

Experiment No. : 01(Group-1)

DETERMINATION OF THERMAL CONDUCTIVITY OF A GOOD CONDUCTOR BY SEARLE'S METHOD

I. Objective(s):

To determine the thermal conductivity of a good conductor by Searle's method.

II. Apparatus:

Searle's set-up, Thermometers, Measuring cylinder, Steam source, Continuous water flow system etc.

III. Theory:

Thermal conductivity of a material is defined as “the amount of heat flowing per unit time across one square unit of cross sectional area of one unit thickness (length) with one degree temperature difference between the faces across which heat is assumed to flow perpendicularly”.

In steady state condition, the amount of heat passing across the material normally per

unit time is given by- $dQ = \frac{KA(\theta_1 - \theta_2)}{d}$ (1)

Where **d** is the thickness (length) of the good conductor, **A** is the cross sectional area of the good conductor, **θ₁** and **θ₂** are the temperature recorded by the thermometers **T₁** and **T₂** respectively. **K** is the thermal conductivity of the given good conductor.

If '**m**' grams of water flows through the good conductor per seconds and **θ₃** and **θ₄** are the steady state temperatures recorded for out flowing and inflowing water respectively, the amount of heat '**dQ**' taken by water per unit time is given by

$$dQ = m(\theta_3 - \theta_4) \dots\dots\dots(2)$$

By equation (1) and (2), we get

$$K = \frac{m(\theta_3 - \theta_4)d}{A(\theta_1 - \theta_2)} \quad \text{or,} \quad K = \frac{4m(\theta_3 - \theta_4)d}{\pi D^2(\theta_1 - \theta_2)} \dots\dots\dots(3)$$

Where, cross sectional area of the good conductor bar $A = \frac{\pi D^2}{4}$, **D** is the diameter. In C.G.S. the unit of Thermal conductivity is Cal/cm/sec/°C.

IV. Experimental Set-up:

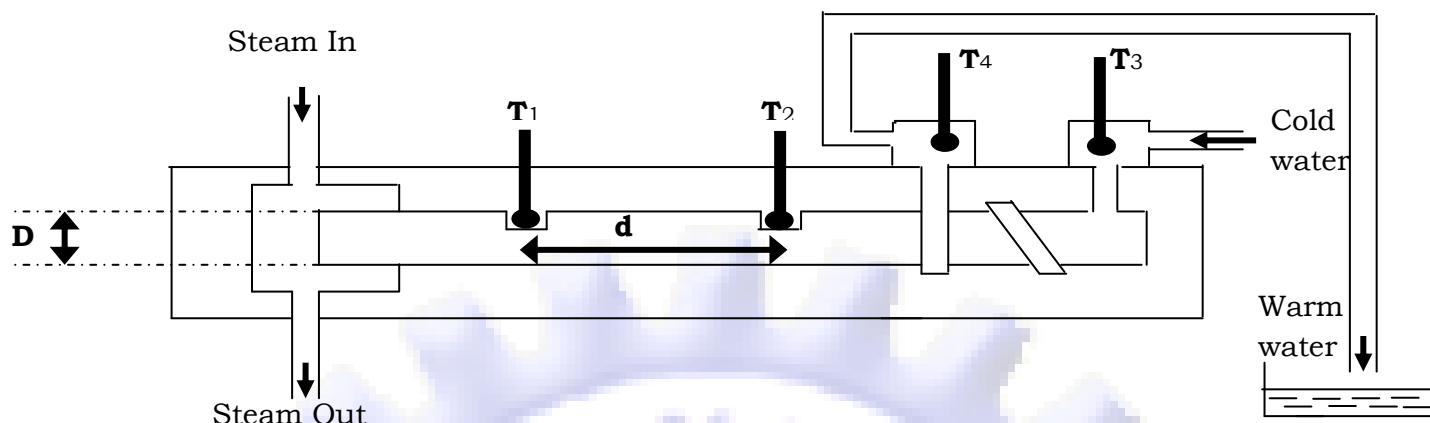


Fig.1: Searle's Experimental Set-up

V. Procedure:

- (i) Heat is allowed to flow through the good conductor bar by means of steam in one end and a current of cold water is allowed to flow spirally in the other end from a constant level of water.
- (ii) The flow of cold water is adjusted by means of a pinch cork so that the temperature difference between θ_4 and θ_3 is about 10°C . The temperature difference is maintained steadily by regulating the flow of cold water with pinch cork.
- (iii) When the temperature of T_3 and T_4 are steady, and then collect the water from outlet end by means of a measuring cylinder for at least 5 minutes. During the collection of water the temperatures of T_1 , T_2 , T_3 and T_4 are recorded.
- (iv) Find out the mass of the collected water per second by multiplying the volume with density of the water at that temperature.
- (v) Repeat (iii) and (iv) at least five times.

VI. Experimental Observations:

Thickness (length) of the good conductor bar (d) = (cm)

Diameter of the cross sectional area of the good conductor bar (D) = (cm)

Table – 1
Time Temperature data

Time (minutes)	Temperature in $^{\circ}\text{C}$				Temperature Differences ($^{\circ}\text{C}$)	
	$T_1 (\theta_1)$	$T_2 (\theta_2)$	$T_3 (\theta_3)$	$T_4 (\theta_4)$	$(\theta_1 - \theta_2)$	$(\theta_3 - \theta_4)$
0						
5						
10						
15						
20						
25						
30						
35						
40						
45						
50						
55						
60						

Table – 2
Mass of Water Collection Data

 Temperature of water collected (t) = $^{\circ}\text{C}$

 Density of water at t $^{\circ}\text{C}$ =gm/cc

No. of Observations	Time of Collection (sec)	Vol. of collected water (V) in c.c.	Mass of water collected per second (M) = $V \cdot \rho / \text{time}$ (gm)	Mean of M (gm)
1.				
2.				
3.				
4.				
5.				
6.				

From Table 1 & 2, we can calculate the thermal conductivity of the good conductor by using equation (3).

The Conductivity of the Good Conductor is **K =Cal/cm/sec/ $^{\circ}\text{C}$**

VII. Error Calculation:

$$K = \frac{4m(\theta_3 - \theta_4)d}{\pi D^2(\theta_1 - \theta_2)}$$

The maximum error is given by

$$\left(\frac{\partial K}{K}\right)_{\max} = \frac{\partial d}{d} + \frac{\partial m}{m} + \frac{2\partial D}{D} + \frac{\partial(\theta_3 - \theta_4)}{(\theta_3 - \theta_4)} + \frac{\partial(\theta_1 - \theta_2)}{(\theta_1 - \theta_2)}$$

The maximum % error is given by

$$\left(\frac{\partial K}{K}\right)_{\max} \times 100\% = \left[\frac{\partial d}{d} + \frac{2\partial D}{D} + \frac{2\partial\theta}{(\theta_3 - \theta_4)} + \frac{2\partial\theta}{(\theta_1 - \theta_2)} \right] \times 100\%$$

VIII. Discussion(s):

- (i) The water flow through the good conductor must be steady in nature. To ensure it the upper level of water in the reservoir should remain always constant.
- (ii) The temperature difference between the thermometers T_1 , T_2 , T_3 and T_4 should be of same order of magnitude.
- (iii) The temperature difference ($T_4 - T_3$) between the inflowing and outflowing water should not exceed 10°C , otherwise the error due to thermometers T_1 and T_2 will be very high.

Experiment No. : 02 (Group-1)

DETERMINATION OF THERMAL CONDUCTIVITY OF A BAD CONDUCTOR IN THE FORM OF DISC BY LEE'S AND CHORLTON'S METHOD

I. Objective:

To determine the thermal conductivity of a bad conductor by Lee's and Chorlton's method

II. Apparatus:

Lee's apparatus, steam chamber, two thermometer, Bunsen burner, circular disc of bad conductor (rubber, wood) etc.

III. Theory:

Let θ_1 and θ_2 be the steady state temperatures recorded by the thermometers T_1 and T_2 respectively (see Fig.1) and K be the thermal conductivity of the bad conducting disc S. If d is the thickness and A is the cross sectional area of the disc S, then the quantity of heat conducted through the disc per second is given by

$$Q = KA (\theta_1 - \theta_2) / d$$

If m is the mass, s is the specific heat and $d\theta/dt$ is the rate of cooling at θ_2 of the lower metal slab B, then

$$Q = ms \, d\theta/dt \text{ at } \theta_2$$

$$\text{So, } KA (\theta_1 - \theta_2) / d = ms \, d\theta/dt \text{ at } \theta_2$$

$$\text{Or, } K = ms \frac{d}{A(\theta_1 - \theta_2)} \frac{d\theta}{dt} \dots\dots\dots(1)$$

This is the working formula.

If m is measured in gm, $d\theta/dt$ in $^{\circ}\text{C}$ per sec and s is given in cal/gm. $^{\circ}\text{C}$ then Q is obtained in cal per sec. Again, when d is measured in cm, A in cm^2 , θ_1 and θ_2 in $^{\circ}\text{C}$ then K is given in $\text{cal. sec}^{-1}.\text{cm}^{-1} .^{\circ}\text{C}^{-1}$.

[Note: In the present method, the rate of cooling of the lower disc B is determined without the experimental disc S on it. So to obtain the correct value of $d\theta/dt$ at θ_2 under the condition of experiment, the quantity $d\theta/dt$ should be multiplied by a factor f given by $f = (r+2d_1) / (2r+2d_1)$. Where r and d_1 are the radius and thickness of the metal disc B respectively. This correction is called the Bedford correction. Thus -

$$K = ms \frac{d}{A(\theta_1 - \theta_2)} \frac{d\theta}{dt} \times \frac{r + 2d_1}{2r + 2d_1} \dots\dots\dots(2)$$

IV. Schematic Diagram:

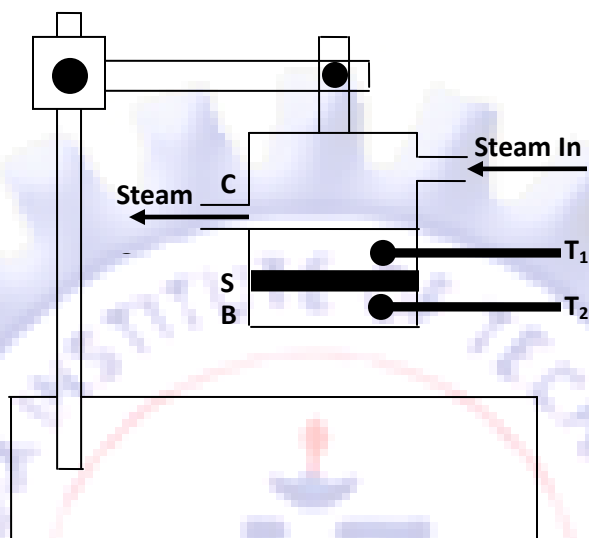


Fig.1: Bad Conductor Experimental Set-up

V. Procedure:

1. Connect the chamber to a distant boiler. Record the temperatures of C and B at intervals of 5 minutes until the thermometers show steady state temperature for a period of at least 10 to 15 minutes, and note the steady state temperatures θ_1 and θ_2 .
2. Remove the steam chamber and experimental disc. Heat the metal slab B slowly by means of a heat source and simultaneously observe the temperature. Raise the temperature to a value which is about 12°C higher than the steady value θ_2 noted in step 1. Do not raise the temperature beyond the upper limit of the thermometer T_2 .
3. Remove the heating source. Temperature of B will start decreasing. When the temperature reaches a value roughly 10°C above its steady temperature θ_2 , record the temperature with time by means of a stop watch at intervals of quarter a minute until temperature falls below θ_2 by about 10°C .
4. Draw a graph by plotting the temperature of cooling θ (in $^\circ\text{C}$) of B along Y -axis and the corresponding time (sec.) along X -axis. The graph will be a non-linear curve line. Draw a tangent to the curve around θ_2 and then find $d\theta/dt$ around θ_2 .

