EXPERIMENT 1

AIM

Use of Vernier Callipers to

(i) measure diameter of a small spherical/cylindrical body,

(ii) measure the dimensions of a given regular body of known mass and hence to determine its density; and

(iii) measure the internal diameter and depth of a given cylindrical object like beaker/glass/calorimeter and hence to calculate its volume.

APPARATUS AND MATERIAL REQUIRED

Vernier Callipers, Spherical body, such as a pendulum bob or a glass marble, rectangular block of known mass and cylindrical object like a beaker/glass/calorimeter

DESCRIPTION OF THE MEASURING DEVICE

1. A Vernier Calliper has two scales–one main scale and a Vernier scale, which slides along the main scale. The main scale and Vernier scale are divided into small divisions though of different magnitudes.

The main scale is graduated in cm and mm. It has two fixed jaws, A and C, projected at right angles to the scale. The sliding Vernier scale has jaws (B, D) projecting at right angles to it and also the main scale and a metallic strip (N). The zero of main scale and Vernier scale coincide when the jaws are made to touch each other. The jaws and metallic strip are designed to measure the distance/ diameter of objects. Knob P is used to slide the vernier scale on the main scale. Screw S is used to fix the vernier scale at a desired position.

2. The least count of a common scale is 1mm. It is difficult to further subdivide it to improve the least count of the scale. A vernier scale enables this to be achieved.
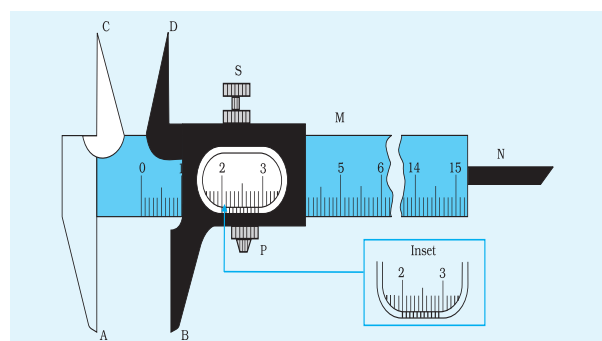

Fig. E 1.1 *Vernier Calliper*

PRINCIPLE

The difference in the magnitude of one main scale division (M.S.D.) and one vernier scale division (V.S.D.) is called the least count of the instrument, as it is the smallest distance that can be measured using the instrument.

$$n \text{ V.S.D.} = (n-1) \text{ M.S.D.}$$

Formulas Used

(a) Least count of vernier callipers

$$= \frac{the\ magnitude\ of\ the\ smallest\ division\ on\ the\ main\ scale}{the\ total\ number\ of\ small\ divisions\ on\ the\ vernier\ scale}$$

(b) Density of a rectangular body $= \dfrac{mass}{volume} = \dfrac{m}{V} = \dfrac{m}{l.b.h}$ where m is its mass, l its length, b its breadth and h the height.

(c) The volume of a cylindrical (hollow) object $V = \pi r^2 h' = \dfrac{\pi D'^2}{4} . h'$

where h' is its internal depth, D' is its internal diameter and r is its internal radius.

PROCEDURE

(a) Measuring the diameter of a small spherical or cylindrical body.

1. Keep the jaws of Vernier Callipers closed. Observe the zero mark of the main scale. It must perfectly coincide with that of the vernier scale. If this is not so, account for the zero error for all observations to be made while using the instrument as explained on pages 26-27.

2. Look for the division on the vernier scale that coincides with a division of main scale. Use a magnifying glass, if available and note the number of division on the Vernier scale that coincides with the one on the main scale. Position your eye directly over the division mark so as to avoid any parallax error.

3. Gently loosen the screw to release the movable jaw. Slide it enough to hold the sphere/cylindrical body gently (without any undue pressure) in between the lower jaws AB. The jaws should be perfectly perpendicular to the diameter of the body. Now, gently tighten the screw so as to clamp the instrument in this position to the body.

4. Carefully note the position of the zero mark of the vernier scale against the main scale. Usually, it will not perfectly coincide with

any of the small divisions on the main scale. Record the main scale division just to the left of the zero mark of the vernier scale.

5. Start looking for exact coincidence of a vernier scale division with that of a main scale division in the vernier window from left end (zero) to the right. Note its number (say) N, carefully.

6. Multiply 'N' by least count of the instrument and add the product to the main scale reading noted in step 4. Ensure that the product is converted into proper units (usually cm) for addition to be valid.

7. Repeat steps 3-6 to obtain the diameter of the body at different positions on its curved surface. Take three sets of reading in each case.

8. Record the observations in the tabular form [Table E 1.1(a)] with proper units. Apply zero correction, if need be.

9. Find the arithmetic mean of the corrected readings of the diameter of the body. Express the results in suitable units with appropriate number of significant figures.

(b) Measuring the dimensions of a regular rectangular body to determine its density.

1. Measure the length of the rectangular block (if beyond the limits of the extended jaws of Vernier Callipers) using a suitable ruler. Otherwise repeat steps 3-6 described in (a) after holding the block lengthwise between the jaws of the Vernier Callipers.

2. Repeat steps 3-6 stated in (a) to determine the other dimensions (breadth b and height h) by holding the rectangular block in proper positions.

3. Record the observations for length, breadth and height of the rectangular block in tabular form [Table E 1.1 (b)] with proper units and significant figures. Apply zero corrections wherever necessary.

4. Find out the arithmetic mean of readings taken for length, breadth and height separately.

[c] Measuring the internal diameter and depth of the given beaker (or similar cylindrical object) to find its internal volume.

1. Adjust the upper jaws CD of the Vernier Callipers so as to touch the wall of the beaker from inside without exerting undue pressure on it. Tighten the screw gently to keep the Vernier Callipers in this position.

2. Repeat the steps 3-6 as in (a) to obtain the value of internal diameter of the beaker/calorimeter. Do this for two different (angular) positions of the beaker.

3. Keep the edge of the main scale of Vernier Callipers, to determine the depth of the beaker, on its peripheral edge. This should be done in such a way that the tip of the strip is able to go freely inside the beaker along its depth.

4. Keep sliding the moving jaw of the Vernier Callipers until the strip just touches the bottom of the beaker. Take care that it does so while being perfectly perpendicular to the bottom surface. Now tighten the screw of the Vernier Callipers.

5. Repeat steps 4 to 6 of part (a) of the experiment to obtain depth of the given beaker. Take the readings for depth at different positions of the breaker.

6. Record the observations in tabular form [Table E 1.1 (c)] with proper units and significant figures. Apply zero corrections, if required.

7. Find out the mean of the corrected readings of the internal diameter and depth of the given beaker. Express the result in suitable units and proper significant figures.

OBSERVATIONS

(i) Least count of Vernier Callipers (Vernier Constant)

1 main scale division (MSD) = 1 mm = 0.1 cm

Number of vernier scale divisions, N = 10

10 vernier scale divisions = 9 main scale divisions

1 vernier scale division = 0.9 main scale division

Vernier constant = 1 main scale division – 1 vernier scale division

$$= (1 - 0.9) \text{ main scale divisions}$$

$$= 0.1 \text{ main scale division}$$

Vernier constant (V_c)   = 0.1 mm = 0.01 cm

Alternatively,

$$\text{Vernier constant} = \frac{1\text{MSD}}{N} = \frac{1 \text{ mm}}{10}$$

Vernier constant (V_c) = 0.1 mm = 0.01 cm

(ii) Zero error and its correction

When the jaws A and B touch each other, the zero of the Vernier should coincide with the zero of the main scale. If it is not so, the instrument is said to possess zero error (e). Zero error may be
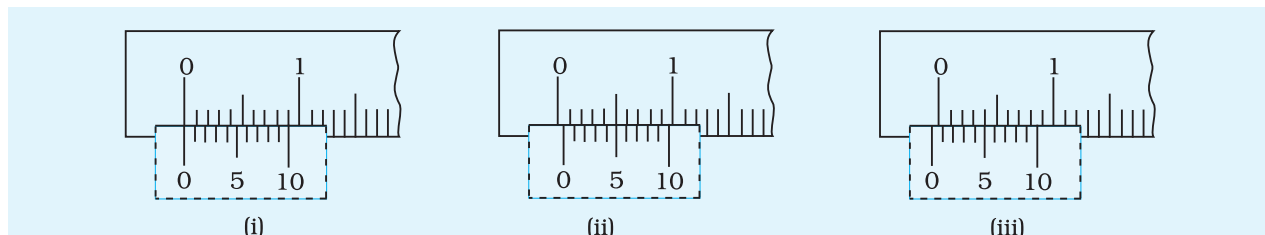
Fig. E 1.2: Zero error (i) no zero error (ii) positive zero error (iii) negative zero error

positive or negative, depending upon whether the zero of vernier scale lies to the right or to the left of the zero of the main scale. This is shown by the Fig. E1.2 (ii) and (iii). In this situation, a correction is required to the observed readings.

