Laboratory Manual

EPHY108L, Mechanics

B.Tech, 1st Year, 2nd Semester

Department of Physics

School of Engineering and Applied Sciences

BENNETT
UNIVERSITY

Table of Contents

Instructions, Rules and Regulations
First year Physics Laboratory,
Department of Physics

1. Attendance in the lab is mandatory for all students.
2. Students must join the lab session through Microsoft Teams on time and conduct the experiment during the lab session.
3. Students should login well prepared by reading the description of the experiment assigned to them.
4. Students are required to prepare a hand-written write-up / lab record, draw graphs on a graph paper (if needed), scan the entire thing and send it for evaluation via LMS.
5. In the write-up for each experiment, the following needs to be written:
    a) Name and Roll No. of the student and date of experiment
    b) Aim of the experiment
    c) Formula used
    d) Observation table/tables
    e) Calculations and / or graphs
    f) Results and Conclusions
6. **Students must submit the write-up of an experiment by the end of the corresponding lab session**. A grace period of extra 10 minutes will be allowed after the class ends. Any write-up submitted after this time period will not be evaluated.
7. The file name of submitted write-up should be as follows: Batch_No._Enrollment_No._Expt._No. (For e.g. EB05_ E20CSE001_1).

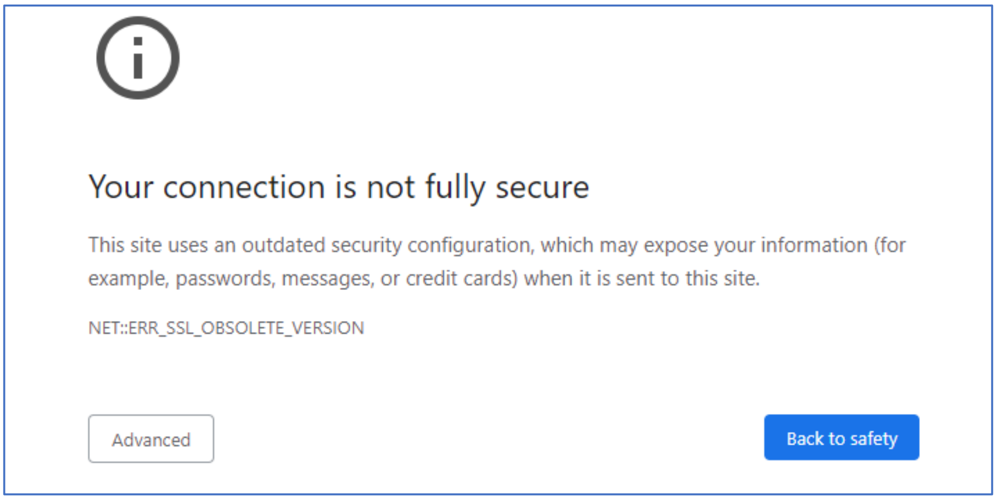
Total Lab marks: 20

Split-up of Lab Marks among different components:

Components:	Continuous Lab Evaluation (Lab Record)	End Term Lab Exam
Marks:	10	10
Total Marks	20	

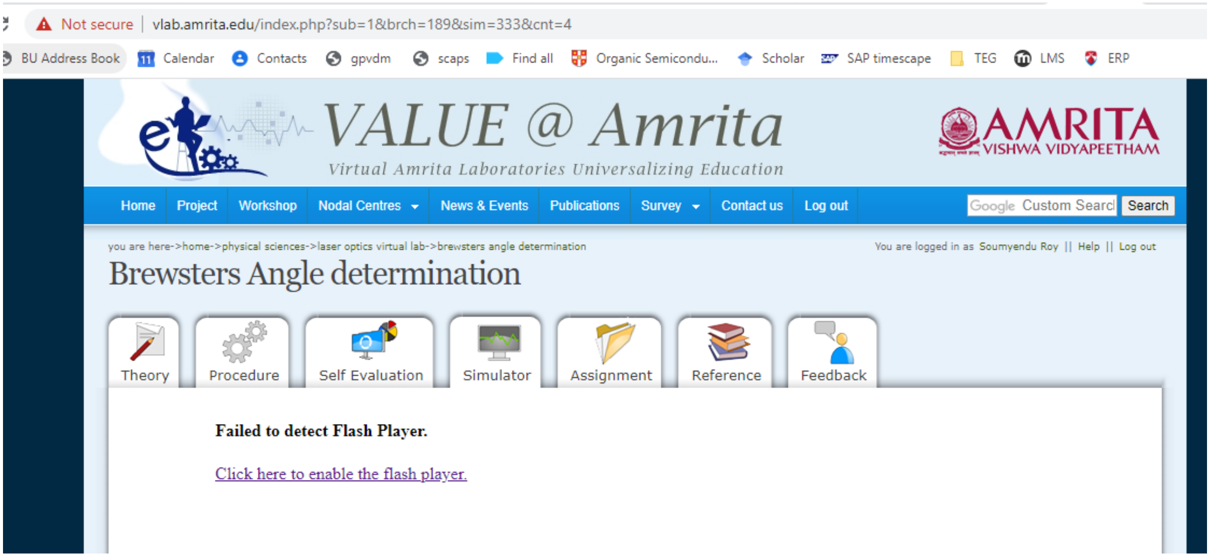
Instructions for Accessing Virtual Lab and performing the experiments.

1. You will need to register yourself at the website of Amrita Vishwa Vidyapeetham's Virtual labs (https://vlab.amrita.edu/index.php?pg=bindex&bsub=guest_registration_form). Create a password to access the site
2. When opening the site your browser may not connect saying that the site is not secure. Click on "Advanced" and then "Proceed to vlab.amrita.edu".



3. You may have to allow flash player for running the simulation. You can click on "Not secure" indication on the left of URL and select "Allow" from the drop down list beside Flash (see the figure below). You may have to reload the webpage after this.

The above procedure is for Google Chrome in Windows 10. The option may be accessed differently in other browsers and operating systems.
Alternatively, you can use the “Click here to enable the flash player” option. This opens a set of instructions for different browsers. You may follow those and change the settings of your browser so that it can use the flash player.



You may have to try different options depending on your browser and operating system.

4. If you face any issues you can seek help from your faculty.

Experiment No. 1
Instrumental Error

Aim:

To measure volume of a given object using Vernier Calipers & Screw Gauge and estimate the error in the measurements.

Apparatus:

Vernier Calipers, Screw Gauge, metal spheres, blocks, glass beaker, thin wire

Theory:

All experimental measurements even with the most sophisticated equipment are constrained by errors of measurement caused due to various factors. Errors can be reduced by using accurate instruments and performing the experiment carefully, but the final result will still have errors.

There are primarily two types of errors: systematic and random.

***Systematic errors*:** These come primarily from the measurement instruments and could be due to limitations in accuracy of the instrument, incorrect calibration or due to errors in using the instruments. For example a defect in the thermometer that is used to measure the temperature will lead to systematic errors. Such errors will lead to results of multiple measurements which are close to each other but deviated from the true value.

***Random errors*:** These are caused due to random variations in the conditions of the experiment. For example, while measuring the time period of a simple pendulum the randomness in starting and stopping of the stop watch will lead to random errors in the measured time period of the pendulum. In the presence of random errors, the results will be crowded around a mean value which is close to the true value of the measured quantity. The distribution of the values around the mean value is usually Gaussian in nature.

Examples of systematic or instrumental errors in measurements

Example 1: Time period of a simple pendulum

let us consider the estimation of the acceleration due to gravity using a simple pendulum. It is well known that the time period T of a simple pendulum is given by

$$T = 2\pi\sqrt{\frac{l}{g}} \tag{1}$$

where l is the length of the pendulum and g is the acceleration due to gravity. In order to estimate the value of g we take a simple pendulum of length l and measure the time period T of the pendulum. From these measurements, we can obtain the value of g.

The question is what is the error in the value of g obtained from the experiment? We first note that when the length l and the time period T are measured, both these quantities would have errors due to the limitations of measuring instruments. Thus, if we use a scale with a ***least count*** of 1 mm in measuring the length of the pendulum then the maximum possible error in the length of the pendulum is ± 1 mm. Note that this is a matter of convention. Some books and articles may consider half of the least count as the maximum possible error. Both choices are valid. Similarly, to measure the time period of the pendulum we measure the time *t* taken by the pendulum for say 10 oscillations and estimate the time period from the formula

$$T = t/10$$

If the stop watch has a least count of 0.1 s then the measurement of *t* has a maximum error of 0.1 s and the maximum error in the time period (T) is 0.01 s.

These errors in the measurement of *l* and *T* will result in error in the estimation of g. In order to relate these, we write Eq. (1) as

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

We now take natural logarithm of Eq. (2) to obtain

$$\ln(g) = \ln(4) + 2\ln(\pi) + \ln(l) - 2\ln(T)$$

We now differentiate the above equation to obtain

$$\frac{dg}{g} = 0 + 0 + \frac{dl}{l} - 2\frac{dT}{T} = \frac{dl}{l} - 2\frac{dT}{T} \tag{3}$$

where *dg* is the error in the value of *g*, *dl* is the error in the value of *l* and *dT* is the error in the value of *T*.

Since errors can be both positive or negative, we estimate the ***maximum probable error*** by adding the individual errors in *l* and *T* and obtain

$$\frac{dg}{g} = \frac{dl}{l} + 2\frac{dT}{T} \tag{4}$$

Since *T* is estimated by measuring the time taken for *n* oscillations, the error in *T* will be $dT = dt/n$ where *dt* is the least count of the stop watch used to measure the time taken for n oscillations. Thus

$$\frac{dg}{g} = \frac{dl}{l} + 2\frac{dt}{t} \tag{5}$$

As an example, we have *dl* = 1mm, *dt* = 0.1 s, *n* = 10, *l* = 20 cm, *t* = 9s and we have

$$\frac{dg}{g} = \frac{10^{-3}}{0.2} + 2\frac{0.1}{9} \approx 0.005 + 0.02222 \approx 0.027$$

Thus, the ***fractional error*** in the estimation of *g* is about 2.7%. The value of g, as given by the calculator, comes out to be 9.747757 m/s^2. Now since *dg/g* is 0.027, we obtain *dg* = 0.26318 m/s^2.

