Experiment 10. Young's Modulus

Is rubber more elastic than steel?
The answer lies in the concept of elasticity.

Objective:

To determine the Young's modulus of the material of a wire.

Apparatus:

Young's modulus apparatus, a micrometer, a vernier caliper, a meter stick.

Theory:

If a balanced system of forces is applied to a body, the shape and/or size of the body change and the body is said to have developed strain. Due to this, internal forces are produced within the body which tend to bring the body back to its original shape and size when the external forces are withdrawn. This property of matter to develop these internal forces (of stress) is known as elasticity.

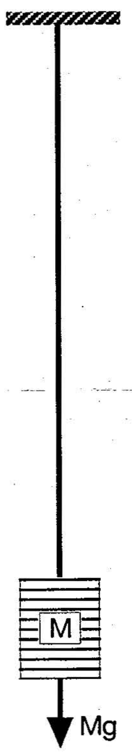

Fig. 1

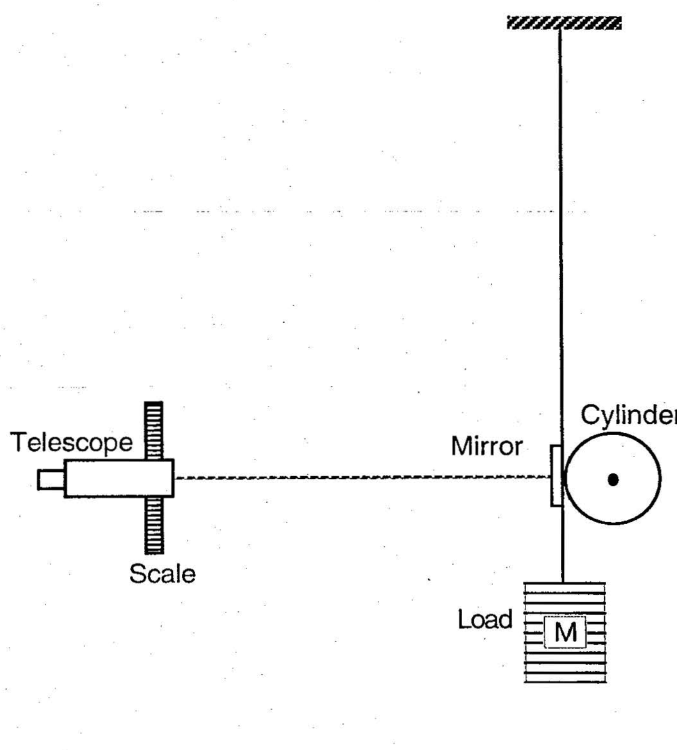

Fig. 2. Schematic Diagram of Young's Modulus Apparatus

If one end of a wire (Fig. 1) is fixed and a mass M is suspended from the other end of the wire, equal and opposite forces of magnitude Mg are applied to the wire by the mass M and by the support at the top. Due to this, the length of the wire increases. (There is also a slight change in other dimensions of the wire but we will not consider them.) If the increase in the length of the wire is ΔL and the original length of the wire is L, then

longitudinal strain or tensile strain = $\Delta L/L$.

Further, the internal forces over any cross-section of the wire are equal to the external force Mg. Thus

longitudinal stress or tensile stress = $Mg/\pi r^2$.

Here r is the radius of the wire.

According to Hooke's law, within elastic limits, stress is directly proportional to strain.

Thus tensile stress = Y (tensile strain), where Y is called the Young's modulus or modulus of longitudinal elasticity or stretch modulus of the material of the wire.

$$\text{Thus } Y = \frac{\text{Tensile stress}}{\text{Tensile strain}} = \frac{Mg/\pi r^2}{\Delta L/L} = \frac{MgL}{\pi r^2 \Delta L} \qquad (1)$$

The wire whose Young's modulus is to be determined passes over a small cylinder which is free to rotate about a horizontal axis (Fig. 2). When the length of the wire increases by an amount ΔL, the cylinder of radius r_1 rotates through an angle θ which is given by

$$\theta = \frac{\Delta L}{r_1} \qquad (2)$$

There is a small plane mirror attached to the cylinder which rotates along with the cylinder. The increase in length ΔL and thus angle θ are very small and so an optical lever (an arrangement of scale, mirror and telescope shown in Figs. 2) is used to determine θ and ΔL.

The image of a vertical scale formed by the mirror is observed through the telescope. When the mirror is in the vertical position MP (Fig. 3), the image of point N of the scale is seen through the telescope. When the cylinder and mirror rotate through an angle θ and is in position M_1P_1, the image of point Q is seen through the telescope. In both cases, the reflected ray is ON while NO is the incident ray when the mirror is position MP and QO is the incident ray when the mirror is in position M_1P_1. It easy to see that when the mirror rotates through an angle θ, the incident ray rotates through an angle 2θ. Angle θ is small. Thus angle 2θ (in radian) is nearly equal to $\tan 2\theta = x/D$, where x = distance NQ and D = distance NO.