VI. Experimental Observations:

Mass (m) of the lower disc B = gm

Specific heat (s) of B =cal/gm. °C

Radius (r) and the cross sectional area (A) of the disc S: r =cm, A =cm²

Thickness (length) (d) of S =cm

Table 1

Temperature of C and B with time and the values of steady state temperatures θ_1 and θ_2

Time in minutes	0	5	10	15	20	25	30	35	40
Temp. of C (°C)									
Temp. of B (°C)									

Table 2

Record of temperature of B with time during cooling

Time in Sec.	0	15	30	45	60	75	90	105	120	135	150	165	180	195
Temp. of C (°C)														

Graph Plotting:

Draw a graph with t along X-axis and θ along Y-axis. Find $d\theta/dt$ at θ_2 from the graph.

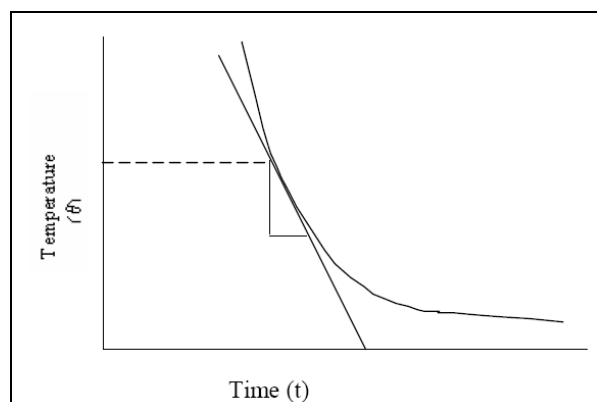


Fig.2: Temperature vs. time curve to determine $d\theta/dt$.

Table 3

Determination of K from graph

m (gm)	s (cal.gm ⁻¹ .cm ⁻¹)	d (cm)	$d\theta/dt$ at θ_2 (°C.sec)	A (cm ²)	$\theta_1 - \theta_2$ (°C)	K (cal.sec.cm ⁻¹ .°C ⁻¹)

VII. Computation of percentage error:

We have, $K = ms \frac{d\theta}{dt} \text{ (at } \theta_2) \cdot d / A(\theta_1 - \theta_2)$

If the lower disc B cools by radiation from θ' °C to θ'' °C through in time t , we can write $\frac{d\theta}{dt} \text{ (at } \theta_2) = (\theta' - \theta'')/t$. Also $A = \pi r^2$. Hence

$$K = \{msd (\theta' - \theta'')/t\} / \{\pi r^2(\theta_1 - \theta_2)\}$$

The maximum proportional error in K is, therefore,

$$\delta K/K = \delta m/m + \delta d/d + \delta(\theta' - \theta'')/(\theta' - \theta'') + \delta t/t + 2\delta r/r + \delta(\theta_1 - \theta_2)/(\theta_1 - \theta_2) + \delta s/s$$

Since m , r , d and s are supplied, thus $\delta m = \delta d = \delta s = \delta r = 0$

Thus, the maximum percentage error is given by

$$(\delta K/K) \times 100 \% = [\delta(\theta' - \theta'')/(\theta' - \theta'') + \delta t/t + \delta(\theta_1 - \theta_2)/(\theta_1 - \theta_2)] \times 100\%$$

VIII. Discussions:

Write discussions in your word in points.

Experiment No. : 04 (Group-1)

MEASUREMENT OF RESISTANCE PER UNIT LENGTH OF THE BRIDGE WIRE BY CAREY FOSTER'S METHOD AND HENCE TO DETERMINE THE UNKNOWN RESISTANCE

I. Objectives:

To determine the resistance per unit length of the bridge wire by Carey Foster method and hence to determine the unknown resistance.

II. Apparatus:

1. A meter bridge with four gaps (Carey Foster Bridge)
2. Two equal resistances (say 1 ohm each)
3. A fractional resistance box (0.10 to 10.00 ohm).
4. A DC power supply (apply 2 V only).
5. A table galvanometer (range 30-30 mV, 1 smallest div=.....mV).
6. A plug commutator.
7. Connecting wire.
8. Unknown resistance (in ohm).

III. Circuit diagram:

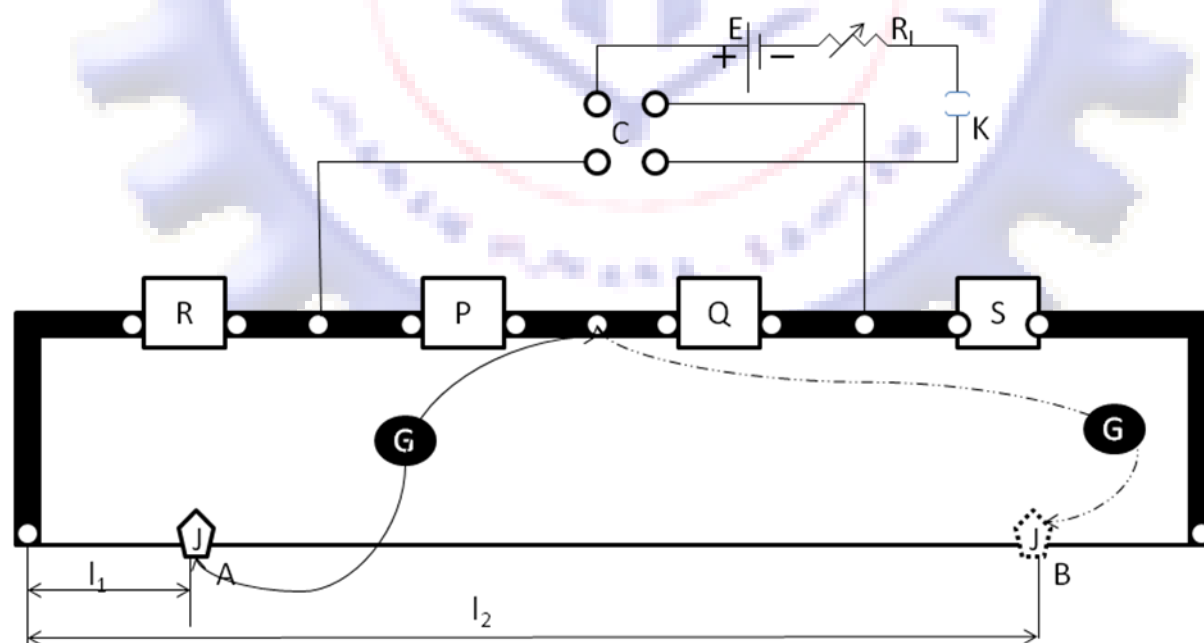


Figure-1: Circuit connection of a Carey Foster's bridge

[Here P & Q are two nearly equal resistances (each of one ohm); S is a metal strip having zero resistance, R is the fractional resistance box; E is a D.C regulated power supply; C is a Commutator, R₁ is a rheostat in the battery circuit; G is a galvanometer]

IV. Theory:

When the Carry Foster's bridge is balanced condition, let the null point be l_1 cm from the left end of the bridge wire, then from Wheatstone bridge principle, we can write -

$$\frac{P}{Q} = \frac{R + \alpha + l_1 \rho}{S + \beta + (100 - l_1) \rho} \quad (1)$$

Where α and β are the end connections at the two ends of the bridge wire and ρ is the resistance per unit length of the bridge wire.

If by interchanging R & S in the circuit, the null point is obtained at l_2 cm from the same end, then

$$\frac{P}{Q} = \frac{S + \alpha + l_2 \rho}{R + \beta + (100 - l_2) \rho} \quad (2)$$

Solving these two equations, we get

$$\rho = \frac{R - S}{l_2 - l_1} \quad (3)$$

Since the strip has almost zero resistance (*i.e.* S=0), then

$$\rho = \frac{R}{l_2 - l_1} \quad (4)$$

Again, if the fractional resistance box 'R' is inserted in the extreme right gap and strip 'S' in the extreme left gap at first and their positions are interchanged, giving l_1 and l_2 as the null point lengths, then

$$\rho = \frac{R}{l_1 - l_2} \quad (5)$$

Therefore in general the working formula of this experiment is

$$\rho = \frac{R}{l_2 - l_1} \quad (6)$$

Determination of the unknown resistance: Let the given metal strip S be replaced by a known resistance r and R be replaced by the given wire whose resistance is unknown. Suppose that the unknown resistance of the given wire is R_x and that l_1 is the distance of the null point from the left end of the bridge wire obtained with this circuit. Let l_2 be the distance of the null point from the same end obtained with circuit, when r and R_x are interchanged. Then using equation (3) we get -

$$R_x = r + \rho(l_2 - l_1) \quad (7)$$

Equation (6) and (7) are the working formulas of the experiment.

V. Procedure:

1. Make the circuit connections as shown in the figure 1. The fractional resistance box is connected in the extreme left gap and strip in the extreme right gap. Close tightly all the plugs of the box and observe the null point. The null point should be obtained near middle of the bridge wire; if not, the resistance P & Q are unequal.
2. Take out a plug to insert a small resistance (say 1 ohm) from the box R. Note the null point readings for both direct and reverse currents. The null point l_1 should be located towards the left end of the bridge wire. Increase gradually the resistance R (say, 1.2Ω, 1.4Ω, 1.6Ω etc) and each time record the null points for both direct and reverse currents till end of the bridge wire approached.
3. Interchanged the copper strip 'S' and resistance box R. Put those resistance serially from the box which were used before, i.e. in step(ii) and record the null points l_2 in the previous manner. In this case, the null points will be located between the midpoint and right end of the bridge.
4. Find the value of ρ of the bridge wire from each set of reading using equation (6) and obtain the mean ρ .
5. Repeat the same with replacing R by R_x and S by r (known resistance).

VI. Experimental Observation(s):

Table-1

 Determination of ρ of the bridge wire for $P = Q = 1 \text{ Ohm}$

No of Obs.	Resistance in the extreme		Position of null point for (cm)			$(l_2 - l_1)$ cm	$\rho = \frac{R}{l_2 - l_1}$ Ohm /cm	Mean ρ Ohm /cm
	Left gap (Ω)	Right gap (Ω)	Direct Current	Reverse current	Mean			
1	R(1)	0			$l_1 = \dots$			
	0	R(1)			$l_2 = \dots$			
2	R(1.2)	0						
	0	R(1.2)						
3								
4								

Table-2

 Determination of unknown resistance for $P = Q = 1 \text{ Ohm}$
 $r = \dots \text{ Ohm}, \rho = \dots \text{ Ohm/cm}$

No of Obs.	Resistance in the extreme		Position of null point for (cm)			$(l_2 - l_1)$ cm	$R_x = r + \rho(l_2 - l_1)$ Ohm	Mean R_x Ohm
	Left gap (Ω)	Right gap (Ω)	Direct Current	Reverse current	Mean			
1	r(1)	0			$l_1 = \dots$			
	0	r(1)			$l_2 = \dots$			
2	r(1.2)	0						
	0	r(1.2)						
3								
4								

VII. Calculations:

$$\rho_1 = \frac{R}{l_2 - l_1} = \dots \text{ Ohm/cm}$$

$$\rho_2 = \frac{R}{l_2 - l_1} = \dots \text{ Ohm/cm etc.}$$

$$\text{Mean } \rho = \frac{\rho_1 + \rho_2 + \dots + \rho_n}{n} = \dots\dots\dots \text{ Ohm/cm}$$

$$R_x = r + \rho(l_2 - l_1) = \dots\dots\dots \text{ Ohm}$$

VIII. Result(s):

The resistance per unit length of the bridge wire (ρ) =.....Ohm/cm

The resistance of the unknown wire =.....Ohm

IX. Error Calculation:

$$\rho = \frac{R}{l_2 - l_1}$$

Hence

$$\frac{\partial \rho}{\rho} = \frac{\partial(l_2 - l_1)}{l_2 - l_1} = \frac{2\partial l}{l_2 - l_1}$$

Since, R is not been measured and $\partial l = 1$ smallest division of the measuring scale.