Although the calculator gives many ***significant digits*** for the value of *g*, since there is a fractional error of about 2.7 % in the experiment, it implies that the value of *g* that is calculated has uncertainty of about 2.7 %. Hence, we need to quote the value of *g* appropriately keeping the uncertainty in account.

For this we first round off the error to one significant digit and obtain dg = 0.3 m/s^2. Since the value of error in the estimation of g goes up to the 1st decimal place, we need to round off the value of measured g to the 1st decimal place, i.e. 9.7 m/s^2. Thus, in this example the measured value of g is

$$g \approx (9.7 \pm 0.3)\ \mathrm{m/s^2}$$

This implies that due to the instrumental errors in the measurement of the length and time period of the pendulum, although the measured value of g is 9.747757 m/s^2, the actual value lies between 9.4 m/s^2 and 10.0 m/s^2. The actual value of g is within the two limits.

Example 2: Volume of a spherical object

To measure the volume of a spherical object we measure the diameter D of the object using a Vernier calipers or screw gauge. The volume V is then given by

$$V = \frac{4\pi}{3} R^3 = \frac{\pi}{6} D^3 \tag{6}$$

In order to calculate the maximum probable error in the volume we take logarithm of both sides and obtain

$$\ln(V) = \ln\left(\frac{\pi}{6}\right) + 3\ln\,(D) \tag{7}$$

We now differentiate the above equation and get

$$\frac{dV}{V} = 0 + 3\,\frac{dD}{D} = 3\,\frac{dD}{D} \tag{8}$$

Now dD corresponds to the least count of the Vernier calipers or screw gauge and D is the average diameter of the spherical object. Thus, substituting for all values, we can calculate dV the error in the estimated value of volume V.

Description of Apparatus:

Vernier calipers: A normal scale that we all use generally has a minimum measurable distance of 1 mm. Thus any measurement of length using a standard scale will have an uncertainty of ± 1 mm. In order to measure lengths more accurately we use an instrument called Vernier Calipers.

It consists of a fixed main scale and a movable Vernier scale as shown in Fig. 1. Using a Vernier caliper, we can measure lengths of objects, internal diameter of holes, depth of a hole, height of a step, etc. In a typical Vernier caliper nine main scale divisions (corresponding to 9 mm) are divided into ten Vernier scale divisions such that when the zero of the Vernier scale coincides with any main scale division the tenth Vernier division will coincide with another main scale division which is nine millimeters away. None of the other Vernier divisions will coincide with any main scale division.

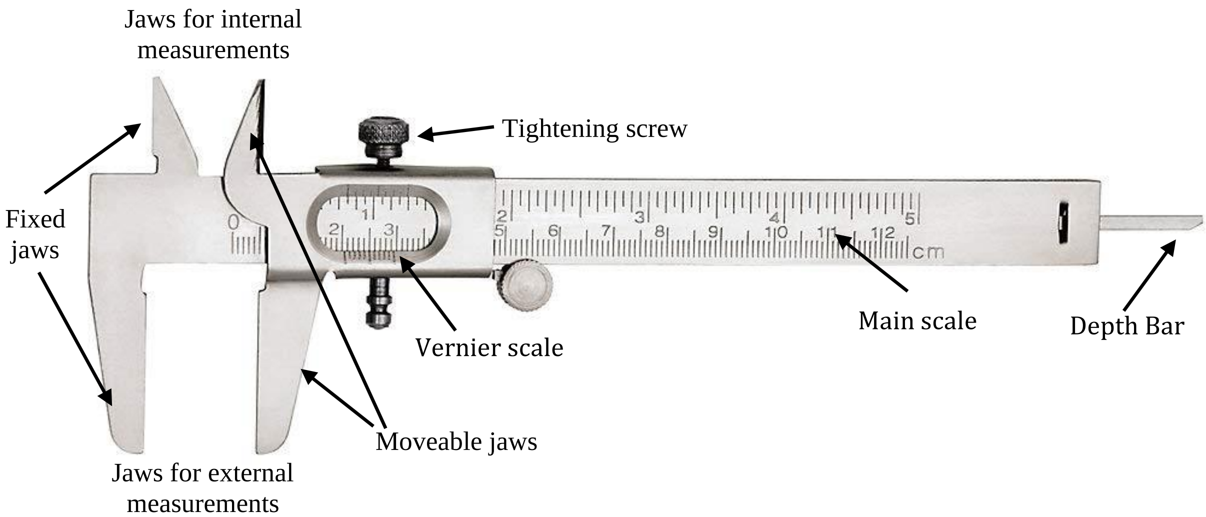


Figure 1: Typical Vernier calipers

We can estimate the ***least count (LC)*** of the Vernier calipers as follows:

- 1 main scale division = 1 mm
- Since 9 main scale divisions (MSD) are divided into 10 Vernier scale divisions (VSD), length of one Vernier scale division = 9/10 mm.
- Least count of the Vernier calipers = 1 main scale division – 1 Vernier scale division = 1.0 mm - 0.9 mm = 0.1 mm. Please note that this is a specific example, there are Vernier instruments which have a different least counts.

Thus, this Vernier caliper has a minimum measurable length of 0.1 mm. The maximum possible instrumental error is ± 0.1 mm, which is ten times smaller than a standard scale. Hence a Vernier caliper is more accurate than a scale.

We can also write the least count as

$$\text{Least count} = 1 \text{ MSD } \times \left(1 - \frac{\text{Number of MSD}}{\text{Number of VSD}}\right)$$

How to measure length using Vernier calipers:

- When the Vernier calipers is used to measure lengths, the total distance is estimated by first noting the position of the first VSD with regard to MSD. Thus if the zero of the Vernier scale lies between 11 and 12 mm divisions of the main scale, then the main scale value is taken as 11 mm.
- We also note down the particular number of the VSD that coincides with a division of the main scale. Thus, let us assume that the 6^{th} VSD coincides with some MSD.
- The total length then is the sum of the value in the main scale and the product of the least count and the number of the Vernier scale that coincides with the main scale.
- Thus, in this example the length is $11 + 6 \times 0.1 = 11.6$ mm

- Since the instrumental error is same as the least count, i.e. 0.1 mm, we quote the measured length as 11.6 ± 0.1 mm.

Zero error: It is possible that when the Vernier scale is moved to the extreme left position, the zero of Vernier does not coincide with the zero of the main scale. In such a case the Vernier calipers has zero error. This is a systematic error and needs to be taken into account when estimating lengths using the Vernier caliper. The ***zero error is subtracted*** from the length measured using the faulty Vernier calipers to get the actual length.

As an example, we first move the Vernier scale to the extreme left position so that the jaws of the main scale and Vernier scale touch each other. In this position for example if the zero of the Vernier does not coincide with zero of the main scale, then the Vernier has zero error. Let us assume that the zero of the Vernier is slightly to the right of the zero of the main scale. There will be a particular division of the Vernier that will coincide with some main scale division. Let us assume that the 4^{th} Vernier division coincides with a main scale division. Then since the least count is 0.1 mm, in our example the zero error is $4 \times 0.1 = 0.4$ mm. So, even though the actual length is 0, the Vernier calipers is showing a reading of 0.4 mm. The zero error needs to be subtracted from all measured values of lengths using this Vernier calipers. Thus, if our measured length using this Vernier is 11.6 mm then the actual length will be $11.6 - 0.4 = 11.2$ mm.

If the zero of the Vernier lies to the left of the zero of the main scale when the jaws of the Vernier and main scale touch each other then the zero error is negative. As before if the 4^{th} Vernier division coincides with a main scale division, the zero error is -0.4 mm and the actual length in this case will be $11.6 - (-0.4) = 12.0$ mm

Screw Gauge: A screw gauge (see Fig. 2) is used to measure even smaller dimensions than Vernier calipers and is basically a fine screw with an accurate and constant pitch. An object such as a wire whose diameter is to be measured is placed between the anvil and spindle of the screw gauge and the thimble is rotated on the sleeve until the wire is held between the anvil and the thimble. The screw gauge contains a rachet knob which ensures that we always have the same amount of tightening of the given object between the anvil and the spindle.

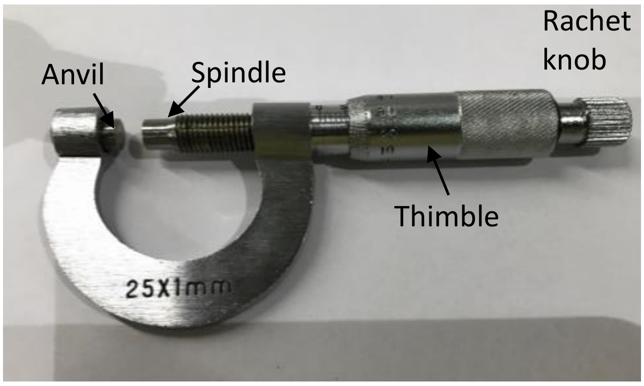


Figure 2: Typical Screw gauge

The screw gauge contains a main scale on the spindle and a number of divisions on the rotating thimble. Typically, the main scale will have divisions every 1 mm and the circular scale will have 100 divisions. When the thimble is given one complete revolution, the thimble will move a certain distance along the main scale (also called the ***pitch of the screw gauge***). In this example, when the thimble is rotated by one full revolution, the thimble will move 1 mm along the main scale. Thus, we find that 1 mm length is effectively divided into 100 divisions on the circular scale. Thus, the least count of the screw gauge will be 1/100 = 0.01 mm or 0.001 cm. Please note this is a specific example. Screw gauges with different least counts also exist.

