GENERAL PHYSICS

2.1 Principle of vernier scale :

This is a device (invented by P. Vernier in 1931) by which a very small length, even smaller than the smallest division of the main scale, can be measured very accurately. For this purpose a small auxiliary scale (V_1V_2) known as the **vernier scale** is taken, which can slide along-side the main scale (S_1S_2). [Fig. 2.1-1(a) shows a straight vernier with a linear scale and Fig. 2.1-1 (b) shows a circular vernier with a circular scale]. Usually, one division of the vernier scale is slightly smaller than one smallest division of the main scale. The length of the gap between one vernier division and one smallest division of the main scale is called **vernier constant.** This vernier constant (*v.c.*) is given by

$$v.c. = 1 \text{ scale division } (s.d.) - 1 \text{ vernier division } (v.d.)$$

$$\text{or, } v.c. = 1\ s.d. - 1\ v.d. \quad \text{... (2.1-1)}$$

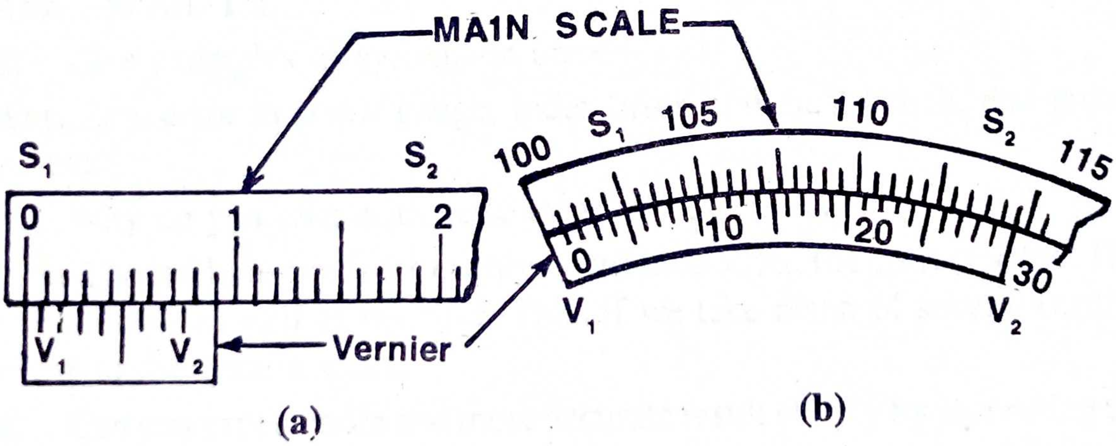

Fig. 2.1-1 : Vernier scale

• **Determination of vernier constant :** Let the value of one smallest division of the main scale (= 1 *s.d.*) be *s* [this may be *s* mm. for linear scale or s^0 for circular scale]. If the number of divisions present in the vernier scale be *n* and these *n* divisions of the vernier scale (*v.d.*) coincide with (n–1) smallest divisions of the main scale (*s.d.*) then $n\ v.d. = (n-1)\ s.d.$ or, $1\ v.d. = (n-1)/n\ s.d.$ Hence vernier constant = $v.c. = 1\ s.d. - 1\ v.d. = \{1-(n-1)/n\}\ s.d.$

$$\text{or, } v.c. = 1/n\ s.d. = s/n \quad \text{... (2.1-2)}$$

If one $s.d. = s$ mm then $v.c. = s/n$ mm whereas if $1\ s.d. = s^0$ then $v.c. = (s/n)^0$.

