B.Sc. PHYSICS LAB MANUAL

1st Semester

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Physics

MIDNAPORE CITY COLLEGE

Course No: C2 P2: Mechanics Lab

1. **Measurements of length (or diameter) using vernier caliper, screw gauge and travelling microscope.**
2. **To study the random error in observations.**
3. **To determine Coefficient of Viscosity of water by Capillary Flow Method (Poiseuille's method).**
4. **To determine the Young's Modulus of a Wire by Optical Lever Method.**
5. **To determine the elastic Constants of a wire by Searle's method.**
6. **To determine the Moment of Inertia of a Flywheel.**
7. **To determine the value of g using Bar Pendulum.**
8. **To determine the value of g using Kater's Pendulum.**
9. **To study the Motion of Spring and calculate, (a) Spring constant, (b) g and (c) Modulus of rigidity.**

[*This manual can be followed for a ready reference in addition to consulting standard text books on the respective topics.***]**

Practical 1

Measurements of length (or diameter) using vernier caliper, screw gauge and travelling microscope.

SCREW GAUGE

Aim

To determine the thickness of a glass plate.

Apparatus required

Screw gauge and glass plate

Description

It is based upon the principle of a screw. It consists of a U-shaped metal frame. One end of which carries a fixed stud A whereas the other end B is attached to a cylindrical tube as shown in Fig. 1. A scale graduated in millimetres is marked on the cylindrical tube along its length. It is called Pitch scale.

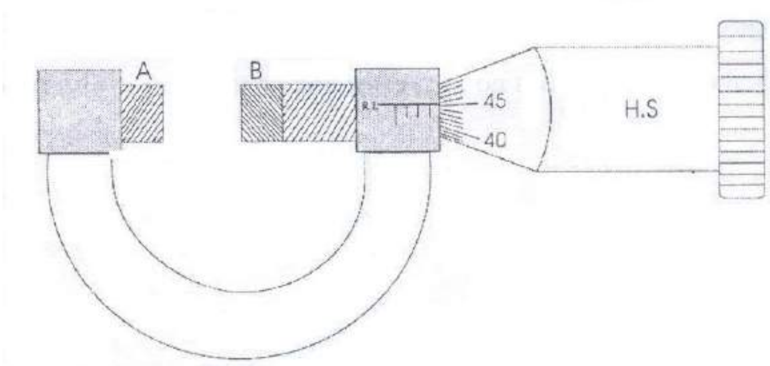


Fig.1 Screw Gauge

The screw carries a head H which has a beveled edge. The edge is divided into 100 equal divisions. It is called the Head scale H.S. When the head is rotated, the head scale moves on the pitch scale.

Procedure:

To find the least count (LC) of the screw gauge

The pilch of the screw is defined as its axial displacement for a complete rotation.
The least count of the screw gauge refers to the axial displacement of the screw for a rota ion one circular division. Thus, if n represents the number of divisions on the circular scale and the pitch of the screw is m scale divisions, then the least count (l.c.) of the screw gauge is given by least count (l.c.) = m/n scale divisions.

To find the pitch, the head or the screw is given say 5 rotations and the distance moved by the head scale on the pitch scale is noted. Then by using the above formula, the least count of the screw gauge is calculated.

$$\text{Pitch} = 5\text{ mm} / 5 = 1\text{ mm}$$

$$\text{Least Count} = 1\text{ mm} / 100 = 0.01\text{ mm}$$

The screw head is rotated until the two plane faces A and B are just in contact.

1. To find the zero correction (ZC)

i) Nil error

If the zero of the head scale coincides with the zero of the pitch scale and also lies on the base line (B.L), the instrument has no zero error and hence there is no zero correction (See Fig.

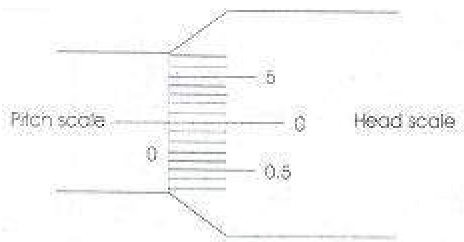


Fig. 2 Nil Error

ii) Positive zero error

If the zero of the head scale lies below the base line (B.L) of the pitch scale then the zero error is positive and zero correction is negative. The division on the head scale, which coincides with the base line of pitch scale, is noted. The division multiplied by the least count gives the value of the positive zero error. This error is to be subtracted from the observed reading i.e. the zero correction is negative (See Fig.3).

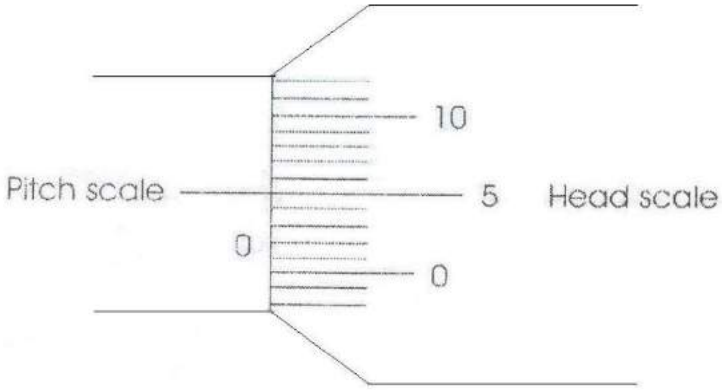


Fig. 3. Positive Zero Error

Example

If 5th division of the head scale coincides with the base line of the pitch scale then Zero error = +5 divisions

Zero correction = (Z.E x LC) = -(5 x 0.01) = - 0.05 mm.

iii) Negative zero error

If the zero of head scale lies above the base line (B.L) of the pitch scale, then the zero error is negative and zero correction is positive. The division on the head scale which coincides on the base line of pitch scale is noted. This value is subtracted from the total head scale divisions. This division multiplied by the least count gives the value of the negative error. This error is to be added to the observed reading i.e. zero correction is positive (See Fig. 4).

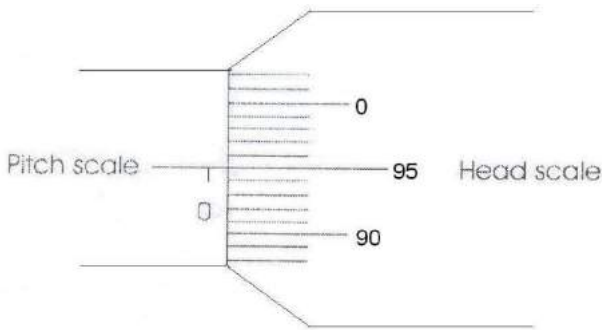


Fig. 4 Negative Zero Error

Example

If the 95th division of the head scale coincides with the base line of the pitch scale then, Zero error = -5 divisions

Zero correction = + 0.05 mm

2. To find the thickness of the glass plate

The glass plate is gently gripped between the faces A and B. The pitch scale reading and the head scale coincidence are noted. The readings are tabulated.

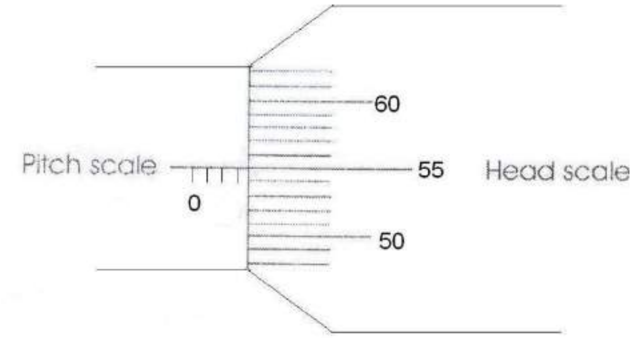


Fig. 5 Screw Gauge

Readings Pitch Scale Reading (P.S.R)

Number of pitch scale division just in front of the head scale fully completed is noted (see Fig. 5). It is measured in millimeter.

Head Scale Coincidence (H.S.C)

Coincidence of head scale division on the base line of the pitch scale is also noted.

Example:

Screw gauge readings: (see Fig. 5)

LC = 0:01 mm Zero error = -3 divisions Zero correction (Z.C.) = +0.03 mm

S.No.	P.S.R mm	H.S.C div	H.S.R = (H.S. C x LC) mm	Total Reading = P.S.R+ H.S.R mm	Corrected Reading = T.R. ± Z.C. mm
1	4	56	0.56	4.56	4.59
2					
3					,
4					

Mean thickness of the glass plate =

VERNIER CALIPERS

Aim

To measure the dimensions of the given object.

Apparatus

Vernier Calipers and Wooden block

Description

The vernier calipers consist of a long rigid rectangular steel strip called the main scale (M.S) with a jaw (A) fixed at one end at right angles to its length as shown in Fig.l. The main scale is graduated both in centimeters and inches. The second jaw (B) carrying a vernier scale and capable of moving along the main scale can be fixed to any position by means of a screw cap S. The vernier scale i s divided into 10 divi sions, which is equivalent to 9 main scale divisions (M.S.D). So the value of 1 vernier scale division is equal to 9/10 M.S.D. The value of 1 M.S.D. is 1 mm

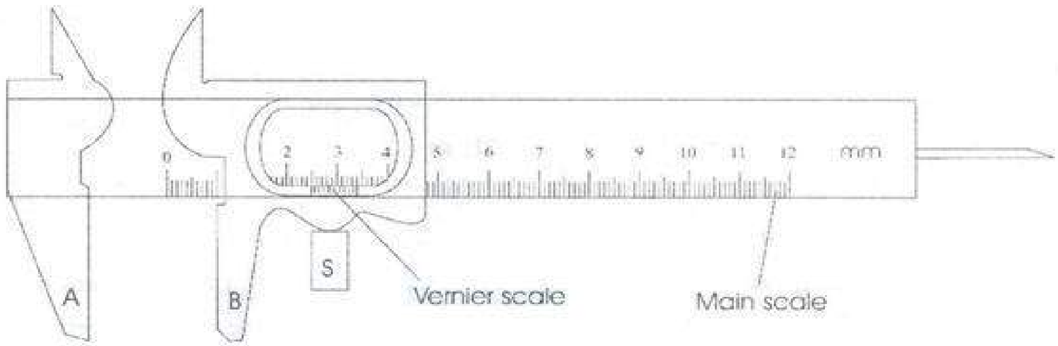


Fig.1. Vernier Calipers

Procedure:

1. To find the Least Count (LC) of the vernier calipers (see Fig. 2)

It is the smallest length that can be measured accurately by the vernier calipers and is measured as the difference between one main scale division and one vernier scale division.

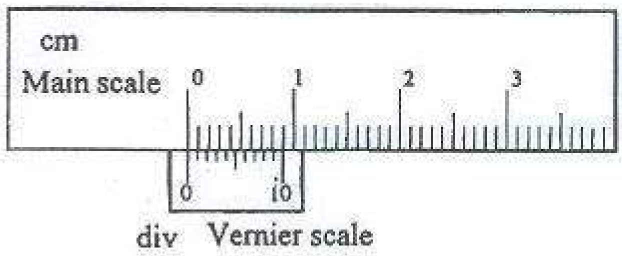


Fig. 2 Vernier scale and main scale

Least Count (LC) = 1 M.S.D — 1 V.S.D

Value of 1 M.S.D = 1 mm

No of divisions on the vernier scale = 10 divisions.