(iii) Positive zero error

Fig E 1.2 (ii) shows an example of positive zero error. From the figure, one can see that when both jaws are touching each other, zero of the vernier scale is shifted to the right of zero of the main scale (This might have happened due to manufacturing defect or due to rough handling). This situation makes it obvious that while taking measurements, the reading taken will be more than the actual reading. Hence, a correction needs to be applied which is proportional to the right shift of zero of vernier scale.

In ideal case, zero of vernier scale should coincide with zero of main scale. But in Fig. E 1.2 (ii), 5th vernier division is coinciding with a main scale reading.

∴Zero Error = + 5 × Least Count = + 0.05 cm

Hence, the zero error is positive in this case. For any measurements done, the zero error (+ 0.05 cm in this example) should be 'subtracted' from the observed reading.

∴True Reading = Observed reading – (+ Zero error)

(iv) Negative zero error

Fig. E 1.2 (iii) shows an example of negative zero error. From this figure, one can see that when both the jaws are touching each other, zero of the vernier scale is shifted to the left of zero of the main scale. This situation makes it obvious that while taking measurements, the reading taken will be less than the actual reading. Hence, a correction needs to be applied which is proportional to the left shift of zero of vernier scale.

In Fig. E 1.2 (iii), 5th vernier scale division is coinciding with a main scale reading.

∴Zero Error = – 5 × Least Count

= – 0.05 cm

Note that the zero error in this case is considered to be negative. For any measurements done, the negative zero error, (–0.05 cm in this example) is also substracted 'from the observed reading', though it gets added to the observed value.

∴True Reading = Observed Reading – (– Zero error)

Table E 1.1 (a): Measuring the diameter of a small spherical/cylindrical body

S. No.	Main Scale reading, M (cm/mm)	Number of coinciding vernier division, N	Vernier scale reading, $V = N \times V_c$ (cm/mm)	Measured diameter, $M + V$ (cm/mm)
1				
2				
3				
4				

Zero error, e = ± … cm

Mean observed diameter = … cm

Corrected diameter = Mean observed diameter – Zero Error

Table E 1.1 (b) : Measuring dimensions of a given regular body (rectangular block)

Dimension	S. No.	Main Scale reading, M (cm/mm)	Number of coinciding vernier division, N	Vernier scale reading, $V = N \times V_c$ (cm/mm)	Measured dimension $M + V$ (cm/mm)
Length (l)	1 2 3				
Breadth (b)	1 2 3				
Height (h)	1 2 3				

Zero error = ± … mm/cm

Mean observed length = … cm, Mean observed breadth = … cm

Mean observed height = … cm

Corrected length = … cm;   Corrected breath = … cm;

Corrected height = …cm

Table E 1.1 (c) : Measuring internal diameter and depth of a given beaker/ calorimeter/ cylindrical glass

Dimension	S. No.	Main Scale reading, M (cm/mm)	Number of coinciding vernier division, N	Vernier scale reading, $V = N \times V_c$ (cm/mm)	Measured diameter/depth, $M + V$ (cm/mm)
Internal diameter (D')	1 2 3				
Depth (h')	1 2 3				

Mean diameter = ... cm

Mean depth= ... cm

Corrected diameter = ... cm

Corrected depth = ... cm

CALCULATION

(a) **Measurement of diameter of the sphere/ cylindrical body**

Mean measured diameter, $D_o = \dfrac{D_1 + D_2 + ... + D_6}{6}$ cm

D_o = ... cm = ... $\times 10^{-2}$ m

Corrected diameter of the given body, $D = D_o - (\pm e) = ... \times 10^{-2}$ m

(b) **Measurement of length, breadth and height of the rectangular block**

Mean measured length, $l_o = \dfrac{l_1 + l_2 + l_3}{3}$ cm

l_o = ... cm = ... $\times 10^{-2}$ m

Corrected length of the block, $l = l_o - (\pm e) = ...$ cm

Mean observed breadth, $b_o = \dfrac{b_1 + b_2 + b_3}{3}$

Mean measured breadth of the block, b_0 = ... cm = ... $\times 10^{-2}$ m

Corrected breadth of the block,

$b = b_O - (\pm e)$ cm = ... $\times 10^{-2}$ m

Mean measured height of block $h_o = \dfrac{h_1 + h_2 + h_3}{3}$

Corrected height of block $h = h_o - (\pm e) = \dots$ cm

Volume of the rectangular block,

$$V = lbh = \dots \text{ cm}^3 = \dots \times 10^{-6} \text{ m}^3$$

Density ρ of the block,

$$\rho = \dfrac{m}{V} = \dots \text{ kg m}^{-3}$$

(c) Measurement of internal diameter of the beaker/glass

Mean measured internal diameter, $D_o = \dfrac{D_1 + D_2 + D_3}{3}$

$$D_o = \dots \text{ cm} = \dots \times 10^{-2} \text{ m}$$

Corrected internal diameter,

$$D = D_o - (\pm e) = \dots \text{ cm} = \dots \times 10^{-2} \text{ m}$$

Mean measured depth of the beaker, $h_o = \dfrac{h_1 + h_2 + h_3}{3}$

$$= \dots \text{ cm} = \dots \times 10^{-2} \text{ m}$$

Corrected measured depth of the beaker

$$h = h_o - (\pm e) \dots \text{ cm} = \dots \times 10^{-2} \text{ m}$$

Internal volume of the beaker

$$V = \dfrac{\pi D^2 h}{4} = \dots \times 10^{-6} \text{ m}^3$$

RESULT

(a) Diameter of the spherical/ cylindrical body,

$$D = \dots \times 10^{-2} \text{m}$$

(b) Density of the given rectangular block,

$$\rho = \dots \text{ kg m}^{-3}$$

(c) Internal volume of the given beaker

$$V = \dots \text{ m}^3$$

PRECAUTIONS

1. If the vernier scale is not sliding smoothly over the main scale, apply machine oil/grease.

2. Screw the vernier tightly without exerting undue pressure to avoid any damage to the threads of the screw.

3. Keep the eye directly over the division mark to avoid any error due to parallax.

4. Note down each observation with correct significant figures and units.

SOURCES OF ERROR

Any measurement made using Vernier Callipers is likely to be incorrect if-

(i) the zero error in the instrument placed is not accounted for; and

(ii) the Vernier Callipers is not in a proper position with respect to the body, avoiding gaps or undue pressure or both.

DISCUSSION

1. A Vernier Callipers is necessary and suitable only for certain types of measurement where the required dimension of the object is freely accessible. It cannot be used in many situations. e.g. suppose a hole of diameter 'd' is to be drilled into a metal block. If the diameter d is small - say 2 mm, neither the diameter nor the depth of the hole can be measured with a Vernier Callipers.

2. It is also important to realise that use of Vernier Callipers for measuring length/width/thickness etc. is essential only when the desired degree of precision in the result (say determination of the volume of a wire) is high. It is meaningless to use it where precision in measurement is not going to affect the result much. For example, in a simple pendulum experiment, to measure the diameter of the bob, since L >> d.

SELF ASSESSMENT

1. One can undertake an exercise to know the level of skills developed in making measurements using Vernier Callipers. Objects, such as *bangles/kangan*, marbles whose dimensions can be measured indirectly using a thread can be used to judge the skill acquired through comparison of results obtained using both the methods.

2. How does a vernier decrease the least count of a scale.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Determine the density of glass/metal of a (given) cylindrical vessel.

2. Measure thickness of doors and boards.

3. Measure outer diameter of a water pipe.

ADDITIONAL EXERCISE

1. In the vernier scale normally used in a Fortin's barometer, 20 VSD coincide with 19 MSD (each division of length 1 mm). Find the least count of the vernier.

2. In vernier scale (angular) normally provided in spectrometers/sextant, 60 VSD coincide with 59 MSD (each division of angle 1°). Find the least count of the vernier.