Thus maximum percentage of error,

$$\frac{\partial \rho}{\rho} * 100\% = \frac{2\partial l}{l_2 - l_1} * 100\%$$

X. Discussion(s):

(i). Before proceeding with the measurements, ensure that there is no loose contact anywhere in the circuit.

(ii). At the beginning, it should be seen whether with $S = R = 0$, the null point is obtained at a point very near at 50 cm mark (*i.e.* the midpoint of the bridge wire). If the null point is obtained more on the right of 50 cm mark, the resistance P is defective. If on the other hand, the null point is more on the left of the of 50 cm mark, the resistance Q is defective.

Experiment No. : 05 (Group-2)

DETERMINATION OF YOUNG'S MODULUS BY FLEXURE METHOD AND CALCULATION OF BENDING MOMENT AND SHEAR FORCE AT A POINT ON THE BEAM

I. Objective(s): To determine the Young's Modulus by Flexure method and calculation of Bending Moment and Shear Force at a point on the beam.

II. Apparatus:

A solid bar, Two stout iron stands, Rectangular stirrup with a knife- edge and a vertical pointer, A traveling microscope, Standard weights, Spirit level, Meter scale, A slide calipers.

III. Theory:

A uniform rectangular bar supported symmetrically on two horizontal and parallel knife-edges is depressed by a load of mass M , suspended from the beam midway between the knife-edges. Then the depression x of the middle of the bar is given by

$$x = \frac{M \cdot g \cdot L^3}{4 b d^3 Y}$$

$$\text{Or, } Y = \frac{M \cdot g \cdot L^3}{4 b d^3 x} = \frac{g L^3}{4 b d^3} \cdot \frac{M}{x}$$

Where, Y = Young's Modulus, L = Length of the bar between the two knife-edges, b = Breadth of the bar, d = Depth of the bar, g = Acceleration due to gravity at laboratory, M = Load suspended at the middle point of the bar, and x = depression at the middle point of the bar,

IV. Experimental Set-up:

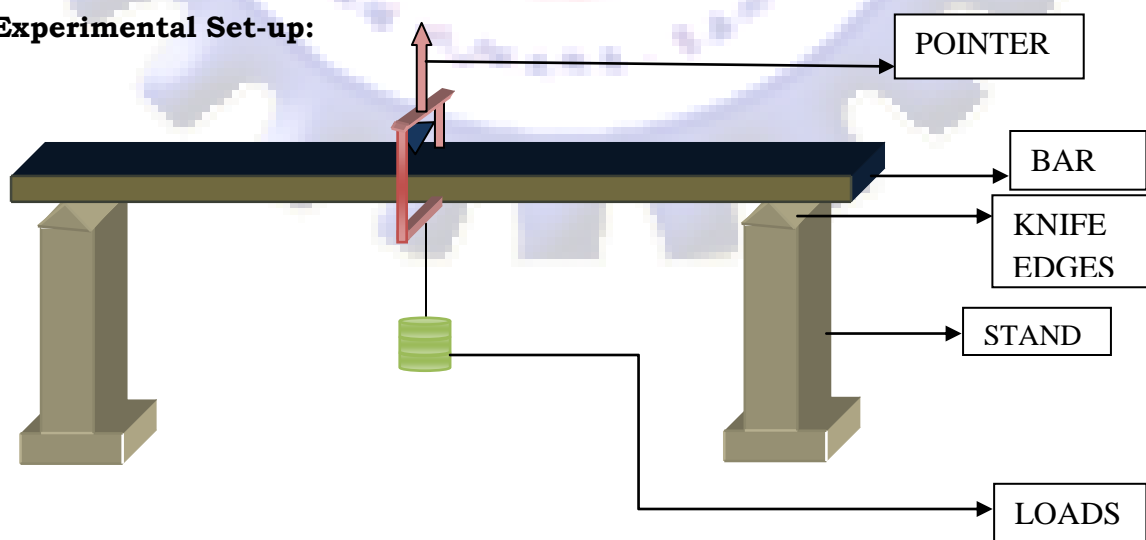


Fig.1: Schematic diagram of Young's Modulus Experiment.

V. Procedure:

1. Measure the breadth and depth of the rectangular bar.
2. Mark the mid-point of the beam with the help of meter scale and chalk.
3. Mark two point symmetrically from the midpoint so that the distance between these two points (L) is the order of 90 cm.
4. Put the beam on the knife-edges. Bring the knife-edges below points marked in step 3. The beam should be placed so that the shorter dimension on remains vertical. Bring the hanger on the midpoint of the beam.
5. Focus the traveling microscope on the indicator of the hanger. Take the reading of the vertical scale. This is the depression with no load.
6. Apply the 0.5 kg load and find the shifted reading of the indicator.
7. Increase the load up to 2.5 kg on steps of 0.5 kg and take readings of the indicator in each case.
8. Reduce the loads in step of 0.5 kg and take readings.
9. Determine the average of the position of the indicator while the load is increasing and when it is decreasing.
10. Determine the difference of position at each value of load with respect to no load. This gives the depression corresponding to the load.
11. Plot a graph of depression vs. load. This should be a straight line passing through the origin. Taking slope of the graph, find Young's Modulus.

VI. Experimental Observation(s):
Table -1
To determine the Vernier Constant (V.C.) of the Traveling Microscope.

Value of one Smallest Main Scale Division (m) cm	Total Number of Vernier Scale Division (n)	Vernier Constant (m/n) cm

Table-2
Load-Depression data
Distance between the knife-edges (L) = cm

No. Of Obs.	Load (M) Kg	Microscopic reading for increasing load			Microscopic reading for decreasing load			Mean Reading (cm) $\frac{1}{2}(d_1 + d_2)$	Depression (x) (cm)
		Main Scale (cm)	Vernier	Total (cm) d_1	Main Scale (cm)	Vernier	Total (cm) d_2		
1.	0							(a)	0
2.	0.5							(b)	(a)~(b)
3.	1.0							(c)	(a)~(c)
4.	1.5							(d)	(a)~(d)
5.	2.0							(e)	(a)~(e)
6.	2.5							(f)	(a)~(f)

Note: Repeat table -2 for different values of L
Table-3
Measurement of the breadth (b) and depth (d) of the bar
Vernier Constant of the slide calipers=..... cm

Quantity to be Measured	No. Of Obs.	Main scale reading (cm)	Vernier scale reading (cm)	Total reading (cm)	Mean reading (cm)	Instrumental error (if any)	Corrected reading (cm)
Breadth (b)	1.	.....	.....	.....
	2.	.....	.....	.....	.....	.....	.....
	3.	.....	.....	.....
Depth (d)	1.	.....	.....	.....
	2.	.....	.....	.....	.....	.....	.....
	3.	.....	.....	.....

Graph(s): Plot a graph of depression (x) vs. load (M) as shown in Fig.2.

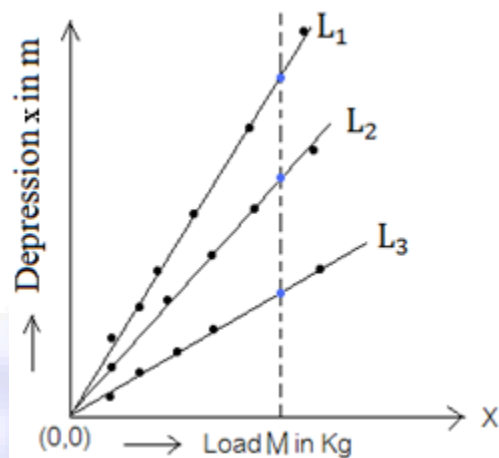


Fig.2: Load-depression curves.

Table-4

Determination of $\frac{ML^3}{x}$ from Load –Depression graph

Chosen value of Load(M) on the Graph (kg)	Length of the bar Between the knife-Edges (L) meter	Depression (x) From the graph (meter)	Value of $\frac{ML^3}{x}$ $kg.m^2$

Table-5

Determination of Y

Value of $\frac{ML^3}{x}$ From table-4 $kg.m^2$	Value of “b” From table-3 (meter)	Value of “d” From table-3 (meter)	Value of “g” m/sec^2	Value of “Y” $Newton/m^2$

Hence, the measured value of Young’s Modulus (Y) of the material of the given bar is

=..... $Newton/m^2$

VII. Maximum proportional error:

$$Y = \frac{g L^3}{4 \cdot b \cdot d^3} \cdot \frac{M}{x}$$

The measured quantities in this experiment are L, b, d, x .

The maximum proportional error in “Y” due to errors in the measurement of L, b, d, x is given by

$$\frac{\delta Y}{Y} = 3 \frac{\delta L}{L} + \frac{\delta b}{b} + 3 \frac{\delta d}{d} + \frac{\delta x}{x}$$

Where δL = one smallest division of the meter scale by which the length of the bar between two knife edges is measured.

$\delta b = \delta d$ = the vernier constant of the slide calipers.

δx = Vernier constant of the traveling microscope.

Now, multiply $\frac{\delta Y}{Y}$ by 100 to obtain the maximum percentage error.

VIII. Discussion(s):

- (i) In the working formula, Young's modulus Y is the function of the cube of length (L) and depth (d), they should be measured very carefully, otherwise a large error will occur in the value of Y .
- (ii) The beam should be made horizontal and the loading should be made exactly at the middle of the bar.
- (iii) As the breaking load of the bar is very high, the maximum load on the hanger is usually far below the breaking load. Hence it is unnecessary to find the breaking load of the bar.
- (iv) To minimize the error in measuring Y , it is available to find Y for three different lengths of the bar and the length of the bar should not be below 80 cm.
- (v) While measuring depression, to avoid back-lash error the microscope screw should allow be rotated in the same direction.
- (vi) After adding a load to the hanger, reading is to be taken after waiting for sometime show that the depression is complete.

Additional information about Young's Modulus Experiment (Some oral questions and answer):

1. What do you mean by the terms beam and cantilever?

Ans. If the length of the rod of uniform cross-section is very long in comparison its breadth, so that shearing stress over any section of the bar may be negligible than that rod is called a *beam*. A bar fixed at one end and loaded at free end is called *cantilever*.

2. How are longitudinal stress and strain produced by bending?

Ans. The upper surface of the bent bar will be concave which will be shorter while the lower surface of the bent bar will be convex and hence this face will be longer than the normal length. This increase and decrease of the length of the bar is due to the force acting along the length of the bar and due to these forces longitudinal forces will be developed.

3. What is neutral surface of the bent beam?

Ans. In between the upper convex and lower concave surface there is layer of the bar which retains its original length. This layer of the bar is called *neutral surface*.