10 V.S.D =9 M.S.D

1 V.S.D =9/10 M.S.D = 9/10 x 1 mm =
9/10 mm L.C.=1 M.S.D —1 V.S.D

= 1 mm - 9/10 mm

= 0.1 mm = 0.01 cm

L.C. = 0.01 cm

2. To find the Zero Correction (ZC)

Before taking the readings with the vernier calipers, we must note the zero error of the vernier calipers. When the two jaws of the vernier calipers are pressed together, if the zero of the vernier scale coincides with the zero of the main scale the instrument has no error, otherwise there is a zero error. The zero error is positive if the vernier zero is after the main scale zero. The zero error is negative when the vernier zero is before the main scale zero. Ordinarily, the zero error is negligible in the case of vernier calipers and so zero error can be considered to be nil.

3. To find the length of the given object

The given object is firmly gripped between the jaws, taking care not to press it too hard. The main scale reading and the vernier coincidence are noted. The main scale reading is the reading on the main scale that is just before the vernier zero. The vernier scale coincidence is found by noting the vernier division that coincides with any one of the main scale. Then the vernier scale reading is found by multiplying the vernier coincidence with the least count. The observations are repeated for various positions of the object.

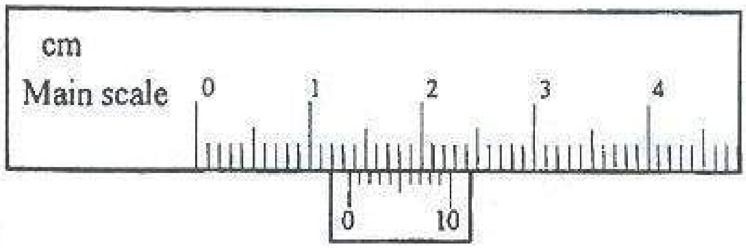


Fig. 3 Vernier Caliper readings

Vernier Calipers readings: (See Fig. 3)

LC = 0.01cm

S. No.	M.S.R cm	V.S.C.- div	V.S.R = (V.S.0 x LC) cm	Total Reading = M.S.R+ V.S.R cm	Corrected Reading = T.R. ± Z.C. cm
1	1.3	6	0.06	1.36	1.36
2					
3					
4					

Mean length of the given object =

THE TRAVELLING MICROSCOPE

Aim

Apparatus:

Reading lens and capillary tube

Description:

It is a compound microscope attached to a graduated vertical pillar, which is mounted on rigid platform (Fig. 1). The platform is provided with three levelling screws. The microscope can be set with its axis either in the vertical or the horizontal position. The microscope can be moved in the vertical or horizontal direction by means of a screw arrangement attached to it. The distance through which the microscope is moved is read on the scale. There are two scales one for horizontal movement and the other for the vertical movement. Each scale has a main scale (M_1, M_2) and a vernier scale (V1, V2). The vernier moves with the microscope. As in the spectrometer, there is a set of main screw and fine adjustment screw, for the horizontal and the vertical movements. One set is fixed to the pillar for vertical movement and the other set is fixed to the platform for horizontal movement. The eyepiece of the microscope is provided with cross-wires. The image of an object is focussed by the microscope using a side screw (focusing screw) attached to the microscope.

Procedure:

1. To find the Least Count (LC) of the travelling microscope

The main scale is graduated in mm. There are 50 V.S.D equivalent to 49 M.S.D. The value of one M.S.D. is 0.5mm=0.05cm

LC	=	1 M.S.D –1 V.S.D.
1 M.S.D	=	0.05 cm
50 V.S.D	=	49 M.S.D
1 V.S.D	=	49/50 x 0.05 = 0.049 cm
LC	=	0.05 - 0.049 cm
LC	**=**	**0.001cm**

To learn the parts of a Travelling Microcope and to read a reading.

Fig. 1 Travelling Microscope

2. To read a reading

When the microscope is clamped by the main screw or fine adjustment screw at any position, the reading is taken in the vertical scale or in the horizontal scale according to the requirement. M.S.R and V.S.R are taken as in the vernier calipers. For example see Fig. 2. And write the M.S.R and V.S.R.

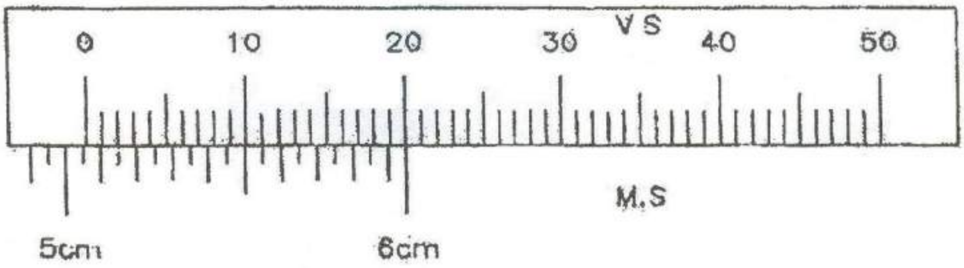


Fig. 2 Vernier and Main scale

Note:

In the Vernier calipers, travelling microscope and the spectrometer, the MS zero may coincide with the VS zero. In such cases, the MSD, which coincides with the VS zero is the MSR reading.

Example:

Travelling microscope readings:

LC = 0.001cm

S. No.	M.S.R cm	V.S.C div	V.S.R = (V.S.C x LC) Cm	T.R = M.S.R + V.S.R cm
1	5.05	20	0.02	5.07
2				
3				
4				
5				

Result:

The parts and functions of the travelling microscope are studied and a few readings are taken.

Practical 2

To study random error in observations

Part A-Measurement of Length and Error Analysis

Equipments:

1 Ruler

1 Vernier Caliper

1 Micrometer Caliper Several Coins.

Objective:

The object of this experiment is twofold:

1. To learn to measure lengths using a ruler, vernier caliper, and micrometer caliper.

2. To become acquainted with types of error and statistical methods for analyzing one's data and for estimating its accuracy.

3. To determine the density of a block of metal.

Theory:

In using a ruler three things must be remembered: (1) the reading should be estimated to one half of the smallest division;

(2) The ends of the ruler should not be used since the ends may have become damaged and nolonger be square

(3) Errors of parallax should be avoided by placing the scale against the object to be measured.

In using a vernier caliper, tenths of a division are not estimated; they are read off the vernier scale. Notice that 10 divisions on the vernier scale correspond to 9 divisions on the main scale. Therefore, the mark on the vernier scale which best lines up with a mark on the main scale gives the reading of a tenth of the smallest division on the main scale (see fig. 1. 1).

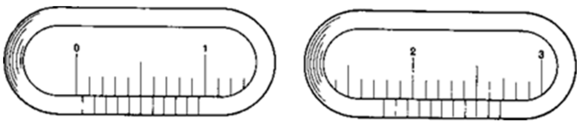


Fig 1.1

In using a micrometer caliper, centimeters and tenths of a centimeter are read from the scale on the barrel. Then thousandths of a centimeter are read from the scale on the thimble. Since this scale only goes from 0 to 50 thousandths the thimble must be turned twice to move one-tenth ofa centimeter. If the scale is over halfway between the marks on the barrel, then 50 thousandths must be added to the reading. Ten-thousandths of a centimeter should be estimated. (See fig. 1.2.) A zero correction for the micrometer caliper should be deter- mined and recorded. For example, if the micrometer caliper reads 0.002 cm when closed, thenevery reading will be too large by this amount and the zero correction must be subtracted from each reading. When closing the micrometer caliper the small knurled knob must be used so that the caliper will not be damaged by over tightening.

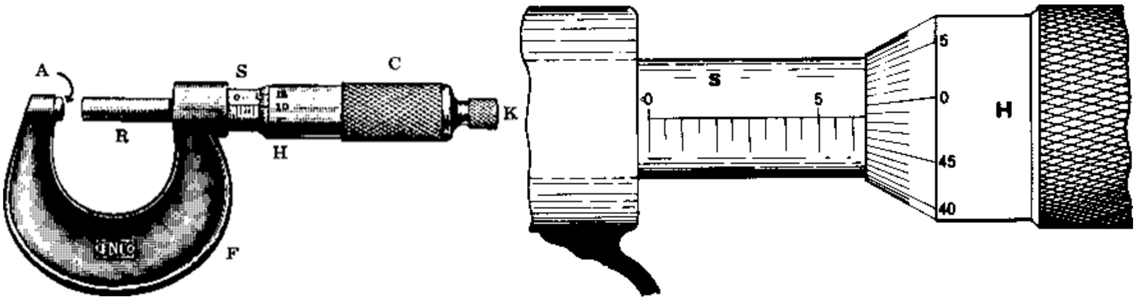


Fig 1.2

Statistical Analysis of Data and Errors

Mean

If one makes a series of n measurements with results x_1, x_2, …..x_n, the mean, or average value x will be the most probable value for the quantity being measured.

$$\bar{x} = \frac{1}{n}\left(x_1 + x_2 + ... + x_n\right)$$

By itself, however x gives no indication of the reliability of the results, that is, of what statistical error there may be in the results. To analyze this facet of the problem one needs the standard deviation or root mean square of the data.

Standard Deviation or Root Mean Square

The standard deviation (or root mean square) of the above n measurements is defined as

$$\sigma = \left[\frac{\left(x_1 - \bar{x}\right)^2}{n-1}\right]^{\frac{1}{2}}$$

σ is a measure of the scatter to beexpected in the measurements. Ifone measured a large number ofvalues x1, then statistically about67% of the xl's would lie between $\bar{x}$ - σ and $\bar{x}$ + σ and about 97% of the x1's would lie between $\bar{x}$ - 2σ and $\bar{x}$ + 2σ.

The error discussed here is experimental or random error which results because one does not always get the same result in making a series of measurements. This type of error is unavoidable because, no matter how accurately one makes one's measurements; there will always be some uncertainty in the measurements. The above error is not the only type of error which may be present, however. Systematic errors may be present, and if they are present they may be difficult to account for unless one is aware of them. A few examples will explain what systematic error is. The speedometer in most automobiles reads too high so that one's speed is systematically lower than the indicated speed, and the speedometer introduces a systematic error into any calculations of the speed of the auto. A second example is using asteeltape measure in cold weather; the tape must have contracted due to thermal effects so that its length is shorter than the length indicated on the rule. A final example is presented by most electrical meters which have an indicated accuracy stamped on the meter. If the accuracy is indicated as 5% then one's measurements made with the meter may be too large or too small by up to 5%. One way of compensating for systematic errors is to calibrate one's instruments if more accurate results are desired.

Personal or human error is a third type of error. Often the person taking data is biased by the first result obtained. In taking measurements one should not try to make them all come out the same, but should merely make each measurement as accurately as possible. Another type of human error is to be sloppy in one's experimental technique; for ex- ample, if one allows parallax errors to occur in making a measurement, this is an avoidable human error. In the present experiment, one must be careful to avoid parallax errors.