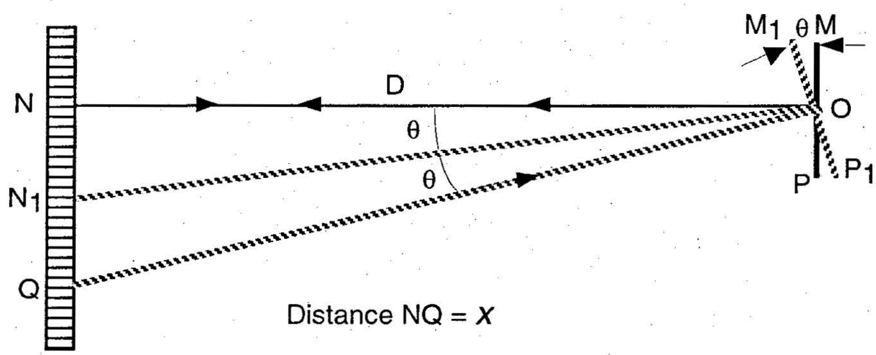

Fig. 3

$$\theta = \frac{x}{2D} = \frac{\Delta L}{r_1}, \text{ by Eq. (2).}$$

Hence $\Delta L = \dfrac{x\ r_1}{2D}$.

Finally, by substituting the value of ΔL into Eq. (1), we get

$$Y = \frac{MgL}{\pi r^2 \Delta L} = \frac{2MgLD}{\pi r^2 x\ r_1}. \tag{3}$$

Procedure:

1. Make sure that the apparatus is arranged as shown in Fig. 2. Do not disturb the setup or try to make any adjustments. Do not take off the initial load placed on the hanger.
2. Look through the telescope and read the position of the cross wires on the scale. Record load on the hanger as zero along with this reading in the first row and second and third columns of Table I.
3. Increase the load and take the reading of the position of the cross wires. Record the load on the hanger and this reading in the next row of Table I.

4. Increase the load on the hanger in equal steps and repeat step 3. Thus fill out the second and third columns of Table I.
5. Increase the load on the hanger by 250 gm. Gently take off this weight and take the reading of the cross wires. Record this reading in the last row of the fourth column of Table I.
6. Decrease the load on the hanger in equal steps (by the same amount as it was increased), take the readings of the cross wires and thus fill out the rest of the fourth column of Table I. Note that this column is filled out from last row to the first row as the load is decreased in equal steps. If the color of the graduations of the scale changes from red to black (or from black to red), change the sign (from + to -) of the readings.
7. Find the least count of the micrometer and take 8 readings of the diameter of the wire, measuring one diameter and then perpendicular diameter at four different points.
8. Measure the length of the wire twice.
9. Measure the distance between the mirror and the scale twice.
10. Take two readings of the diameter of the cylinder.

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York College of The City University of New York

Physics I   Name:

Experiment No. 10: Pre-Lab Questionnaire

1. Briefly describe how an optical lever works.

2. Calculate Young's modulus from the following data:

Load on the hanger (gm)	Readings of the scale (cm)			Change in the reading of the scale when the load is increased by M = ______ gm
	when the load is		Average s	
	increased (s_i)	decreased (s_d)		
100	8.4	8.5		
300	6.2	6.3		$s_4 - s_1 = x_1 =$
500	3.9	4.0		$s_5 - s_2 = x_2 =$
700	1.7	1.8		$s_6 - s_3 = x_3 =$
900	-0.5	-0.4		
1100	-2.7	-2.6		Average x =

Average diameter of the wire = 0.036 cm

Average length of the wire = 96.7 cm

Average diameter of the cylinder = 1.24 cm

Average distance between the mirror and the scale = 84.6 cm

Experiment No. 10

Name:

Marks:

Partner:

Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

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Data Sheet

Table I

Readings for the determination of ΔL:
Change the load on the hanger in equal steps.
Number of sets of readings must be even.

No.	Load on the hanger (gm)	Positions of the cross wires (cm)			Change in the position of cross wires when load is changed by M = gm
		Load increasing (S_i)	Load decreasing (S_d)	Average (S)	
1					$S_5 - S_1 = x_1 =$
2					
3					$S_6 - S_2 = x_2 =$
4					
5					$S_7 - S_3 = x_3 =$
6					
7					$S_8 - S_4 = x_4 =$
8					

Average x =

Table II

Readings for the diameter of the wire:
Least count of the micrometer = ; Zero error =

No.	1	2	3	4	Average
One diameter					
Perpendicular diameter					

Average diameter of the wire =
Diameter of the wire corrected for zero error =
Radius of the wire, r =
Length of the wire (reading 1) =
Length of the wire (reading 2) =
Average length of the wire, L =

Distance between mirror and the scale (reading 1) =
Distance between mirror and the scale (reading 2) =
Average distance between mirror and the scale, D =
Diameter of the cylinder (reading 1) =
Diameter of the cylinder (reading 2) =
Average diameter of the cylinder =
Radius of the cylinder, r_1 =

Calculations:
Calculate Y by using the values of M and *x*. Determine the percent error.

Plot a graph between M and average S. Determine Y from the slope of the graph. Again calculate the percent error in Y.

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Experiment No. 10: Questions

1. Using your data, find the increase in the strain in the wire when the load is increased by 400 gm.

2. Using your data, find the increase in the stress in the wire when the load is increased by 400 gm.

3. What is Hooke's law? How does the straight line graph of M and S (the readings of the scale) verify Hooke's law?

4. Is rubber more elastic than steel? Explain your answer.

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