4. What are the (i) geometrical moment of inertia and (ii) flexural rigidity?

Ans. (i) *Geometrical moment of inertia (I)* of a section of the beam is the product of the area (A) of that section and the square of the radius of gyration (K^2) of the section about the line which represent the transverse section of the neutral surface. Thus $I = AK^2$. For a beam of rectangular cross-section $A = b \times d$ and $K^2 = d^2/12$.

(ii) *Flexural rigidity* is measured by $Y \times I$ and it represents external bending moment require to bend the beam so as to produce unit radius of curvature so its natural section.

5. How would you support the beam of given length to produce minimum bending?

Ans. The bar should be supported on depth.

6. What is bending moment?

Ans. When a beam is fixed at one end and loaded at the free end a couple will act on it due to which it will bent. Due to this bending, the length of different layers (excepting neutral layer) will change due to which longitudinal forces will be developed. These forces will be acting on a cross-section of the bar will constitute a couple known as the *bending moment* and measured by the product $(Y \times I)/\rho$ where ρ is the radius of curvature of the neutral of the beam. In the equilibrium condition this bending moment will be equal and opposite to the external bending couple.

7. Define (a) Stress (b) Strain (c) Elastic limit and (d) Young modulus.

Ans. (a) **Stress:** When a body is deformed by the application of external forces the internal reactionary forces will develop per unit area of the body is known as the *stress* and S.I unit of stress is N/m^2 .

(b) **Strain:** Strain is the fractional change of the deformation and as it represents the ratio of two similar quantities, it is a pure number.

(c) **Elastic limit:** The range of deformation over which the body return to its original state when deforming forces are withdrawn, is called *elastic limit*.

(d) **Young's Modulus(Y):** It is the ratio of the longitudinal stress and longitudinal strain and its unit in S.I system is N/m².

8. Will the value of Y change if l, b or d is change?

Ans. No. Y is the property of the material only.

9. Why don't you take into account the depression due to the hanger?

Ans. Depression caused by the weight of hanger cancels out because we measure depression by taking difference of the two readings.

10. Why do you support the beam with smaller dimension (d) in the vertical direction?

Ans. Since depression $\delta \propto \frac{1}{d^3}$, it causes greater depression. If b and d are interchanged δ will be very small.

11. Does the weight of the beam have any effect in the result?

Ans. The weight causes some depression, but since depressions for difference loads are calculated by taking difference of the two readings, the initial depression cancels out. So the weight of the bar does not affects the results.

12. State the Hooke's law.

Ans. Within elastic limit stress is proportional to strain.

$$\text{i.e. } \frac{\text{stress}}{\text{strain}} = k \text{ (constant)}$$

Here k is known as *coefficient of elasticity*.

Experiment No. : 06 (Group-2)

DETERMINATION OF RIGIDITY MODULUS OF THE MATERIAL OF A WIRE BY DYNAMICAL METHOD

I. Objective(s): To determine the rigidity modulus of the material of a wire by dynamical method.

II. Apparatus: A screw gauge, measuring tape, stop watch, slide calipers, rigidity modulus experimental set-up etc..

III. Theory:

Within the elastic limit of a body, the ratio of tangential stress to the shearing strain is called **rigidity modulus** of elasticity. The period (**T**) with which the bob of a torsion pendulum oscillates with its suspension wire as axis, is given by-

$$T = 2\pi \sqrt{\frac{I}{C}}, \text{ or } C = \frac{4\pi^2 I}{T^2} \quad (i)$$

Where, **I** is the moment of inertia of the suspended cylinder about its own axis and is given by

$$I = \frac{1}{2} (\text{Mass}) \cdot (\text{Radius})^2 \quad (ii)$$

Here **C** represents the restoring couple exerted by the suspension wire of length **l** for one radian twist at its free end and is given by,

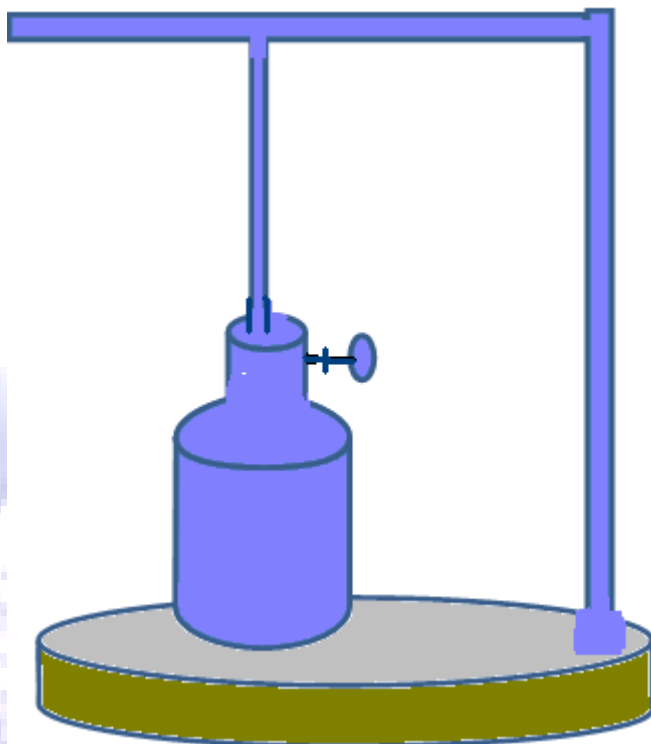
$$C = \frac{n\pi r^4}{2l} \quad (iii)$$

Where **n** is the rigidity of the material of the wire, while **l** and **r** are respectively the length and radius of the suspension wire.

From (i) and (iii) we get

$$\frac{n\pi r^4}{2l} = \frac{4\pi^2 I}{T^2} \text{ or, } n = \frac{8\pi I l}{T^2 r^4} \quad (iv)$$

Calculating **I** from the relation (ii) and by measuring **l**, **r** and **T** experimentally, we can find the rigidity (**n**) of the wire by employing the relation (iv). If **l** and **r** are put in meters, **I** in kg.m² then **n** will be in N/m².

IV. Experimental set-up:**Fig.1: Schematic diagram of Rigidity modulus experimental set-up.****V. Procedure:**

(i) If the cylinder is detachable from the suspension wire, then it should be detached from the suspension wire and its mass (***M***) is to be found out either by a rough balance or by a spring balance, [if this cylinder is not detachable from the suspension wire then its mass (***M***) should be supplied].

(ii) The diameter ***D*** of the cylinder is to be determined by a slide calipers at least in six different places and at each place, the diameter in two perpendicular directions should be found out. The mean of these diameters when halved we get the radius (***R***) of the cylinder. Thus **$R = D/2$** . Knowing the mass ***M*** and the radius ***R*** of the cylinder, its moment of inertia ***I*** about its own axis is calculated by using the formulae **$I = \frac{1}{2} MR^2$** .

(iii) The cylinder is then attached to the lower end of the suspension wire (provided the cylinder is detachable from the suspension wire) and the length ***l*** of wire, from its

point of suspension to the point where the cylinder is attached, is measured by a scale thrice and its mean value is found out.

(iv) The diameter of the suspension wire is measured by a screw gauge at least in eight different places and at each place this diameter is found out in two perpendicular directions. When the mean of these diameters (***d***) is halved and corrected for the instrumental error of the screw gauge we get the mean corrected radius ***r = d/2*** of the suspension wire.

(v) To find the time period ***T*** of a chalk-mark is given on the circular scale just below the pointer when the cylinder is at rest. (if there is no pointer, a vertical line N is marked on the cylinder and is focused by a telescope from a distance such that the line coincides with the vertical cross-wire of the telescope). The cylinder is then twisted by a certain angle and is released to perform torsional oscillations about the vertical axis. The pendulum linear oscillation (if any) should be stopped by leveling the base of the pendulum stand. When the pointer is going towards right by crossing the chalk mark (or when the vertical line of the cross-wire of the telescope) a stop-clock is started and note the total time for 30 complete oscillations. The time for 30 complete oscillations is noted thrice independently and the mean of this time when divided by 30, we get the period (***T***) of oscillation of the cylinder.

(vi) The value of the rigidity ***n*** is then calculated by putting the values of ***I***, ***l***, ***r*** and ***T*** in the relation (iv).

VI. Experimental Observation(s):**(A) Determination of the moment of inertia (I) of the suspended cylinder:**

Mass of the cylinder (M) =gm. =kg.

Table-1

Measurement Diameter (D) of the cylinder by slide calipers:

No. of Obs.	M.S.R.	V.C.	V.S.R.	Diameter of cylinder (m)	Mean Diameter (m)

Moment of Inertia (I): $= \frac{1}{2} MR^2 = \frac{1}{2} M \left[\frac{D}{2} \right]^2 = \dots\dots\dots \text{Kg-m}^2$

(B) Length (l) of the suspension wire from the point of suspension to the point where the cylinder is attached

$l = \frac{\dots + \dots + \dots}{3} = \dots\dots\dots \text{cm} = \dots\dots\dots \text{m}$

Table-2

Measurement of the diameter (d=2r) of the wire by Screw gauge

No. of Obs.	M.S.R.	L.C.	C.S.R.	Diameter of wire (m)	Mean Diameter (m)

Radius of the wire (r) =cm =m

Table-3
Determination of the period (T) of torsional oscillation of the cylinder:

No. of obs.	Time for 30 oscillations (t) in sec	Mean time (t) in sec	Time Period (T) = $\frac{t}{30}$ in sec

VII. Calculations and Result:
VIII. Error Calculation:

We know that-

$$n = \frac{8\pi Il}{T^2 r^4}$$

Or $n = \frac{8\pi Il}{T^2 r^4} = \frac{8\pi \times l}{T^2 r^4} \times \frac{1}{2} M \left(\frac{D}{2} \right)^2$; Where $T = \frac{t}{30}$, t = time for 30 oscillations

Hence maximum proportional error is

$$\left(\frac{\partial n}{n} \right)_{\max} = \left(\frac{\partial l}{l} \right) + \frac{2\partial t}{t} + 4 \frac{\partial r}{r} + \frac{\partial M}{M} + \frac{2\partial D}{D}$$

Where

 $\partial l = 0.2 \text{ cm}$ (Two minimum division of meter scale)

 $\partial t = 2 \times 0.5 \text{ sec}$ (Two division of stop watch-one at the start and another at the stop.)

$\partial r = 0.001$ cm (L.C of screw gauge)

$\partial D = 0.01$ cm (V.C of slide calipers)

As M is large $\left(\frac{\partial M}{M}\right)$ can be neglected. Now putting a typical set of observed data for l, t, r and D we can calculate $\left(\frac{\partial n}{n}\right)_{\max}$

Next multiplying it by 100, we get % error of ' n '.

IX. Discussion(s):

- (i) The pendulum oscillation of the cylinder (if any) should be stopped.
- (ii) Care is to be taken to see that the suspension wire may coincide with the axis of the cylinder.
- (iii) The radius r of the suspension wire occurs in 4th power and hence it should be measured very carefully otherwise a small error in the measurement of r will increase the error in the determination of n by four times.
- (iv) The period (T) of the oscillation should also be measured very carefully for it occurs in the second power in the expression of n .

Additional information:

Different Moduli of Elasticity are given below-

1. Young's modulus (Y): Within the elastic limit of a body, the ratio between the longitudinal stress and the longitudinal strain is called the Young's modulus of elasticity.

$$Y = \frac{\text{longitudinal stress}}{\text{longitudinal strain}} = \frac{F l}{A \Delta l} \text{ (N/m}^2\text{)}$$

Where F is the force acting on the surface of area A , Δl is the increase in length in a

length l of the wire.

