

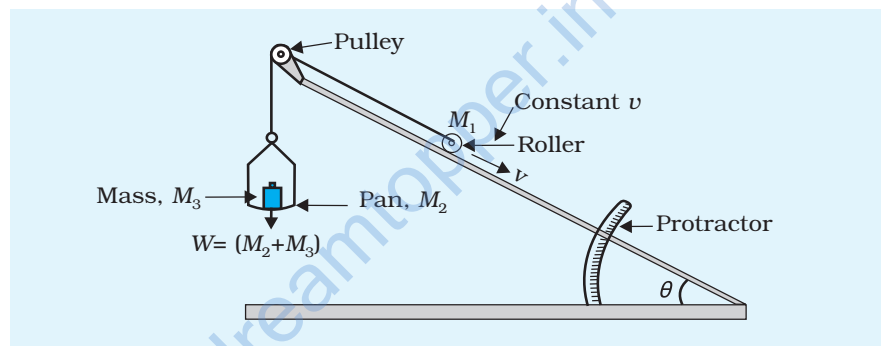
# EXPERIMENT 8

## AIM

To find the downward force, along an inclined plane, acting on a roller due to gravity and study its relationship with the angle of inclination by plotting graph between force and  $\sin \theta$ .

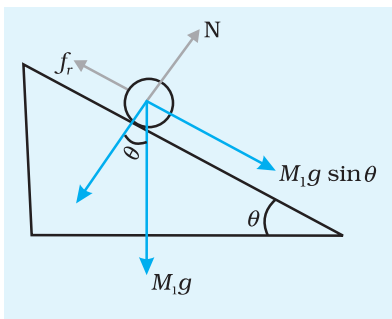
## APPARATUS AND MATERIAL REQUIRED

Inclined plane with protractor and pulley, roller, weight box, spring balance, spirit level, pan and thread.



**Fig. E 8.1:** Experimental set up to find the downward force along an inclined plane

## PRINCIPLE



**Fig. E 8.2:** Free body diagram

Consider the set up shown in Fig. E 8.1. Here a roller of mass  $M_1$  has been placed on an inclined plane making an angle  $\theta$  with the horizontal. An upward force, along the inclined plane, could be applied on the mass  $M_1$  by adjusting the weights on the pan suspended with a string while its other end is attached to the mass through a pulley fixed at the top of the inclined plane. The force on the mass  $M_1$  when it is moving with a constant velocity  $v$  will be

$$W = M_1 g \sin \theta - f_r$$

where  $f_r$  is the force of friction due to rolling,  $M_1$  is mass of roller and  $W$  is the total tension in the string

( $W$  = weight suspended). Assuming there is no friction between the pulley and the string.

## PROCEDURE

1. Arrange the inclined plane, roller and the masses in the pan as shown in Fig. E. 8.1. Ensure that the pulley is frictionless. Lubricate it using machine oil, if necessary.
2. To start with, let the value of  $W$  be adjusted so as to permit the roller to stay at the top of the inclined plane at rest.
3. Start decreasing the masses in small steps in the pan until the roller just starts moving down the plane with a constant velocity. Note  $W$  and also the angle  $\theta$ . Fig. E 8.2 shows the free body diagram for the situation when the roller just begins to move downwards.
4. Repeat steps 2 and 3 for different values of  $\theta$ . Tabulate your observations.