It is possible that when the spindle is brought into contact with the anvil with no object placed in between, the zero of the circular scale does not coincide with the main scale line of the main scale. Thus, the screw gauge gives us a finite reading instead of zero. We need to find the ***zero error*** and subtract it from all subsequent readings.

For example, if the zero of the circular scale is below the main scale line and the 5th division of the circular scale coincides with the main scale, then the zero error would be $5 \times 0.01 = 0.05$ mm. The zero error is positive in this case.

If the zero of the circular scale is above the main scale line and say the 97th division of the circular scale coincides with the main scale line then zero error would be $-(100 - 97) \times 0.01 = -0.03$ mm. In such a case the zero error is negative.

For more details on Vernier calipers, screw gauge and spherometer, please visit the following site (IIT-PAL lecture by Prof Sanjeev Sanghi, IIT Delhi):

https://www.youtube.com/watch?v=DgMdre5q0tc&index=3&list=PLl9LSbHKSR63XPvso0DqKu5B029dS3MII

In this experiment the objective is to use a Vernier caliper and a Screw gauge to estimate the volume of a given object.

Procedure:

Measurements using Vernier calipers

1. Go to the Amrita Vishwa Vidyapeetham virtual lab website for Vernier calipers using the link: http://amrita.olabs.edu.in/?sub=1&brch=5&sim=16&cnt=4
2. Browse through the different tabs and read the material provided on the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure provided in the site.
3. Click on the “simulator” tab to start the experiment. Note that you do not need to login for this experiment.
4. Calculate the least count of the Vernier calipers and show the calculations.

5. Use the magnified view of the Vernier scale (circled in the figure 3) to check if there is any zero error and note down its value.
6. Click on the “sphere” in the navigation panel on the left side, to select it for measurement. The sphere is transferred to the jaws of the calipers as shown in figure 3.

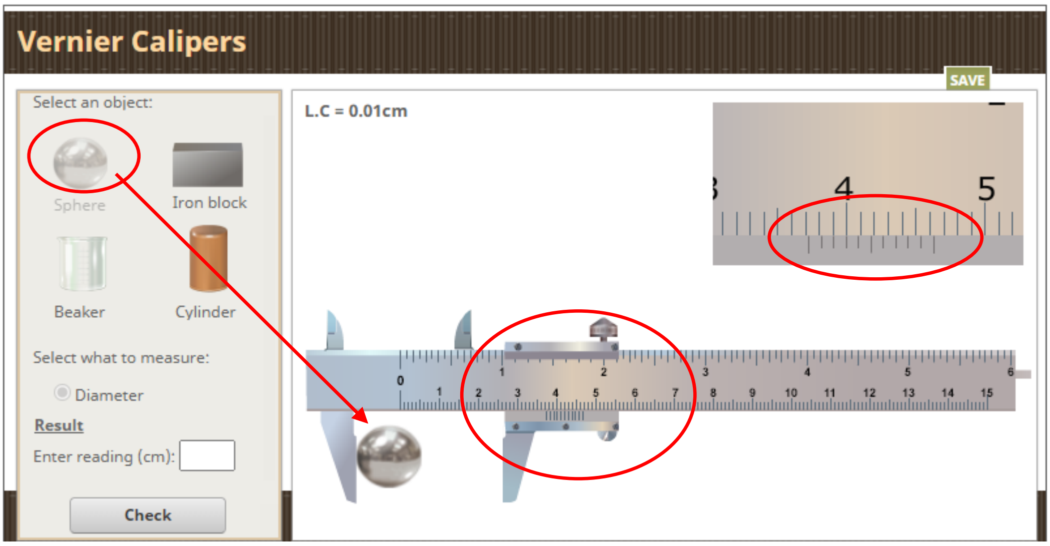


Figure 3: Measuring the diameter of a spherical object using Vernier calipers.

7. Drag the moveable jaw towards left till the sphere is held firmly between the jaws of the calipers. Use the magnified view of the Vernier scale to measure the diameter (D) of the sphere.
8. Since the object may not be perfectly spherical, in a real experiment one needs to make multiple measurements along different diameters. But in the virtual experiment we will record only one value.
9. Subtract the zero error from the value of diameter (D).
10. Note down the error in diameter (dD).
11. Calculate the volume of the spherical object using eqn. 6 from example 2 above.
12. Calculate the error in volume using eqn. 8 from example 2 and note down its value.
13. Click on “iron block” to put the block in between the jaws on the calipers. Notice that the circle beside the option “Length” is selected in the navigation panel. Drag the moveable jaw of the calipers to the left and measure the length (l) of the block.
14. Select the option “Breadth” and measure breadth (b) of the block.
15. Select the option “Thickness” and measure thickness (t) of the block.
16. Also note down the errors in these parameters.
17. Correct for the zero error in these values, if any.
18. The block is a cuboid. Calculate its volume (V) using the relation: $V = lbt$.
19. Derive an expression for the maximum probable fractional error in the volume of a block (cuboid).
20. Calculate and note down the error in the volume of the block.
21. Click on “Beaker” and use the upper jaws of the Vernier calipers to measure its “inner diameter” (D').
22. Select the option “Depth” and use the depth bar of the Vernier calipers to measure the inner depth (d') of the beaker.

23. Correct for zero errors.
24. The beaker is a cylindrical object. Calculate its inner volume using:

Volume (V) = Area of inner cross-section x inner depth → $V = \frac{\pi D'^2 d'}{4}$

25. Derive an expression for the maximum probable fractional error in the volume of a beaker (cylinder).
26. Calculate the error in the volume of the beaker.

Measurements using Screw Gauge

1. Go to the Amrita Vishwa Vidyapeetham virtual lab website for screw gauge using the link: http://amrita.olabs.edu.in/?sub=1&brch=5&sim=156&cnt=4
2. Follow steps 2 and 3 above.
3. Use the option "select screw gauge" from navigation panel on the left (see figure 4) to choose a least count (LC) of 0.01 mm or 0.001 cm. Note down this value.

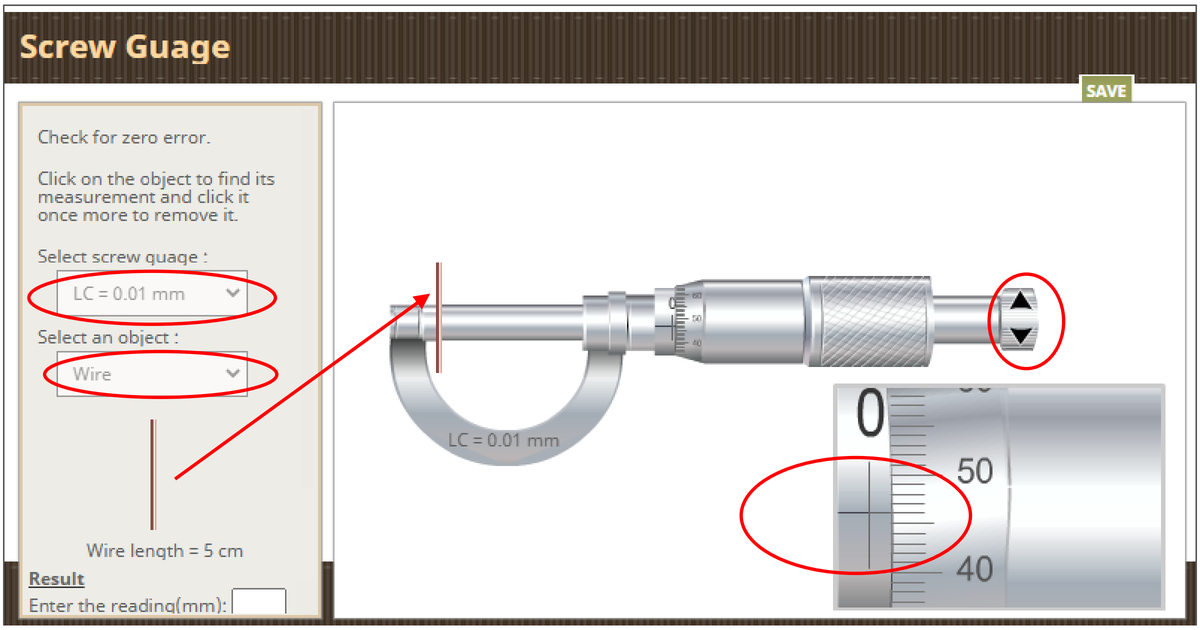


Figure 4: Measuring the diameter of a thin wire using Screw Gauge.

4. Click on the arrows in the rachet knob (circled in the figure 4) to make the anvil and spindle touch each other, without any object being placed there.
5. You will now see a magnified view of the circular scale. Use it to check if there is any zero error and note down its value.
6. Use the option "select an object" from navigation panel (see figure 4) and choose "wire". We will be measuring its diameter.
7. Note down the length (l) of the wire (5 cm) as given in the navigation panel. The error in length is 0. Since it is being supplied to us and not measured, we will assume that it is error free.

8. Click on the image of the wire to put it between the anvil and spindle of the screw gauge.
9. Click on the arrows in the rachet knob till the spindle makes contact with the wire.
10. Note down the diameter (D) of the wire from the magnified view of the circular scale.
11. Also note down the error in diameter (dD).
12. The wire is cylindrical. Calculate its volume (V) using the relation: $V = \frac{\pi D^2 l}{4}$
13. Derive an expression for the maximum probable fractional error in the volume of the wire (cylinder).
14. Calculate the error in the volume of the wire.
15. Click on the wire to remove it from the screw gauge.
16. Use the option “select screw gauge” from navigation panel to choose a least count (LC) of 0.005 mm or 0.0005 cm. Note down the value.
17. Repeat steps 4 - 14 with the new screw gauge. No need to derive the fractional error again. You can use the expression derived in step 13 above. Note that the wire now has a different diameter but the same length.