3. How would the precision of the measurement by Vernier Callipers be affected by increasing the number of divisions on its vernier scale?

4. How can you find the value of π using a given cylinder and a pair of Vernier Callipers?

   [**Hint** : Using the Vernier Callipers, - Measure the diameter D and find the circumference of the cylinder using a thread. Ratio of circumference to the diameter (D) gives π.]

5. How can you find the thickness of the sheet used for making of a steel tumbler using Vernier Callipers?

   [**Hint:** Measure the internal diameter (D_i) and external diameter (D_o) of the tumbler. Then, thickness of the sheet $D_t = (D_o - D_i)/2$.]

AIM

Use of screw gauge to

(a) measure diameter of a given wire,

(b) measure thickness of a given sheet; and

(c) determine volume of an irregular lamina.

APPARATUS AND MATERIAL REQUIRED

Wire, metallic sheet, irregular lamina, millimetre graph paper, pencil and screw gauge.

DESCRIPTION OF APPARATUS

With Vernier Callipers. you are usually able to measure length accurately up to 0.1 mm. More accurate measurement of length, up to 0.01 mm or 0.005 mm, may be made by using a screw gauge. As such a Screw Gauge is an instrument of higher precision than a Vernier Callipers. You might have observed an ordinary screw [Fig E2.1 (a)]. There are threads on a screw. The separation between any two consecutive threads is the same. The screw can be moved backward or forward in its nut by rotating it anti-clockwise or clockwise [Fig E2.1(b)].

Fig.E 2.1 *A screw (a) without nut (b) with nut*

The distance advanced by the screw when it makes its one complete rotation is the separation between two consecutive threads. This distance is called the Pitch of the screw. Fig. E 2.1(a) shows the pitch (*p*) of the screw. It is usually 1 mm or 0.5 mm. Fig. E 2.2 shows a screw gauge. It has a screw 'S' which advances forward or backward as one rotates the head C through rachet R. There is a linear
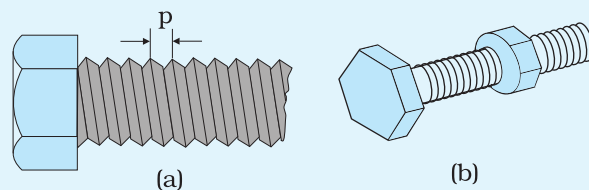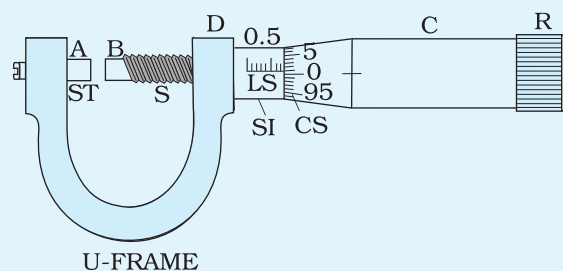

Fig.E 2.2: *View of a screw gauge*

scale 'LS' attached to limb D of the U frame. The smallest division on the linear scale is 1 mm (in one type of screw gauge). There is a circular scale CS on the head, which can be rotated. There are 100 divisions on the circular scale. When the end B of the screw touches the surface A of the stud ST, the zero marks on the main scale and the circular scale should coincide with each other.
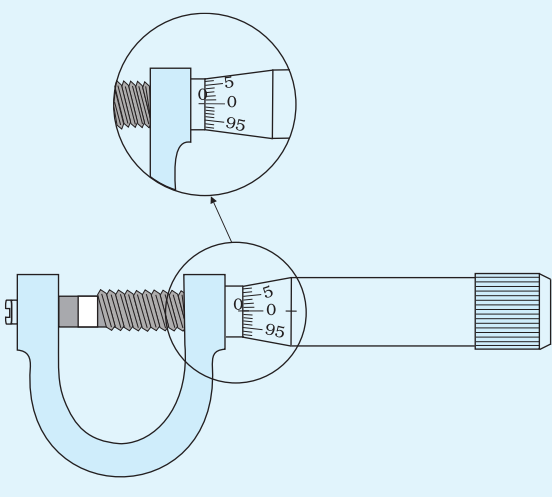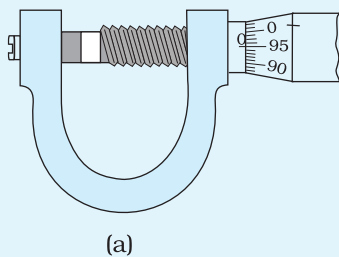

Fig.E 2.3: *A screw gauge with no zero error*

(a)

Fig.E 2.4 (a): *Showing a positive zero error*

Fig.E 2.5: *Measuring thickness with a screw guage*

ZERO ERROR

When the end of the screw and the surface of the stud are in contact with each other, the linear scale and the circular scale reading should be zero. In case this is not so, the screw gauge is said to have an error called zero error.
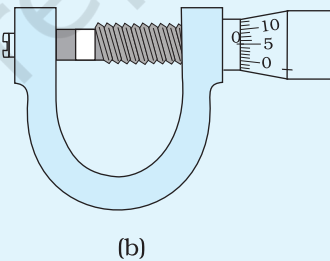
Fig. E 2.3 shows an enlarged view of a screw gauge with its faces A and B in contact. Here, the zero mark of the LS and the CS are coinciding with each other.

When the reading on the circular scale across the linear scale is more than zero (or positive), the instrument has **Positive zero error** as shown in Fig. E 2.4 (a). When the reading of the circular scale across the linear scale is less than zero (or negative), the instrument is said to have **negative zero error** as shown in Fig. E 2.4 (b).

(b)

Fig.E 2.4 (b): *Showing a negative zero error*

TAKING THE LINEAR SCALE READING

The mark on the linear scale which lies close to the left edge of the circular scale is the linear scale reading. For example, the linear scale reading as shown in Fig. E 2.5, is 0.5 cm.

TAKING CIRCULAR SCALE READING

The division of circular scale which coincides with the main scale line is the reading of circular scale. For example, in the Fig. E 2.5, the circular scale reading is 2.

TOTAL READING

Total reading

= linear scale reading + circular scale reading × least count

= 0.5 + 2 × 0.001

= 0.502 cm

PRINCIPLE

The linear distance moved by the screw is directly proportional to the rotation given to it. The linear distance moved by the screw when it is rotated by one division of the circular scale, is the least distance that can be measured accurately by the instrument. It is called the least count of the instrument.

$$\text{Least count} = \frac{\text{pitch}}{\text{No. of divisions on circular scale}}$$

For example for a screw gauge with a pitch of 1mm and 100 divisions on the circular scale. The least count is

1 mm/100 = 0.01 mm

This is the smallest length one can measure with this screw gauge.

In another type of screw gauge, pitch is 0.5 mm and there are 50 divisions on the circular scale. The least count of this screw gauge is 0.5 mm/50 = 0.01 mm. Note that here two rotations of the circular scale make the screw to advance through a distance of 1 mm. Some screw gauge have a least count of 0.001 mm (i.e. 10^{-6} m) and therefore are called micrometer screw.

(a) Measurement of Diameter of a Given Wire

PROCEDURE

1. Take the screw gauge and make sure that the rachet R on the head of the screw functions properly.

2. Rotate the screw through, say, ten complete rotations and observe the distance through which it has receded. This distance is the reading on the linear scale marked by the edge of the circular scale. Then, find the pitch of the screw, i.e., the distance moved by the screw in one complete rotation. If there are n divisions on the circular scale, then distance moved by the screw when it is rotated through one division on the circular scale is called the least count of the screw gauge, that is,

$$\text{Least count} = \frac{\text{pitch}}{n}$$

3. Insert the given wire between the screw and the stud of the screw gauge. Move the screw forward by rotating the rachet till the wire is gently gripped between the screw and the stud as shown in Fig. E 2.5. Stop rotating the rachet the moment you hear a click sound.

4. Take the readings on the linear scale and the circular scale.

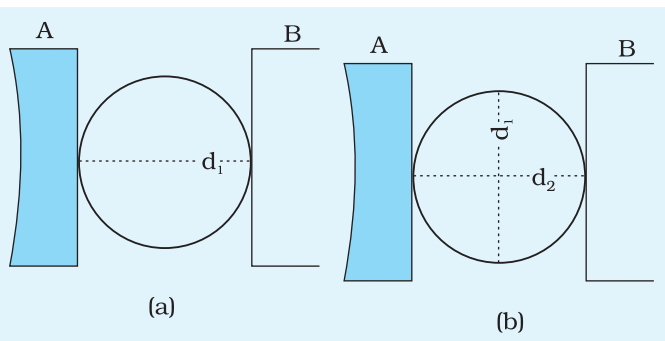5. From these two readings, obtain the diameter of the wire.