In analyzing the error in your data tries to estimate the magnitudes of the various kinds of error which may be present and discussthem in your laboratory report.

Procedure:

A. Ruler

Measure the diameter of a coin three times with the ruler recording the results on your data sheet, and then let your partner do the same recording his results. Make your measurements at different points so that a good average dimension will be obtained. You should always be able to estimate the fractional part of the smallest division to get your last significant figure.

Calculate the mean diameter and the standard deviation. Discard any nonsignificant figures before recording the mean diameter.

B. Vernier Caliper

Make three measurements of the diameter of the coin as in part I.A but using the vernier caliper this time. Let your partner do the same. Record the results on your data sheet. Calculate the standard deviation and mean diameter as in part A.

C. Micrometer Caliper

Repeat the measurements and calculations made in parts I.Aand I.B using the micrometer caliper this time. Record the results on your data sheet.

D. Measurement of Density

Density is defined as the ratio of the mass of an object divided by its volume. Using the triple beam balance, determine the mass of your coin, and then assume it is a cylinder and determine its volume. Try to identify the composition of your coin from the density you calculated. Note: Coins are made of various alloys. However, you should be able to determine the most abundant metal used in the minting of the coin. You should be able to find the exact composition on the web.

Part B- Random Error Analysis

Objective:

The purpose of this experiment is to make a series of measure- ments involving a sufficient number of trials to permit the use of a statistical theory of errors to evaluate the results.

Part 1:

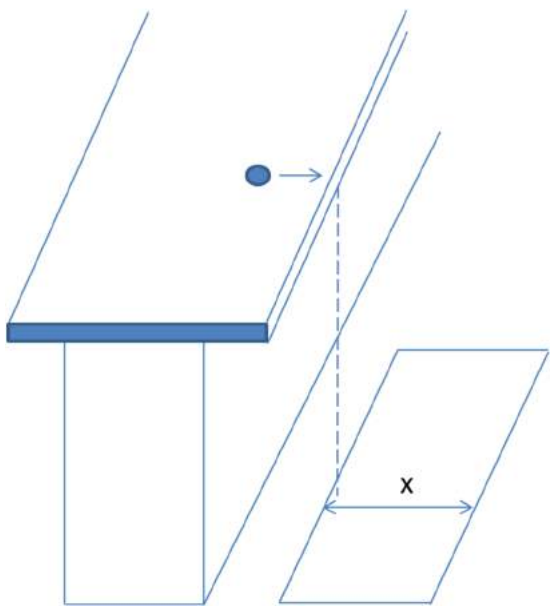
Equipment:

Steel Ball Carbon Paper

Sheets of Ruled Paper ruler

Procedure:

Place a sheet of paper over a layer of carbon paper approximately 30 cm from the table on the laboratory floor. Mark a line on the paper which is parallel to the edge of the table. Using a plumb bob, locate the position of the edge of the table on the floor and accurately measure x, the distance from the table and attempt to hit the line on the paper as the ball strikes the floor. Measure the horizontal distance from the position of the edge of the table to the actual impact point, call it x1 (measure to the nearest cm). Repeat these in a vertical column. We will now obtain two numbers which will give a measure of the variability of your skill in this experiment.



Ball shown on table with paper beneath

1) Calculation of the average value:

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N}$$

The xi's are simply the measured values for x for the different trials. A comparison of this value with the true distance from the table edge to the line shows whether or not the results are consistently too short or too long.

2) Calculation of the standard deviation: This quantity gives an indication of the consistency of the trials.

$$\sigma^2 = \frac{\sum_{i=1}^{N} \left(x_i - \overline{x} \right)^2}{N-1}$$

3) Plot of the distribution of hits versus position (i.e., a histogram):

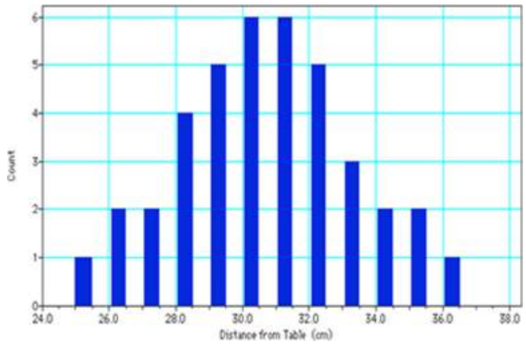
Draw a graph of the number of times the ball hit within a specified distance from the line versus the distance from the table in centimeter intervals.

Include on the graph:

1) The average value of the measured value of x (the arithmetic average).

2) The true value of x (actual position of the line).

3) The calculated standard deviation.



Part 2

Equipment:

Compressed Pills

Digital Balance (0.001g resolution)

Procedure:

Measure the mass of at least 30 of these compressed pills and calculate:

a) The average value of the mass

b) The standard deviation of this distribution

c) Plot the distribution of mass versus number for the pills in your measurement set.

Practical 3

To determine Coefficient of Viscosity of water by Capillary Flow Method (Poiseuille's method).

Objective

To determine the value of the coefficient of viscosity for water using Poiseuille' method.

Equipment needed

Water bottle, bottle stand, plastic tube, clamp, beaker, basin, meter stick, thermometer, timer.

Theory

Theory If a liquid flows in stream lines through a horizontal capillary tube of internal radius r and length ,then the volume V of this liquid that flows out per second under a steady pressure difference P between its ends is given by

$$V = \pi P r^4 / 8\eta l$$

where η is the coefficient of viscosity of the given liquid. Thus (i) Equation (ii) represents the working formula óf the present experiment. Here the coefficient of visCosity η is determined by measuring P,r,l and V. In SI units, P is expressed in Pa (= N/m^2), r and in m, and V in m^3/s. Then η is in $N.s/m^2$, also called poiseulle (Pl).

Experimental Set-up

Two types of apparatus are commonly used in the laboratory for the measurement of the coefficient of viscosity of a liquid. We describe both of them separately.

(A) One set of apparatus is shown in Fig. It consists of a constant level tank from the liquid is allowed to flow through a capillary tube C, held slightly inclined horizontal. The liquid enters the tank from the reservoir through a rubber tube A. The flow of the liquid into the tank through A is adjusted slightly in excess of the outflow through the capillary tube C. The excess liquid is continuously driven out from the bottom by another tube B. This gives a steady level of the liquid in the tank. The height of the liquid level in the tank above the free end of the capillary tube is measured by a cathetometer.

(B) The second type of set-up is shown in Fig.. The experimental liquid is contained in a glass vessel V. The vessel is closed by a rubber cork R through which a glass tube, open at both ends, is inserted in such a way that the lower end of the glass tube remains always well below the liquid surface in V. As the liquid is drawn from the vessel V, the air bubbles from the atmosphere enters the vessel through the tube. This keeps the end O of the tube at the atmospheric pressure.

The liquid from the vessel flows to the junction J, through a pinch-cack S. From the junction, the liquid goes simultaneously to an arm of a manometer M and to a capillary tube C which connects a second junction J. The liquid from this junction goes to the second arm of the manometer and to a beaker through a rubber tube. The thermometer T is used to measure the temperature of the liquid of the beaker. The pinch-cock S is adjusted in such a way that the liquid flws to the beaker in a very slow stream or in succession of drops. This condition is possible if the difference in heights h of the liquid in the two arms of the manometer is maintained at a steady low value. Sometimes a second pinch-cock is used in the outlet rubber tube after J, to maintain this condition. The collection of the liquid in the beaker 1s started after this steady state condition is achieved.

Procedure

1. Measure the length (l) of the capillary tube three times by a metre scale and find its mean value. To determine the mean radius (r) of the capillary tube adopt the following procedure:

Clean the tube by passing first dilute nitric acid, then a strong solution of caustic soda, and finally cold water for a few minutes. Dry the tube completely by passing hot air through it. Now insert by sucking a column of mercury covering almost the entire length of the tube. Measure the length (L) of the mercury column three times by a metre scale and calculate its mean value. Take an empty crucible and weigh it accurately. Transfer the mercury from the tube to the crucible and weigh it correctly Obtain the weight of the mercury (W) from the difference of the two weights. Determine square of the radius (r^2) of the tube from the relation

$$r^2 = W/(\pi l \rho')$$

where p'is the density of mercury (p'= 13.6 gm. cm'').

2. Set up the apparatus as in Fig.

3. The pressure difference P is given by $P = h\rho g$ where ρ is the density of the experimental liquid and g is the local acceleration due to gravity. To ensure that the liquid flows in streamlines in the experiment, h should be much less than the critical height h_c. A rough estimate of the critical height h can be made in terms of Reynold's number k as follows. The critical velocity 'marking the transition from the streamline to the turbulent motion of the liquid is given by

$$v_c = k\eta/(\rho r) \quad \text{..........................(iv)}$$

The velocity of the liquid in the capillary tube is a maximum along the axis of the tube; this maximum value is

$$u_{max} = h\rho g r^2/(4\eta l) \qquad \text{..........(v)}$$

As the velocity of the liquid drops off as one moves away from the axis, v_c is put to $u_{max}/2$. Then h =h_c, and we have from Eqs. (iv) and (v)

$$h_c = 8k\eta^2 l/(\rho^2 g r^3) \qquad \text{.........(vi)}$$

Taking h=2 (or 3) cm (as measured by a metrescale), find the volume V of the outflowing liquidper second by collecting the liquid in a measuring cylinder and dividing the collected volume by the time of collection. Then find a rough value of n from Eq. (i). With this valueof n, the critical heighth is calculated from Eq. (vi), takingk = 1000, the value of Reynold's numberfor narrow tubes. The experiment is now performed for different valuesof h much less than h, (typically below $h_c/2$).

4. Fix the cathetometer at a convenient distance and level it so that its pillar is vertical and the telescope axis is horizontal. Determine the vernier constant of the cathetometer scale.

5. Focus the telescope cross-wires sucessively on the surface of the liquid in the tank and the axis of the outflow end of the capillary tube C for the set-up of Fig.. For the set-up of Fig. 3.G2(), focus the telescope cross-wires successively on the surface of the liquid in the two arms of the manometer. Note the readings of the main scale and the vernier in the two settings of the telescope. Designate the readings by R, and R, respectively. The difference (R~ R_2) of the two readings gives h, i.e., the pressure difference in terms of the heightof the liquid column.

Note the temperature (T°C) of the liquid in the tank by a thermometer. Obtain the density (p) of the liquidat this temperature from physical tables.

Table 12.1.

Determination of the coefficient of viscosity

Measured quantity	The number and unit of measure	Absolute error
h_1		
h_2		
$(h_1+h_2)/2$		
The length *l* of the capillary		
The volume *V* of out flowed water		
The radius *r* of the capillary		
The duration *t* of flow		
The temperature of the water		

5. Questions

1) Define the coefficient of viscosity.
2) Define the units of viscosity in SI-and CGS system.
3) What does the velocity gradient mean? What kind of directions acquires the coefficient of viscosity which has an influence on conceivable plane layer of liquid in the flowing fluid?
4) How depends the coefficient of viscosity of liquid and gas on temperature? Why?
5) Why the capillary tube is used in given method?
6) Find the pressure in the ocean 1 km below the water surface.
7) Why there can't be any air bubbles in the fluid during measurements?
8) Why the size of the water bottle *A* and the tube *B* must be large?
9) Why the pressure of atmosphere is not taken into account?
10) Why the water level must stay in the water bottle *A*?
11) If extent the capillary tube *C* the water does not flow out from certain length. Why?
12) Why it is necessary in this experiment to take large diminishing of water level in water bottle *A*?