Observations and Calculations:

Measurements using Vernier calipers

Calculation of least count of Vernier calipers:

Zero error in the Vernier calipers = …….

Derivation of fractional error in the measured volume of a block (cuboid):

Derivation of fractional error in the measured volume of a beaker (cylinder):

Table 1: Measurements made with Vernier calipers

Object	Parameter measured	Observed Value (cm)			Value after subtracting zero error (cm)
		Main Scale	Vernier	Total	
Sphere	Diameter (D)				
Iron block	Length (l)				
	Breadth (b)				
	Thickness (t)				
Beaker	Inner diameter (D')				
	Depth (d')				

Table 2: Error in the measurements with Vernier calipers

Object	Parameter measured	Value after subtracting zero error (cm)	Error in parameter measured (cm)	Parameter with error (cm)	Volume (cm^3)	Error in Volume (cm^3)	Volume with error (cm^3)
Sphere	Diameter (*D*)			….. ± …..			….. ± …..
Iron block	Length (*l*)						
	Breadth (*b*)						
	Thickness (*t*)						
Beaker	Inner diameter (*D′*)						
	Depth (*d′*)						

Measurements using screw gauge

Length (*l*) of the wires = ……

Derivation of fractional error in the measured volume of a wire (cylinder):

Table 3: Measurements made with screw gauge

Screw gauge no.	LC (cm)	Zero error (cm)	Object	Observed value of diameter (*D* cm)			Diameter after subtracting zero error (cm)
				Main Scale	Circular scale	Total	
1			Wire 1				
2			Wire 2				

Table 4: Error in the measurements with screw gauge

Screw gauge no.	Diameter after subtracting zero error (cm)	Error in diameter (cm)	Diameter with error (cm)	Volume (cm^3)	Error in Volume (cm^3)	Volume with error (cm^3)
1			….. ± …..			….. ± …..
2						

<u>Results and Conclusions:</u>

Write down the measured volumes of the different objects along with the errors in them.

What did you achieve by using a screw gauge with smaller least count?

Experiment No. 2

Newton's Second Law of Motion

Aim: To study the motion of objects using Newton's second law

Apparatus: Toy cart, weight, pulley, stopwatch,

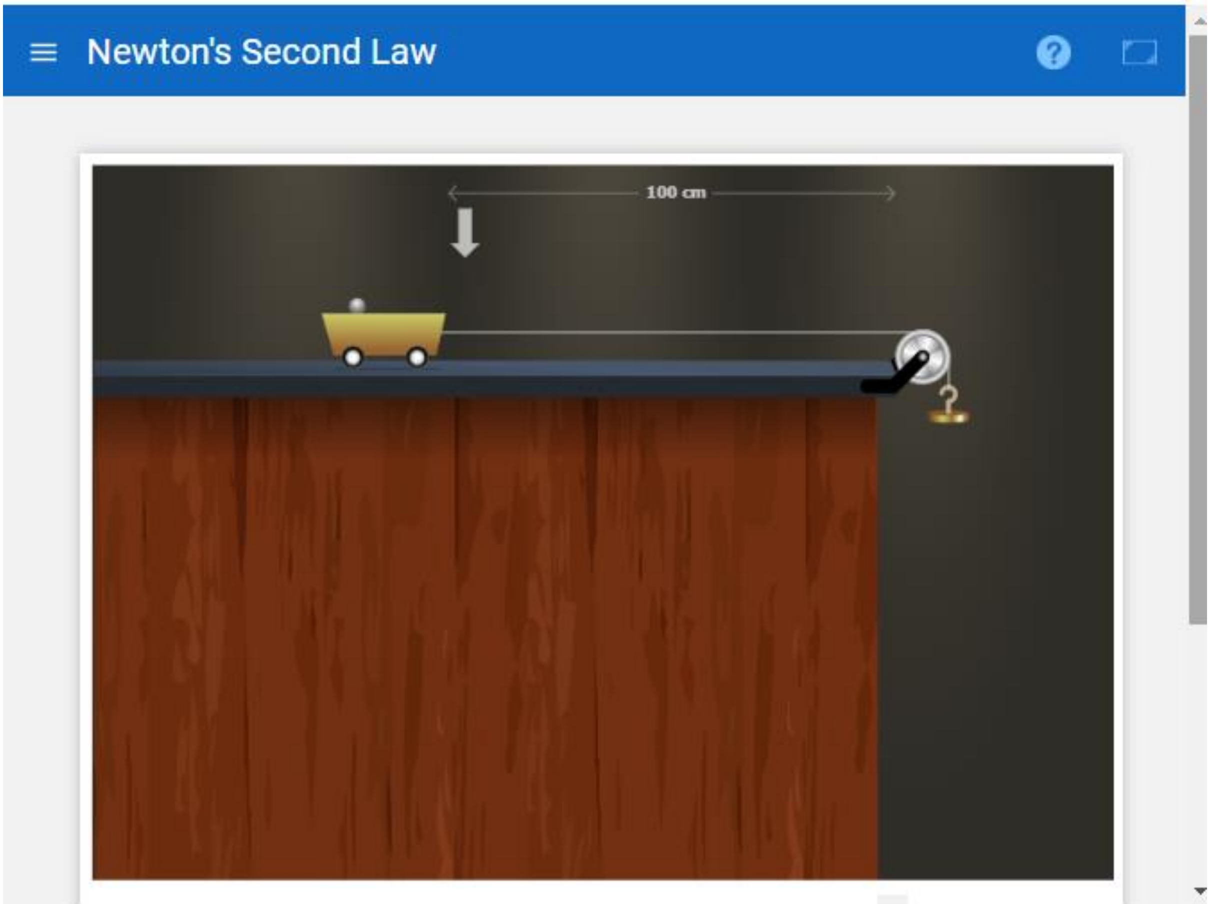


Figure 1: Experimental setup

Theory: This experiment is based on the equations of motion that can be derived from Newton's laws. Consider a toy cart of mass m moving on a frictionless horizontal track. The cart is being pulled by a string passing over a frictionless pulley and attached to a hanging mass.

The free body diagrams of the cart and the hanging mass are shown in figure 2.

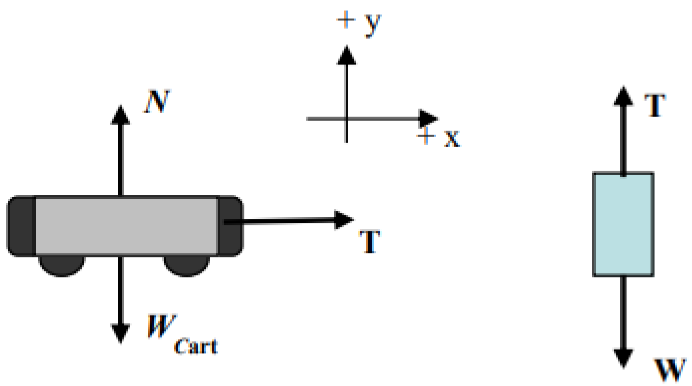


Figure 2: Free body diagram of the toy cart (left) and the weight (right).

Here we assume that the positive x-axis is parallel to the track and points to the right. The y-axis points to the perpendicular direction. The free body diagram on the left in figure 2 represents the toy cart. When the cart is moving in its track, we can write using Newton's second law of motion

$$F = ma^{x}_{cart} \qquad (1)$$

Here, F and a^{x}_{cart} represent the force acting on the cart and the resultant acceleration of the cart along x direction. Since it is on a horizontal track, the normal force N balance the weight of the cart, W_{cart}. The only force acting on the cart along the x-direction is the tension of the rope, T. From Newton's second law, for the x direction, we obtain,

$$T = m\, a^{x}_{cart} \qquad (2)$$

Now, if the track has some non-zero friction with friction coefficient, μ, equation (2) needs to be modified accordingly. In that case, the tension is given by

$$T = m\, a^{x}_{cart} + \mu m g \qquad (3)$$

We can apply Newton's second law to the hanging mass in order to obtain the tension, T. For this, consider the free body diagram on the right in figure 2. The positive y-axis is assumed to be pointing downward. From Newton's second law, for the y direction,

$$Mg - T = Ma^{y}_{mass} \qquad (4)$$

Here, $W = Mg$ is the weight of the hanging mass and a^{y}_{mass} represents the acceleration of the hanging mass along y direction. Since the cart and the hanging mass are connected by a string passing over a frictionless pulley, the acceleration of the cart and the hanging mass must be equal in magnitude. Hence, we can write,

$$a^{x}_{cart} = a^{y}_{mass} = a \qquad (5)$$

Using equations (3), (4) and (5) we obtain the constant acceleration of the cart

$$a = \frac{Mg - \mu m g}{m + M} \qquad (6)$$

From equation (3), we can calculate the tension by replacing the expression for the acceleration from equation (6). It is given by,

$$T = \frac{m(Mg-\mu mg)}{m+M} + \mu mg \qquad (7)$$

The distance (s) travelled by the cart under the influence of this external force in time, t is given by

$$s = \frac{1}{2}at^2 \qquad (8)$$

<u>Procedure:</u>

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website for the Newton's second law of motion experiment:

2. https://vlab.amrita.edu/?sub=1&brch=74&sim=207&cnt=4

3. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure provided in the site.

4. Click on the "simulator" tab and login with your registered credentials to initiate the virtual experiment.

5. Click on the menu button. To start the experiment, click on "START". The set up along side the control panel looks like figure 3.