(a)

(b)

Fig.E 2.6 (a): *Two magnified views (a) and (b) of a wire showing its perpendicular diameters d_1 and d_2. d_2 is obtained after the rotating the wire in the clockwise direction through 90°.*

6. The wire may not have an exactly circular cross-section. Therefore. it is necessary to measure the diameter of the wire for two positions at right angles to each other. For this, first record the reading of diameter d_1 [Fig. E 2.6 (a)] and then rotate the wire through 90° at the same cross-sectional position. Record the reading for diameter d_2 in this position [Fig. E 2.6 (b)].

7. The wire may not be truly cylindrical. Therefore, it is necessary to measure the diameter at several different places and obtain the average value of diameter. For this, repeat the steps (3) to (6) for three more positions of the wire.

8. Take the mean of the different values of diameter so obtained.

9. Substract zero error, if any, with proper sign to get the corrected value for the diameter of the wire.

OBSERVATIONS AND CALCULATION

The length of the smallest division on the linear scale = ... mm

Distance moved by the screw when it is rotated
through x complete rotations, y　　　　　　　　　　 = ... mm

Pitch of the screw = $\dfrac{y}{x}$ = ... mm

Number of divisions on the circular scale n = ...

Least Count (L.C.) of screw guage

$$= \frac{pitch}{No.\ of\ divisions\ on\ the\ circular\ scale} = ...\ mm$$

Zero error with sign (No. of div. × L. C.) = ... mm

Table E 2.1: Measurement of the diameter of the wire

S. No.	Reading along one direction (d_1)			Reading along perpendicular direction (d_2)			Measured diameter $d = \dfrac{d_1 + d_2}{2}$
	Linear scale reading M (mm)	Circular scale reading (n)	Diameter $d_1 = M + n \times$ L.C. (mm)	Linear scale reading M (mm)	Circular scale reading (n)	Diameter $d_2 = M + n \times$ L.C. (mm)	(mm)
1							
2							
3							
4							

Mean diameter = ... mm

Mean corrected value of diameter

= measured diameter – (zero error with sign) = ... mm

RESULT

The diameter of the given wire as measured by screw gauge is ... mm

PRECAUTIONS

1. Rachet arrangement in screw gauge must be utilised to avoid undue pressure on the wire as this may change the diameter.

2. Move the screw in one direction else the screw may develop "play".

3. Screw should move freely without friction.

4. Reading should be taken atleast at four different points along the length of the wire.

5. View all the reading keeping the eye perpendicular to the scale to avoid error due to parallax.

SOURCES OF ERROR

1. The wire may not be of uniform cross-section.

2. Error due to backlash though can be minimised but cannot be completely eliminated.

BACKLASH ERROR

In a good instrument (either screw gauge or a spherometer) the thread on the screw and that on the nut (in which the screw moves), should tightly fit with each other. However, with repeated use, the threads of both the screw and the nut may get worn out. As a result a gap develops between these two threads, which is called "play". The play in the threads may introduce an error in measurement in devices like screw gauge. This error is called backlash error. In instruments having backlash error, the screw slips a small linear distance without rotation. To prevent this, it is advised that the screw should be moved in only one direction while taking measurements.

3. The divisions on the linear scale and the circular scale may not be evenly spaced.

DISCUSSION

1. Try to assess if the value of diameter obtained by you is realistic or not. There may be an error by a factor of 10 or 100 . You can obtain a very rough estimation of the diameter of the wire by measuring its thickness with an ordinary metre scale.

2. Why does a screw gauge develop backlash error with use?

SELF ASSESSMENT

1. Is the screw gauge with smaller least count always better? If you are given two screw gauges, one with 100 divisions on circular scale and another with 200 divisions, which one would you prefer and why?

2. Is there a situation in which the linear distance moved by the screw is not proportional to the rotation given to it?

3. Is it possible that the zero of circular scale lies above the zero line of main scale, yet the error is positive zero error?

4. For measurement of small lengths, why do we prefer screw gauge over Vernier Callipers?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Think of a method to find the 'pitch' of bottle caps.

2. Compare the 'pitch' of an ordinary screw with that of a screw guage. In what ways are the two different?

3. Measure the diameters of petioles (stem which holds the leaf) of different leaf and check if it has any relation with the mass or surface area of the leaf. Let the petiole dry before measuring its diameter by screw gauge.

4. Measure the thickness of the sheet of stainless steel glasses of various make and relate it to their price structure.

5. Measure the pitch of the 'screw' end of different types of hooks and check if it has any relation with the weight each one of these hooks are expected to hold.

6. Measure the thickness of different glass bangles available in the Market. Are they made as per some standard?

7. Collect from the market, wires of different gauge numbers, measure their diameters and relate the two. Find out various uses of wires of each gauge number.

(b) Measurement of Thickness of a Given Sheet

PROCEDURE

1. Insert the given sheet between the studs of the screw gauge and determine the thickness at five different positions.

2. Find the average thickness and calculate the correct thickness by applying zero error following the steps followed earlier.

OBSERVATIONS AND CALCULATION

Least count of screw gauge = ... mm

Zero error of screw gauge = ... mm

Table E 2.2 Measurement of thickness of sheet

S. No.	Linear scale reading M (mm)	Circular scale reading n	Thickness $t = M + n \times$ L.C. (mm)
1			
2			
3			
4			
5			

Mean thickness of the given sheet = ... mm

Mean corrected thickness of the given sheet

= observed mean thickness – (zero error with sign) = ... mm

RESULT

The thickness of the given sheet is ... m.

SOURCES OF ERROR

1. The sheet may not be of uniform thickness.

2. Error due to backlash though can be minimised but cannot be eliminated completely.

DISCUSSION

1. Assess whether the thickness of sheet measured by you is realistic or not. You may take a pile of say 20 sheets, and find its thickness using a metre scale and then calculate the thickness of one sheet.

2. What are the limitations of the screw gauge if it is used to measure the thickness of a thick cardboard sheet?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Find out the thickness of different wood ply boards available in the market and verify them with the specifications provided by the supplier.

2. Measure the thickness of the steel sheets used in steel almirahs manufactured by different suppliers and compare their prices. Is it better to pay for a steel almirah by mass or by the guage of steel sheets used?

3. Design a cardboard box for packing 144 sheets of paper and give its dimensions.

4. Hold 30 pages of your practical notebook between the screw and the stud and measure its thickness to find the thickness of one sheet.

5. Find the thickness of plastic ruler/metal sheet of the geometry box.

(C) Determination of Volume of the Given Irregular Lamina

PROCEDURE

1. Find the thickness of lamina as in Experiment E 2(b).

2. Place the irregular lamina on a sheet of paper with mm graph. Draw the outline of the lamina using a sharp pencil. Count the total number of squares and also more than half squares within the boundary of the lamina and determine the area of the lamina.

3. Obtain the volume of the lamina using the relation mean thickness × area of lamina.

OBSERVATIONS AND CALCULATION

Same as in Experiment E 2(b). The first section of the table is now for readings of thickness at five different places along the edge of the

lamina. Calculate the mean thickness and make correction for zero error, if any.

From the outline drawn on the graph paper:-

Total number of complete squares   = ... mm^2 = ... cm^2

Volume of the lamina   = ... mm^3 = ... cm^3

RESULT

Volume of the given lamina   = ... cm^3

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1.   Find the density of cardboard.
2.   Find the volume of a leaf (neem, bryophyte).
3.   Find the volume of a cylindrical pencil.

A_{IM}

To determine the radius of curvature of a given spherical surface by a spherometer.

A_{PPARATUS AND MATERIAL REQUIRED}

A spherometer, a spherical surface such as a watch glass or a convex mirror and a plane glass plate of about 6 cm × 6 cm size.