Practical 4

To determine the Young's Modulus of a Wire by Optical Lever Method.

Apparatus:

Laser mount, Laser, Knife Edges, Slotted weights, Material Bar, Meter Scale, Screw gauge, Vernier Caliper.

Purpose of Experiment:

To determine the Young's Modulus of the material of the bar subjected to non-uniform bending by measuring the depression at the center using optical lever.

Introduction:

Young's modulus, also known as the elastic modulus, is a measure of the stiffness of a solid material. It is a mechanical property of linear elastic solid materials. It defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material.

$$Y = \frac{Stress}{Strain} = \frac{F/A}{\Delta L/L}$$

A solid material will deform when a load is applied to it. If it returns to its original shape after the load is removed, this is called elastic deformation. In the range where the ratio between load and deformation remains constant, the stress-strain curve is linear.

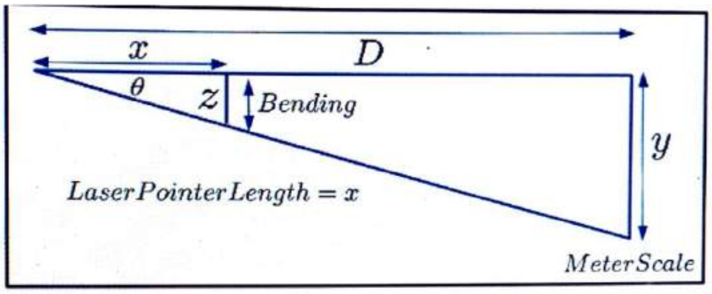
In this experiment we are using three different kind of plates whose Young's Modulus we need to measure. In order to do so we are hanging some weights at the center of the plates placed on knife edges, by noting the depression we are estimating how much strain we have applied for a given stress.

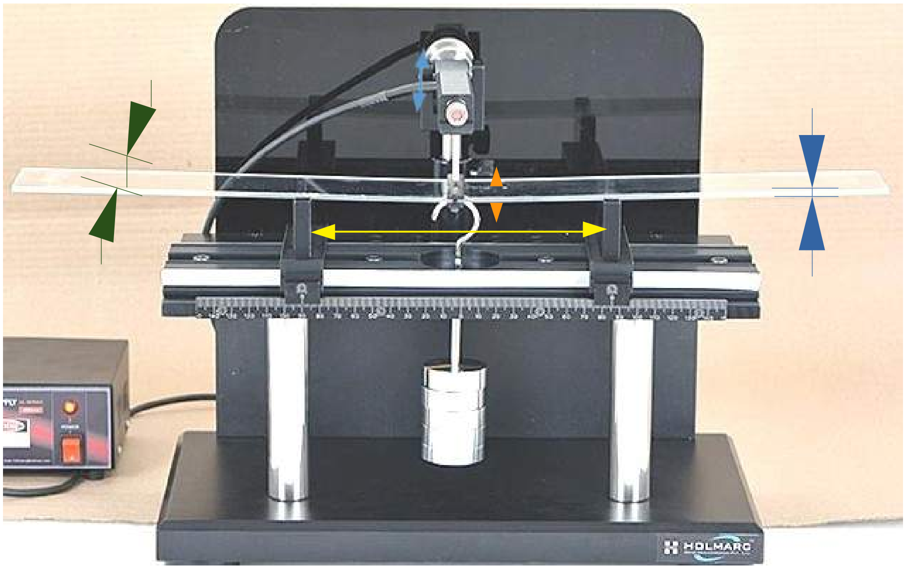
In non uniform bending, the beam (meter scale) is supported symmetrically on two knife edges and loaded at its center. The maximum depression is produced at its center. Since the load is applied only at a point of the beam, this bending is not uniform throughout the beam and the bending of the beam is called non-uniform bending.

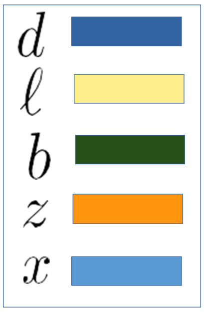
According to the theory of non-uniform bending, for a bar of thickness and breadth , supported by two knife edges distance apart, the depression at the midpoint due to load is given by,

$$z = \frac{Mg\ell^3}{4Ybd^3} \implies Y = \frac{Mg\ell^3}{4zbd^3}$$

$$\tan\theta = \frac{z}{x} = \frac{y}{D} \implies z = \frac{xy}{D}$$







Setup and Procedure:

1. The bar is symmetrically placed on two knife edges.
2. A weight hanger is suspended at the center of the bar.
3. Optical lever is placed with its front leg at the center of the bar from where the weight hanger is suspended.
4. A vertical scale is arranged at a distance of about one meter from the laser module.
5. Laser is focused on to the vertical scale.
6. The bar is loaded and unloaded a number of times to measure its depression with loading and unloading of the mass.
7. With the weight hanger of mass W_0 alone to the bar, note the scale reading corresponding to the laser spot.
8. Add the mass M in steps and scale readings are noted.
9. The experiment is repeated by unloading the masses in steps and the mean value of the scale reading for each mass is noted.
10. Repeat the experiment for 2 given plates and compare their respective Young's modulus.

Dimensions of the plates:

Material	**Thickness d (cm)**	**Breadth b (cm)**
Acrylic	0.6	5
Brass	0.2	5

Determination of Young's modulus

Observations:

Plate 1:

Thickness d =   cm   Breadth b =   cm

Length between Laser pointer leg and its pivot x =
cm

Distance between scale and optical lever D =
cm

Young's modulus need to be calculated using following expression,

$$Y = \frac{Mgl^3D}{4bd^3xy}$$

Trail No.	Dist. between knife edges , l (cm)	Mass Suspended M(grams)	Scale Reading (cm)			Mean shift (cm)		Young's Modulus Y
			Loading	Unloading	Mean	For 4M ( )	For M $(\alpha/4)$	
1.		W_0	X_{0L}				=	
		$W_0 + M$	X_{1L}	X_{1U}		$0.25y_1+$		
		$W_0 + 2M$	X_{2L}	X_{2U}	$y_1 = 0.5\ (X_{4L} - X_{0L}) + 0.5\ (X_{5U} - X_{1U})$	$0.25y_2+$		
		$W_0 + 3M$	X_{3L}	X_{3U}	$y_2 = 0.5\ (X_{5L} - X_{1L}) + 0.5\ (X_{6U} - X_{2U})$	$0.25y_3+$		
		$W_0 + 4M$	X_{4L}	X_{4U}	$y_3 = 0.5\ (X_{6L} - X_{2L}) + 0.5\ (X_{7U} - X_{3U})$	$0.25y_4$		
		$W_0 + 5M$	X_{5L}	X_{5U}	$y_4 = 0.5\ (X_{7L} - X_{3L}) + 0.5\ (X_{7L} - X_{4U})$			
		$W_0 + 6M$	X_{6L}	X_{6U}				
		$W_0 + 7M$	X_{7L}	X_{7U}				
2.		W_0	X_{0L}				=	
		$W_0 + M$	X_{1L}	X_{1U}		$0.25y_1+$		
		$W_0 + 2M$	X_{2L}	X_{2U}	$y_1 = 0.5\ (X_{4L} - X_{0L}) + 0.5\ (X_{5U} - X_{1U})$	$0.25y_2+$		
		$W_0 + 3M$	X_{3L}	X_{3U}	$y_2 = 0.5\ (X_{5L} - X_{1L}) + 0.5\ (X_{6U} - X_{2U})$	$0.25y_3+$		
		$W_0 + 4M$	X_{4L}	X_{4U}	$y_3 = 0.5\ (X_{6L} - X_{2L}) + 0.5\ (X_{7U} - X_{3U})$	$0.25y_4$		
		$W_0 + 5M$	X_{5L}	X_{5U}	$y_4 = 0.5\ (X_{7L} - X_{3L}) + 0.5\ (X_{7L} - X_{4U})$			
		$W_0 + 6M$	X_{6L}	X_{6U}				
		$W_0 + 7M$	X_{7L}	X_{7U}				

Average Value of Young's modulus Y =____________Appropriate Units

Repeat the experiment for 2 plates.

Result:

The Young's Modulus of two different materials is measured using non-uniform bending technique and is found to be,

1. For Acrylic =
2. For Brass =

Practical 5

To determine Young's modulus, modulus of rigidity and Poisson's ratio of the material of a given wire by Searle's dynamical method.

Apparatus Used: Two identical bars, given wire, stop watch, screw gauge, vernier callipers, meter scale, physical balance, candle and match box

Formula Used: The Young's modulus of the material of the wire is given by-

$$Y = \frac{8\pi Il}{T_1^2 r^4}$$

Modulus of rigidity is given by- .....(1)

$$\eta = \frac{8\pi Il}{T_1^2 r^4}$$

Poisson's ratio is given as- .....(2)

$$\sigma = \frac{T_2^2}{2T_1^2}$$

Here, I = Moment of inertia of the bar about a vertical axis through its centre of gravity l = Length of the given wire between the two clamping screws

r = Radius of the wire

T_1 = Time period when the two bars execute simple harmonic motion together T_2 = Time period for the torsional oscillations of a bar

About apparatus:In this experiment, two identical rods PQ and RS of square or circular cross section connected together at their middle points by the specimen wire, are suspended by two silk fibres from a rigid support such that the plane passing through these rods and wire is horizontal as shown in figure.

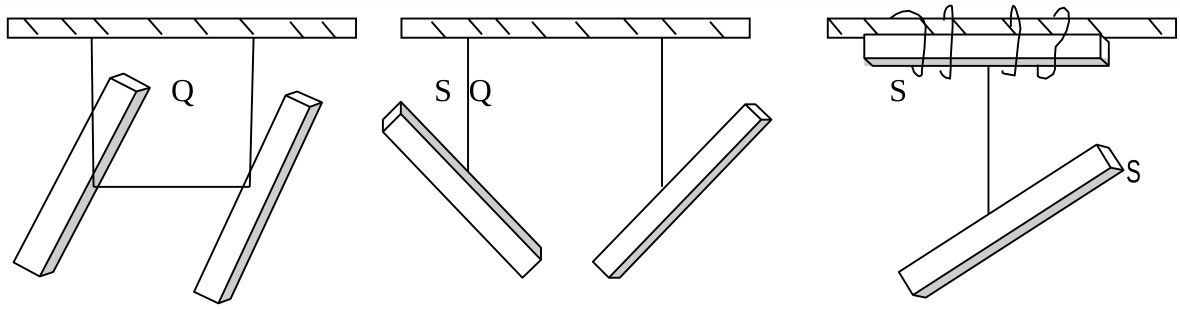


Figure 1

Procedure:

(i) Take the weight of both bars with the help of physical balance and find the mass 'M' of each bar.