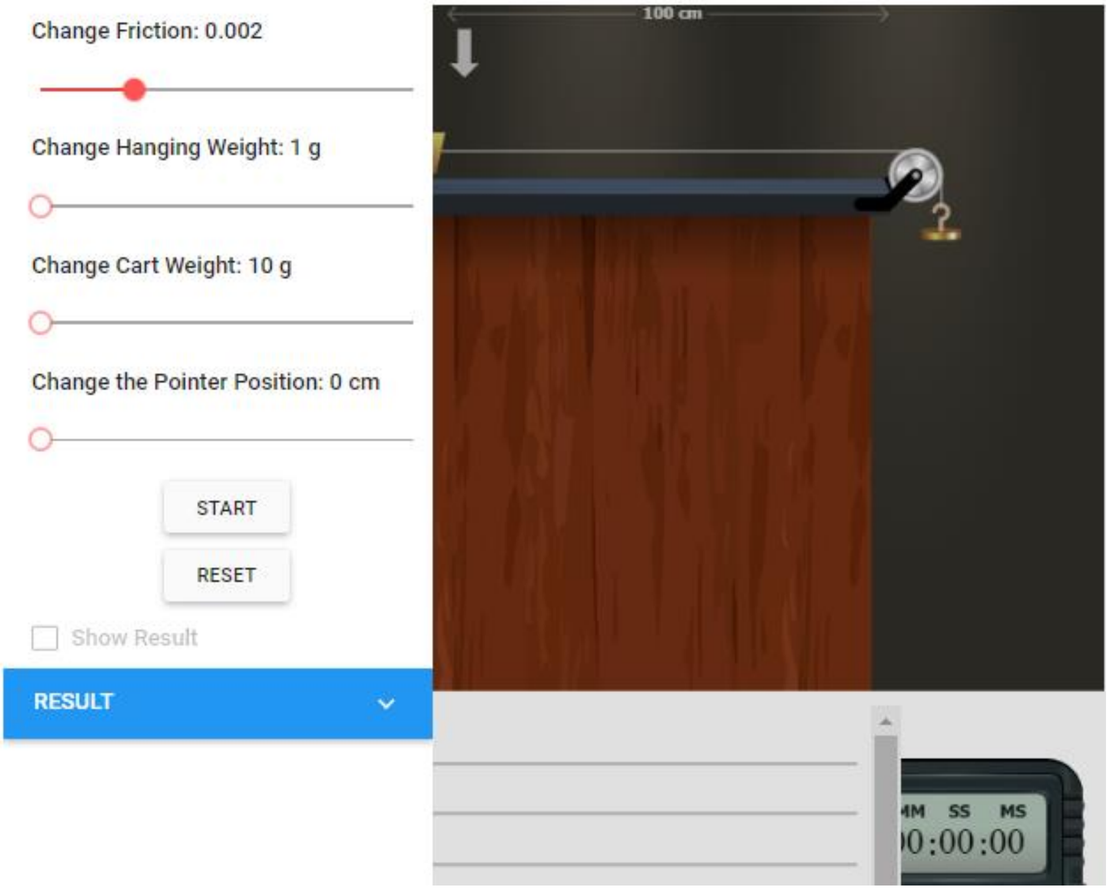


Figure. 3: Experimental setup alongside the control panel

6. From the stopwatch, note down the time taken by the cart to travel the 100 cm distance with the set up shown in figure 3 keeping $\mu = 0.002$, $M = 1\ g$ and $m = 10\ g$.
7. Change the value of m in five steps from 10 g to 50 g and note down the time taken in each case for the cart to travel the 100 cm distance.
8. Keep m fixed at 30 g and vary the weight in five steps from 2 g to 10 g. Note down the time taken in each case for the cart to travel the 100 cm distance.

<u>Observations and Calculations:</u>

1. Calculate the acceleration (a) and tension (T) in the string in each case using equation (6) and (7) respectively.
2. Make a plot with acceleration on the y-axis and $\frac{1}{t^2}$ on the x-axis. Note from equation (8) that the slope of this line should be equal to twice the distance travelled $(2s)$ by the cart.
3. Find the slope to determine s and calculate percentage error in the measurement.

*Some parameters relevant for numerical calculation***:

Distance travelled by the cart (s) : 100 cm
Coefficient of friction (μ) : 0.002
Gravitational acceleration (g) : 9.80655 m/s^2

Mass of the cart, m (g)	Mass of the weight, M (g)	Time taken by the cart to travel the distance, t	Acceleration (a) from eq. (6) (cm/sec^2)	Tension (T) from eq. (7) $(g.cm/sec^2)$	Distance travelled (s) obtained from slope (cm)	Percentage error	Average percentage error
10							
20							
30	1						
40							
50							
	2						
	4						
	6						
30	8						
	10						

Table 1: Data for the measurements for different masses of the cart and weight.

<u>Results and Conclusions:</u>

Experiment No. 3

Elastic and inelastic collisions

Aim:
To study conservation of momentum and kinetic energy during collisions

Theory:
The law of conservation of linear momentum states that the total linear momentum of all constituent units or objects within an isolated system remains constant unless the system is acted upon by external forces. This means in the event of collision of two objects, if the net external force on them is zero, then the total momentum before the collision must be equal to the total momentum after the collision, i.e.,

$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1' + m_2\vec{v}_2' \tag{1}$$

where m_i, $\vec{v}_i$, $\vec{v}_i'$ are the mass, initial velocity (before collision) and final velocity (after collision) of the i^{th} object. For motion in one dimension there are two possible directions, which can be indicated by "+" and "–" signs.

Kinetic Energy (K.E.) of a system is not always conserved, even if the net external force on them is zero. The collisions in which kinetic energy is conserved are called *elastic collisions*, while those in which kinetic energy is not conserved are called *inelastic collisions*. One example of inelastic collision is when the colliding objects stick to each other after collision.

kinetic energy in elastic collisions: $\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1{v_1'}^2 + \frac{1}{2}m_1{v_2'}^2$ (2)

kinetic energy in inelastic collisions: $\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 \neq \frac{1}{2}m_1{v_1'}^2 + \frac{1}{2}m_1{v_2'}^2$ (3)

Elastic Collision: From equations (1) and (2), the velocities of the objects after the collision can be written as

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2}v_1 + \frac{2m_2}{m_1 + m_2}\, v_2 \tag{4}$$

and

$$v_2' = \frac{2m_1}{m_1 + m_2}v_1 + \frac{m_2 - m_1}{m_1 + m_2}\, v_2 \tag{5}$$

Perfectly Inelastic Collision: If the objects stick together after the collision, then the collision is *perfectly inelastic*. In this case, the final velocities of the two objects are the same. From the conservation of momentum, the expression for final velocities can be written as

$$v_1' = v_2' = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} \quad (6)$$

Procedure:

1. Open the virtual lab by clicking on the following web link.
   https://vlab.amrita.edu/?sub=1&brch=74&sim=189&cnt=4

2. Click on the tab "Simulator" and login with your email id and password.

3. Set the parameters for *elastic collision*:
   Select type of test: Elastic
   Coefficient of restitution (k): 1
   Set mass and velocity of objects A and B as per table-I .

4. Press the button "START EXPERIMENT".

5. The result of the experiment is given in the "RESULT" window. Note down the final velocities, initial and final momenta, and K.E.s of objects A and B in table-I.

6. Calculate the expected final velocities from equations (4) and (5) and tabulate them in table-I. Also calculate the final momenta and K.E.s of both objects and compare them with the results of the experiment.

7. Repeat the experiment from step 3 for different sets of masses and velocities of objects A and B as given in table-I. You need to press the "RESET" button every time to change the parameters.

8. Now set the parameters for *inelastic collision*:
   Select type of test: Inelastic
   Coefficient of restitution (k): 0
   Set mass and velocity of objects A and B as per table-II.

9. Repeat the steps 4-7 for the parameters of table-II.

<u>Observations and Calculations</u>:

Table- I: Elastic collision

S.No.	Mass of object A m_1 (kg)	Initial velocity of object A $\vec{v}_1$ (m/s)	Mass of object B m_2 (kg)	Initial velocity of object B $\vec{v}_2$ (m/s)	Initial momentum (Object A + Object B)	Initial K.E. (Object A + Object B)	Final velocities (Experiment)	
							Object A $\vec{v}_1'$ (m/s)	Object B $\vec{v}_2'$ (m/s)
1	1.0	12	1.0	0				
2	2.0	15	2.0	-15				
3	2.0	20	1.0	5				
4	1.0	20	2.0	-12				

Table – I (continuation)

S.No.	Final momentum (Object A + Object B) (Experiment)	Final K.E. (Object A + Object B) (Experiment)	Final velocities (Calculation)		Final momentum (Object A + Object B) (Calculation)	Final K.E. (Object A + Object B) (Calculation)
			Object A $\vec{v}_1'$ (m/s)	Object B $\vec{v}_2'$ (m/s)		
1						
2						
3						
4						

Table- II: Inelastic collision

S.No.	Mass of object A m_1 (kg)	Initial velocity of object A $\vec{v}_1$ (m/s)	Mass of object B m_2 (kg)	Initial velocity of object B $\vec{v}_2$ (m/s)	Initial momentum (Object A + Object B)	Initial K.E. (Object A + Object B)	Final velocities (Experiment)	
							Object A $\vec{v}_1'$ (m/s)	Object B $\vec{v}_2'$ (m/s)
1	1.0	12	1.0	0				
2	2.0	20	1.0	6				
3	1.0	16.0	2.0	-8				

Table – II (continuation)

S.No.	Final momentum (Object A + Object B) (Experiment)	Final K.E. (Object A + Object B) (Experiment)	Final velocities (Calculation)		Final momentum (Object A + Object B) (Calculation)	Final K.E. (Object A + Object B) (Calculation)
			Object A $\vec{v}_1'$ (m/s)	Object B $\vec{v}_2'$ (m/s)		
1						
2						
3						

<u>Results and Conclusions:</u>

1. Compare experimental and calculated final velocities, momenta, and K.E.s.

2. Check conservation of momentum and K.E. for both elastic and inelastic collisions.

Experiment No. 4

Kater's Pendulum

Aim: To determine the value of 'g', the acceleration due to gravity, by Kater's pendulum

Apparatus: Kater's pendulum, stop watch, meter scale and knife edges

Theory: Kater's pendulum is a compound pendulum constructed on the principle that the center of suspension and center of oscillation are interchangeable. It consists of a long cylindrical metal rod of circular cross-section and can oscillate about the two knife edges K1 and K2. The rod carries a heavy metal cylinder W1 and identical metal wooden cylinder W2, and a much smaller cylinder 'w' capable of sliding along the rod. The sliding object can be fixed at any position on the rod by using a screw.