D_{ESCRIPTION OF APPARATUS}

A spherometer consists of a metallic triangular frame F supported on three legs of equal length A, B and C (Fig. E 3.1). The lower tips of the legs form three corners of an equilateral triangle ABC and lie on the periphery of a base circle of known radius, r. The spherometer also consists of a central leg OS (an accurately cut screw), which can be raised or lowered through a threaded hole V (nut) at the centre of the frame F. The lower tip of the central screw, when lowered to the plane (formed by the tips of legs A, B and C) touches the centre of triangle ABC. The central screw also carries a circular disc D at its top having a circular scale divided into 100 or 200 equal parts. A small vertical scale P marked in millimetres or half-millimetres, called main scale is also fixed parallel to the central screw, at one end of the frame F. This scale P is kept very close to the rim of disc D but it does not touch the disc D. This scale reads the vertical distance which the central leg moves through the hole V. This scale is also known as pitch scale.
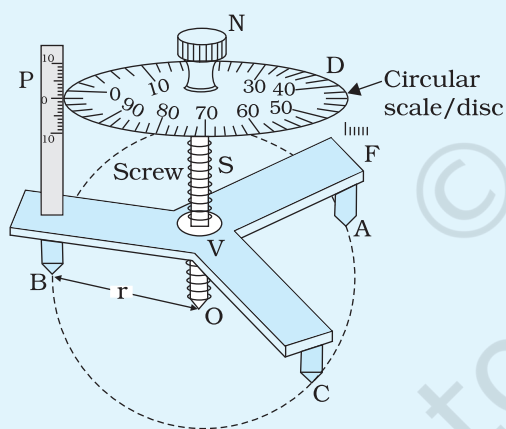

Fig. E 3.1: *A spherometer*

T_{ERMS AND DEFINITIONS}

Pitch: It is the vertical distance moved by the central screw in one complete rotation of the circular disc scale.

Commonly used spherometers in school laboratories have graduations in millimetres on pitch scale and may have100 equal divisions on circular disc scale. In one rotation of the circular scale, the central screw advances or recedes by 1 mm. Thus, the pitch of the screw is 1 mm.

Least Count: Least count of a spherometer is the distance moved by the spherometer screw when it is turned through one division on the circular scale, *i.e.,*

Least count of the spherometer $= \dfrac{\text{Pitch of the spherometer screw}}{\text{Number of divisions on the circular scale}}$

The least count of commonly used spherometers is 0.01 mm. However, some spherometers have least count as small as 0.005 mm or 0.001 mm.

PRINCIPLE

FORMULA FOR THE RADIUS OF CURVATURE OF A SPHERICAL SURFACE

Let the circle AOBXZY (Fig. E 3.2) represent the vertical section of sphere of radius R with E as its centre (The given spherical surface is a part of this sphere). Length OZ is the diameter ($= 2R$) of this vertical section, which bisects the chord AB. Points A and B are the positions of the two spherometer legs on the given spherical surface. The position of the third spherometer leg is not shown in Fig. E 3.2. The point O is the point of contact of the tip of central screw with the spherical surface.

Fig. E 3.3 shows the base circle and equilateral triangle ABC formed by the tips of the three spherometer legs. From this figure, it can be noted that the point M is not only the mid point of line AB but it is the centre of base circle and centre of the equilateral triangle ABC formed by the lower tips of the legs of the spherometer (Fig. E 3.1).

In Fig. E 3.2 the distance OM is the height of central screw above the plane of the circular section ABC when its lower
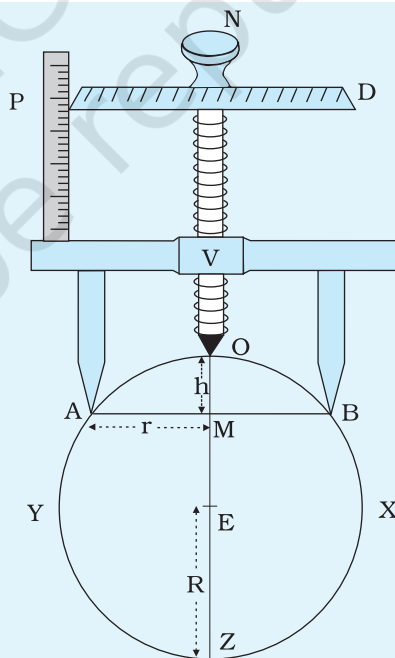

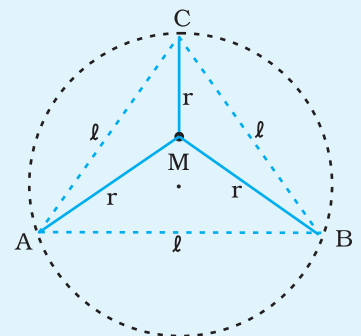*Fig. E 3.2: Measurement of radius of curvature of a spherical surface*

Fig. E 3.3: The base circle of the spherometer

tip just touches the spherical surface. This distance OM is also called sagitta. Let this be h. It is known that if two chords of a circle, such as AB and OZ, intersect at a point M then the areas of the rectangles described by the two parts of chords are equal. Then

$$AM.MB = OM.MZ$$

$$(AM)^2 = OM (OZ - OM) \text{ as } AM = MB$$

Let EZ (= OZ/2) = R, the radius of curvature of the given spherical surface and AM = r, the radius of base circle of the spherometer.

$$r^2 = h (2R - h)$$

Thus,
$$R = \frac{r^2}{2h} + \frac{h}{2}$$

Now, let l be the distance between any two legs of the spherometer or the side of the equilateral triangle ABC (Fig. E 3.3), then from geometry we have

Thus, $r = \dfrac{l}{\sqrt{3}}$, the radius of curvature (R) of the given spherical surface can be given by

$$R = \frac{l^2}{6h} + \frac{h}{2}$$

PROCEDURE

1. Note the value of one division on pitch scale of the given spherometer.

2. Note the number of divisions on circular scale.

3. Determine the pitch and least count (L.C.) of the spherometer. Place the given flat glass plate on a horizontal plane and keep the spherometer on it so that its three legs rest on the plate.

4. Place the spherometer on a sheet of paper (or on a page in practical note book) and press it lightly and take the impressions of the tips of its three legs. Join the three impressions to make an equilateral triangle ABC and measure all the sides of ∆ABC. Calculate the mean distance between two spherometer legs, l.

   In the determination of radius of curvature R of the given spherical surface, the term l^2 is used (see formula used). Therefore, great care must be taken in the measurement of length, l.

5. Place the given spherical surface on the plane glass plate and then place the spherometer on it by raising or lowering the central screw sufficiently upwards or downwards so that the three spherometer legs may rest on the spherical surface (Fig. E 3.4).

6. Rotate the central screw till it gently touches the spherical surface. To be sure that the screw touches the surface one can observe its image formed due to reflection from the surface beneath it.

7. Take the spherometer reading h_1 by taking the reading of the pitch scale. Also read the divisions of the circular scale that is in line with the pitch scale. Record the readings in Table E 3.1.
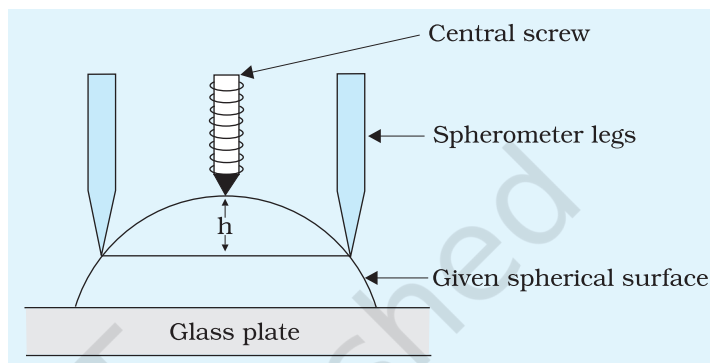

Central screw

Spherometer legs

h

Given spherical surface

Glass plate

Fig.E 3.4: *Measurement of sagitta h*

8. Remove the spherical surface and place the spherometer on plane glass plate. Turn the central screw till its tip gently touches the glass plate. Take the spherometer reading h_2 and record it in Table E 3.1. The difference between h_1 and h_2 is equal to the value of sagitta (h).

9. Repeat steps (5) to (8) three more times by rotating the spherical surface leaving its centre undisturbed. Find the mean value of h.

OBSERVATIONS

A. Pitch of the screw:

(i)   Value of smallest division on the vertical pitch scale = ... mm

(ii) Distance q moved by the screw for p complete rotations of the circular disc = ... mm

(iii) Pitch of the screw ($= q/p$) = ... mm

B. Least Count (*L.C.*) of the spherometer:

(i)   Total no. of divisions on the circular scale (N) = ...

