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General Properties of Matter Lab
PH29001

EXPERIMENT-1

TO DETERMINE YOUNG'S MODULUS OF ELASTICITY OF THE MATERIAL OF A BAR BY THE METHOD OF FLEXURE

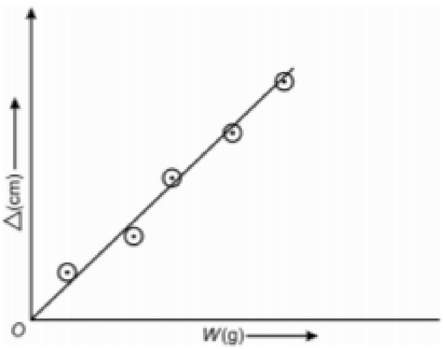
Aim: To determine Young's modulus of elasticity of the given material.

Apparatus: Spirit level, meter scale, screw gauge, travelling microscope and slide calipers

Theory: If a light bar of breadth b and depth d is placed horizontally on two knife-edges separated by a distance L, and a load of mass m, applied at the mid-point of the bar, produces a depression l of the bar, then Young's modulus Y of the material of the bar is given by -

$$\boxed{Y = \frac{gL^3m}{4bd^3l} \quad L \gg b \gg d}$$

Where g is the acceleration due to gravity. This is the working formula of the experiment which is valid until the slope of the bar at any point with respect to the unstrained position is quite less than unity. Here, Young's modulus(Y) is to be determined by measuring the quantities b, d, L and the mean depression corresponding to a load m. If b, d, L and l are measured in cm, m in gm,g is expressed in cm/sec^2, and then Y is obtained in $dyne/cm^2$ Young's Modulus is independent of the shape and size of the bar. It depends only on the material of the bar. When a bar is supported at its ends and weight is loaded at its centre, it shows maximum depression at its centre, but the depression produced depends on the material of the bar. On plotting a graph depression (in cm) vs load (in g), a straight line is obtained as shown below and its slope gives the value of Young's Modulus of the bar.



Observations:

Least Count of Meter Scale = 0.1cm and temperature of the laboratory while taking the measuring the values of the parameters = 30°C

Table-1-

Vernier Constant (V.C.) of the Travelling microscope-

Value of 1 smallest main scale division = 0.5mm = 0.05cm

Total number of smallest divisions on Vernier Scale=50

Vernier Constant (V.C) = $0.05/50 = 0.001cm$

Value of 1 smallest main scale division (l_1) (cm)	Value of 1 vernier division $l_2 = (n/m)l_1$ (cm)	Vernier constant (vc) = $(l_1 - l_2)$ = 0.001 cm & Zero error = 0 cm
0.05	0.049	

Table-2-

Load-depression data for chosen length-

Length of Bar	Sl. No.	Load in (kg)	Microscope reading for Increasing load (cm)			Microscope reading for decreasing load (cm)			Mean reading (cm)	Depression L_1- L_2 (cm)
			Main scale	Vernier	Total	Main scale	Vernier	Total		
70 cm	1	0.0	5.35	0	5.350	5.35	9	5.359	5.355	0.000
	2	0.5	5.25	21	5.271	5.30	0	5.300	5.286	0.069
	3	1.0	5.20	39	5.239	5.20	40	5.240	5.240	0.115
	4	1.5	5.15	25	5.175	5.15	25	5.175	5.175	0.180
	5	2.0	5.10	35	5.135	5.10	35	5.135	5.135	0.220
80 cm	1	0.0	5.15	0	5.150	5.15	35	5.185	5.168	0.000
	2	0.5	5.05	6	5.056	5.05	0	5.050	5.053	0.115
	3	1.0	4.95	36	4.986	4.95	30	4.980	4.983	0.185
	4	1.5	4.90	2	4.902	4.90	0	4.900	4.901	0.267
	5	2.0	4.80	15	4.815	4.80	15	4.815	4.815	0.353
90 cm	1	0.0	4.95	0	4.95	4.95	8	4.958	4.954	0.000
	2	0.5	4.80	0	4.80	4.75	37	4.787	4.794	0.161
	3	1.0	4.70	0	4.70	4.70	0	4.70	4.700	0.254
	4	1.5	4.60	0	4.60	4.60	0	4.60	4.600	0.354
	5	2.0	4.45	18	4.468	4.45	0	4.45	4.459	0.495

Table-3-

Vernier Constant (V.C.) of the slide calipers-

Value of 1 smallest main scale division = 0.1cm
Total number of smallest divisions on Vernier Scale=10
Vernier Constant (V.C) = $0.1/10 = 0.01cm$

Value of 1 smallest main scale division (l_1) (cm)	Value of 1 vernier division $l_2 = (n/m)l_1$ (cm)	Vernier constant (vc) = $(l_1 - l_2) =$ 0.01 cm & Zero error = 0 cm
0.1	0.09	