- **Example : (*i*) In the straight vernier shown in Fig. 2.1-1(*a*),**
  10 *v.d.* = 9 *s.d.*

or, $1\ v.d. = \frac{9}{10}\ s.d.$

$\therefore\ v.c. = 1\ s.d. - 1\ v.d.$

$= \left(1-\frac{9}{10}\right)\ s.d.$

$= \frac{1}{10}\ s.d.$

$= \frac{1}{10}\times 1\text{ mm}\quad [\because 1\ s.d. = 1\text{ mm}]$

$= 0{\cdot}1\text{ mm}$

(ii) Let in another vernier arrangement,

1 *s.d.* = 0.5 mm and

50 *v.d.* = 49 *s.d.*

or, $1\ v.d. = \frac{49}{50}\ s.d.$

$\therefore\ v.c. = 1\ s.d. - 1\ v.d. = \left(1-\frac{49}{50}\right)\ s.d.$

$= \frac{1}{50}\ s.d. = \frac{1}{50}\times 0{\cdot}5\text{ mm} = 0{\cdot}01\text{ mm.}$

(iii) Sometimes *a special type of vernier* is used, in which 10 *v.d.* equal 19 *s.d.* In this case it is convenient to define

v.c. = 2 *s.d.* – 1 *v.d.*

For example, if 1 *s.d.* = 1 mm then

v.c. = 2 mm – 1.9 mm

= 0.1 mm

The advantage of this 19, 10 coincidence over the more common 9,10 coincidence lies in the **wider spacing of vernier divisions.** This makes it easier to read the vernier.

(iv) In the **circular vernier** shown in Fig. 2.1-1 (*b*)

30 *v.d.* = 29 *s.d.*

or, $1\ v.d. = \frac{29}{30}\ s.d.$

$\therefore\ v.c. = 1\ s.d. - 1\ v.d.$

$= \left(1-\frac{29}{30}\right)\ s.d.$

$= \frac{1}{30}\ s.d. = \frac{1}{30}\times 30' = 1' \qquad [\because 1\ s.d. = \frac{1^{0}}{2} = 30']$

Thus by this vernier we can measure upto 1′. This vernier is used in common spectrometer.

2.2 Slide callipers and its use :

• **Construction :** Slide callipers consists of a steel plate (*P*) at one edge of which a centimetre scale (cm) is marked while at its other edge an inch scale is marked [Fig. 2.2-1]. At right angles to the steel plate (*P*) there are two jaws (AA_1 and BB_1), one of which (AA_1) is fixed at one end of the plate while the other jaw (BB_1) is provided with a vernier scale (*V*) and can slide over the main scale on the plate (*P*). When the two jaws touch each other the gap between them becomes zero and the zero-line of the vernier usually coincides with that of the scale. If it does not happen so, then there is a zero error in the instrument and this should be determined for correct result. Sometimes a narrow thin steel strip *(H)* is attached parallel to the plate *P*, which can move with the movable jaw BB_1. This is useful for depth measurement.