2. Rigidity modulus (n): Within the elastic limit of a body, the ratio of tangential stress to the shearing strain is called rigidity modulus of elasticity. The rigidity modulus

$$n = \frac{\text{tangential stress}}{\text{shearing strain}} = \frac{F/A}{l/\Delta x} = \frac{F\Delta x}{Al} \quad (\text{N/m}^2)$$

Where F/A is the tangential stress, Δx the displacement in a length l in the perpendicular direction

3. Bulk modulus (K): It is defined as the ratio of stress to volumetric strain.

$$K = \frac{\text{stress}}{\text{bulk strain}} = \frac{-P\Delta V}{V} \quad (\text{N/m}^2)$$

Where P is the pressure, V is the original volume and ΔV is the change in volume of the material

4. Compressibility: The reciprocal of the bulk modulus is called compressibility.

$$\text{Compressibility} = 1/K$$

Poisson's ratio: When a sample of material is stretched in one direction, it tends to get thinner in the other two directions. Poisson's ratio (ν), is a measure of this tendency. Poisson's ratio is the ratio of the relative contraction strain, or transverse strain (normal to the applied load), divided by the relative extension strain, or axial strain (in the direction of the applied load). For a perfectly incompressible material deformed elastically at small strains, the Poisson's ratio would be exactly 0.5. Most practical engineering materials have between 0.0 and 0.5. Cork is close to 0.0, most steels are around 0.3, and rubber is almost 0.5.

Standard values of different elastic constants are listed below-

Material	Rigidity Modulus (10^{10} N/m ²)	Young's Modulus (10^{10} N/m ²)	Poisson's Ratio
Steel	7.9 - 8.9	19.5 - 20.6	0.28
Aluminium	2.67	7.50	0.34
Copper	4.55	12.4 - 12.9	0.34
Iron (Wrought)	7.7 - 8.3	19.9 - 20.0	0.27
Brass	3.5	9.7-10.2	0.34 - 0.38

Possible Questions:

- 1) Define rigidity modulus and state its unit.
- 2) The formulae for rigidity involves length and radius of the wire, how do they influence rigidity modulus?
- 3) Which quantity would you measure very accurately and why?
- 4) How rigidity modulus (n) is related to Young's modulus (Y)?
- 5) What is the effect of increase of temperature on the rigidity of the wire?
- 6) Does the period of oscillation depend on the amplitude of oscillation of the cylinder?
- 7) What is the difference between simple rigidity and torsional rigidity?
- 8) How will the period of oscillation of a torsional pendulum be affected when the length and diameter of the suspension wire is increased?
- 9) How will be the period of oscillation be affected if the bob of the pendulum be made heavy?
- 10) Will the period be affected by the change in the acceleration due to gravity?
- 11) Why do you call the method a dynamical method?
- 12) Is the motion simple harmonic?

Experiment No. : 07 (Group-2)

DETERMINATION OF COEFFICIENT OF VISCOSITY OF WATER BY POISEULLE'S METHOD

I. Objective: The aim of this experiment is to determine the coefficient of viscosity of water by Poiseulle's method.

II. Theory:

When water is allowed to flow in a stream line manner through a uniform capillary tube of length ' l ' and radius ' r ', volume ' V ' of water flowing per second is given by-

$$V = \frac{\pi P r^4}{8 \eta l} \quad \text{or} \quad \eta = \frac{\pi P r^4}{8 V l} \quad (i)$$

Where P is the pressure difference between the two ends of the capillary tube, η is the coefficient of viscosity of water.

If the pressure difference P be measure by U –type water manometer then

$$P = h \rho g \quad (ii)$$

Where h be the difference of water levels in two arms of the tube and ρ is the density of water. Hence

$$\eta = \frac{\pi h \rho g r^4}{8 V l} \quad (iii)$$

If P is expressed in dyne/cm^2 , r in cm and V in cm^3/sec then η will be in $\text{dyne sec}/\text{cm}^2$ or *poise*.

In order to be sure that the motion of the liquid is in streamline the value of h should be kept below the critical height(h_c). By finding one nominal value of η from relation (iii) the critical value can be found out from the relation

$$h_c = \frac{4 k \eta^2 l}{\rho^2 r^3 g} \quad (iv)$$

Where k is the Reynold's number ($k \approx 1000$ for narrow tube) and ρ is the density of the liquid.

III. Experimental Set up:

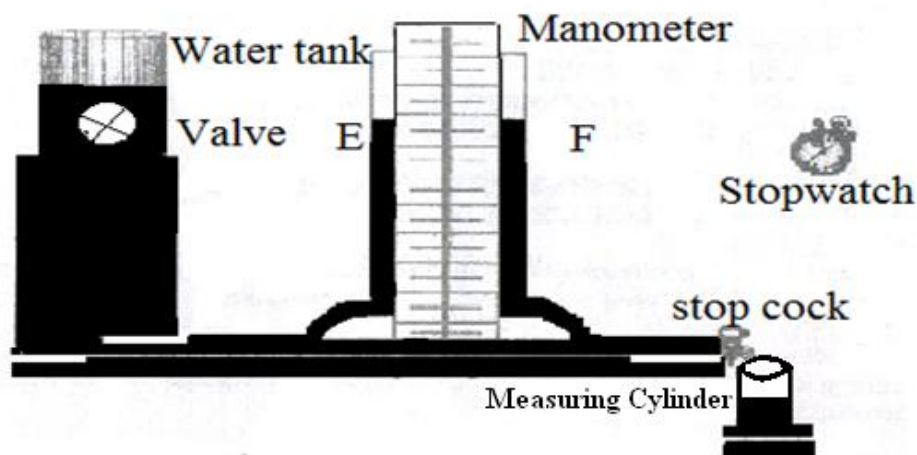


Fig.1:

Experimental arrangement to show the necessary apparatus for this experiment.

IV. Experimental Procedure:

Step 1: Set up the apparatus as shown in figure

Step 2: Control the pinch cock 'S' so that water flows through the capillary at slow rate and collects in the beaker, drop by drop. When the columns of water in the manometer tubes 'E' & 'F' are in steady, note the levels of water in 'E' & 'F'. Designate the reading by R_1 and R_2 respectively, the difference ($R_1 - R_2$) of the two readings gives h i.e. pressure difference in terms of the height of the liquid column.

Step 3: Note the temperature (t in $^{\circ}\text{C}$) of the liquid in the beaker by a thermometer. Take the value of the density ρ of the liquid at this temperature from physical table.

Step 4: When the flow of water through the capillary tube T has been steady, put a clean & dry glass beaker below the exit tube at the end B, As soon as water starts collecting in beaker, start a stop watch. Allow the water to collect a little more than half volume of the beaker. When the collection is over, remove the beaker and stop the stop watch.

Step 5: V (rate of flow of water) may be determined the measuring the volume of the liquid collected in t sec. with the help of a measuring cylinder and dividing by t .

Step 6: Measure V several other value of h . Each value of h should be so chosen that the liquid flows in the capillary tube in stream lines.

Step 7: Draw a graph by plotting h (cm) along X-axis and the corresponding V (cm^3/sec) along Y-axis. The graph will be straight line and passing through the origin (0,0).

Step 8: On the graph choose a point and obtain the corresponding values of h and V . Calculate the value of P from the relation, $P = h \rho g$. Compute the co-efficient of viscosity by using equation (iii).

V. Experimental Observations:

- Length of the capillary tube =cm
- Radius of the capillary tube =cm
- Critical height: = cm

Table- 1

Pressure difference in terms of height (h) from manometer readings:

Temperature of water = $^{\circ}\text{C}$

Density of water at that temperature (ρ) =gm/cc.

Value of $g = 980\text{cm/sec}^2$

No. of observation	Height of water level in 1 st arm (R_1) in cm	Height of water level in 2 nd arm (R_2) in cm	Difference height $h = R_1 - R_2$	Pressure difference $P = h \rho g$ dyne/cm ²

Table-2
Measurement of Rate of flow of water:

No. of observation	Pressure difference from Table-1	Volume of the collected water (v_t) in cc	Time for collection of water (t) (sec)	Rate of flow of water $V=v_t/t$ (c.c./sec)

VI. Calculation and Result:

Table-3
Data for (h Vs V) graph:

No. of observation	h from Table-1 (cm)	Corresponding V (from Table-2) (cm^3/sec)

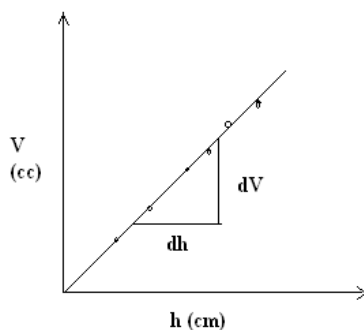


Fig.2: h vs. V graph

Table-4

Calculation of Co-efficient of viscosity (η) of water at t °C from graph:

Δh from graph	ΔV from graph	Slope of the graph $m = \frac{\Delta V}{\Delta h}$	length l in cm	r^4 in cm^4	$\eta = \frac{\pi r^4 \rho g}{8 m l}$ (Poise)

Hence, Co-efficient of viscosity at temperature°C =dyne. Sec/cm² or Poise

VII. Error calculation:

We know $\eta = \frac{\pi h \rho g r^4 t}{8 v_t l}$; $h = R_1 \sim R_2$

Where, v_t represents the volume of the liquid collected in time t . the maximum proportional error in the measurement of η is given by

$$\frac{\delta \eta}{\eta} = 2 \frac{\delta h}{h} + 4 \frac{\delta r}{r} + \frac{\delta t}{t} + \frac{\delta v_t}{v_t} + \frac{\delta l}{l} + \frac{\delta g}{g} + \frac{\delta \rho}{\rho}$$

Since, ρ , g , r & l are not measured (supplied). Then

$$\frac{\delta \eta}{\eta} = 2 \frac{\delta h}{h} + \frac{\delta t}{t} + \frac{\delta v_t}{v_t}$$

Therefore maximum proportional error

$$\frac{\delta \eta}{\eta} \times 100 \% = \dots \times 100 \% = \dots \%$$

VIII. Precaution & Discussions:

1. Since radius r occurs in the fourth power, the radius of the capillary tube should be uniform and measured it very carefully.
2. Due to capillary action the out-flowing liquid from the end of the tube may run back along the outside of the tube. To prevent this, a little vaseline should be smeared on the outside of the tube near its free end.
3. The height difference of the two arms of manometer should be below the critical height; otherwise flow of water through capillary tube would be turbulent.
4. You should check the beaker in which you will collect the water is completely dry or not. If not then first dry it as much as possible and then collect water for a known interval of time until the beaker is greater than half full.
5. The temperature of the water should be noted carefully as the value of the coefficient of viscosity changes rapidly with temperature.

Additional information:

Viscosity of water at different temperature:

substance	Temperature (°C)	Viscosity (Poise)	substance	Temperature (°C)	Viscosity (Poise)
Water	0	0.00179	Water	25	0.00089
	5	0.00152		30	0.00080
	10	0.00131		40	0.00066
	15	0.00114		50	0.00055
	20	0.00101		60	0.00047

Experiment No.: 08 (Group-3)

DETERMINATION OF WAVELENGTH OF LIGHT BY NEWTON'S RINGS METHOD

I. Objective: The objective of this experiment is to determine the wavelength of sodium light by forming Newton's rings.

II. Apparatus: Sodium Vapour Lamp, Newton's rings set-up.

III. Ray diagram:

A thin wedge shaped air film is created by placing a plano-convex lens on a flat glass plate. A monochromatic (sodium vapour lamp) beam of light is made to fall at almost normal incidence on the arrangement. Ring like interference fringes (fig.2) are observed through eyepiece due to reflected light.