(ii) Least count (L.C.) of the spherometer

$$= \frac{\text{Pitch of the spherometer screw}}{\text{Number of divisions on the circular scale}}$$

$$\text{L.C.} = \frac{\text{Pitch of the screw}}{N} = \text{... cm}$$

C. Determination of length l (from equilateral triangle ABC)

(i)   Distance AB = ... cm

(ii) Distance BC = ... cm

(iii) Distance CA = ... cm

$$\text{Mean } l = \frac{AB + BC + CA}{3} = \text{... cm}$$

Table E 3.1 Measurement of sagitta h

S. No.	Spherometer readings								$(h_1 - h_2)$
	With Spherical Surface				Horizontal Plane Surface				
	Pitch Scale reading x (cm)	Circular scale division coinciding with pitch scale y	Circular scale reading $z=y\times$L.C (cm)	Spherometer reading with spherical surface $h_1 = x + z$ (cm)	Pitch Scale reading x' (cm)	Circular scale division coinciding with pitch scale y'	Circular scale reading $z'=y\times$L.C. (cm)	Spherometer reading with spherical surface $h_2=x'+z'$ (cm)	

Mean h = ... cm

CALCULATIONS

A. Using the values of l and h, calculate the radius of curvature R from the formula:

$$R = \frac{l^2}{6h} + \frac{h}{2};$$

the term $h/2$ may safely be dropped in case of surfaces of large radii of curvature (In this situation error in $\left(\frac{l^2}{6h}\right)$ is of the order of $h/2$).

RESULT

The radius of curvature R of the given spherical surface is ... cm.

PRECAUTIONS

1. The screw may have friction.

2. Spherometer may have backlash error.

SOURCES OF ERROR

1. Parallax error while reading the pitch scale corresponding to the level of the circular scale.

2. Backlash error of the spherometer.

3. Non-uniformity of the divisions in the circular scale.

4. While setting the spherometer, screw may or may not be touching the horizontal plane surface or the spherical surface.

DISCUSSION

Does a given object, say concave mirror or a convex mirror, have the same radius of curvature for its two surfaces? [**Hint:** Does the thickness of the material of object make any difference?]

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Determine the focal length of a convex/concave spherical mirror using a spherometer.

2. (a) Using spherometer measure the thickness of a small piece of thin sheet of metal/glass.

   (b) Which instrument would be precise for measuring thickness of a card sheet – a screw gauge or a spherometer?

A IM

To determine mass of two different objects using a beam balance.

A PPARATUS AND MATERIAL REQUIRED

Physical balance, weight box with a set of milligram masses and forceps, spirit level and two objects whose masses are to be determined.

D ESCRIPTION OF PHYSICAL BALANCE

A physical balance is a device that measures the weight (or gravitational mass) of an object by comparing it with a standard weight (or standard gravitational mass).
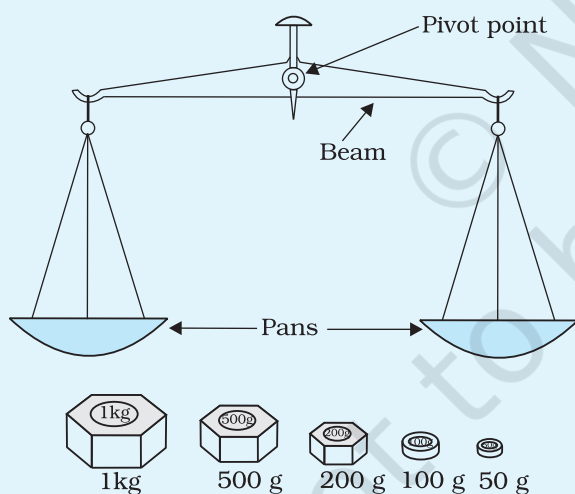

Fig. E 4.1: A beam balance and set of weights

The most commonly used two-pan beam balance is an application of a **lever**. It consists of a rigid uniform bar (beam), two pans suspended from each end, and a pivotal point in the centre of the bar (Fig. E 4.1). At this pivotal point, a support (called *fulcrum*) is set at right angles to the beam. This beam balance works on the principle of moments.

For high precision measurements, a physical balance (Fig. E 4.2) is often used in laboratories. Like a common beam balance, a physical balance too consists of a pair of scale pans P_1 and P_2, one at each end of a rigid beam B. The pans P_1 and P_2 are suspended through stirrups S_1 and S_2 respectively, on inverted knife-edges E_1 and E_2, respectively, provided symmetrically near the end of the beam B. The beam is also provided with a hard material (like agate) knife-edge (E) fixed at the centre pointing downwards and is supported on a vertical pillar (V) fixed on a wooden baseboard (W). The baseboard is provided with three levelling screws W_1, W_2 and W_3. In most balances, screws W_1 and W_2 are of adjustable heights and through these the baseboard W is levelled horizontally. The third screw W_3, not visible in Fig. E 4.2, is not of adjustable height and is fixed in the middle at the back of board W. When the balance is in use, the

knife-edge E rests on a plane horizontal plate fixed at the top of pillar V. Thus, the central edge E acts as a *pivot* or *fulcrum* for the beam B. When the balance is not in use, the beam rests on the supports X_1 and X_2, These supports, X_1 and X_2, are fixed to another horizontal bar attached with the central pillar V. Also, the pans P_1 and P_2 rest on supports A_1 and A_2, respectively, fixed on the wooden baseboard. In some
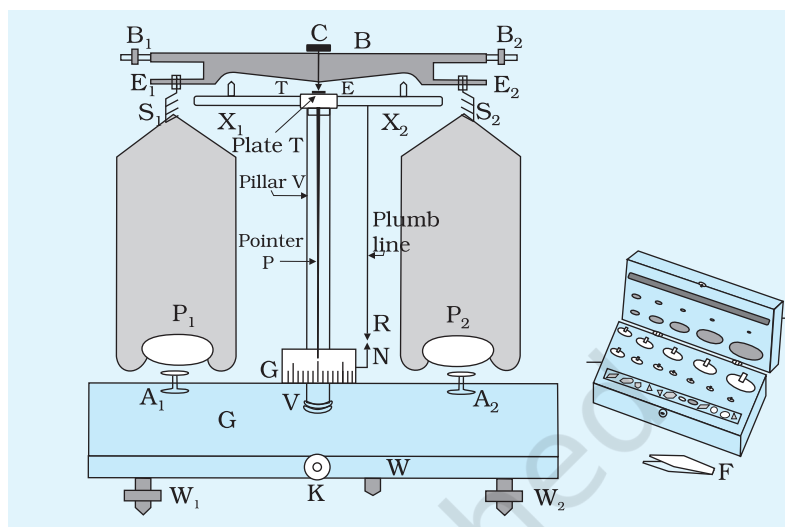

Fig. E 4.2: *A physical balance and a weight box*

balances, supports A_1 and A_2 are not fixed and in that case the pans rest on board W, when the balance is not in use.

At the centre of beam B, a pointer P is also fixed at right angles to it. A knob K, connected by a horizontal rod to the vertical pillar V, is also attached from outside with the board W. With the help of this knob, the vertical pillar V and supports A_1 and A_2 can be raised or lowered simultaneously. Thus, at the 'ON' position of the knob K, the beam B also gets raised and is then suspended only by the knife-edge E and oscillates freely. Along with the beam, the pans P_1 and P_2 also begin to swing up and down. This oscillatory motion of the beam can be observed by the motion of the pointer P with reference to a scale (G) provided at the base of the pillar V. When the knob K is turned back to 'OFF' position, the beam rests on supports X_1 and X_2 keeping the knife-edge E and plate T slightly separated; and the pans P_1 and P_2 rest on supports A_1 and A_2 respectively. In the 'OFF' position of the knob K, the entire balance is said to be *arrested*. Such an arresting arrangement protects the knife-edges from undue wear and tear and injury during transfer of masses (unknown and standards) from the pan.

On turning the knob K slowly to its 'ON' position, when there are no masses in the two pans, the oscillatory motion (or swing) of the pointer P with reference to the scale G must be same on either side of the zero mark on G. And the pointer must stop its oscillatory motion at the zero mark. It represents the vertical position of the pointer P and horizontal position of the beam B. However, if the swing is not the same on either side of the zero mark, the two balancing screws B_1 and B_2 at the two ends of the beam are adjusted. The baseboard W is levelled horizontal1y to make the pillar V vertical.