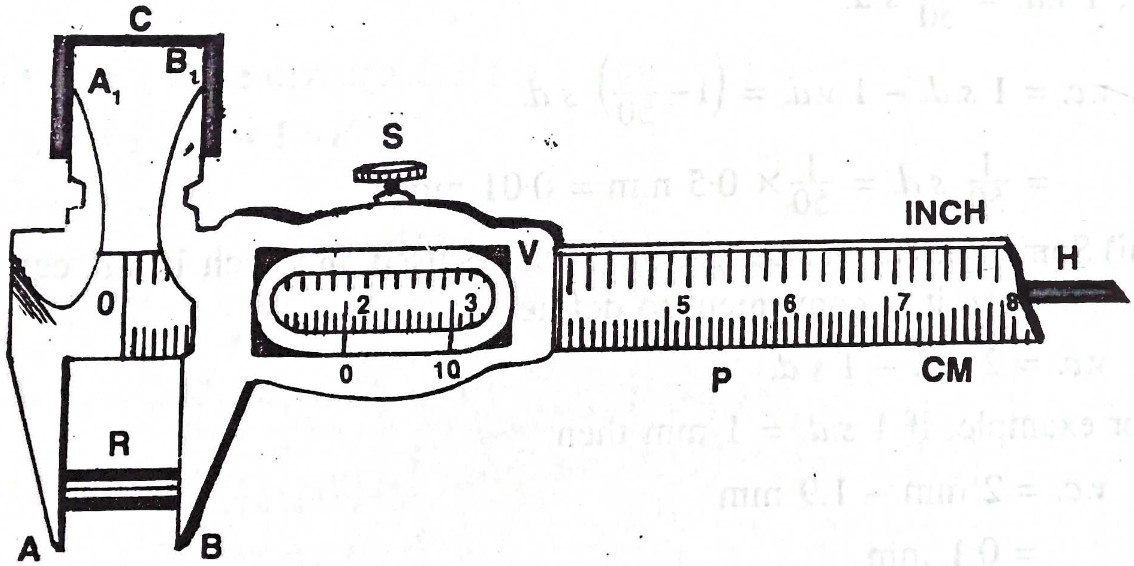

Fig. 2.2-1 : Slide callipers

• **Measurement :** At first the vernier constant is to be determined as discussed in Art. 2.1.

The movable jaw (BB_1) is drawn outward to create a gap between the two jaws. If we are to measure the length of a small rod *R* (as shown in Fig. 2.2-1) or the diameter of a bob, it should be put between the jaws *A* and *B*. If we are to measure the internal diameter of a hollow cylinder *C* (as shown in Fig. 2.2-1) the jaws A_1 and B_1 are to be put into the hollow of the cylinder. The position of the sliding jaw BB_1 is then adjusted till the jaw *B* touches one end of the object *R* or the jaw B_1 touches the inner surface of the hollow cylinder *CC*. Now let the value of integral number of main scale divisions, remaining just on the left side of the zero-line of vernier be *S* cm. If a certain number of divisions of the vernier scale (say *v.r.*) are seen to coincide with the main scale then the value of the fraction of one scale division, just on the left of the zero-line of vernier, would be $V = (v.r.) \times (v.c.)$ cm. Hence the total length of the gap between the two jaws is

$$l = S + (v.r.) \times (v.c.) = S + V \text{ cm} \qquad \dots (2.2\text{-}1)$$

• **Zero error :** To find the zero-error of the instrument, the two jaws (AA_1 and BB_1) are put in contact with each other. If the zero-lines of the main and vernier scales coincide then zero-error does not exist. But if the zero-lines of the main and vernier scales do not coincide then zero-error exists. Suppose the zero-line of the vernier is on the right of the zero-line of the main scale. If y divisions of vernier (*counted from the left end of the vernier scale*) are now found to coincide with a certain mark of the main scale, then zero-error $e = +y \times v.c.$ Here the error is taken to be **positive** and it is to be **subtracted** from the measured length.

On the other hand if the zero-line of the vernier is on the left of the zero-line of the main scale then error is taken to be **negative** and it is to be **added** to the measured length. Here if y divisions of vernier (*counted from the right end of the vernier scale*) are found to coincide with a certain mark of the main scale, then zero-error $e = -y \times v.c.$ Thus,

Corrected length = Measured length − e

• **Experimental data :**

(A) *Calculation of vernier constant :*

Value of 1 smallest main scale division = ... cm (say s)

(n) divisions of the vernier scale = (m) divisions of main scale

$$\therefore\ 1\ v.d. = \frac{m}{n}\ s.d.$$

$$\therefore\ v.c. = 1\ s.d. - 1\ v.d.$$

$$= \left(1 - \frac{m}{n}\right) s.d.$$

$$= \left(1 - \frac{m}{n}\right) \times s \text{ cm}$$

(B) *Zero-error :*

$e = \pm\, y \times v.c.$

(C) ***Data for length or diameter :***

TABLE 1

Quantity to be measured	No. of obs.	Readings of				Grand mean of R in cm	Corrected value of R in cm $R - e$
		Scale (S) in cm	Vernier reading $v.r.$	Total $= R$ $= S + v.r.$ $\times$ $v.c.$ cm	Mean R in cm		
External diameter	1. (*a*)	...	...	...	...		
	(*b*)	...	...	...	...		
	2. (*a*)	...	...	...	...		
	(*b*)	...	...	...	...		...
	etc.	etc.	etc.	etc.	etc.	...	$= d_1$
	5. (*a*)	...	...	...	...		
	(*b*)	...	...	...	...		
Length	1.						
	2.						
	etc.						...
	5.						$= l$

