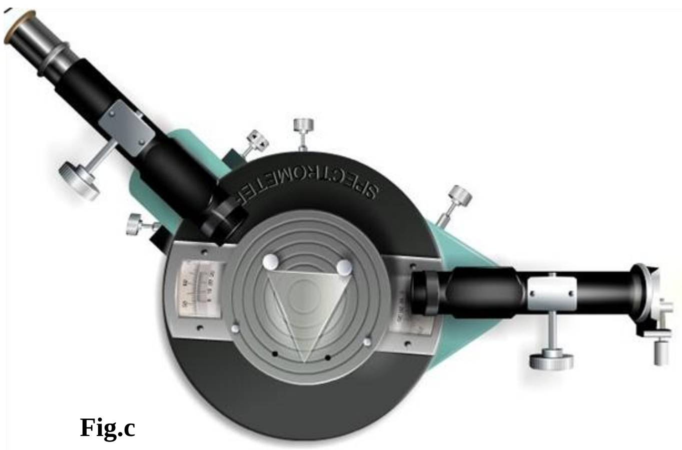


Fig.c

Observation and tabulation

Value of one main scale division (1 m s d) = ……………

Number of divisions on the vernier n = ……………

$$\text{Least count (L C)} = \frac{\text{Value of 1 m s d}}{n} = \ldots\ldots\ldots\ldots$$

[One degree = 60 minute, $(1° = 60')$]

Angle of the prism A'

Readings of the	Ver I			Ver II			Mean $2A'$	A'
	M S R	V S R	Total	M S R	V S R	Total		
Reflected image from first face ‘a’								
Reflected image from second face ‘b’								
Difference between the above readings $2A' = a\sim b$				$2A' = a\sim b$				

Determination of refractive indices for various colours

Colours of spectral lines	Reading corresponding to the minimum deviation position of the refracted rays ‘x’						Reading corresponding to the direct ray ‘y’						Angle of minimum deviation D = x~y			μ
	Ver 1			Ver II			Ver 1			Ver II						
	M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	Ver I	Ver II	Mean	

Calculation

(1) Dispersive power of ………… and ……….. colours.

Refractive index of ………… colour, μ_1 = ………

Refractive index of ………… colour, μ_2 = ………

Dispersive power, $\omega_{\dots\ \dots}$ = ………. = ………

(2) Dispersive power of ………… and ……….. colours.

Refractive index of ………… colour, μ_1 = ………

Refractive index of ………… colour, μ_2 = ………

Dispersive power, $\omega_{\dots\ \dots}$ = ………. = ………

(3) Dispersive power of ………… and ……….. colours.

Refractive index of ………… colour, μ_1 = ………

Refractive index of ………… colour, μ_2 = ………

Dispersive power, $\omega_{\dots\ \dots}$ = ………. = ………

Result

Dispersive power of ………… and ……….. colours = …….

Dispersive power of ………… and ……….. colours = …….

Dispersive power of ………… and ……….. colours = …….