The shape and size of metal and wooden cylinders W1 and W2 are the same. If W1 and W2, and K1 and K2 are constrained to be equidistant from the ends of the metal rod, there will be nearly equal air resistance to the swinging system in either suspension about O1 and O2. The knife-edges and the three weights are kept as shown in Fig. 1. In this position, the center of gravity lies in between and near the knife-edges. The center of mass G can be located by balancing the pendulum on an external knife edge. In Fig. 1, h1 and h2 are the distance from the point of suspensions O1 and O2 to the center of gravity G.

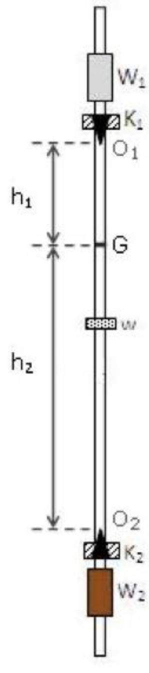


Fig.1: Kater's pendulum

The two knife edges and the weights are so adjusted so that the pendulums' time-periods about the two knife-edges are equal. Fine adjustments in G's position, and thus in h1 and h2, can be made by moving the small metal cylinder w.

In such a case where the pendulums' time-periods about the two knife-edges are equal, one knife-edge is at the center of oscillation while the other at the center of suspension. In this position, the distance between O1 and O2 is equal to the length of the equivalent simple pendulum 'L', and the time period is given by

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad (1)$$

where 'g' is the acceleration due to gravity.

Let T_1 is the time-period about the knife-edge K_1, and h_1 is the distance from the centre of gravity 'G' upto the point of suspension. The length of an equivalent simple pendulum in terms of radius of gyration 'K' and h_1 is given by

$$L = \frac{K^2}{h_1} + h_1 \tag{2}$$

So the time period T_1 about the knife-edge K_1 is now given by

$$T_1 = 2\pi\sqrt{\frac{h_1^2 + K^2}{h_1 g}} \tag{3}$$

Squaring both sides, we get

$$\frac{T_1^2 h_1 g}{4\pi^2} = h_1^2 + K^2 \tag{4}$$

Similarly, the time period T_2 about the knife-edge K_2 is given by

$$T_2 = 2\pi\sqrt{\frac{h_2^2 + K^2}{h_2 g}} \tag{5}$$

and we get

$$\frac{T_2^2 h_2 g}{4\pi^2} = h_2^2 + K^2 \tag{6}$$

Subtracting Eq. (4) and (6), we get

$$\frac{g}{4\pi^2}(T_1^2 h_1 - T_2^2 h_2) = h_1^2 - h_2^2 \tag{7}$$

which allows us to obtain the expression of 'g' as

$$g = 8\pi^2\left[\frac{T_1^2 + T_2^2}{h_1 + h_2} + \frac{T_1^2 - T_2^2}{h_1 - h_2}\right]^{-1} \tag{8}$$

Procedure:

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website for Kater's pendulum experiment: https://vlab.amrita.edu/index.php?sub=1&brch=280&sim=518&cnt=4

2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure provided in the site.

3. Click on the "simulator" tab to get apparatus for the experiment.

4. Choose desired environment: Earth.

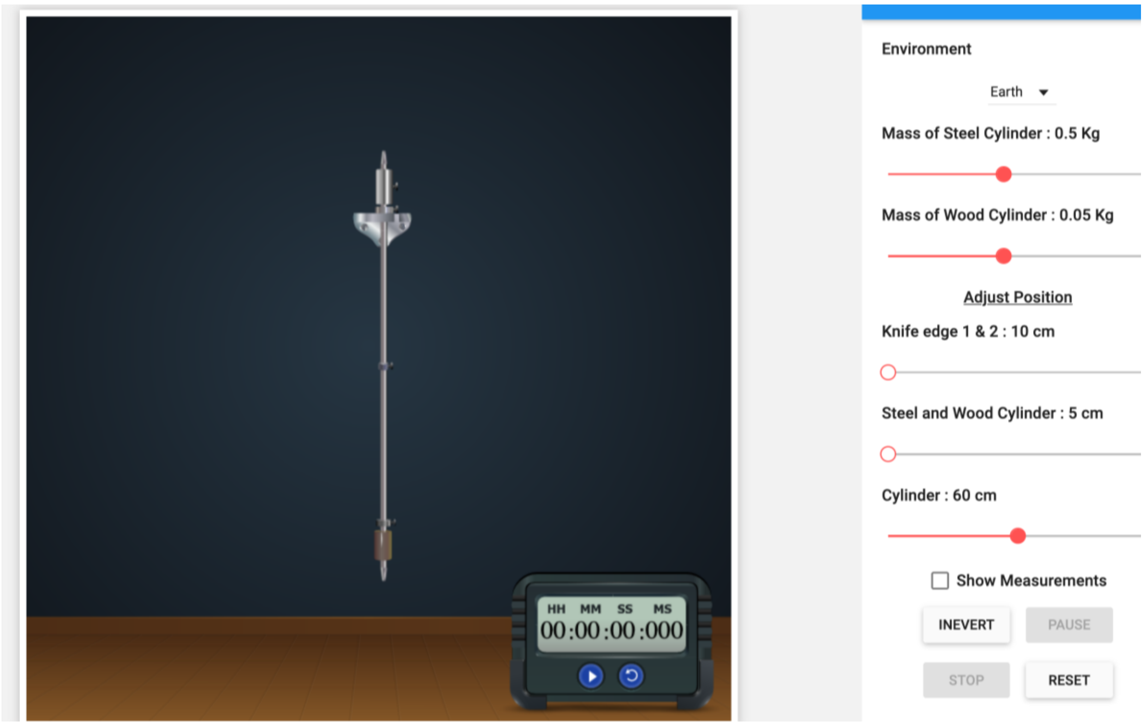


Fig. 2: Kater's pendulum for virtual lab

5. Set mass of steel cylinder as 0.5 kg and mass of wood cylinder as 0.05 kg.

6. Set the position of knife edge at 17 cm from the end points of the rod. Also set steel and wood cylinders at 10 cm.

7. Adjust the position of the sliding cylinder 'w' at proper position so that time periods T_1 and T_2 are nearly equal. Set the position of sliding cylinder 'w' at 58 cm.

8. After choosing values, drag wood cylinder and release it to oscillate.

9. Note the time for 10 oscillations, by clicking on the 'START' and 'STOP' button of stop watch.

10. Invert the pendulum and measure the time taken for 10 oscillations.

11. Click on 'Show Measurements' checkbox to get the values of h_1 and h_2.

<u>Observations:</u>

Table 1: Time periods of the Kater's pendulum

	Time taken for n=10 oscillations			
Knife edge	$t_1(s)$	$t_2(s)$	Mean $t(s)$	Time period (s) $T = t/n$
K_1				$T_1(s)$
K_2				$T_2(s)$

Distance of knife edge K_1 from C.G, $h_1 =$………. m
Distance of knife edge K_2 from C.G, $h_2 =$………. m

Actual value of $g_a = 9.8ms^{-2}$

Calculations:

1. Find the value of g.

$$g = 8\pi^2 \left[\frac{T_1^2 + T_2^2}{h_1 + h_2} + \frac{T_1^2 - T_2^2}{h_1 - h_2}\right]^{-1}$$

Acceleration due to gravity, g = …………… ms^{-2}.

2. Calculate the % error

%error = $\frac{|g - g_a|}{g_a} \times 100$

Results and Conclusions:

1. The experimental value of ‘g’ obtained by using Kater’s pendulum is …….
2. The % error of ‘g’ is …….

Experiment No. 5

Young's Modulus

Aim:

Determination of Young's Modulus of the given sample by the method of bending

Apparatus:

Sample Stand, Weights of 500 gm, Samples (Iron, Aluminium, Brass), DC Adaptor, Weight Holder, Spherometer, Stand with Buzzer.

Theory:

Young's modulus

Young's modulus (Y) is a mechanical property that measures the stiffness of a solid material. It defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material in the linear elasticity regime. So, in this regime stress is directly proportional to strain. When stress and strain are not directly proportional, Y may be represented as the slope of the tangent or the slope of the secant connecting two points on the stress-strain curve. The modulus is then designated as tangent modulus or secant modulus at stated values of stress. Young's modulus can be used to predict the elongation or compression of an object as long as the stress is less than the yield strength of the material.

Young's modulus (Y) = Applied load per unit area of cross section/increase in length per unit length.

According to Hooke's law, strain is proportional to stress, and therefore the ratio of the two is a constant that is commonly used to indicate the elasticity of the substance. Young's modulus is the elastic modulus for tension, or tensile stress, and is the force per unit cross section of the material divided by the fractional increase in length resulting from the stretching of a standard rod or wire of the material.