Table-4-

Measurement of breadth (b) of the bar by slide calipers-

No. of obs.	Readings (cm) of the		Breadth b (cm)	Mean b (cm)
	Main scale	Vernier		
1	2.6	0	2.60	2.59
2	2.5	9	2.59	
3	2.5	9	2.59	

Table-5-

Least count (L.C.) of the screw gauge-

Pitch of the screw (p) = 0.05cm
Total number of divisions on Circular Scale (n)=50
Least count (L.C) = $0.05/50 = 0.001cm$

Pitch of the screw p (cm)	No. of divisions n on the circular scale	Least count = p/n = 0.001 cm & Zero error = 0 cm
0.05	50	

Table-6-

Measurement of thickness (d) of the bar by the screw gauge-

No. of obs.	Readings (mm) of the		Thickness d (mm)	Mean d (mm)	Mean d (cm)
	Main scale	Vernier			
1	6.5	15	15	6.657	0.666
2	6.5	16	15		
3	6.5	16	15		

Graph of Depression versus Mass Plot-

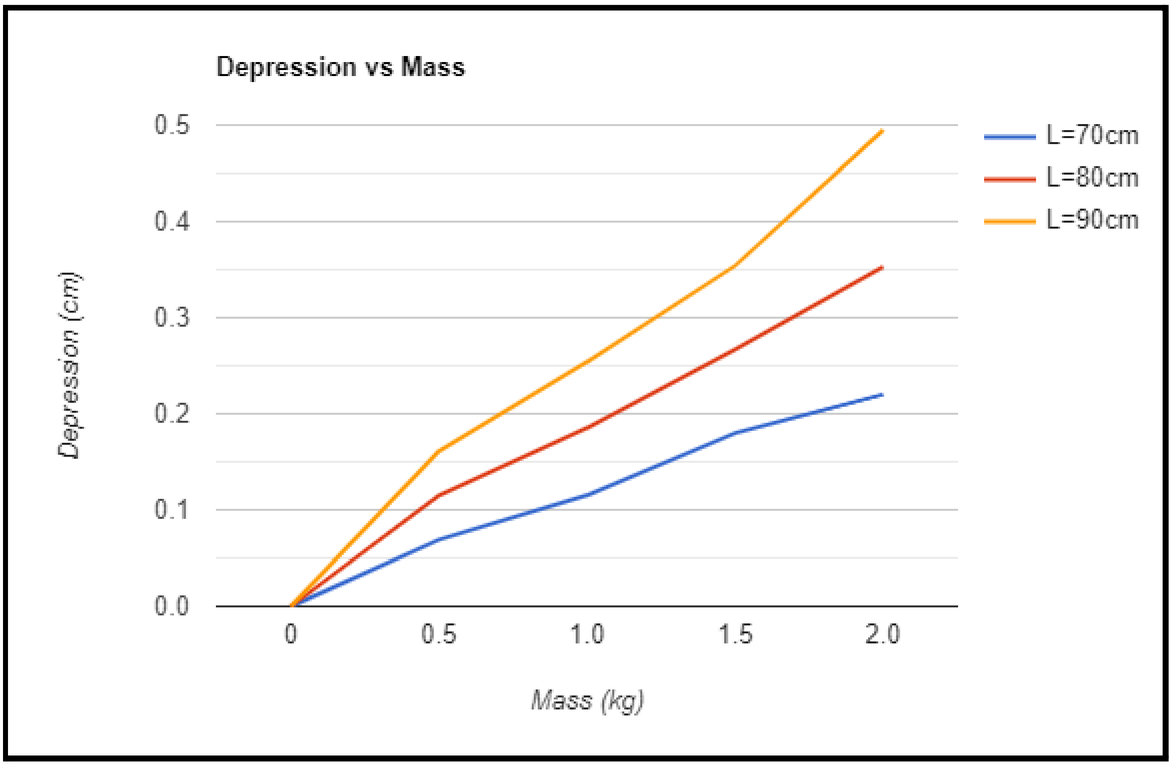


Table-7-

Length (L cm)	Δm/Δl (gm/cm) from graph	Mean d (cm)	Mean b (cm)	$Y = \frac{gL^3\Delta m}{4bd^3\Delta l}$	Mean, Y (N/m^2)
70 cm	9.0×10^3	0.666	2.59	9.90×10^{11}	9.72×10^{10}
80 cm	5.8×10^3	0.666	2.59	9.50×10^{11}	
90 cm	4.2×10^3	0.666	2.59	9.78×10^{11}	

Analysis-

From the graph and table-7, the metal which is used to make the bar is <u>Brass</u> whose Young's Modulus lies in the range of $102\times 10^9\ N/m^2$ - $125\times 10^9\ N/m^2$, as the difference between the mean value calculated ($97.2\times 10^9 N/m^2$) and true value ($102\times 10^9\ N/m^2$) is $4.8\times 10^9\ N/m^2$.

Error Analysis:

<u>Following data has been considered for error calculation:</u>

L = 90 cm, ΔL = 0.1 cm least count of **meter scale** used to measure the length of the rod.

m = 2 kg. That is given, ∴, Δm = 0

At m = 2 kg, depression *l* = 0.486 cm and Δ***l*** = 0.001 cm is the least count of **travelling microscope** used to measure the depression of the rod.