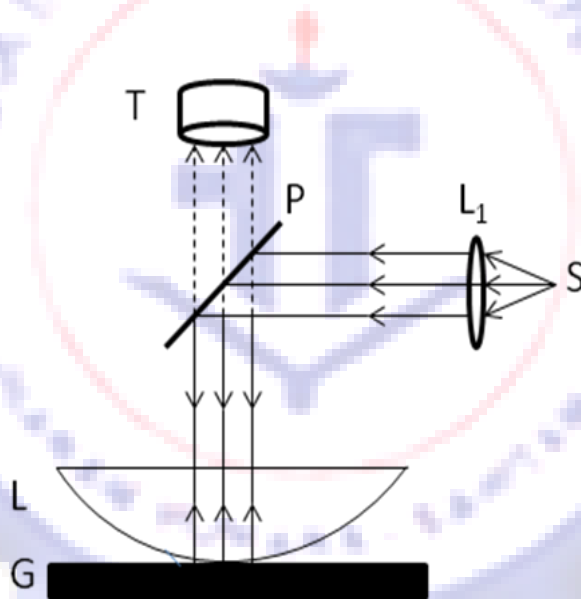


Fig.1: Ray diagram of Newton's Rings Experiment

A horizontal beam of light falls on the glass plate G at an angle of 45° . The reflected beam from the air film is viewed with a microscope. Interference takes place and dark and bright circular fringes are produced. This is due to the interference between the light reflected at the lower surface of the lens and the upper surface of the plate G by division of amplitude.

III. Theory:

The phenomenon of Newton's rings is an illustration of the interference of light waves reflected from the opposite surfaces of a thin film of variable thickness. The two interfering beams, derived from a monochromatic source satisfy the coherence condition for interference. Ring shaped fringes are produced by the air film existing between a convex surface of a long focus plano-convex lens and a plane of glass plate.



Fig.2: Newton's Rings for reflected light

A thin air film enclosed between the spherical surface of *plano-convex lens* and a plane surface glass plate, gives circular rings such that as shown in the figure 3, and r_m is the radius of the m^{th} order dark ring, t is the thickness of the air film. If D_n be the diameter of the n^{th} dark ring, D_m be the diameter of the m^{th} dark ring and R be the radius of curvature of the surface of the plano-convex lens in contact with glass plate, the wavelength λ of light given by-

$$\lambda = \frac{D_m^2 - D_n^2}{4R(m-n)} \quad (1)$$

Equation (1) represent the working formula for this experiment.

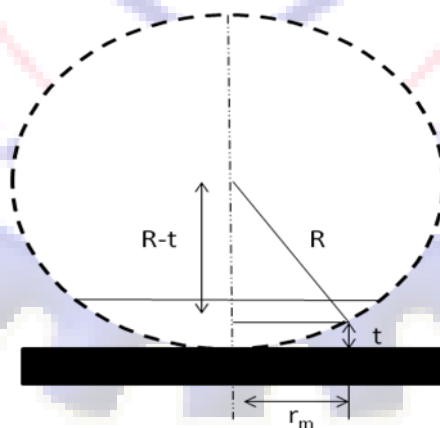


Fig.3: Geometrical diagram for measurement radius/diameter of Newton's rings

V. Procedure:

1. Determine the least count of the circular scale associated with the apparatus.
2. Switch on the sodium vapour lamp. Wait till it turns yellow. Adjust the mirror such that light is reflected on the lens. Focus the microscope to see sharp circular fringes. Adjust the mirror if necessary to increase the contrast in the fringes.
3. Adjust the screws to bring the central dark spot at the crosswire. Now, move horizontally to a dark ring of large diameter, say the 20th ring. Place the crosswire tangentially to the ring. Take the horizontal main scale and the circular scale readings.
4. Move the crosswire towards the centre to another ring skipping 4 rings. Note the ring number and the microscope reading.
5. Repeat the step 4 till the smallest distinct circular ring is reached (*i.e.* 16th, 12th, 8th and 4th). Continue towards the other direction and take readings for the order ends of the same rings as before (*i.e.* 4th, 8th, 12th, 16th and 20th).
6. Repeat the step 4 and step 5 but this time moving in opposite direction. Thus, the diameters of each ring will be measured twice.
7. Draw a graph with D_m^2 in the coordinate and m in the abscissa, where m is the order number of the ring. Determine the slope of this straight line with integer values of m . This will yield the value of $\frac{D_m^2 - D_n^2}{m - n}$ in the working formula for wavelength.

VI. Experimental Observations:

Table 1

To determine the least count of the circular scale

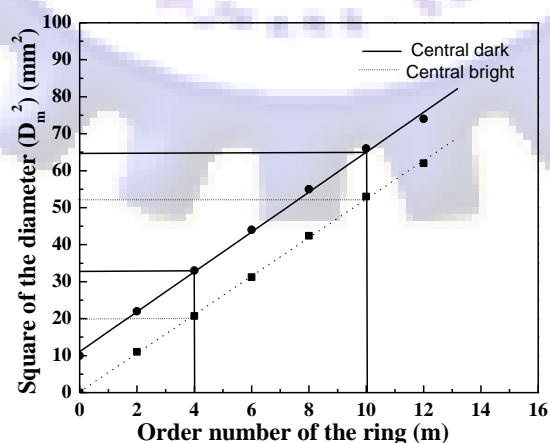
No of div. in the circular scale (n)	Screw Pitch (x) in mm	Least Count L.C=x/n in mm

Table 2

Experimental data to measure the diameter of Newton's Rings

Moving right to left										Moving left to right																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
No of rings										Microscopic reading								$D_m = X \sim Y$ (cm)	Avg D_m	D_m^2 in cm^2	$D_m^2 - D_n^2$	m-n																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
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Graph Plotting: A graph will be plotted between D_m^2 (along Y axis) vs. m (along X axis) and then find λ from this graph considering $m-n=6$.

Fig.4: D_m^2 vs. m plot for Newton's rings.

VII. Calculations and Result:

$$\lambda = \frac{D_m^2 - D_n^2}{4R(m-n)} =$$

VIII. Maximum Percentage of Error:

The Maximum Percentage of Error can be calculated by using this relation

$$\frac{\partial \lambda}{\lambda} \times 100\% = \frac{8 \times \text{V.C. of microscope}}{\text{measured lowest value of } (D_{m+n}^2 - D_n^2)} \times 100\%$$

IX. Discussions:

Notice that, as you go away from the central dark spot, the fringe width decreases. In order to minimize the errors in measurement of the diameter of the rings the following precautions should be taken:

- i) The microscope should be parallel to the edge of the glass plate.
- ii) If you place the cross wire tangential to the outer side of a perpendicular ring on one side of the central spot then the cross wire should be placed tangential to the inner side of the same ring on the other side of the central spot.
- iii) The traveling microscope should move to and fro only in one direction.

Experiment No. : 09 (Group-3)

DETERMINATION OF THE WAVELENGTH OF A MONOCHROMATIC LIGHT BY FRESNEL'S BI-PRISM METHOD

- I. Objectives:** To determine the wavelength of a monochromatic light by Fresnel's bi-prism method.
- II. Apparatus:** Fresnel's bi-prism, source of monochromatic light (Sodium vapour lamp), a slit, a micrometer eyepiece, a convex lens, an optical bench with four stands.
- III. Theory and Working Formula:**

A bi-prism may be regarded as made up of two prisms of very small refracting angles placed base to base. In actual practice a single glass plate is suitably grinded and polished to give a single prism of obtuse angle 179° leaving remaining two acute angles of $30'$ each. If monochromatic light of wavelength λ from a point source S is made emergent on the two halves of the bi-prism LMN then the emergent beam from the bi-prism appears to diverge from two virtual images S_1 and S_2 (Fig. 1). Thus two coherent sources have been formed (S_1 and S_2) from a single source (S) by the division of wavefront with the help of the bi-prism. Fig. 1 shows ray diagram of the experimental arrangement to determine the wavelength of monochromatic light using Fresnel's bi-prism. Rays from the two virtual sources interfere with each other and form alternating dark and bright bands. The fringes are hyperbolic, but due to high eccentricity they appear to be straight lines in the focal plane of the eyepiece (E). The Fringe width (β) is given by-

$$\beta = \frac{D\lambda}{d} \quad (1)$$

Where, λ is the wavelength of the monochromatic light, d is the apparent distance between the two coherent virtual sources S_1 and S_2 . D denotes the distance between the slit and the focal plane of the eyepiece.

If β_1 and β_2 represent fringe width at distances D_1 and D_2 respectively, then the wavelength is given by,

$$\lambda = \frac{\beta_2 - \beta_1}{D_2 - D_1} d \quad (2)$$

However, d cannot be directly measured as the sources are virtual. To find out the value of d , a convex lens of focal length f (so that, D_1 or $D_2 > 4f$) is placed between the bi-prism and the eyepiece so that for its two positions L_1 and L_2 real images of S_1 and S_2 may be focused at the focal plane of the eyepiece. If d_1 and d_2 are the separations

between the two real images of S_1 and S_2 for the two positions L_1 and L_2 of the lens, then d is obtained from the relation,

$$d = \sqrt{d_1 d_2} \quad (3)$$

Thus the wavelength of the monochromatic light can be expressed as,

$$\lambda = \frac{\beta_2 - \beta_1}{D_2 - D_1} \sqrt{d_1 d_2} \quad (4)$$

Equation (4) is the working formula for this experiment. By measuring the fringe width (β_1 and β_2), the separation between the two virtual sources (d_1 and d_2) and the distance between the slit and the eyepiece (D_1 and D_2) the wavelength of monochromatic light can be determined.

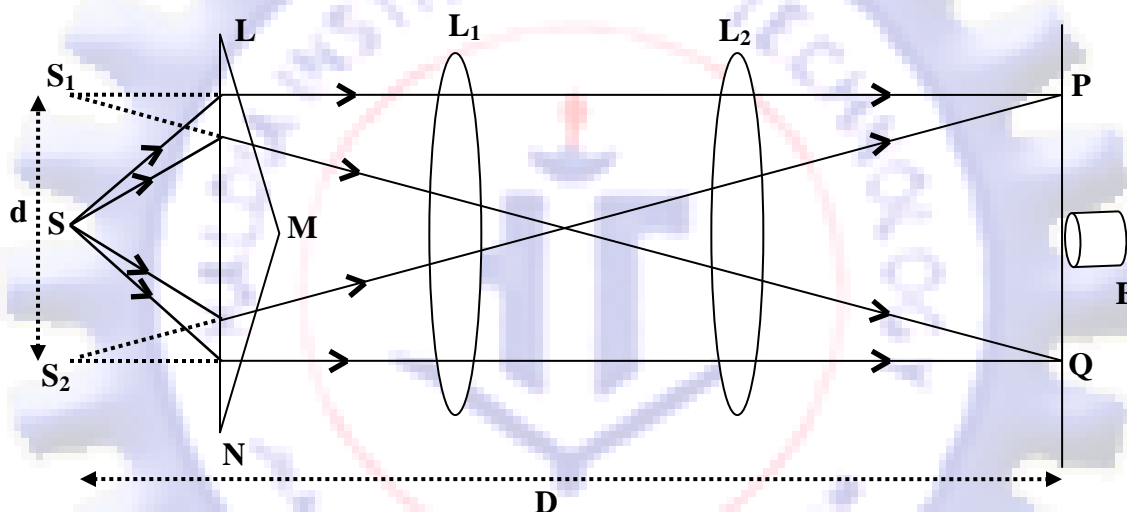


Fig. 1: Ray diagram of the experimental arrangement to determine the wavelength of monochromatic light using Fresnel's bi-prism

IV. Procedure:

1. Set the slit vertical and bright by adjusting the source. Set the bi-prism edge vertical with flat side facing the slit. Adjust the height so that the centre of the slit and the centre of the bi-prism are in the same height. Bring both of them in the middle of the bench.
2. Bring the eyepiece close to the bi-prism. Look through it. Move the eyepiece in the direction perpendicular to the length of the optical bench until its axis passes through the centre of the bi-prism and the slit. Focus the eyepiece so that the

fringes can be seen. If not turn the bi-prism using the transverse and tangent screws.