N.B. [In TABLE I, (*a*) represents readings at a point in one direction while (*b*) represents readings at the same point in perpendicular directions. The readings are taken so as the cross-section at a point may not be perfectly circular.]

☐ Oral Questions and Answers ☐

1. What is a vernier?

Ans. It is an auxiliary scale used with a main scale for measuring fractions of the smallest division of the main scale.

2. What is vernier constant?

Ans. Equal to the difference of 1 smallest main scale division and 1 vernier division. It indicates the smallest distance that can be measured with the vernier.

3. What are the functions of the jaws A_1, B_1 and the tail H?

Ans. A_1, B_1 are used to measure the inside diameter of a tube or a hole. H is used for depth measurement.

2.3 Principle of a micrometer screw, its applications and defects :

• **Principle :** Whenever the head of a screw, fitted in a nut, is rotated by 360^0 it moves linearly by a certain distance, say p mm, which is called the *pitch of the screw.* This linear shift of the screw is usually measured by a linear scale and hence the pitch of the screw will be known. The pitch of the screw will be greater or smaller according as the distance between the two consecutive threads of the screw is greater or smaller. A cylindrical cap or a circular disc, having N number of equal divisions, is fixed to the head of the screw. Hence for one complete rotation of the screw head, there will be N divisions rotations of this circular scale. Thus for the rotation of one division of the circular scale, the linear shift of the screw would be p/N mm which is called the *least count* of the instrument fitted with the screw. Thus least count of the instrument is

$$l.c. = p/N \text{ mm} \qquad \text{... (2.3-1)}$$

• **Example :** *(i)* If the pitch $p = 1$ mm and number of division in the circular scale be $N = 100$ then $l.c. = 1/100$ mm $= 0{\cdot}01$ mm.

(ii) If $p = 1/2$ mm and $N = 100$ then the least count is $l.c. = 1/200$ mm $= 0{\cdot}005$ mm.

• **Applications :** For measurement ~~of very~~ small distance the principle of micrometer screw is employed in (a) *screw gauge* and (b) *spherometer.* These instruments are discussed in detail in the following articles.

• **Defect of a screw :** Usually a screw misfits into the nut in which it moves. This misfit increases with the use of the instrument. Due to this misfit, the axial motion of the screw does not occur for a certain angle of rotation of its head when the direction of motion of its head is reversed. This lag between the linear and circular motion of the screw is called **back-lash error** of the screw. To avoid this error, the *screw should always be turned in the same direction* when taking the readings with its help.

2.4 Screw gauge and its use :

• **Construction :** It consists of a U-shaped piece of solid steel (U) one arm of which carries a fixed stud (A) while the other arm carries a hollow cylinder (C) within which an accurate screw (S) having plane face (B) at its end, can move [Fig. 2.4-1]. On the upper surface of the cylinder (C) there is a horizontal reference line (R) at right angles to which a linear scale (S_1), graduated in mm is marked. The screw head is fitted with a cylindrical cap (D) and a milled head (E). The bevelled edge of the cap (D) is provided with a uniform circular scale (S_2) [S_2 is divided into 100 or 50 equal parts]. When the screw (S) is moved inward to touch its plane face (B) with the fixed plane face (A) the zero-line of the circular scale (S_2) coincides with the reference line (R) while the circular edge of the cap (D) coincides with the zero-line of the linear scale (S_1). If it does not happen so then there is instrumental error (zero-error) and this should be determined for correct result.