Young's modulus, Y, can be calculated by dividing the tensile stress by the tensile strain:

$$Y = \frac{Tensile\ Stress}{Tensile\ strain} = \frac{\sigma}{\epsilon} = \frac{F/A_0}{\Delta L/L_0}.$$

where,

Y is the Young's modulus (modulus of elasticity) measured in Pascal;

F is the force applied to the object;

Ao is the original cross-sectional area through which the force is applied;

ΔL is the amount by which the length of the object changes;

Lo is the original length of the object.

The SI unit of Y is the Pascal (kg $\mathrm{m}^{-1}\mathrm{s}^{-2}$). Some use an alternative unit form, kN/mm^2, which gives the same numeric value as gigapascals. The modulus of elasticity can also be measured in other units of pressure, for example pounds per square inch.

Cantilever

Beam supported at one end and carrying a load at the other end or distributed along the unsupported portion.

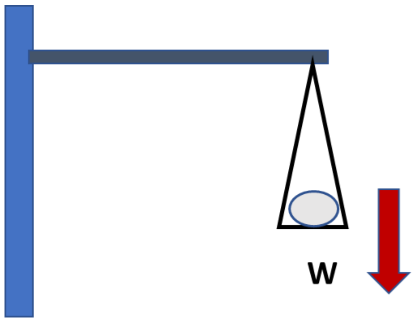


Figure 1: Cantilever

The upper portion of the thickness of such a beam is subjected to tensile stress, tending to elongate the fibers, the lower portion to compressive stress, tending to crush them.
Cantilevers are employed extensively in building construction and in machines. In building, any beam built into a wall and with the free end projecting forms a cantilever. Longer cantilevers are incorporated in a building when clear space is required below, with the cantilevers carrying a gallery, roof, canopy, runway for an overhead traveling crane, or part of a building above.

A cantilever loaded at one end results in bending. In this process the top fibers of the beam will be subjected to tension and the bottom to compression. It is reasonable to suppose, therefore, **that somewhere between the two there are points at which the stress is zero. The locus of all such points is known as neutral axis.** The radius of curvature R is then measured to this axis.

The depression due to a load at one end of the cantilever can be determined by analyzing the bending due to the load.

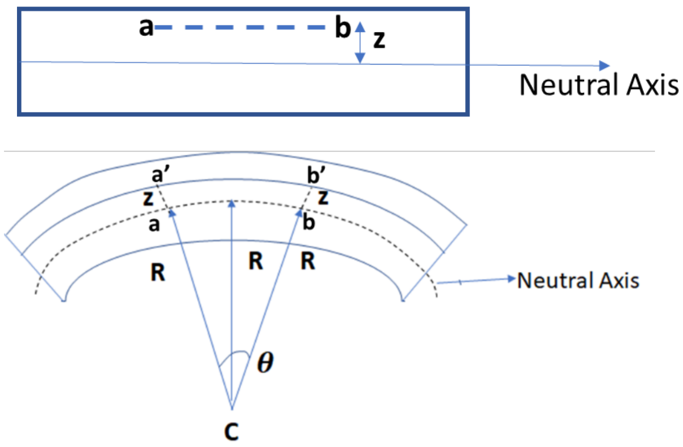


Figure 2: Bending of beam

Consider an arc formation due to the load subtending an angle θ at its center of curvature C. If the original length between two points is ab and modified length between the same two points is $a'b'$ then strain in the beam $= \frac{a'b'-ab}{ab} = \frac{(R+z)\theta - R\theta}{R\theta} = \frac{z}{R}$. Since stress is zero on neutral axis therefore we have considered parallel points of ab on neutral axis as ab after bending.

Young modulus of the material is $Y = \frac{tensile\ stress}{tensile\ strain} = \frac{tensile\ stress}{z/R}$.

Tensile stress on a small area $\delta A = \frac{Yz}{R}$, so force on the area $\delta A = stress \times area = \left(\frac{Yz}{R}\right)\delta A$

Moment about the neutral axis will be $= \frac{Yz}{R}\ \delta A z = \frac{Yz^2}{R}\delta A$.

Total moment for the whole cross-section $= \sum \frac{Yz^2}{R}\delta A$.

Now, $\sum \delta A z^2$ is called geometrical moment of inertia of the cross section of the beam about the neutral axis and let us denote it as I.

<u>Determination of geometrical moment of inertia of rectangular cross section</u>

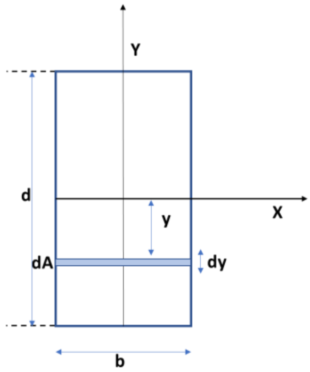


Figure 3: Geometric moment of inertia for rectangular cross-section

Let us calculate moment of inertia of a rectangular cross section of the beam about X axis (horizontal middle line or the neutral axis).

For a rectangular cross-section of height d and width b, the area is area $A = bd$.

So, the moment of inertia about the horizontal middle line, $I = b\int_{-\frac{d}{2}}^{\frac{d}{2}} y^2 dy = \frac{bd^3}{12}$.

Hence bending moment of the beam $M = YI/R$.

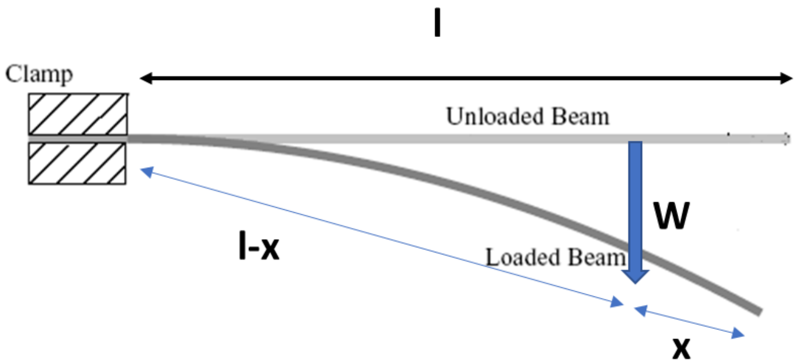


Figure 4: Bending of beam fixed at one end due to load

Bending moment due to load is $W(l - x) = \frac{YI}{R}$.

Now curvature $\frac{1}{R} = \frac{\frac{d^2y}{dx^2}}{\left[1+\left(\frac{dy}{dx}\right)^2\right]^{\frac{3}{2}}}$. Since bending is small therefore we can neglect $\frac{dy}{dx}$. Hence, $\frac{d^2y}{dx^2} = \frac{W(l-x)}{YI} \Rightarrow \frac{dy}{dx} = \frac{W}{YI}\left(lx - \frac{x^2}{2}\right) + C_1$. Since one end ($x = 0$) is fixed therefore $\frac{dy}{dx} = 0$ at $x = 0$, thereby $C_1 = 0$.

So, $\frac{dy}{dx} = \frac{W}{YI}\left(lx - \frac{x^2}{2}\right) \Rightarrow y = \frac{W}{YI}\left(\frac{lx^2}{2} - \frac{x^3}{6}\right) + C_2$. However, at $y = 0$, $x = 0$, thus $C_2 = 0$.

This implies, $y = \frac{W}{YI}\left(\frac{lx^2}{2} - \frac{x^3}{6}\right)$. Now if the cantilever is loaded at one end i.e., $x = l$, the depression $y = d = \frac{Wl^3}{3YI}$

where, W is weight, I is moment of inertia, l is length and Y is young's modulus.

Double Cantilever

If a bar is supported at two knife edges A and B, l meter apart in a horizontal plane so that equal lengths of the bar project beyond the knife edges and a weight W is suspended at the middle point C, then it acts as a double cantilever.

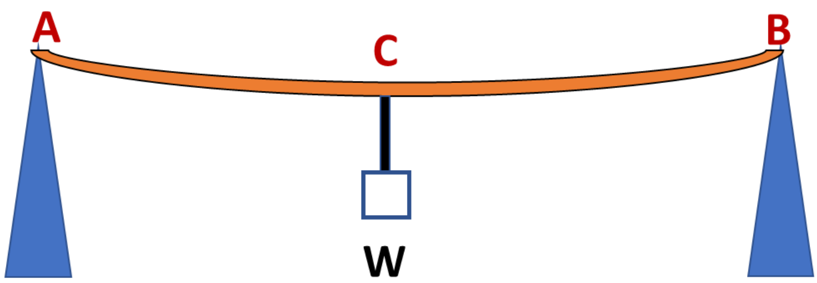


Figure 5: Double Cantilever beam

The middle part of the bar is practically horizontal. It is, therefore, equivalent to two inverted cantilevers fixed at the middle point C and loaded at A and B with load W/2 acting upward.

The depression (D) at C is given by $= \frac{\left(\frac{W}{2}\right)\left(\frac{l}{2}\right)^3}{3YI} = \frac{Wl^3}{48YI}$.

For a rectangular bar of breadth b and thickness d, $I = \frac{bd^3}{12}$.

Depression $D = \frac{Wl^3}{4Ybd^3}$

Young's modulus of elasticity can be determined by using this formula $Y = \frac{mgl^3}{4bd^3D}$

$W = mg$, where m is mass in kg, g is gravity, l is length, b is breadth and d is depth of sample, and D is depression of bar.

Trivia

A good example of double cantilever is Howrah bridge which connects the twin cities of Kolkata and Howrah. Howrah is the 5th longest cantilever bridge in the world and one of the oldest.