Breadth, b = 2.60 cm and Δb = 0.01 cm is the least count of **slide calipers** used to measure the depression of the rod.

Depth, *d*= 0.666 cm and Δd = 0.001 cm is the least count of **screw gauge** used to measure the width or depth of the rod.

$$Y = \frac{gL^3m}{4bd^3l}$$

$$\frac{\Delta Y}{Y} = \frac{\Delta g}{g} + \frac{3\Delta L}{L} + \frac{\Delta b}{b} + \frac{3\Delta d}{d} + \frac{\Delta m}{m} + \frac{\Delta l}{l}$$

$$\Delta g = 0, \Delta m = 0$$

Further, $l \approx l_1 - l_2 \Rightarrow \Delta l = \Delta l_1 + \Delta l_2$

$$\frac{\Delta Y}{Y} = \frac{3\Delta L}{L} + \frac{\Delta b}{b} + \frac{3\Delta d}{d} + \frac{2\Delta l}{l}$$

$$\frac{\Delta Y}{Y} = \frac{3 \times 0.1}{90} + \frac{0.01}{2.60} + \frac{3 \times 0.001}{0.666} + \frac{2 \times 0.001}{0.486} = 0.0157$$

$$\Delta Y = Y \times 0.0157 = 97.2 \times 10^9 \times 0.0157 = 1.52604 \approx 1.5 \times 10^9$$

$$\frac{\Delta Y}{Y} \times 100 = 1.57\%$$

The maximum percentage error in Y (Young's Modulus) is 1.57%
Therefore, Y=(9.72 ± 1.5) × $10^9 N/m^2$.

Results-

1. Therefore, the Young's Modulus of the elasticity of the material of a bar by the method of flexure is $(97.2 \pm 1.5) \times 10^9\ N/m^2$
2. The maximum percentage error in Young's Modulus (Y) is 1.57%.
3. The material which is used to make the bar used in this experiment is brass.

Precautions-

1. To reduce statistical error in measurements, at least 3-5 readings must be taken.
2. The temperature of the laboratory where the experiment is being performed must be noted as the few parameters of young's modulus are temperature-dependent.
3. A uniform metallic bar must be chosen.
4. Care should be taken to make the beam horizontal and to load the bar at its mid-point. The metallic bar must be placed symmetrically on the knife edges.
5. In the expression of Y, d and L are in powers of three. As d is much smaller, it should be carefully calculated to avoid maximum error in Y.
6. The load on beam should not exceed the elastic limit of beam.
7. The number of digits after the decimal point in the measurement of a parameter is equal to the number of decimal places in the least count of instrument used to measure the parameter.
8. An instrument available in the laboratory with the least vernier constant (or least count) must be chosen to minimise the maximum error in Young's Modulus measurement of a parameter whose dimensions are very less (i.e, less than 1), especially when the parameter has a power raised to it, in the formula.
9. The horizontal cross-wire of the travelling microscope must coincide with the tip of the pin. In case they are not coinciding, then move the microscope vertically up or down until they coincide and then the reading of the depression must be taken.
10. After adding or removing a load to/from the hanger, reading must be taken after few minutes.
11. Adding and removing slotted weight should be done gently. Increasing or decreasing weights should be done in regular steps.
12. Parallax and back-lash errors during measurement must be avoided.
13. Zero error must be noted in the measuring instruments.

Discussions-

1. To measure d, we must use a screw gauge instead of a slide caliper as the least count of slide caliper is 0.01cm and that of the screw gauge is 0.001cm. This is done to minimise the maximum error in the measurement of Young's modulus as d has a smaller value and has a power of 3 raised to it, and also the least count of screw gauge is less than that of a slide caliper.
    1. On using a slide caliper, $\frac{\Delta Y}{Y} = \frac{3\Delta L}{L} + \frac{\Delta b}{b} + \frac{3(0.01)}{d} + \frac{2\Delta l}{l}$
    2. On using a screw gauge, $\frac{\Delta Y}{Y} = \frac{3\Delta L}{L} + \frac{\Delta b}{b} + \frac{3(0.001)}{d} + \frac{2\Delta l}{l}$

    Clearly, the maximum error in Y is more in second case than in the first case.

2. Although slide calipers (V.C=0.01cm) have a lesser least count than a meter scale (V.C=0.1cm), they cannot be used to measure the length of the bar as its length is very large and hence the appropriate tool to be used is meter scale. Hence, an appropriate tool must be selected for measurement by considering the size and shape of the bar, the value of the object raised to a power of n (n>1), in the formula, and least count of the tool.
3. When the temperature increases, the atomic thermal vibrations increase, and this will cause the changes of lattice potential energy and curvature of the potential energy curve, so Young's modulus will also change. And with the increase of temperature, the material will have a volume expansion. Hence, it is important to note down the temperature of the laboratory when the experiment is being performed.