3. Replace the sodium (Na) light by white light. A coloured fringe with a white centre will be visible. Move the eyepiece near and farther to the bi-prism, always keeping the central white line on the cross-wire by adjusting the micrometer screw of the eyepiece at all positions.
4. Bring the Na lamp back. Move the eyepiece at a certain distance. Note down the position of the slit and the eyepiece on the optical bench. Look through the eyepiece. Go to the extreme right white band. Note the position of the eyepiece on the micrometer scale. Go to the bright band on the left side keeping 2 to 3 lines. Note eyepiece position. If you have skipped 3 lines then the difference between these two successive readings will give you 4 times the fringe width. Repeat this step unless you reach the left extreme. Now start moving in the opposite direction each time noting the position of the eyepiece.
5. Move the eyepiece to another distance and repeat step 4.
6. Place a convex lens between the eyepiece and the bi-prism. Move the eyepiece to a distance slightly more than four times the focal length of the lens. Look through the eyepiece and change the position of the lens. For two positions of the lens two images of the slit can be seen. Go to one of the positions. Find the separation (d_1) between the images by bringing each of the images on the cross-wire by rotating the micrometer screw and noting the reading in each case. Go to the second position and find the separation (d_2) between the images.

V. Experimental Observations:

Table-1

Determination of Least Count of the micrometer

Screw Pitch (x) in mm	No. of divisions on the circular scale (n)	Least Count (x/n) in mm

Table-2
Measurement of fringe width (β_1) at D_1

 Position of the slit (p_1) =cm

 Position of the eyepiece (p_2) =cm

 Distance between the eyepiece and the slit ($p_2 - p_1$) = D_1 =cm

Direction of the eyepiece movement	Fringe number	Readings of the micrometer movement			Width (X) of three fringes (mm)	Mean X (mm)	Mean fringe width $\beta_1 = X/3$ (mm)
		L.S.R.	C.S.R.	Total Reading (mm)			
L \rightarrow R	1						
	4						
	5						
	8						
R \rightarrow L	9						
	12						
	9						
	6						
	5						
	2						

Table-3
Measurement of fringe width (β_2) at D_2

 Position of the slit (p_1) =cm

 Position of the eyepiece (p_2) =cm

 Distance between the eyepiece and the slit ($p_2 - p_1$) = D_2 =cm

Direction of the eyepiece movement	Fringe number	Readings of the micrometer movement			Width (X) of three fringes (mm)	Mean X (mm)	Mean fringe width $\beta_2 = X/3$ (mm)
		L.S.R.	C.S.R.	Total Reading (mm)			
L \rightarrow R	1						
	4						
	5						
	8						
R \rightarrow L	9						
	12						
	9						
	6						
	5						
	2						

Table-4
Measurement of d_1 and d_2 and hence d

Position of the slit =cm

Position of the bi-prism =cm

Position of the eyepiece =cm

Focal length of the lens = cm

No. of Obs.	Lens position (cm)	Direction of eyepiece movement	Reading of the micrometer (mm)						Separation between the images $r_1 \sim r_2$ (mm)	Mean separation (mm)	$d = \sqrt{d_1 d_2}$ (mm)	
			For Left image			For Right image						
			L.S. R	C.S. R	Total Reading(r_1)	L.S. R	C.S. R	Total Reading (r_2)				
1.		L \rightarrow R								$d_1 =$		
2.		R \rightarrow L										
1.		L \rightarrow R								$d_2 =$		
2.		R \rightarrow L										

Table-5
Determination of wavelength (λ) of monochromatic light

Distance (D) between the slit and the eyepiece in mm	Fringe width (β) in mm	Value of d in mm	Value of λ in Å $\lambda = \frac{\beta_2 - \beta_1}{D_2 - D_1} d \times 10^7$
$D_1 =$	$\beta_1 =$		
$D_2 =$	$\beta_2 =$		

VI. Percentage error:

The working formula is-

$$\lambda = \frac{\beta_2 - \beta_1}{D_2 - D_1} \sqrt{d_1 d_2}$$

Therefore the maximum proportional error can be represented as,

$$\left(\frac{\delta\lambda}{\lambda}\right)_{\max} = \left(\frac{2\delta\beta}{\beta_2 - \beta_1} + \frac{2\delta D}{D_2 - D_1} + \frac{\delta d_1}{2d_1} + \frac{\delta d_2}{2d_2}\right)$$

where, $\delta\beta = \delta d_1 = \delta d_2 =$ smallest measuring distance (least count) of the micrometer.

Hence the maximum percentage error is,

$$\left(\frac{\delta\lambda}{\lambda}\right)_{\max} \times 100\% = \left(\frac{2\delta\beta}{\beta_2 - \beta_1} + \frac{2\delta D}{D_2 - D_1} + \frac{\delta d_1}{2d_1} + \frac{\delta d_2}{2d_2}\right) \times 100\%$$

VII. Discussions:

- (i) The fringe width (β) can be made smaller by increasing the distance between the slit and the bi-prism. Again β can be increased by increasing the distance between the slit and the eyepiece. Hence these distances should be judiciously adjusted to make fringes neither too wide nor too narrow.
- (ii) The convex lens employed to focus the real images of the virtual sources at the focal plane of the eyepiece should be of such focal length (f) so that $D > 4f$.
- (iii) The displacement of the lens to get the real images of the virtual sources at its two positions should not be very large, otherwise proportional error in measuring d would be greater.
- (iv) The measurement of the fringe width is to be done very carefully as it has the maximum contribution in the error calculation.
- (v) The instrument should be properly aligned so that there may not be any relative shift between the fringe and the cross-wires, as the eyepiece is moved along the optical bench.
- (vi) The strongly illuminated part of the source must be placed behind the slit. If necessary, a convex lens may be used to concentrate the light on the slit.

Experiment No. : 10 (Group-3)

DETERMINATION OF THE WAVELENGTH OF He-Ne LASER BY STUDYING THE DIFFRACTION OF MONOCHROMATIC LIGHT BY PLANE TRANSMISSION GRATING

I. Objective: To determine the wavelength of He-Ne Laser by studying the diffraction of monochromatic light by plane transmission grating.

II. Apparatus:

1. Meter Scale
2. He-Ne Laser
3. Plane transmission Grating
4. Optical Bench

III. Theory:

When a wavefront is incident on a grating surface, light is transmitted through the slits and obstructed by the opaque portions. The secondary waves from the positions of the slit interface with one another similar to the interference of waves in Young's experiment. If the spacing between the lines is of the order of the wavelength of light then an appreciable deviation of the light is produced.

We consider a grating of N slits per centimeter having clear space of width a each are separated by opaque space b placed on the optical bench. A parallel beam of laser incident on it at an angle i with the normal to the grating surface.

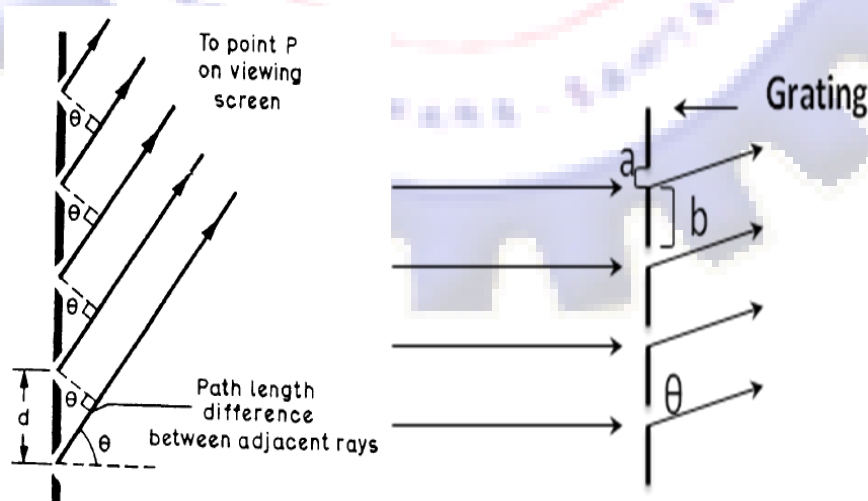


Fig.1: Laser diffraction from a grating of grating element ($d = a+b$).

Superposition of secondary waves coming from the clear space of grating will give diffraction pattern on the screen.

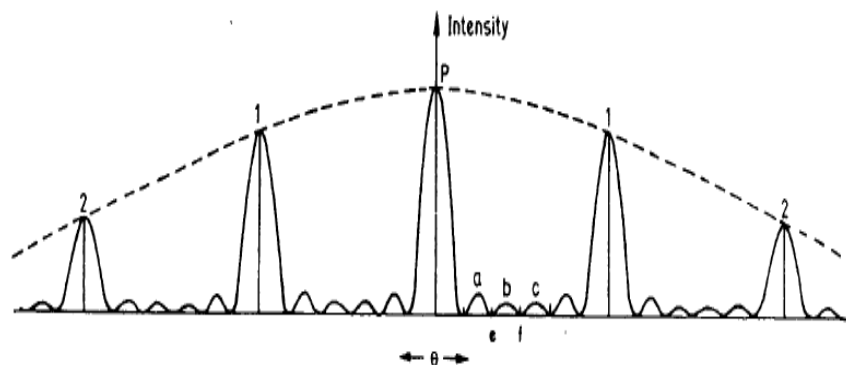


Fig.2: Intensity distribution pattern for diffraction grating.

The intensity distribution pattern of grating is shown in fig 2 and the condition of diffraction maxima is given by

$$d(\sin i \pm \sin \theta) = n\lambda \dots \dots \dots (1)$$

Where θ is the angel of diffraction of the n^{th} order maxima.

For normal incidence $d(\sin \theta) = n\lambda$

If the angle of diffraction is very small, of the order of few degrees, then from the figure

$$\theta_n = \frac{x_n}{D} \text{ and } \sin \theta = \theta - \frac{\theta^3}{3!}$$

$$\lambda = \frac{d \sin \theta}{n} = \frac{d}{n} \left(\theta - \frac{\theta^3}{3!} \right) = \frac{d}{n} \left(\frac{x_n}{D} - \frac{x_n^3}{6D^3} \right)$$

And hence,

$$\lambda = \frac{x_n}{nND} \left(1 - \frac{x_n^2}{6D^2} \right) \dots \dots \dots (2)$$

Here $N=1/d$, number of rulings per centimeter of grating and equation (2) is the working formula for this experiment.