This setting is checked with the help of plumb line (R) suspended by the side of pillar V. The appartus is placed in a glass case with two doors.

For measuring the gravitational mass of an object using a physical balance, it is compared with a standard mass. A set of standard masses (100 g, 50 g, 20 g, 10g, 5 g, 2 g, and 1 g) along with a pair of forceps is contained in a wooden box called *Weight Box.* The masses are arranged in circular grooves as shown in Fig. E 4.2. A set of milligram masses (500 mg, 200 mg, 100 mg, 50 mg, 20 mg 10 mg, 5 mg, 2 mg, and 1 mg) is also kept separately in the weight box. A physical balance is usually designed to measure masses of bodies up to 250 g.

PRINCIPLE

The working of a physical balance is based on the principle of moments. In a balance, the two arms are of equal length and the two pans are also of equal masses. When the pans are empty, the beam remains horizontal on raising the beam base by using the lower knob. When an object to be weighed is placed in the left pan, the beam turns in the anticlockwise direction. Equilibrium can be obtained by placing suitable known standard weights on the right hand pan. Since, the force arms are equal, the weight (i.e., forces) on the two pans have to be equal.

A physical balance compares forces. The forces are the weights (mass × acceleration due to gravity) of the objects placed in the two pans of the physical balance. Since the weights are directly proportional to the masses if weighed at the same place, therefore, a physical balance is used for the comparison of gravitational masses. Thus, if an object O having gravitational mass m is placed in one pan of the physical balance and a standard mass O′ of known gravitational mass m_s is put in the other pan to keep the beam the horizontal, then

Weight of body O in one pan = Weight of body O′ in other pan

Or, $$mg = m_s g$$

where g is the acceleration due to gravity, which is constant. Thus,

$$m = m_s$$

That is,

the mass of object O in one pan = standard mass in the other pan

PROCEDURE

1. Examine the physical balance and recognise all of its parts. Check that every part is at its proper place.

2. Check that set of the weight, both in gram and milligram, in the weight box are complete.

3. Ensure that the pans are clean and dry.

4. Check the functioning of arresting mechanism of the beam B by means of the knob K.

5. Level the wooden baseboard W of the physical balance horizontally with the help of the levelling screws W_1 and W_2. In levelled position, the lower tip of the plumb line R should be exactly above the fixed needle point N. Use a spirit level for this purpose.

6. Close the shutters of the glass case provided for covering the balance and slowly raise the beam B using the knob K.

7. Observe the oscillatory motion of the pointer P with reference to the small scale G fixed at the foot of the vertical pillar V. In case, the pointer does not start swinging, give a small gentle jerk to one of the pans. Fix your eye perpendicular to the scale to avoid parallax. **Caution:** Do not touch the pointer.

8. See the position of the pointer P. Check that it either stops at the central zero mark or moves equally on both sides of the central zero mark on scale G. If not, adjust the two balancing screws B_1 and B_2 placed at the two ends of the beam B so that the pointer swings equally on either side of the central zero mark or stops at the central zero mark. **Caution**: *Arrest the balance before adjusting the balancing screws.*

9. Open the shutter of the glass case of the balance. Put the object whose mass *(M)* is to be measured in the left hand pan and add a suitable standard mass say M_1, (which may be more than the rough estimate of the mass of the object) in the right hand pan of the balance in **its rest (or arrested) position**, *i.e.,* when the beam B is lowered and allowed to rest on stoppers X_1 and X_2. Always use forceps for taking out the standard mass from the weight box and for putting them back.

The choice of putting object on left hand pan and standard masses on right hand pan is arbitrary and chosen due to the ease in handling the standard masses. A left handed person may prefer to keep the object on right hand pan and standard masses on left hand pan. It is also advised to keep the weight box near the end of board W on the side of the pan being used for putting the standard masses.

10. Using the knob K, gently raise the beam (now the beam's knife edge E will rest on plate T fixed on the top of the pillar V) and observe the motion of the pointer P. It might rest on one side of

the scale or might oscillate more in one direction with reference to the central zero mark on the scale G.

Note: Pans should not swing while taking the observations. The swinging of pans may be stopped by carefully touching the pan with the finger in the arresting position of the balance.

11. Check whether M_1 is more than M or less. For this purpose, the beam need to be raised to the full extent.

12. Arrest the physical balance. Using forceps, replace the standard masses kept in the right pan by another mass (say M_2). It should be lighter if M_1 is more than the mass M and vice versa.

13. Raise the beam and observe the motion of the pointer P and check whether the standard mass kept on right hand pan is still heavier (or lighter) than the mass M so that the pointer oscillates more in one direction. If so, repeat step 12 using standard masses in gram till the pointer swings **nearly equal** on both sides of the central zero mark on scale G. Make the standard masses kept on right hand pan to be *slightly lesser* than the mass of object. This would result in the measurement of mass M of object with a precision of 1 g. Lower the beam B.

14. For **fine measurement** of mass add extra milligram masses in the right hand pan in descending order until the pointer swings nearly equal number of divisions on either side of the central zero mark on scale G (use forceps to pick the milligram or fractional masses by their turned-up edge). In the equilibrium position *(i.e.,* when the masses kept on both the pans are equal), the pointer will rest at the centre zero mark. Close the door of the glass cover to prevent disturbances due to air draughts.

Note: The beam B of the balance should not be raised to the full extent until milligram masses are being added or removed. Pointer's position can be seen by lifting the beam very gently and for a short moment.

15. Arrest the balance and take out masses from the right hand pan one by one and note total mass in notebook. Replace them in their proper slot in the weight box. Also remove the object from the left hand pan.

16. Repeat the step 9 to step 15 two more times for the same object.

17. Repeat steps 9 to 15 and determine the mass of the second given object.

Record the observations for the second object in the table similar to Table E 4.1.

OBSERVATIONS

TABLE E 4.1: Mass of First Object

S. No.	Standard mass		Mass of the object $(x + y)$
	Gram weights, x	Milligram weights, y	
	(g)	(mg)	(g)
1			
2			
3			

Mean mass of the first object = ... g

TABLE E 4.2: Mass of Second Object

S. No.	Standard mass		Mass of the object $(x + y)$
	Gram weights, x	Milligram weights, y	
	(g)	(mg)	(g)
1			
2			
3			

Mean mass of the second object = ... g

RESULT

The mass of the first given object is ... g and that of the second object is ... g.

PRECAUTIONS

1. The correctness of mass determined by a physical balance depends on minimising the errors, which may arise due to the friction between the knife-edge E and plate T. Friction cannot be removed completely. However, it can be minimised when the knife-edge is sharp and plate is smooth. The friction between other parts of the balance may be minimised by keeping all the parts of balance dry and clean.

2. Masses should always be added in the descending order of magnitude. Masses should be placed in the centre of the pan.

3. The balance should not be loaded with masses more than capacity. Usually a physical balance is designed to measure masses upto 250 g.

4. Weighing of hot and coId bodies using a physical balance should be avoided. Similarly, active substances like chemicals, liquids and powders should *not* be kept directly on the pan.

SOURCES OF ERROR

1. There is always some error due to friction at various parts of the balance.

2. The accuracy of the physical balance is 1 mg. This limits the possible instrumental error.

DISCUSSION

The deviation of experimental value from the given value may be due to many factors.

1. The forceps used to load/unload the weights might contain dust particles sticking to it which may get transferred to the weight.

2. Often there is a general tendancy to avoid use of levelling and balancing screws to level the beam/physical balance just before using it.

SELF ASSESSMENT

1. Why is it necessary to close the shutters of the glass case for an accurate measurement?

2. There are two physical balances: one with equal arms and other with unequal arms. Which one should be preferred? What additional steps do you need to take to use a physical balance with unequal arms.

3. The minimum mass that can be used from the weight box is 10 g. Find the possible instrumental error.

4. Instead of placing the mass (say a steel block) on the pan, suppose it is hanged from the same hook S_1 on which the pan P_1 is hanging. Will the value of measured mass be same or different?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Determination of density of material of a non-porous block and verification of Archimedes principle:

Hint: First hang the small block (say steel block) from hook S_1 and determine its mass in air. Now put the hanging block in a half water-filled measuring cylinder. Measure the mass of block in water. Will it be same, more or less? Also detemine the volume of steel block. Find the density of the material of the block. From the measured masses of the steel block in air and water, verify Archimedes principle.