## OBSERVATIONS

Acceleration due to gravity,  $g$  = ...  $\text{ms}^{-2}$

Mass of roller,  $m$  =  $(M_1) g$

Mass of the pan =  $(M_2) g$

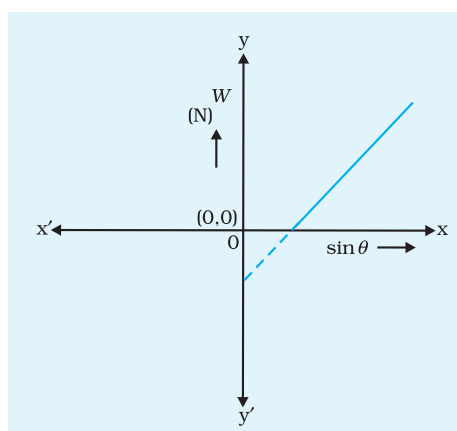
**Table E 8.1**

S. No.	$\theta^\circ$	$\sin \theta$	Mass added to pan $M_3$	Force $W = (M_2 + M_3) g$ (N)
1				
2				
3				

## PLOTTING GRAPH

Plot graph between  $\sin \theta$  and the force  $W$  (Fig. E 8.3). It should be a straight line.

**Fig. E 8.3:** Graph between  $W$  and  $\sin \theta$



## RESULT

Therefore, within experimental error, downward force along inclined plane is directly proportional to  $\sin \theta$ , where  $\theta$  is the angle of inclination of the plane.

## PRECAUTIONS

1. Ensure that the inclined plane is placed on a horizontal surface using the spirit level.
2. Pulley must be frictionless.
3. The weight should suspend freely without touching the table or other objects.
4. Roller should roll smoothly, that is, without slipping.
5. Weight,  $W$  should be decreased in small steps.

## SOURCES OF ERROR

1. Error may creep in due to poor judgement of constant velocity.
2. Pulley may not be frictionless.
3. It may be difficult to determine the exact point when the roller begins to slide with constant velocity.
4. The inclined surface may not be of uniform smoothness/roughness.
5. Weights in the weight box may not be standardised.

## DISCUSSION

As the inclination of the plane is increased, starting from zero, the value of  $mg \sin \theta$  increases and frictional force also increases accordingly. Therefore, till limiting friction  $W = 0$ , we need not apply any tension in the string.

When we increase the angle still further, net tension in the string is required to balance  $(mg \sin \theta - f_r)$  or otherwise the roller will accelerate downwards.

It is difficult to determine exact value of  $W$ . What we can do is we find tension  $W_1 (< W)$  at which the roller is just at the verge of rolling down and  $W_2 (> W)$  at which the roller is just at the verge of moving up. Then we can take

$$W = \frac{(W_1 + W_2)}{2}$$

## SELF ASSESSMENT

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1. Give an example where the force of friction is in the same direction as the direction of motion.
2. How will you use the graph to find the co-efficient of rolling friction between the roller and the inclined plane?
3. What is the relation between downward force and angle of inclination of the plane?
4. How will you ensure that the roller moves upward/downward with constant velocity?

### SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

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1. From the graph, find the intercept and the slope. Interpret them using the given equation.
2. Allow the roller to move up the inclined plane by adjusting the mass in the pan. Interpret the graph between  $W'$  and  $\sin \theta$  where  $W'$  is the mass in pan added to the mass of the pan required to allow the roller to move upward with constant velocity.

## AIM

To determine Young's modulus of the material of a given wire by using Searle's apparatus.

## APPARATUS AND MATERIAL REQUIRED

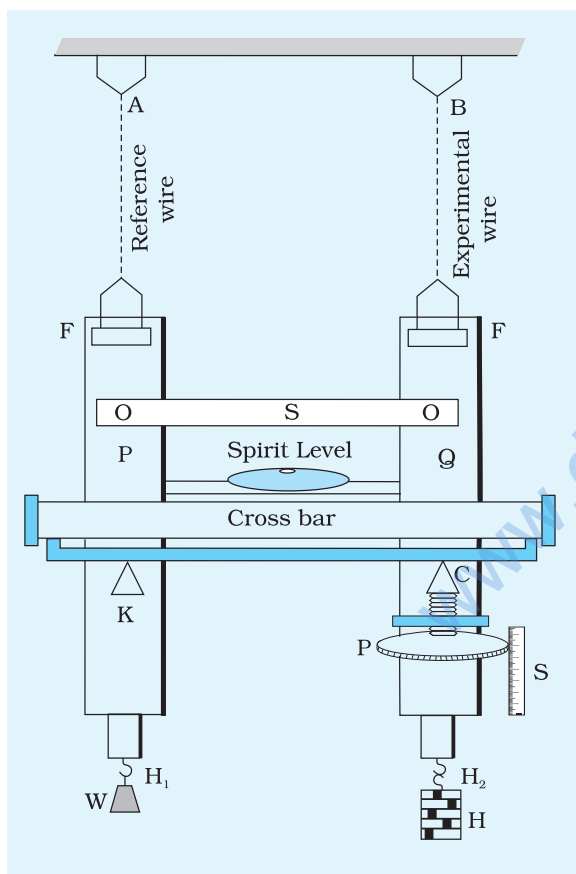
Searle's apparatus, slotted weights, experimental wire, screw gauge and spirit level.