IV. Experimental Procedure:

1. Mount the grating with its plane vertical and set it for normal incidence.
2. Make sure that the laser beam is incident normal to the plane of grating.
3. Obtain the diffraction grating maximum spot (i.e. principal maxima) on the screen of the wall.

- Measure x_n and D by meter scale.
- Calculate the value of λ for each order on both sides and obtain the mean value.
- Repeat it for another D value.

V. Observation and collection of data:

Table-1

Observation data of x_n and D to calculate λ

No of rulings per cm (N)=.....

Least count of the meter scale used.....

Sl.No	Distance between grating and screen (D) cm	Order of diffraction maxima (n)	Distance of nth diffraction maxima from central maxima x_n cm			Wavelength λ in Å	Mean wavelength (λ) in Å
			Left side	Right side	Mean x_n		
1	D_1						
2							
3							
4							
5							
1	D_2						
2							
3							
4							

VI. Graph plotting: A graph will be plotted for x_n (along Y axis) vs. n (along X axis) for both D_1 and D_2 . Then find λ from graph.

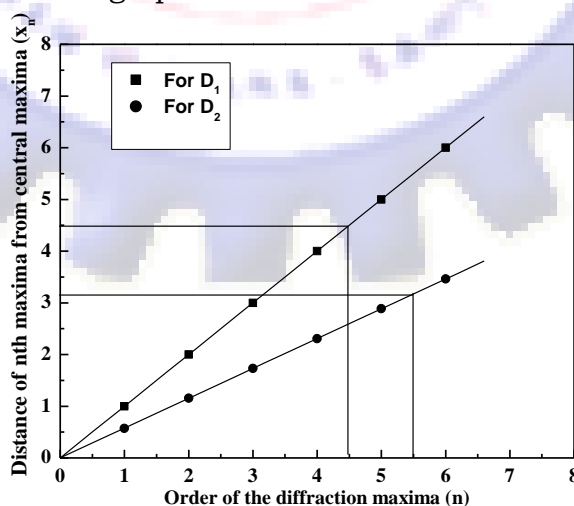


Fig.3: Plot for x_n (along Y axis) vs. n (along X axis).

VII. Error calculation:

Working formula is $\lambda = \frac{x_n}{nND} \left(1 - \frac{x_n^2}{6D^2} \right)$

Here, the maximum proportional error is introduced due to third power of x_n . and D

Hence

$$\frac{d\lambda}{\lambda} = \frac{3dx_n}{x_n} + \frac{3dD}{D}$$

VIII. Result and Discussions:

- (i) From the study of diffraction of monochromatic light beam by plane transmission grating we obtain the wavelength of He-Ne laser and it is.....
- (ii) If we plot a graph for x_n against n, then we find for lower values of the plot is nearly a straight line. We can obtain λ by equating the slope of that straight line with $\frac{\lambda D}{d}$ and compare it with the mean values of λ .
- (iii) LASER light is dangerous, so it should be careful that LASER light can't fall into eye.

Experiment No. : 11 (Group-3)

DETERMINATION OF NUMERICAL APERTURE, ANGLE OF ACCEPTANCE AND BENDING ENERGY LOSSES OF AN OPTICAL FIBRE

I. Objective(s): To determine the numerical aperture, angle of acceptance and bending energy losses of an optical fibre.

II. Theory:

Numerical aperture is a basic descriptive characteristics of a specific fibre. This represents the 'size of openness' of the input acceptance cone. Mathematically, numerical aperture (**NA**) is defined as the Sine of the half angle of the acceptance cone. The light gathering power or flux carrying capacity of a fibre is numerically equal to the square of the aperture, which is the ratio between the area of a unit sphere with the acceptance cone and the area of the hemisphere (2π solid angle).

Snell's law can be used to calculate the maximum angle within which light will be accepted into and conducted through the fibre.

$$NA = \sin \theta_a = (n_1^2 - n_2^2)^{1/2}$$

Where $\sin \theta_a$ is the numerical aperture and n_1 & n_2 are the refractive indices of the core and the cladding. The semi angle θ_a (determined) of the acceptance cone for a step index fibre is determined by the critical angle (θ_c), where $\theta_c = \sin^{-1} (n_2 / n_1)$.

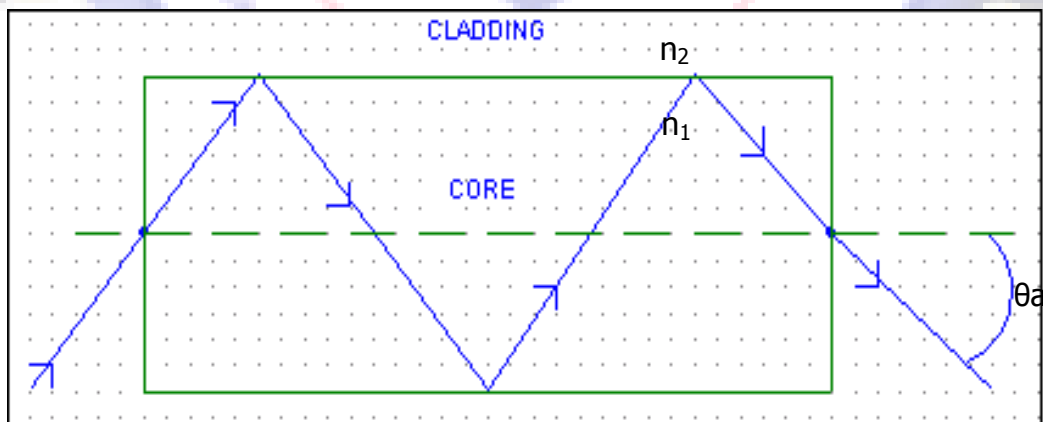


Fig. 1: Propagation of light beam through the fibre.

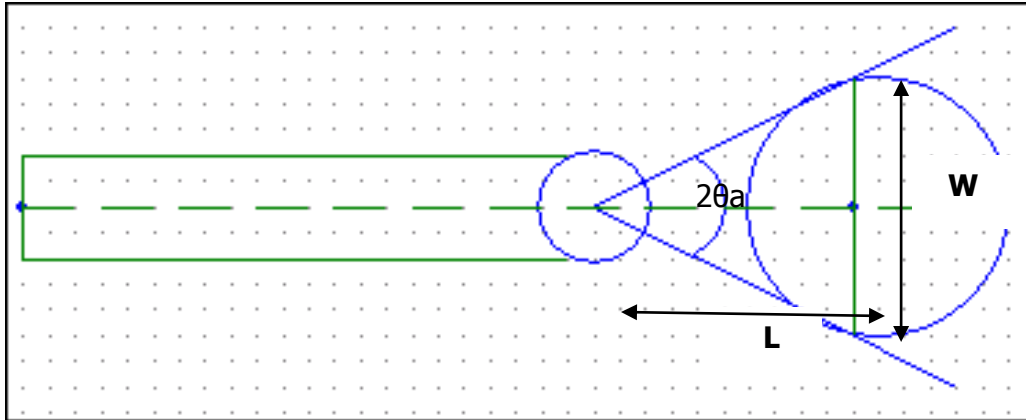


Fig. 2: Schematic of emergent beam from fibre.

From the above figure (Fig. 2), we can find the Numerical aperture of the particular optical fibre.

$$NA = \sin \theta_a = \frac{W}{\sqrt{(4L^2 + W^2)}}$$

Where W is the width of the screen and L is the distance between the screen and optical fibre end as shown in Fig.2.

Energy Loss: The energy loss in an optical fibre is the function of its length expressed in decibels per unit length. Losses may also occur due to the connection of optical fibre by an adapter.

If P_{in} is the input power and ∞ is the loss factor (i.e., loss or attenuation coefficient in decibel (dB) per unit length), then the power loss P_{out} at distance l (i.e., at the output end) is given by –

$$P_{out} = P_{in} e^{-\infty l}.$$

Hence, the loss factor is given by –

$$\infty = (10 / l) . \log (P_{in} / P_{out})$$

Working Formula:

$$NA = \sin \theta_a = \frac{W}{\sqrt{(4L^2 + W^2)}}$$

$$\infty = (10 / l) . \log (P_{in} / P_{out})$$

Practical Application(s) of the Experiment:

1. Higher numerical aperture will carry more optical signal which correspond to much communication paths.

2. Higher numerical aperture carries maximum number of optical mode which causes dispersion of signal. This is the disadvantage of higher NA.

III. Apparatus:

Fibre optic transmission kit, Fibre optic receiver kit, Optical fibre, Screen, Measuring scale.

Function of Each Instrument and Component:

Fibre Optic Transmission Kit:- To produce and transmit laser light through an optical fibre of which we measure the numerical aperture of the fibre.

Fibre Optic Receiver Kit:- To accept the transmitted laser light through an optical fibre of which we measure the loss factor of the fibre.

Screen:- It is simply a graph paper upon which the laser light fallen and measuring distance from screen to fibre & diameter of cone, we can find out the numerical aperture of the fibre.

Optical Fibre:- It is a core tube through we passes the laser beam and of which we measure the numerical aperture.

IV. Experimental Procedure:

1. In a dark room connect the optical fibre with the LED port of transmission kit from which laser light may enter into the fibre. Insert the other end of the fibre through the hole of L – shaped numerical aperture measurement kit. Place the calibrated screen paper vertically on the marked scale of L – shaped kit. Switch on the transmission kit. Make a bright circle on the vertical paper by adjusting the intensity knob. Note down the value of L. Adjust the vertical paper so that the bright circle is symmetrical with respect to scales drawn on it. Measure the value of the diameter of the circle.
2. Move the vertical screen to several other values of L. Note down the value of W in each case.
3. Take out the previous optical fibre cable and connect one end of a long optical fibre cable to the LED port of the transmission kit again. Connect the other end of the optical fibre cable to LED port of the receiver kit. Apply the input voltage / power by turning P_{in} knob of transmission kit. Make the optical fibre cable bended with several coiling. Measure the input power (P_{in}) and output power (P_{out}) with the help of

multimeter or powermeter and the length of the long optical fibre cable. Repeat this step several times by changing input voltage / power.

V. Experimental Observations (Data Recording):

Table – 1
Determination of Numerical Aperture

Sl. No.	L (in mm)	W (in mm)	NA	Mean NA
1				
2				
3				
4				

Table – 2
Determination of Power Loss

Sl. No.	Length of the fibre Cable, L (in m)	Input Power, P_{in} (in W)	Output Power, P_{out} (in W)	Loss Factor, ∞ (in dB/m)	Avg. Loss Factor, ∞_{avg} (in dB/m)
1					
2					
3					
4					

VI. Results:

Numerical Aperture, $NA = \sin \theta_a = \dots\dots\dots$

Angle of Acceptance, $2\theta_a = \dots\dots\dots$, $\theta_a = \dots\dots\dots$

Loss Factor (∞) = $\dots\dots\dots$

VII. % Error Calculations:

VIII. Discussions:

1. In determination of the diameter of the circular spot formed on the screen we used graph paper of mm division. If the diameter is measure using the main scale and the circular scale much accurate result must obtained.
2. The initial error of the screw gauge has been added with all subsequent reading of the distance of the fibre from the screen.
3. As the value of both L and W are very small much accurate measurement has to be taken to achieve the nearly accurate value of the numerical aperture.
4. The distance between the screen and the fibre should be small enough for eye estimation.
5. The end of the fibre must be placed perpendicular to the screen values. Otherwise it is difficult to measure the diameter.
6. For the measurement of loss factor input and output power should be measured by digital multimeter.
7. LASER light is dangerous, so it should be careful that LASER light can't fall into eye.