• **Theory of measurement :** If the screw moves linearly by p mm, when the cylindrical cap (D) of the screw, having N equal divisions at its edge, is revolved to perform one complete rotation then pitch ($= p$) and least count ($= l.c.$) of the instrument are respectively given by

pitch $= p$ mm and *least count* $= l.c. = p/N$ mm ... (2.4-1)

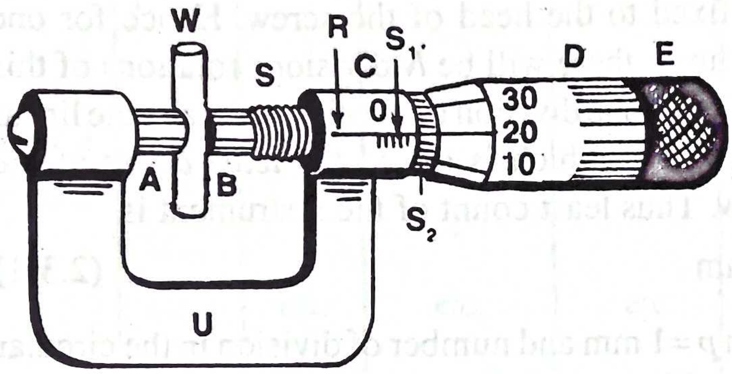

Fig. 2.4-1 : Screw gauge

For a given gap between the fixed face A and movable face B, let the value of integral number of divisions of the linear scale (S_1), remaining on the left side of the bevelled edge of the cap (D), be m mm. Again if the reading of the circular scale (S_2), corresponding to the reference line (R) be ($c.s.r.$) then the value of those divisions of the circular scale would be

$$c = (c.s.r.) \times (l.c. \text{ in mm}) \text{ mm} \qquad \text{... (2.4-2)}$$

Hence the length of the gap between the faces A and B (which for example, may be the diameter of a wire) is given by

$$d = l.s.r. + c.s.r. \times l.c.$$ LC

$$= (m + c) \text{ mm} \qquad \text{... (2.4-3)}$$

• **Zero error :** To find the zero-error of the instrument, the screw is rotated by its milled head (E) till the plane faces A and B touch each other. If now the zero-line of the circular scale (S_2) coincides with the reference line (R) then no zero-error will exist. But a zero-error of magnitude e will exist, if the reference line (R) coincides with a line on the circular scale, which is y divisions away from the zero-line of the circular scale. The error e will be taken positive or negative according as those y divisions of the circular scale (measured with respect to reference line R) are remaining on the positive side of the circular scale (i.e., towards the side of 10 of the circular scale) or on the negative side of the circular scale (i.e., towards the side of 90 of the circular scale). Thus the zero-error of the instrument is,

$e = \pm y \times$ ($l.c.$ in mm) = $\pm$ ... mm ... (2.4-4)

Now the corrected length (diameter) will be given by,

measured length − ($\pm$ zero-error) = $d - e$.

- **Experimental data :**

(A) *Calculation of least count :*

Smallest division of the linear scale = s = ... mm

Pitch of the screw = p = ... mm

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

Least count of instrument = $l.c.$ = p/N ... mm

(B) *Instrumental error :*

Instrumental error = $e = \pm$ y divisions = $\pm y \times$ ($l.c.$ in mm) = $\pm$ ... mm

(C) *Data for diameter :*

TABLE I

No. of obs.		L.S.R. in mm (m)	C.S.R. ($c.s.r.$)	Diameter in mm $d_1 = m + c.s.r. \times l.c.$	Mean diam in mm at one place	Grand mean diam. in mm (d')	Corrected mean diameter in mm $= (d' - e)$
1	a.	...	...	...	...	...	...
	b.	...	...	...			
2	a.	...	...	...	...		
	b.	...	...	...			
etc.		etc.	etc.	etc.	etc.		
5	a.	...	...	...	...		
	b.	...	...	...			

N.B. [In TABLE I—(*a*) Reading at a point of the wire for one direction.