### SEARLE'S APPARATUS

It consists of two metal frames P and Q hinged together such that they can move relative to each other in vertical direction (Fig. E9.1).

A spirit level is supported on a rigid crossbar frame which rests on the tip of a micrometer screw C at one end and a fixed knife edge K at the other. Screw C can be moved vertically. The micrometer screw has a disc having 100 equal divisions along its circumference. On the side of it is a linear scale S, attached vertically. If there is any relative displacement between the two frames, P and Q, the spirit level no longer remains horizontal and the bubble of the spirit level is displaced from its centre. The crossbar can again be set horizontal with the help of micrometer screw and the spirit level. The distance through which the screw has to be moved gives the relative displacement between the two frames.

The frames are suspended by two identical long wires of the same material, from the same rigid horizontal support. Wire B is called the experimental wire and wire A acts as a reference wire. The frames, P and Q, are provided with hooks  $H_1$  and  $H_2$  at their lower ends from which weights are suspended. The hook  $H_1$  attached to the reference wire carries a constant weight W to keep the wire taut.



**Fig. E 9.1:** Searle's apparatus for determination of  $Y$

To the hook  $H_2$  is attached a hanger on which slotted weights can be placed to apply force on the experimental wire.

## PRINCIPLE

The apparatus works on the principle of Hooke's Law. If  $l$  is the extension in a wire of length  $L$  and radius  $r$  due to force  $F (=Mg)$ , the Young's modulus of the material of the given wire,  $Y$ , is

$$Y = \frac{MgL}{\pi r^2 l}$$

## PROCEDURE

1. Suspend weights from both the hooks so that the two wires are stretched and become free from any kinks. Attach only the constant weight  $W$  on the reference wire to keep it taut.
2. Measure the length of the experimental wire from the point of its support to the point where it is attached to the frame.
3. Find the least count of the screw gauge. Determine the diameter of the experimental wire at about 5 places and at each place in two mutually perpendicular directions. Find the mean diameter and hence the radius of the wire.
4. Find the pitch and the least count of the micrometer screw attached to the frame. Adjust it such that the bubble in the spirit level is exactly in the centre. Take the reading of the micrometer.
5. Place a load on the hanger attached to the experimental wire and increase it in steps of 0.5 kg. For each load, bring the bubble of the spirit level to the centre by adjusting the micrometer screw and then note its reading. Take precautions to avoid backlash error.
6. Take about 8 observations for increasing load.
7. Decrease the load in steps of 0.5 kg and each time take reading on micrometer screw as in step 5.

## OBSERVATIONS

Length of the wire ( $L$ ) = ...

Pitch of the screw gauge = ...

No. of divisions on the circular scale of the screw gauge = ...

Least count (L.C.) of screw gauge = ...

Zero error of screw gauge = ...

**Table E 9.1: Measurement of diameter of wire**

S. No.	Reading along any direction			Reading along perpendicular direction			Mean diameter $d = \frac{d_1 + d_2}{2}$ (cm)
	Main scale reading $S$ (cm)	Circular scale reading $n$	Diameter $d_1 = S + n \times \text{L.C.}$	Main scale reading $S$ (cm)	Circular scale reading $n$	Diameter $d_2 = S + n \times \text{L.C.}$ (cm)	
1							
2							
3							
4							
5							

Mean diameter (corrected for zero error) = ...