(ii) Measure the breadth 'b' of the cross bar with the help of vernier callipers.(If the rod is of circular cross-section then measure its diameter 'D' with vernier callipers).

(iii) Take the measurement of length 'L' of the bar with the help of meter scale.

(iv) Now attach the experimental wire to the middle points of the bar and suspend the bars from a rigid support with the help of equal threads such that the system is in a horizontal plane [as shown in figure 1a].

(v) Take the two bars close together (through a small angle) with the help of a small loop of the thread [as shown in figure 1b].

(vi) Now burn the thread with the help of stick of match box and note the time period T_1 in this case.

(vii) Clamp one bar rigidly in a horizontal position so that the other hangs by the wire [as shown in figure 1c]. Rotate the free bar through a small angle and note the time period T_2 for this case also.

(viii) Measure the length 'l' of the wire between the two bars with the help of meter scale.

(ix) Measure the diameter of the experimental wire at a large number of points in mutually perpendicular directions by a screw gauge and find the radius 'r' of the wire.

Observations:

Table 1: Determination of T_1 and T_2

Least count of the stop watch = ...sec.

S.No.	No. of oscillations (n)	Time T_1			Time period T_1 (= a/n) (sec.)	Mean T_1 (sec.)	Time T_2			Time period (=b/n) (sec.)	Mean T_2 (sec.)
		Min.	Sec	Total sec. (a)			Mi n.	Sec.	Total sec (b)		
1	5										
2	10										
3	15										
4	20										
5	25										

Mass of either of the rod PQ or CD, M = ... gm. = ... Kg.

Length of the either bar L=......................... cm.

Table 2: Measurement of the breadth of the given bar

$$\text{Least count of the vernier callipers} = \frac{\text{value of one division of main scale in cm}}{\text{total number of divisions on vernier scale}}$$

Zero error of vernier callipers = ±............... cm.

= cm.

S.No.	Reading along any direction			Reading along a perpendicular direction			Uncorrected breadth b = (X+Y)/2 cm.	Mean corrected breadth b cm.
	M.S. reading	V.S. reading	Total X- cm	M.S. reading	V.S. reading	Total Y- cm.		
1								
2								
3								

b =............ cm. = meter

If the bars are of circular cross section then the above table may be used to determine the diameter D of the rod.

Length ‘l’ of the wire = cm.

Table 3: Measurement of the diameter of the given wire

$$\text{Least count of screw gauge} = \frac{\text{value of one division of main scale in cm}}{\text{total number of divisions on vernier scale}} = \text{...............cm}$$

Zero error of screw gauge = ± ....cm

S.No.	Reading along any direction			Reading along a perpendicular direction			Uncorrected diameter (X+Y)/2 (cm.)	Mean uncorrected diameter (cm.)
	M.S. reading	V.S. reading	Total X (cm)	M.S. reading	V.S. reading	Total Y-(cm.)		
1								
2								
3								

Mean corrected diameter d = Mean uncorrected diameter ± zero error =............................ cm.

Mean radius r = d/2 =..........................cm.

Calculations:

$I = (M(L^2+b^2))/12$ =………. $Kg.\times m^2$ [for square cross-section bar]

$I = M[(L^2/12)+(D^2/16)]$ = ……………. $Kg.\times m^2$ [for circular bar]

Result:

Y = ... $Newton/meter^2$

η = ... $Newton/meter^2$

σ = ...

Standard Result:

Y = ... $Newton/meter^2$

η = ... $Newton/meter^2$

σ = ...

Percentage error:

Y = ...%

η = **..................** %

σ =............ %

Precautions and Sources of Errors:

(1) The length of the two threads should be same.
(2) The radius of the wire should be measured very accurately.
(3) The two bars should be identical.
(4) The amplitude of oscillations should be kept small.
(5) Bars should oscillate in a horizontal plane.

Objectives: After performing this experiment, you should be able to-

- understand Searle's dynamical method
- understand Young's modulus, modulus of rigidity and Poisson's ratio
- calculate Young's modulus, modulus of rigidity and Poisson's ratio

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VIVA-VOCE:

Question 1. Should the moment of inertia of the two bars be exactly equal?

Answer. Yes. If the two bars are of different moment of inertia, then their mean value should be used.

Question 2. How are Y and η involved in Searle's dynamical method?

Answer. The wire is kept horizontally between two bars. When the bars are allowed to vibrate, the experimental wire bent into an arc. Thus the outer filaments are elongated while inner ones are contracted. In this way, Y comes into play. When one bar oscillates like a torsional pendulum, the experimental wire is twisted and η comes into play.

Question 3. What is the nature of vibrations in two parts of Searle's dynamical method?

Answer. In the first part, the vibrations are simple oscillations while in second part, the vibrations are torsional vibrations.

Question 4. What is meant by Poisson's ratio?

Answer. Within the elastic limits, the ratio of the lateral strain to the longitudinal strain is called Poisson's ratio.

Question 5. Which type of bar do you prefer to use in this experiment- heavier or lighter?

Answer. We shall prefer heavier bars because they have large moment of inertia. This increases the time period.

Question 6. Can you use thin wires in place of threads?

Answer. No, we can't use thin wires in place of threads because during oscillations of two bars, the wires will also be twisted and their torsional reaction will affect the result.

Practical 6

To find out the moment of inertia of a flywheel

Apparatus Used:

A fly wheel, a few different masses, hanger, a strong and thin string, a stop watch, a meter rod, a vernier calliper.

1. Formula Used:

Moment of inertia of fly wheel is given by

$$I = \frac{2mgh - mr^2\omega^2}{\omega^2(1 + n_1/n_2)}$$

Where m = mass which allow to fall

h = height through which the mass is fallen

ω= angular velocity $=\frac{4\pi n^2}{t}$

t = time to make n_2 revolution.

n_1 = No. Of revolutions the wheel makes during the decent of mass

n_2= No. Of revolutions made by wheel after the string detached from the axle

Figure 1

Theory

Moment of Inertia:

The movement of inertia of a body is defined as the sum of products of masses distributed at different points and square of distances of mass point and axis where the body is being rotated.

If a body of total mass M is to be made of large number of point masses $m_1, m_2, m_3, \ldots$ distributed at distances $r_1, r_2, r_3, \ldots$ from the axis of rotation then the movement of inertia is defined as

$$I = m_1r_1^2 + m_2r_2^2 + \ldots\ldots\ldots + m_nr_n^2 = \sum mr^2$$

Radius of Gyration:

The radius of gyration is defined as

A body of mass M rotates about an axis and mass M is supposed to be made of small mass $m_1, m_2, m_3, \ldots\ldots$. and $r_1, r_2, r_3,$ are distances from the axis. If the moment of inertia of the

body is I then the radius of gyration (K) is defined as a distance from axis of rotation to a point where the whole mass of the body may be concentrated, and product of total mass and square of this distance gives the same movement of inertia.

$I = \sum mr^2 = MK^2$ Where K is the radiation of gyration.

Some examples of movement of inertia (MI) of different shapes:

1. **Moment of Inertia of a circular ring:** If a circular ring of mass M and radius R is considered then the movement of inertia (I) is given as:

$$I = MR^2$$

2. **Moment of Inertia of a circular Disc:** if a circular disc has mass M and radius R the movement of inertia (I) about the axis passing through centre of gravity (CG) and perpendicular to the disc is given as:

$$I = \frac{1}{MR^2 2}$$

3. **Moment of Inertia of a rectangular lamina:** A lamina is a rectangular bar. If the length of lamina is a and width is b then the movement of inertia (I) of the lamina about the axis passing through the centre of gravity (CG) and perpendicular to the bar is given by: $I = (a^2+b^2)/12$

4. **Moment of Inertia of a sphere:** The movement of inertia of a sphere of radius r about its diameter is given as:

$$I = \frac{2}{Mr^2 5}$$

Moment of Inertia of a fly wheel:

A fly wheel is a heavy circular disc fitted with a strong axle this wheel is designed in such a way that the mass distribution is mostly at the corners so that it provides maximum moment of inertia. The axle is mounted on the ball bearing on two ends of fixed support.In the experiment a small mass m is attached to the axle of the wheel by a string which is wrapped several times around the axle, one end of the string is attached with a hook which can easily be attached or detached from the axle. A suitable length of the string is to be chosen from the axle to the ground. The end of string is attached with a hanger on which suitable manes may be attached.

In this experiment, the potential energy of mass m is converted into its translation kinetic energy and rotational kinetic energy of flywheel and some of the energy is lost in overcoming frictional force. The conservation of energy equation at the instant when the mass touches the ground can be written as,

P.E. of mass = K.E. of mass m + K.E. of wheel + work done to overcome the friction

$$Mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + n_1F$$

Here v (= rω) is the velocity of mass and ω is the angular velocity of flywheel at the instant when the mass touches the ground. Here F is the frictional energy lost per unit rotation of the flywheel and it is assumed to be steady. n_1 is the number of rotations completed by the flywheel, when the mass attached string has left the axle.

Even after the string has left the axle, the fly wheel continue to rotate and its angular velocity would decrease gradually and come to a rest when all is rotational kinetic energy of wheel is used to overcome the friction (frictional energy). If n_2 is the number of rotation made by the flywheel after the string has left the axle then

$$n_2 F = \frac{1}{2}I\omega^2$$

$$F = \frac{1}{2n_2}I\omega^2 \qquad (2)$$

By substituting eq. 2 for F in eq. 1, we get the expression for moment of inertia as,

$$I = \frac{2mgh - mr^2\omega^2}{\omega^2(1+\frac{n_1}{n_2})} \qquad (3)$$

Let t be the time taken by the flywheel to come to rest after the detachment of the mass.

During this time interval, the angular velocity varies from ω to 0. So, the average angular velocity ω/2 is,

$$\frac{\omega}{2} = \frac{2\pi n_2}{t} \quad \text{or } \omega = \frac{4\pi n_2}{t} \qquad (4)$$

Procedure:

1. Setup the experiment as shown in Fig. 1 by taking a string of appropriate length and mass m.
2. Allow the string to unwind releasing the mass.
3. Count the number of rotation of the flywheel n_1 when the mass touches the ground.
4. Switch on the stopwatch when the moment the mass touches the ground and again

   count the number of rotation of flywheel, n_2 before it comes to rest. Stop the watch when the rotation ceases and note down the reading t.
5. Repeat the measurement for at least three times with the same string and mass such that n_1 , n_2 and t are closely comparable. Take their average value.
6. Repeat the measurement for another mass.
7. Measure the radius of axle using a vernier calipers and the length of the string using a scale.
8. Calculate the moment of inertia and maximum angular velocity m using eq. 3 and 4.