(*b*) Reading at the same point for another direction perpendicular to the former.]

❑ Oral Questions and Answers ❑

1. What is screw pitch?

Ans. The distance through which the screw moves when it is given one complete rotation.

2. What is least count?

Ans. The distance through which the screw moves when it is rotated through one circular division.

3. What minimum length can be measured by it?

Ans. Equal to least count.

4. What is backlash error?

Ans. With use of the instrument and due to misfit of the screw into the nut it is found that the axial motion of the screw does not occur for a certain angle of rotation of its head when the direction of its motion is reversed. This lag between linear and circular motion is called backlash error.

5. How can you avoid backlash error?

Ans. The screw is to be rotated always in the same direction while taking readings.

2.5 Spherometer and its use : determination of the radius of curvature of a spherical surface :

• **Description :** Spherometer is an instrument specially designed for the measurement of the radius of curvature of a spherical surface. It is also used to find the thickness of very thin plates. It consists of an accurately cut screw (S) at the head of which a circular disc (D), having uniform graduations at its rim, is fixed. This screw can move within a nut (N) situated at the centre of a three-legged frame. The ends L_1, L_2 and L_3 of the three legs are on the vetrices of an equilateral triangle (Fig. 2.5-1). The disc D can be rotated by turning the milled head (M) and the linear shift of the screw can be obtained from a linear scale L, kept by the side of the disc.

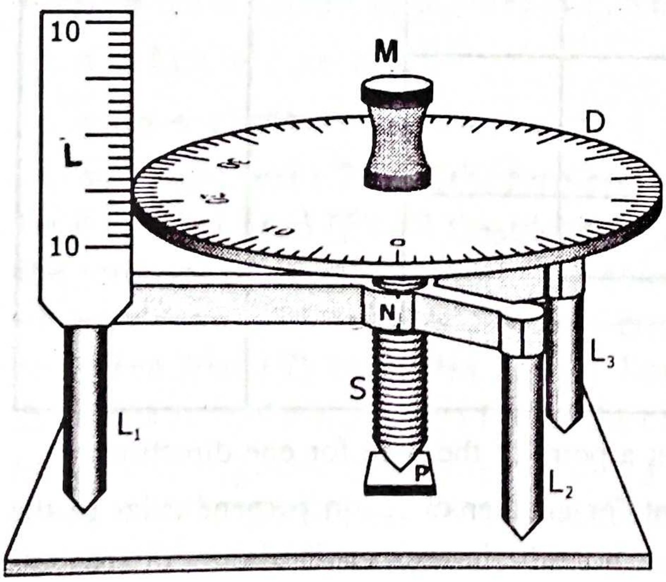

Fig. 2.5-1 : Spherometer

Theory of measuring the radius of curvature of a spherical surface : If the screw (S) moves linearly by p mm during one complete rotation of the circular disc D at its head (the rim of the circular disc is divided into N equal parts) then the pitch and least count of the instrument are respectively given by,

$$pitch = p \text{ mm and } least\ count = l.c. = p/N \text{ mm} \qquad \text{... (2.5-1)}$$

Let the screw touch consecutively the spherical surface and a base plate (which is always in the plane of L_1, L_2, L_3). If for this purpose, the circular disc at the head of the screw is given m complete rotations and also an extra n divisions of the circular scale then the linear shift of the screw would be,

$$h' = (mN + n) \times (l.c.) \text{ mm; or, } h = (h'/10) \text{ cm} \qquad \text{... (2.5-2)}$$

If the mean distance between any two consecutive outer legs of the spherometer be d cm then the radius of curvature of the given surface is given by,

$$r = d^2 / 6h + h/2 \text{ cm} \qquad \text{... (2.5-3)}$$

• **Procedure :** (*i*) The value of each division of the linear scale (L) is noted. Let it be s mm [s is either 1 mm or 1/2 mm]. By counting the number of divisions N (N is usually 100) on the circular scale the pitch ($= p$) and least count ($l.c.$) are determined by using the relation (2.5-1).