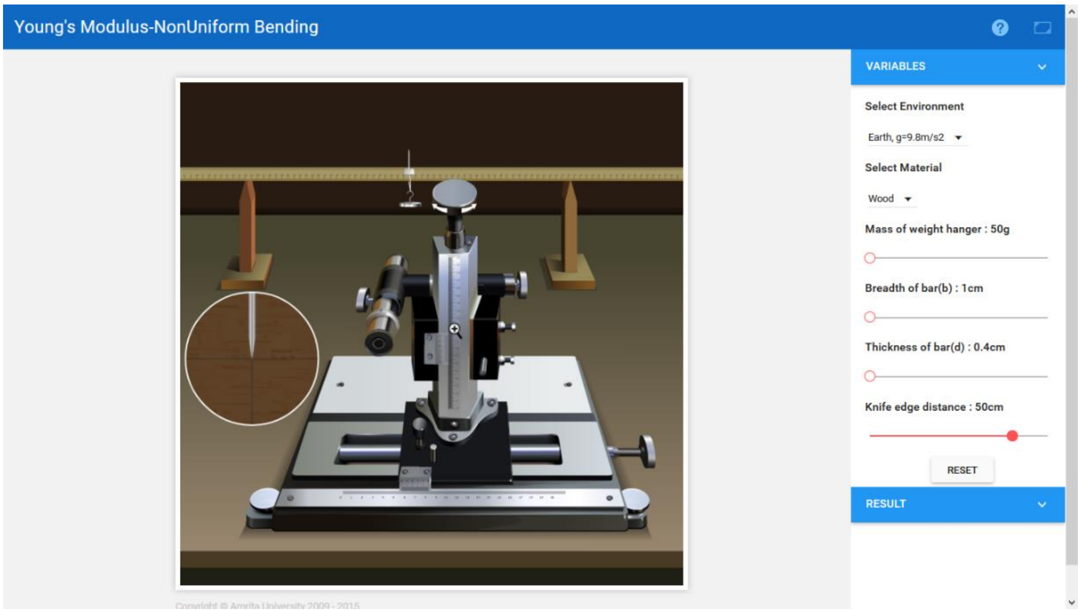
Procedure

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's s website for "Magnetic field along the axis of a circular coil carrying current" https://vlab.amrita.edu/?sub=1&brch=280&sim=1509&cnt=2

2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure in provided in the site.

3. Click on the "simulator" tab and login with your registered credentials to initiate the virtual experiment. You are expected to see the layout as shown here.

4. Select the environment as "Earth" and Material as "Wood".

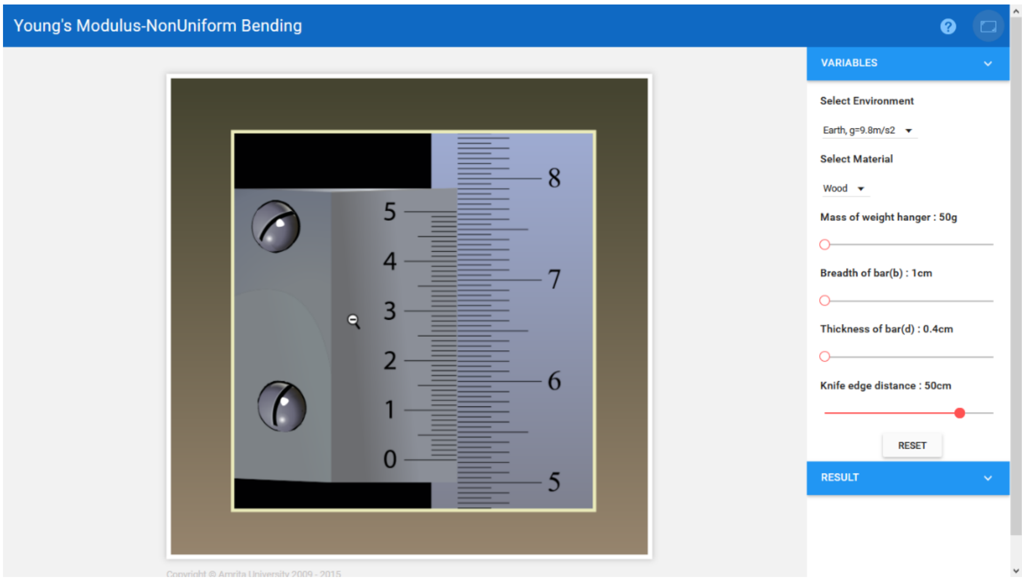


5. Choose mass, length, breadth, and thickness of the material bar using sliders on the right side of the simulator.

6. Fix the distance between knife edges.

7. Focusing the microscope and adjusting the tip of the pin coincides with the point of intersection of the cross wires using left and top knobs on microscope, respectively.

8. Readings are noted using the microscope reading for 0g. Zoomed part of microscope scale is available by clicking the centre part of the apparatus in the simulator.



9. Determine the least count (L.C) of the scale as viewed above.

10. Total reading of microscope is MSR+VSR*LC. MSR is the value of main scale reading of the microscope which is coinciding exactly with the zero of vernier scale. One of the division, in the vernier scale coincides exactly with the main scale is the value of VSR. LC is the least count.

11. Note the main scale (M.S) reading and vernier scale reading (V.S) in observation Table 1 and find total reading as M.S + V.S $=T_i$

12. Weights are added one by one, say 50g each time, then pin moves downwards while viewing through microscope. Again, adjust the pin such that it coincides exactly with the cross wire.

13. Note the readings of M.S. and V.S. in Table 1.
    Determine the differences $T_4 - T_0$, $T_5 - T_1$, and so on. One must be careful here so that all the $T_i's$ should be used only once.

14. Maximum load can be added to the “wood” sample is 400 gm.

15. Now remove 50 gm weight from the weight holder (i.e., decreasing 0.05 kg of load from the sample).

16. Note main scale (M.S) and vernier scale (V.S) readings for the new position of the pin. This position is T_6.

17. Again remove 0.05 kg weight from the weight holder (i.e., decreasing of 0.1 kg load in total from the sample) and note main scale reading (M.S), vernier scale reading (V.S) and calculate the total reading. This is now T_5.

18. Systematically keep on removing the weight till one reaches to the minimum weight.

19. Note all these values in Table 1.

20. Take the mean of displacements or depressions individually $D_1 = \frac{x_1+y_1}{2}$, $D_2 = \frac{x_2+y_2}{2}$, ... and so on.

21. Take the mean of the above depressions (D).

22. Note down the length, breadth, and depth of the sample.

23. Length, breadth, depth all are in cm. Change it into meter.
l = 50 cm
b =1 cm
d =0.4 cm

24. Put all the readings in the given formula: $Y = \frac{mgl^3}{4bd^3D}$,
where Y is elastic constant or Young's modulus of elasticity (N/m^2), 'm' is mass (kg) for which depression had been determined (here it is 0.05 kg), g = 9.8 m/s^2.

25. Find the mean value for the microscope reading corresponding to each load from the readings obtained during increment and decrement of loads,
$T'_n = \frac{T_n \text{ during increment} + T_n \text{ during decrement}}{2}$

26. Determine the net depression corresponding to each load ($\Delta D = T'_0 - T'_n$).

27. Draw load (m) vs net depression (ΔD) graph from Table 2 data.

28. Since, $Y = \frac{mgl^3}{4bd^3D} \Rightarrow \Delta D$ or $D = \frac{gl^3}{4bd^3Y}m$.

29. Hence, the slope, $\mu = \frac{gl^3}{4bd^3Y}$. So Young Modulus $Y = \frac{gl^3}{4bd^3\mu}$.

30. Compare your obtained result from graph in previous step and using formula in step 25 with the standard value.

31. The standard value of Young Modulus for wood is noted as $1.1 \times 10^{10} N/m^2$.

32. Calculate the percentage error in both cases using
$\% \text{ Error} = \frac{|\text{Actual Value} - \text{Experimental Value}|}{\text{Actual Value}}$

<u>Observations and Calculations:</u>

Length (l), breadth (b), depth (d) of the bar.
l =..................
b =.................
d =..................

Least count of the travelling microscope = ………………………..

Table 1

Sl. No.	Load (M) (kg)	Load Increment (mm)			Displacement (x) (cm) $x_n = T_{n+3} - T_{n-1}$	Load Decrement (mm)			Displacement (y) (cm) $y_n = T_{n+3} - T_{n-1}$	Mean Displacement (cm) $D = \frac{x+y}{2}$
		$M.S$	$V.S \times L.C$	$T = M.S + (V.S \times L.C)$		$M.S$	$V.S \times L.C$	$T = M.S + (V.S \times L.C)$		
1	0.05			T_0=				T_0=		
2	0.1			T_1=				T_1=		
3	0.15			T_2=				T_2=		
4	0.2			T_3=				T_3=		
5	0.25			T_4=	x_1=			T_4=	y_1=	D_1=
6	0.3			T_5=	x_2=			T_5=	y_2=	D_2=
7	0.35			T_6=	x_3=			T_6=	y_3=	D_3=
8	0.4			T_7=	x_4=			T_7=	y_4=	D_4=

Table 2

Sl. No.	**Load, *m* (kg)**	**Mean Reading, T'_n (cm)**	**Net Depression, (ΔD) (cm)**
1	0.05	T'_0=	$T'_0 - T'_0$= 0
2	0.1	T'_1=	$T'_0 - T'_1$=
3	0.15	T'_2=	$T'_0 - T'_2$=
4	0.2	T'_3=	$T'_0 - T'_3$=
5	0.25	T'_4=	$T'_0 - T'_4$=
6	0.3	T'_5=	$T'_0 - T'_5$=
7	0.35	T'_6=	$T'_0 - T'_6$=
8	0.4	T'_7=	$T'_0 - T'_7$=

<u>Results and Conclusions:</u>