Observations:

Vernier Constant = ------------------

Diameter of the Axle D_1 = __________

D_2 = __________

D_3 = __________

Mean diameter of the axle $D = \frac{D_1 + D_2 + D_3}{3}$

Radius of axel r = D/2 = ___________

Observation table:

S. No.	MASS (in gm)	NO. OF REVOLUTION n_1			NO. OF REVOLUTION n_2			Time (t)		
		1st reading	2nd Reading	Mean n_1	1st reading	2nd Reading	Mean n_2	1st reading	2nd Reading	Mean t
1.	100									
2.	200									
3.	300									

Average angular velocity m_1 __________

m_2 __________

m_3 __________

Movement of inertia of the fly wheel for For mass m_1 : I_1 = ________________________ For mass m_2 : I_2 = _______________ For Mass m_3 : I_3 = _____

Mean of I = __________

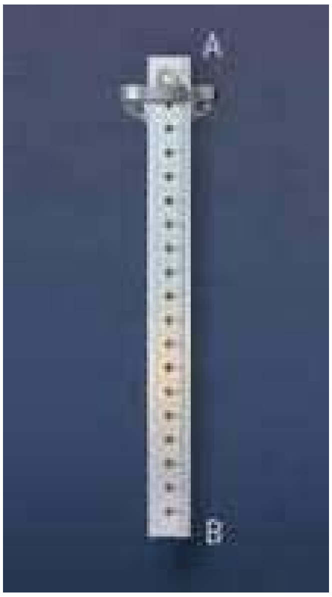
RESULT

Movement of inertia of a fly wheel =____________Kg m^2

PRECAUTIONS

1. There should be a possible friction in the wheel. The tied to the end of the cord should be of such a value that it is able to overcome friction at the beginning and thus automatically stats falling.

2. The length of the string should less than the height of the axle of the fly wheel from the floor.
3. The string should be thin and should be wound evenly.
4. The stop watch should be started just when the string is detached.



Time period of a compound pendulum:

Consider a rigid body i.e. a bar pendulum of mass m capable of oscillating freely about a horizontal axis passing through it perpendicular to its plane.

Let O be the center of suspension of the body and G its center of gravity in the position of rest. When the body is slightly displace through a small angle 8, the centre of gravity is shifted to the position G and its weight mg acts vertically downward at G.

If the pendulum is now released a restoring couple acts on it and brings it back to the initial position. But due to inertia it starts oscillating about the mean positions.

The moment of the restoring couple of torque

τ = -mg x GA = - mgl sinθ = - mgl θ

Since the angle θ through which the pendulum is displace is small so that sin θ = θ

This restoring couple provides an angular acceleration α in the pendulum.
If I is the moment of inertia of the rigid body (bar pendulum) about an axis through its center of suspension restoring couple (torque) is given by

$$\tau = I\alpha = I\frac{d^2\theta}{dt^2}$$

From the above equations we can write

$$I\frac{d^2\theta}{dt^2} = -mgl\theta$$

$$\frac{d^2\theta}{dt^2} = -mgl\theta/I$$

$$\frac{d^2\theta}{dt^2} \alpha\ \theta$$

This is the condition for simple harmonic motion. As the angular acceleration is proportional to angular displacement, the motion of the pendulum is simple harmonic and its time period T is given by

$$T = 2\pi\sqrt{(I/mgl)}$$

If I_{cg} is the moment of inertia of the body (or compound pendulum) about an axis passing through center of gravity (C.G.) and I is the moment of inertia of the body about a new axis Z' parallel to the given axis then according to the theorem of parallel axis, we have

$$I = I_{cg} + ml^2$$

Where l is the parallel distance about two axis as shown in figure.

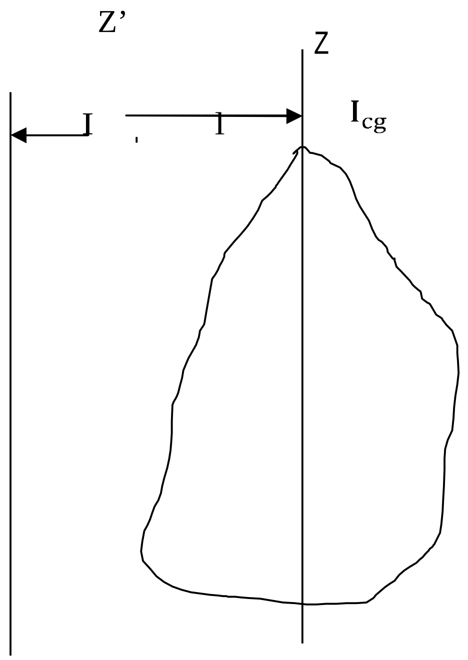


Figure 1

Now, moment of inertia center of gravity $I_{cg} = mk^2$, where k is the radius of gyration.

$$I = mk^2 + ml^2 = m(k^2 + l^2)$$

Substituting the value of I in relation of time period, we get

$I = 2\pi\sqrt{\{ m(k^2 + l^2)/mgl\}} = 2\pi\sqrt{\{ (k^2 + l^2)/gl\}}$

In case of simple pendulum time period T is given as

$T = 2\pi\sqrt{(l/g)}$

On comparing above two relations

$$L = \frac{k^2}{l} + l$$

which is called equivalent length.

Thus relation shows that the time period of a compound pendulum is the same as that of a simple pendulum of length $L = \frac{k^2}{l} + l$

Since k^2 is always a positive quantity, the length of an equivalent simple pendulum is always greater than l.

Centre of suspension: As stated above, the point O through which the horizontal axis about which the pendulum vibrates, passes is called the center of suspension. If l_S is the distance of O from the center of gravity G, then

Time period $T = 2\pi\sqrt{\{ (k^2 + l_1^2)/gl_1\}}$

Centre of Oscillation: A point C on the other side of center of gravity G and at a distance

$$OC = OG + GC = 1_1 + \frac{k^2}{1_1 g} = 1_1 + 1_2 = L$$

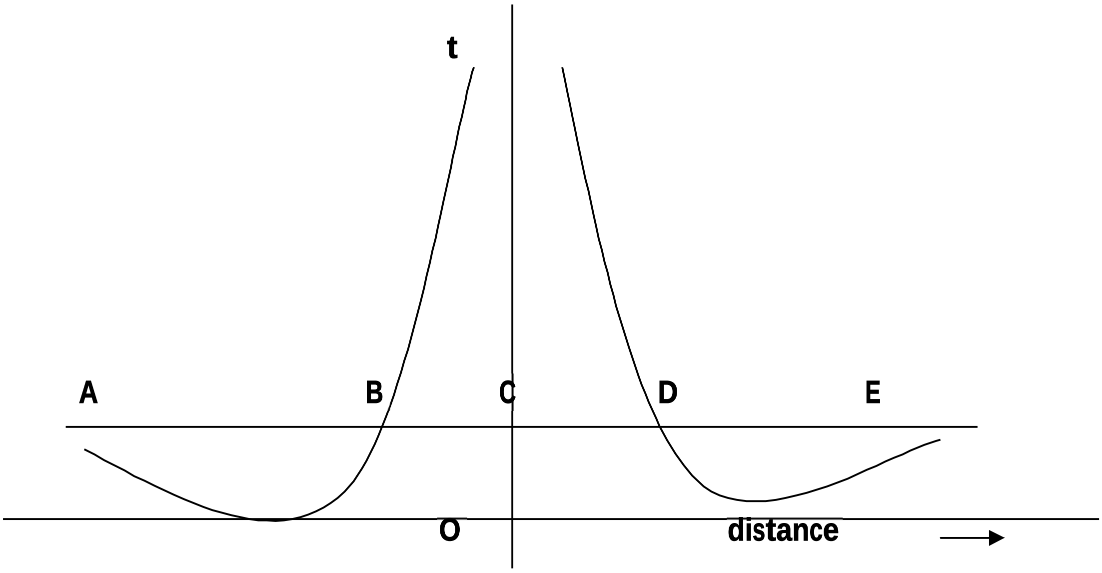
If pendulum is suspended at center of oscillation then time period

$T = 2\pi\sqrt{\{ (k^2 + l_2^2)/gl_2\}} = 2\pi\sqrt{\{ (k^2 + l_1^2)/gl_1\}}$

Thus the time period of the compound pendulum about a horizontal axis through C is the same as about O. Thus the point C at a distance equal to the length of an equivalent simple pendulum from the point of suspension O on the straight line passing through the center of gravity G is called the center of oscillation. Mathematically, the time period is same for both center of suspension and the center of oscillation therefore the center of suspension and the center of oscillation are interchangeable. The time period of a compound pendulum is minimum when the distance of the point of suspension from C.G. is equal to the radius of gyration.

Procedure:

1. A graph is plotted between the distance of the knife-edges from the center of gravity taken along the x-axis and the corresponding time period t taken along the Y-axis for a bar pendulum, then the shape of the graph is as shown in figure.
2. If a horizontal line ABCDE is drawn, it cuts the graph in points A. B and D, E about which the time period is the same. The points A and D or B and E lie on opposite sides of the center of gravity at unequal distances such that the time period about these points is the same. Hence one of these corresponds to the center of suspension and the other to the centre of oscillation. The distance AD or BE gives the length of the equivalent simple pendulum L. If t is the corresponding time period, and $l_1$and l_2 are the distances of the point of suspension and the point of oscillation from the centre of gravity, M is the mass of the bar pendulum then



Observation:

1. The reading for distance and time period is to be taken as shown in table.

No. of Hole	Side A			Side B		
	Total time for 20 oscillations	**Time period T=t/20**	**Distance from CG in cm**	**Total time for 20 oscillations**	**Time period T=t/20**	**Distance from CG in cm**
1						
2						
3						
4						
5						
6						

2. Plot the graph Take the Y-axis in the middle of the graph paper. Represent the distance from the C.G. along the x-axis and the time period along the y-axis.
3. Plot the distance on the side A to the right and the distance on the side B to the left of the origin.
4. Draw a smooth curves on either side of the Y-axis passing through the plotted points taking care that the two curves are exactly symmetrical as shown in fig. 14.5.

   Calculation: From graph For line ABCDE $T=L_1= L_2=L = L_{1+}L_2$ Radius of gyration $K=\sqrt{l_1 l_2}$ And Moment of inertia $I=Mk^2$

Precaution:

1. Mark one end of the Bar pendulum as A and the other as B.
2. Suspend the pendulum from the knife-edge on the side A so that the knie-edge is perpendicular to the edge of the slot and the pendulum is hanging parallel to the wall.
3. Measure the distance between the C.G. and the inner edge of the knife-edge.
4. Now suspend it on the knife-edge on the side B and repeat the observations.
5. Repeat the observations with the knife-edges in the 2^{nd}, 3^{rd} 4^{th} etc. holes on either side of the center of gravity.
6. See that the knife edges are always placed symmetrically with respect to C.G.
7. The knife-edges should be horizontal and the bar pendulum parallel to the wall.
8. Amplitude should be small.
9. The two knife-edges should always lie symmetrically with respect to the C.G.
10. The distance should be measure from the knife-edges.
11. The graph drawn should be a free hand curve.

Sources of error:

1. Slight error is introduced due to (i) resistance of air, (ii) curvature of knife-edges. (iii) yielding of support and (iv) finite amplitude.
2. The stop watch may not be very accurate.
3. The time period should be noted after the pendulum has made a few vibration and the vibrations have become regular.
4. The two knife-edges should always lie symmetrically with respect to the c.g.
5. The distance should be measured from the knife –edges.
6. The graph drawn should be a free-hand curve.