(*ii*) By rotating the milled head (M) in anti-clockwise direction the tip (P) of the screw is raised and then it is placed on the given spherical surface. By rotating the screw again in the reversed direction, its tip (P) is made to touch the given spherical surface and the reading R_1 of the circular scale is noted.

(*iii*) By withdrawing the spherometer from the spherical surface, it is now placed on a plane glass plate and its screw tip (P) is lowered (for convex spherical surface) until it touches the plate.

(*iv*) In performing the operation (*iii*), if the circular disc (D) at the screw head makes m complete rotations and R_2 indicates the final circular scale reading then the total number of circular scale divisions rotated for the performance of operation (*iii*) would be $x = (Nm + n)$. Here n is the extra number of circular scale divisions rotated, over and above the m number of complete rotation of the disc (D). The value of n can be obtained from the initial reading R_1 [in operation (*ii*)] and final reading R_2 [in operation (*iv*)] of the circular scale. The linear shift ($=h$) of the screw can then be calculated from the relation (2.5-2). This determination of h should be repeated thrice and their mean value is to be accepted.

(*v*) By raising the screw, the three outer legs are pressed on a paper to get three points on it. The distance between any two consecutive points is measured by employing a divider and scale. The mean of these three distances gives d.

(*vi*) Knowing h and d (both should be expressed in cm) the value of the radius r of the given surface can be calculated from the relation (2.5-3).

• **Experimental data :**

(A) *Determination of least count (l.c.) :*

Value of each division of the linear scale = s = ... mm

No. of divisions on the circular disc = N = ...

Pitch of the screw = p = ... mm

Least count of the instrument = $l.c.$ = p/N = ... mm

Distance between the outer legs = d = (... + ... + ...)/3 = ... cm

(B) *Determination of h :*

[*Numerical figures given in the table are for illustrations only* (Here the screw is moved downward and this downward movement decreases the circular scale reading)]

No. of obs	Initial C.S. reading when the screw touches the convex* spherical surface (R_1)	When the screw touches the plate			Total no. of C.S.D. rotated = x = $Nm + n$	Values of these divisions in mm (h') = $x \times$ (*l.c.*)	Mean (h') in mm	Value of $h = h'/10$ in cm
		No. of full rotation of circular disc (m)	Final circular scale reading (R_2)	Add no. of C.S. divisions rotated (n)*				
1.	29	3	98	31	331	...		
2.	30	3	0	30	330	...	...	...
3.	29	3	99	30	330	...		

***N.B.** (*a*) If the direction of movement of the screw (downward) decreases the circular scale reading, then $n = [N-(R_2 - R_1)]$, when $R_2 > R_1$ and $n = (R_1 - R_2)$, when $R_1 > R_2$.

(*b*) For **concave spherical surface** place the spherometer first on the plane glass plate and then on the concave surface.

• **Calculations :** $r = \frac{d^2}{6h} + \frac{h}{2}$ = ... + ... = ... cm

• **Precautions :** (*i*) To touch the screw with the surface it (the screw) should be lowered down always in one direction (to avoid backlash error) until the tip of screw just touches the tip of its **own image** below the surface.

(*ii*) Three different readings should be taken by touching the screw to three different points of the surface.

▢ Oral Questions and Answers ▢

1. Why is the instrument called a spherometer?

Ans. Because it is chiefly used to measure the curvature of a spherical surface.

2. What minimum thickness can be measured by it?

Ans. Equal to its least count.

3. What is screw pitch?

Ans. Distance through which the screw moves when it is given one complete rotation.

4. What is least count? Why is it so-called?

Ans. Least count equals the distance through which the screw moves when the circular disc is rotated through one division. Least count is the minimum thickness that can be 'counted'.

5. Why don't you count zero-error here?

Ans. Here we measure length by taking difference of two readings. So if there is any zero-error it cancels out.