Mean radius = ...

**MEASUREMENT OF EXTENSION I**

Pitch of the micrometer screw = ...

No. of divisions on the circular scale = ...

Least count (L.C.) of the micrometer screw = ...

Acceleration due to gravity,  $g = \dots$

**Table E 9.2: Measurement of extension with load**

S. No.	Load on experimental wire $M$ (kg)	Micrometer reading		Mean reading $\frac{x + y}{2}$ (cm)
		Load increasing $x$ (cm)	Load decreasing $y$ (cm)	
1	0.5			a
2	1.0			b
3	1.5			c
4	2.0			d
5	2.5			e
6	3.0			f
7	3.5			g
8	4.0			h

## CALCULATION

Observations recorded in Table E 9.2 can be utilised to find extension of experimental wire for a given load, as shown in Table E 9.3.

**Table E 9.3: Calculating extension for a given load**

S. No.	Load (kg)	Mean extension (cm)	Load (kg)	Mean extension (cm)	Extension $l$ for 1.5 kg
1.	0.5	(a)	2.0	(d)	$d - a$
2.	1.0	(b)	2.5	(e)	$e - b$
3.	1.5	(c)	3.0	(f)	$f - c$

$$\therefore \text{Mean } l = \frac{(a - d) + (b - c) + (c - f)}{3}$$

$$= \dots \text{ cm for 1.5 kg}$$

Young's modulus,  $Y$ , of experimental wire  $Y = \frac{MgL}{\pi r^2 l} = \dots \text{ N/m}^2$

## GRAPH

The value of  $Y$  can also be found by plotting a graph between  $l$  and  $Mg$ . Draw a graph with load on the x-axis and extension on

the y-axis. It should be a straight line. Find the slope  $= \frac{\Delta l}{\Delta M}$  of the line. Using this value, find the value of  $Y$ .

## RESULT

The Young's modulus  $Y$  of the material of the wire

(using half table method)  $= Y \pm \Delta Y \text{ N/m}^2$

(using graph)  $= Y \pm \Delta Y \text{ N/m}^2$

## ERROR

Uncertainty,  $\Delta M$ , in the measurement of  $M$  can be determined by a beam/physical balance using standard weight box/or by using water bottles of fixed capacity.



Find the variation in  $M$  for each slotted weight of equal mass say  $\Delta M_1$  and  $\Delta M_2$ . Find the mean of these  $\Delta M$ . This is the uncertainty ( $\Delta M$ ) in  $M$ .

$\Delta L$  – the least count of the scale used for measuring  $L$ .

$\Delta r$  – the least count of the micrometer screw gauge used for measuring  $r$ .

$\Delta l$  – least count of the device used for measuring extension.

## PRECAUTION

1. Measure the diameter of the wire at different positions, check for its uniformity.
2. Adjust the spirit level only after sufficient time gap following each loading/unloading.

## SOURCES OF ERROR

1. The diameter of the wire may alter while loading.
2. Backlash error of the device used for measuring extension.
3. The nonuniformity in thickness of the wire.

## DISCUSSION

Which of the quantities measured in the experiment is likely to have maximum affect on the accuracy in measurement of  $Y$  (Young's modulus).

## SELF ASSESSMENT

1. If the length of the wire used is reduced what will be its effect on (a) extension on the wire and (b) stress on the wire.
2. Use wire of different radii ( $r_1, r_2, r_3$ ) but of same material in the above experimental set up. Is there any change in the value of Young's modulus of elasticity of the material? Discuss your result.

### SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Repeat the experiment with wires of different materials, if available.
2. Change the length of the experimental wire, of same material and study its effect on the Young's modulus of elasticity of the material.