Practical 8

To determine the value of acceleration due to gravity with the help of a Keter's pendulum.

Aim

To determine *g*, the acceleration of gravity at a particular location.

Apparatus

Kater's pendulum, stopwatch, meter scale and knife edges.

Theory

Kater's pendulum, shown in Fig. 1, is a physical pendulum composed of a metal rod 1.20 m in length, upon which are mounted a sliding metal weight W_1, a sliding wooden weight W_2, a small sliding metal cylinder w, and two sliding knife edges K_1 and K_2 that face each other. Each of the sliding objects can be clamped in place on the rod. The pendulum can suspended and set swinging by resting either knife edge on a flat, level surface. The wooden weight W_2 is the same size and shape as the metal weight W_1. Its function is to provide as near equal air resistance to swinging as possible in either suspension, which happens if W_1 and W_2, and separately K_1 and K_2, are constrained to be equidistant from the ends of the metal rod. The centre of mass G can be located by balancing the pendulum on an external knife edge. Due to the difference in mass between the metal and wooden weights W_1 and W_2, G is not at the centre of the rod, and the distances h_1 and h_2 from G to the suspension points O_1 and O_2 at the knife edges K_1 and K_2 are not equal. Fine adjustments in the position of G, and thus in h_1 and h_2, can be made by moving the small metal cylinder w.

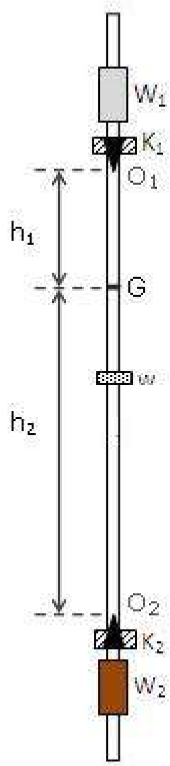


Figure 1

In Fig. 1, we consider the force of gravity to be acting at G. If h_i is the distance to G from the suspension point O_i at the knife edge K_i, the equation of motion of the pendulum is

$$I_i\ddot{\theta} = -Mgh_i \sin\theta$$

where I_i is the moment of inertia of the pendulum about the suspension point O_i, and i can be 1 or 2. Comparing to the equation of motion for a simple pendulum

$$Ml_i^2\ddot{\theta} = -Mgl_i \sin\theta$$

we see that the two equations of motion are the same if we take

$$Mgh_i / I_i = g / l_i \tag{1}$$

It is convenient to define the radius of gyration of a compound pendulum such that if all its mass M were at a distance from O_i, the moment of inertia about O_i would be I_i , which we do by writing

$$I_i = Mk_i^2$$

Inserting this definition into equation (1) shows that

$$k_i^2 = h_i l_i \tag{2}$$

If I_G is the moment of inertia of the pendulum about its centre of mass G, we can also define the radius of gyration about the centre of mass by
writing

$$I_G = Mk_G^2$$

The parallel axis theorem gives us

$$k_i^2 = h_i^2 + k_G^2$$

so that, using (2), we have

$$l_i = \frac{h_i^2 + k_G^2}{h_i}$$

The period of the pendulum from either suspension point is then

$$T_i = 2\pi\sqrt{\frac{l_i}{g}} = 2\pi\sqrt{\frac{h_i^2 + k_G^2}{gh_i}} \tag{3}$$

Squaring (3), one can show that

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

and in turn,

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

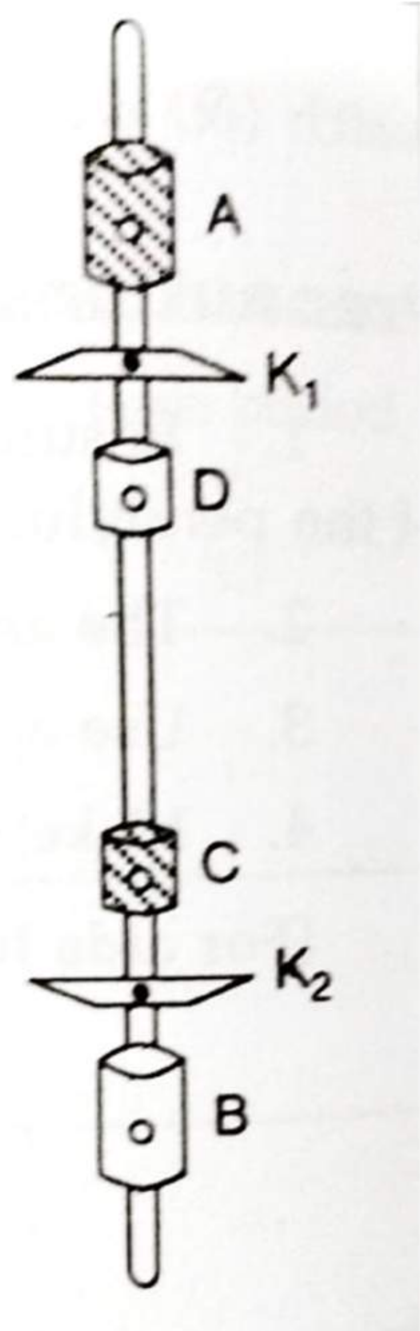
which allows us to calculate g,

$$g = 8\pi^2 \left[\frac{T_1^2 + T_2^2}{h_1 + h_2} + \frac{T_1^2 - T_2^2}{h_1 - h_2} \right]^{-1} \quad (4)$$

Apparatus and Accessories:

(i) A Kater's pendulum, (il) a stop watch, (ii) a telescope, and (iv) a meter scale. We give below a description of Kater's pendulum.

Kater's pendulum : It conaists of a metal rod of about one metre long. The rod is provided with two knife edges K_1 and K_2 which are turned inwards to face each other. Two equal cylinders A and B, A made of box wood and B made of a metal, are placed beyond the knife edges. Between the knife edges two equal cylinders C and D, smaller in size, are also mounted. The cylinders C is made of box wood whereas the cylinder D is made of a metal. The cylinders C and D are capable of moving along the rod and their positions on the rod determine the position of the centre of gravity of the system. The knife edges K_1 and K_2, are generally movable and can be fixed at any desired positions. The pendulum is allowed to oscillate about any of the knife edges by placing the corresponding knife edge on a. metallic plate which, in turn, is rigidly fixed on a permanent support.



Procedure :

1. Place one of the knife edges (say, K_1) of the pendulum on a rigid support so that the metallic cylinder B is in the downward direction. Draw a vertical sharp mark along the length of the pendulum and focus the sharp mark through a low power telescope by keeping it at a distance in front of the pendulum. Allow the oscillations through the telescope. pendulum to oscillate through a very small amplitude and observe the oscillations through the telescope.

2. Measure the time taken for a small number of oscillations (say, 5) by means of a precision stop watch. Now, place the pendulum on the second knife-edge, i.e., K, and after allowing it to oscillate measure the time taken for the same number of oscillations, i.e., 5.

The times in the two cases may be widely different.

3. Shift the position of the cylinder D in one direction and measure again the timesfor the same number of oscillations as before when the pendulum oscillates first aboutthe knife-edge K, and then about the knife-edge K,. If the shift of the cylinder D increases the difference in the timesof oscillations aboutthe two knife-edges then shift the position of the cylinder D in the opposite direction. Otherwise, shift the cylinder D in the same direction by a small amount and repeat operation 2.

4. The shifting of the cylinder D and the repeatation of operation 2 are to be continued till the two times are nearly equal.

5. Repeat the process now with more number of oscillations (say, 10, 15, 20 etc.) until the time for 50 oscillations about the two knife-edges are very nearly equal. Note these two very nearly eqa times. While observing times for more than 20 oscillations, the equality of the two times is to e approached by finer adjustments attached with the cylinder C and shifting it precisely.

6. Measure the time for 50 oscillations about each knife edge three times and then calculate tnte mean time for 50 oscillations about each of the knife edges. From these, determine the time perioas 1 and T about the knife edges.

7. Now placethe pendulum horizontally on a sharp wedge which is mounted on a horiz01 table to locate the C.G. of the pendulum. Mark the positionof the C.G. and measure the distances the knife-edges, i.e., and I from the C.G. by a metre scale. ntal 8. Substituting the values of l_1, l_2 T_1 and T_2 in Eq. (ii) calculate g.

Precautions and Discussions:

1. The amplitude of oscillations must be kept very small so that the motion is truly simple harmonic.

2. The knife-edges must be horizontal and parallel to each other so that the oscillations are confined in a vertical plane and the pendulum remains in a stable position.

3. To save time, preliminary observations of the times of oscillations should be made witn smaller number of oscillations. As the difference between the periods decreases, the number o oscillations observed should be increased. Correction for the finite arc of swing of the pendulum may be included by measuring the na half

4. angles of the swing in radians (a, a) at the start and at the end respectively, and using the formu To-T1- where To is the correct period and T is the observed period. 16

5. For greater accuracy, measure the time period by the methods of coincidence.

About apparatus:

Let us know about the apparatus. The given figure 1 shows a mass spring system. A spiral spring whose restoring force per unit extension is to be determined is suspended from a rigid support as shown in the figure. At the lower end of the spring, a small scale-pan is fastened. A small horizontal pointer is also attached to the scale pan. A scale is also set in front of the spring in such a way that when spring vibrates up and down, the pointer freely moves over the scale.

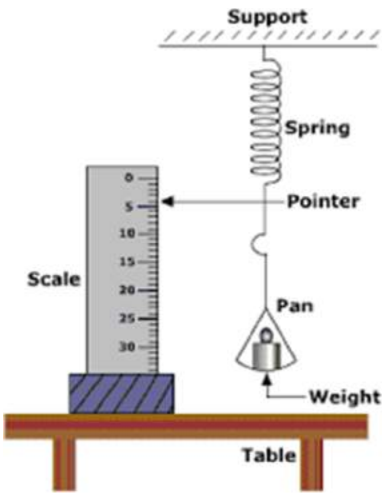


Figure 1: Mass spring system

Procedure:

Let us perform the experiment to determine the restoring force per unit extension of a spiral spring and mass of the spring. We shall perform the two methods in the following way-

StatisticalMethod:

(i) Without no load in the scale-pan, note down the zero reading of the pointer on thescale.

(ii) Now place gently 10 gm. load (weight) in the pan. Stretch the spring slightly and the pointer moves down on the scale. In this steady position, note down the reading of the pointer. The difference of the two readings is the extension of the spring for the load in thepan.

(iii) Let us increase the load in the pan in equal steps until maximum permissible load is reached and note down the corresponding pointer readings on thescale.

(iv) The experiment is repeated with decreasing weights(loads).

Observations:

S.No.	Load(weight) in the pan (gm.)	Reading of pointer on the scale (meter)			Extension for 30 gm. (meter)	Mean extension (meter)
		Load increasing	Load decreasing	Mean		
1	10				(3)-(1)=	
2	20					
3	30				(4)-(2)=......	
4	40					
5	50				(5)-(3)=.......	