A~IM~

Measurement of the weight of a given body (a wooden block) using the parallelogram law of vector addition.

A~PPARATUS AND MATERIAL REQUIRED~

The given body with hook, the parallelogram law of vector apparatus (Gravesand's apparatus), strong thread, slotted weights (two sets), white paper, thin mirror strip, sharp pencil.

D~ESCRIPTION OF MATERIAL~

Gravesand's apparatus: It consists of a wooden board fixed vertically on two wooden pillars as shown in Fig. E 5.1 (a). Two pulleys P_1 and P_2 are provided on its two sides near the upper edge of the board. A thread carrying hangers for addition of slotted weights is made to pass over the pulleys so that two forces P and Q can be applied by adding weights in the hangers. By suspending the given object, whose weight is to be determined, in the middle of the thread, a third force X is applied.
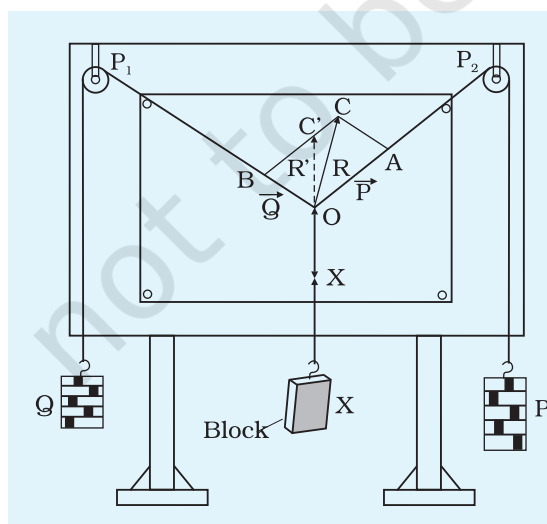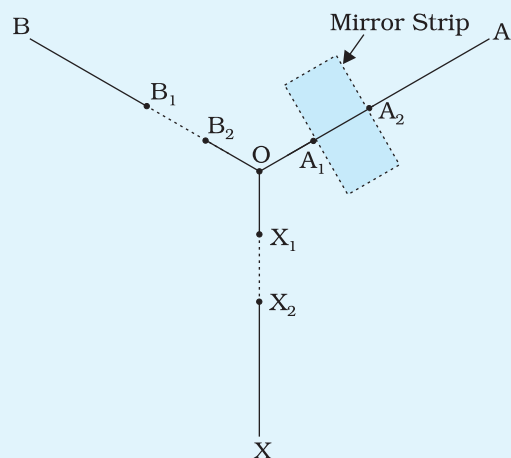

Fig. E 5.1(a): *Gravesand's apparatus*

Fig. E 5.1(b): *Marking forces to scale*

PRINCIPLE

Working of this apparatus is based on the parallelogram law of vector addition. The law states that "when two forces act simultaneously at a point and are represented in magnitude and direction by the two adjacent sides of a parallelogram, then the resultant of forces can be represented both in magnitude and direction by the diagonal of the parallelogram passing through the point of application of the two forces.

Let P and Q be the magnitudes of the two forces and θ the angle between them. Then the resultant R of P and Q is given by

$$R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$$

If two known forces P and Q and a third unknown force due to the weight of the given body are made to act at a point O [Fig. 5.1 (a)] such that they are in equilibrium, the unknown force is equal to the resultant of the two forces. Thus, the weight of a given body can be found.

PROCEDURE

1. Set the board of Gravesand's apparatus in vertical position by using a plumb-line. **Ensure that the pulleys are moving smoothly**. Fix a sheet of white paper on the wooden board with drawing pins.

2. Take a sufficiently long piece of string and tie the two hangers at its ends. Tie another shorter string in the middle of the first string to make a knot at 'O'. Tie the body of unknown weight at the other end of the string. Arrange them on the pulley as shown in Fig. E 5.1 (a) with slotted weights on the hangers.

3. Add weights in the hangers such that the junction of the threads is in equilibrium in the lower half of the paper. **Make sure that neither the weights nor the threads touch the board or the table**.

4. Bring the knot of the three threads to position of no-friction. For this, first bring the knot to a point rather wide off its position of no-friction. On leaving there, it moves towards the position of no-friction because it is not in equilibrium. While it so moves, tap the board gently. The point where the knot thus come to rest is taken as the position of no-friction, mark this point. Repeat the procedure several times. Each time let the knot approach the position of no-friction from a different direction and mark the point where it comes to rest. Find by judgement the centre of those points which are close together. Mark this centre as O.

5. To mark the direction of the force acting along a string, place a mirror strip below the string on the paper . Adjust the position of the eye such that there is no parallax between the string and its image. Mark the two points A_1 and A_2 at the edges of the mirror where the image of the string leaves the mirror [Fig E 5.1 (b)].

Similarly, mark the directions of other two forces by points B_1 and B_2 and by points X_1 and X_2 along the strings OB and OX respectively.

6. Remove the hangers and note the weight of each hanger and slotted weights on them.

7. Place the board flat on the table with paper on it. Join the three pairs of points marked on the paper and extend these lines to meet at O. These three lines represent the directions of the three forces.

8. Choose a suitable scale, say 0.5 N (50 g wt) = 1cm and cut off length OA and OB to represent forces P and Q respectively acting at point O. With OA and OB as adjacent sides, complete the parallelogram OACB. Ensure that the scale chosen is such that the parallelogram covers the maximum area of the sheet.

9. Join points O and C. The length of OC will measure the weight of the given body. See whether OC is along the straight line XO. If not, let it meet BC at some point C′ . Measure the angle COC′ .

10. Repeat the steps 1 to 9 by suspending two different sets of weights and calculate the mean value of the unknown weight.

OBSERVATIONS

Weight of each hanger = … N

Scale, 1cm   = … N

Table E 5.1: Measurement of weight of given body

S. No.	Force $P = wt$ of (hanger + slotted weight)		Force $Q = wt$ of (hanger + slotted weight)		Length OC $= L$	Unknown weight $X = L \times s$	Angle COC′
	P (N)	OA (cm)	Q (N)	OB (cm)	(cm)	(N)	
1							
2							
3							

RESULT

The weight of the given body is found to be ... N.

PRECAUTIONS

1. Board of Gravesand's apparatus is perpendicular to table on which it is placed, by its construction. Check up by plumb line that it is vertical. If it is not, make table top horizontal by putting packing below appropriate legs of table.

2. Take care that pulleys are free to rotate, i.e., have little friction between pulley and its axle.

SOURCES OF ERROR

1. Friction at the pulleys may persist even after oiling.

2. Slotted weights may not be accurate.

3. Slight inaccuracy may creep in while marking the position of thread.

DISCUSSION

1. The Gravesand's apparatus can also be used to verify the parallelogram law of vector addition for forces as well as triangle law of vector addition. This can be done by using the same procedure by replacing the unknown weight by a standard weight.

2. The method described above to find the point of no-friction for the junction of three threads is quite good experimentally. If you like to check up by an alternative method, move the junction to extreme left, extreme right, upper most and lower most positions where it can stay and friction is maximum. The centre of these four positions is the point of no-friction.

3. What is the effect of not locating the point of no-friction accurately? In addition to the three forces due to weight, there is a fourth force due to friction. These four are in equilibrium. Thus, the resultant of P and Q may not be vertically upwards, i.e., exactly opposite to the direction of X.

4. It is advised that values of P and Q may be checked by spring balance as slotted weights may have large error in their marked value. Also check up the result for X by spring balance.

Self assessment

1. State parallelogram law of vector addition.

2. Given two forces, what could be the

   (a) Maximum magnitude of resultant force.

   (b) Minimum magnitude of resultant force.

3. In which situation this parallelogram can be a rhombus.

4. If all the three forces are equal in magnitude, how will the parallelogram modify?

5. When the knot is in equilibrium position, is any force acting on the pulleys?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Interchange position of the body of unknown weight with either of the forces and then find out the weight of that body.

2. Keeping the two forces same and by varying the unknown weight, study the angle between the two forces.

3. Suggest suitable method to estimate the density of material of a given cylinder using parallelogram law of vectors.

4. Implement parallelogram law of vectors in the following situations:-

   (a) Catapult   (b) Bow and arrow   (c) Hand gliding
   (d) Kite   (e) Cycle pedalling