Table 1: The measurement of extension of the spring

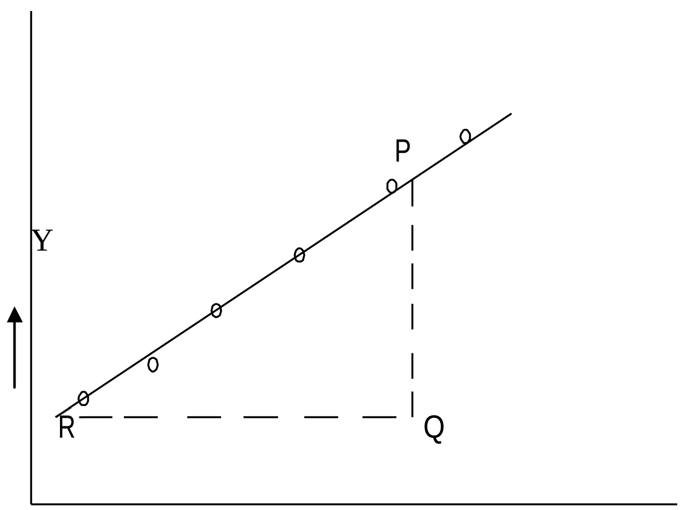
Calculations:

Statistical Experiment:

The restoring force per unit extension of the spring is given by-

$$K = \frac{Mg}{l} = \text{........................ Newton/meter}$$

Let us draw a graph between the load and scale readings by taking the load as abscissa and the corresponding scale readings as ordinates. You will see that the graph comes out to be a straight line as shown in figure2.



Scale reading

Load

Figure 2

From the graph, we measure PQ and QR. Now the restoring force per unit extension is givenby-

$$K = \frac{RQ}{PQ} \times g = \text{............................ Newton/meter}$$

Result:

The restoring force per unit extension of thespring= .... Newton/meter

Precautions and Sources of Errors:

StatisticalMethod:

(1) The axis of the spring must bevertical.

(2) The spring should not be stretched beyond elasticlimits.

(3) The pointer should move freely on thescale.

(4) Load (weight) should be placed gently in the scalepan.

(5) The scale should be set vertical. It should be arranged in such a way that it should give almost the maximum extensionallowable.

(6) Readings should be taken very carefully from the frontside.

Determination of modulus of rigidity of material of a given spring

When a spring is loaded with certain mass it oscillates in a vertical plane.Suppose, radius of spring and wire are R and r respectively and mass M is hung from spring .Mg exerts a coupletending the wire to twist.N is the number of turns of the spring.Then, torque is given by

$$\tau = \frac{\pi r^4 \eta \theta}{2Nl}$$

Displacement at the end of the spring is x = R□

Therefore,

$$x = R\frac{4\pi RN\tau}{\eta r^4}$$

If f is restoring force due to wire then τ = f R. Hence equation of motion is

$$M\frac{d^2x}{dt^2} = -\frac{\eta r^4}{4Nr^3}x$$

Comparing with standard equation of SHM we get

$$T = \frac{2\pi}{r^2}\sqrt{\frac{4MNR^3}{\eta}}$$

$$\eta = 4\pi^2 \frac{M}{T^2}\frac{4NR^3}{r^4}$$

From the equation it is evident that if we plot M vs T 2 graph,it turns out to be a straight line i.e. ratio of M and T^2 is almost constant.

Apparatus:

1. Spring
2. Slide calipers
3. Screw gauge
4. Different masses
5. Stopwatch

Experiment:

Firstly, measure the diameter of the spring several times using slide calipers and take the mean value. Then attach it to a stand.Diameter of the wire is then measured by screw gauge. Then twice the diameter of wire is substracted from outer diameter of spring to get inner diameter and average of that two is taken as diameter of spring.Now a certain mass is hung from spring .Mean position is marked. Lift it slightly and let it make a vertical oscillation. Measure the time for 20 oscillations and record the corresponding data.The same process is repeated for 3 times. Then plot the graph (T^2vsM),calculation of k and and error analysis is done based on the obtained data.

Calculation:

Radius of the spring= 6.3×10^{-3} m.

Radius of wire = 6.8×10^{-4} m.

No of turns = 216

Table 1: Mass(M)- m1 kg.

Time for 20 oscillations (sec)	Mean time (sec)	Time period(T) (sec)	T^2 (sec^2)	$\frac{M}{T^2}$ (kg/sec^2)

Table 2 : Mass(M)- m2 kg.

Time for 20 oscillations (sec)	Mean time (sec)	Time period(T) (sec)	T^2 (sec^2)	$\frac{M}{T^2}$ (kg/sec^2)

Table 3 : Mass(M)- m3 kg.

Time for 20 oscillations (sec)	Mean time (sec)	Time period(T) (sec)	T^2 (sec^2)	$\frac{M}{T^2}$ (kg/sec^2)

Analysis and result:
From the data (ratio of mass and time^2) find the value of M/T^2 and take the average.So, modulus of rigidity of material of spring can be calculated by using the expression given above.

<u>Measurement of radius of wire/spring and weight</u>
1. Some instrumental error may arise if main scale zero doesn't coincide with circular scale zero .That has been taken care of by adding or substracting the error.
2. If the wire is not uniform then readings have totake at different points and mean of them is the best reading
3. While hanging the weights that should lie along the axis of spring .This doesn't occur during experiment.

<u>Measurement of time period</u>
1. Firstly measurement of time period is not accurate due to personal observation error.
2. Oscillations should occur in vertical plane but it oscillates little in a horizontal plane also.

Error Analysis:
Error in η can be defined as

$$\frac{d\eta}{\eta} = \frac{dM}{M} + 2\frac{dT}{T} + 3\frac{dR}{R} + 4\frac{dr}{r}$$

VIVA-VOCE:

Question 1. What is a spiral spring?

Answer. A long metallic wire in the shape of a regular helix of given radius is called a spiral spring.

Question 2. What is effective mass of a spring?

Answer. In calculations, we have a quantity (M + m/3) where M is the mass suspended and m, the mass of the spring. The factor m/3 is called the effective mass of the spring.

Question 3. What do you mean by restoring force per unit extension of a spring?

Answer. The restoring force per unit extension of a spring is defined as the elastic reaction produced in the spring per unit extension which tends to restore it back to its initial conditions.

Question 4. What is the unit of restoring force per unit extension of a spring?

Answer. The unit of restoring force per unit extension of a spring is Newton/meter.

Question 5. How does the restoring force change with length and radius of spiral spring?

Answer. This is inversely proportional to the total length of wire and inversely proportional to the square of radius ofcoil.

Question 6. How the knowledge of restoring force per unit extension is of practical value?

Answer. By the knowledge of restoring force per unit extension, we can calculate the correct mass and size of the spring when it is subjected to a particular force.

OBJECT: To determine the modulus of rigidity of material of given wire by dynamical method using Maxwell needle.

Apparatus used: Maxwell needle, stop watch, screw gauge, meter scale.

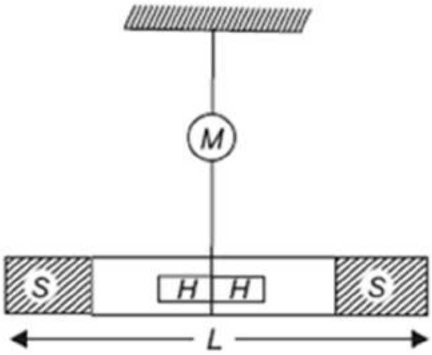
Formula: The following formula is used for the determination of modulus of rigidity (□).

$$\eta = \frac{2\pi l \left(m_s - m_H\right) L^2}{r^4 \left(T_1^2 - T_2^2\right)}$$

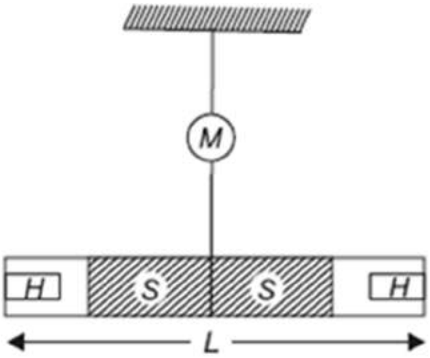
Where l: length of wire, L: length of Maxwell needle, r: radius of wire, m_S: mean mass of solid cylinders, m_H; mean mass of hollow cylinders,

T_1: time period of oscillation when solid cylinders are outside,

T_2: time period of oscillation when solid cylinders are inside



Arrangement 1: Solid cylinders at outside



Arrangement 2: *Solid cylinders at inside*

Procedure:

(1) Measure the length of wire using meter scale through which the Maxwell needle is hanged. This will give you value of l.

(2) Measure the length of Maxwell needle using meter scale. This will give you value of L.

(3) Measure the mass of both solid cylinders using balance and do its half, this will provide the value of m_S.

(4) Measure the mass of the both hollow cylinders and do its half, this will provide the value of m_H.

(5) Find out the least count of screw gauge and zero error in it.

(6) Using screw gauge, measure the diameter of wire. Its half will provide the value of radius of wire.

(7) Find out the least count of stop watch.

(8) Now put the hollow cylinders at inside and solid cylinders at outside of the Maxwell needle. Oscillate it in horizontal plane about vertical axis. Note the time for 10, 20 and 30 oscillations. Divide the time with number of oscillations and find its mean. This will provide the value of T_1.

(9) Now place solid cylinders at inside and hollow cylinders at outside of the Maxwell needle. Oscillate it in horizontal plane about vertical axis. Note the time for 10, 20 and 30 oscillations. Divide the time with number of oscillations and find its mean. This will provide the value of T_2.

(10) Put all the value in given formula and solve it with logmethod.

Observations:

(1) Length of wire (l)=… cm

(2) Length of Maxwell needle (L)=… cm

(3) Mean mass of solid cylinders (mS)= gm

(4) Mean mass of hollow cylinders (mH)=……gm

(5) Least count of screw gauge = $\frac{pitch}{number\ of\ divisions\ on\ circular\ scale} = \quad cm$

(6) Zero error in screw gauge = cm

(7) Table for diameter of wire

Sr. no.	M.S. (cm)	C.S. (div)	un-corrected diameter (d= MS + CS x LC) (cm)	Mean un-corrected diameter (d: cm)	corrected diameter (D=d□ zero error) (cm)
1.					
2.					
3.					
4.					
5.					
6.					

(8) Radius of wire (R) = D/2 in cm

(9) Least count of stop watch= sec

(10) Table for T_1 and T_2

Sr. no.	Number of oscillations (N)	For outside solid cylinders			For inside solid cylinders		
		t_1 (sec)	$T_1=t_1/N$ (sec)	MeanT_1 (sec)	t_2 (sec)	$T_2=t_2/N$ (sec)	MeanT_2 (sec)
1.	10						
2.	20						
3.	30						

Calculation: Put the values in eqn. (1) and solve with log method.

Precautions:

1. There should be no kink in the wire.
2. The Maxwell needle should remain horizontal and should not vibrate up and down.
3. The amplitude of vibration/oscillation should be small so that wire is not twisted beyond the elastic limit.
4. To avoid the back less error, the circular scale of screw gauge should be moved in one direction.