EXPERIMENT – 0

Aim of the experiment: To make measurements on a provided object using the basic or simple measuring instrument in the laboratory, account for the incurred errors and report them methodically.

Principle: No measurement is perfect, and measurement uncertainties are inherent to any system. It is likely that the instrument reading is all the time off by a certain margin, i.e., it has a bias error.
It is also equally likely that upon making multiple measurements on the same object we get variations in the observations.
Accuracy is the closeness of agreement between a measured value and a true or accepted value. Measurement *error* is the amount of inaccuracy.
Precision is a measure of how well a result can be determined (without reference to a theoretical or true value). It is the degree of consistency and agreement among independent measurements of the same quantity; also, the reliability or reproducibility of the result.
The *uncertainty* estimate associated with a measurement should account for both the accuracy and precision of the measurement.
measurement = (best estimate ± uncertainty) units
Note: The terms *errors* and *uncertainty* are often used interchangeably to describe both, imprecision and inaccuracy. This usage is so common that it is impossible to avoid entirely. Whenever you encounter these terms, make sure you understand whether they refer to accuracy or precision, or both.
To estimate the measurement uncertainty, we use *standard deviation* (SD), that is a measure of how spread out the numbers in a data set are. It indicates the amount of variation from the average. A low standard deviation means the data points are close to the mean, while a high standard deviation means the data points are spread out over a larger range. Mathematically the standard deviation is given by,

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

where:
x_i are the individual data points
$\bar{x}$ is mean of the data
n is the number of data points in the population

We may define another parameter, *standard error* (SE), given by

$$\bar{\sigma} = \frac{\sigma}{\sqrt{n}} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n(n-1)}}$$

The standard error measures how much the sample means would vary from the actual population mean. It is the uncertainty of the sample mean. The standard error decreases as the sample size increases, because a larger sample size provides a more precise estimate of the population mean. A smaller standard error indicates that the sample mean is a more precise estimate of the population mean.
If the actual value or standard value of a quantity to be determined is known, accuracy or bias error (instrumental error) can be calculated as percentage error,

$$\%\ error = \frac{|actual\ value - value\ obtained|}{actual\ value} \times 100\%$$

EXPERIMENT – 0 A

Aim of the experiment: To measure the diameter of a rigid, cylindrical rod using Vernier calipers and assess the measurement uncertainty to report them methodically.

Equipment and devices required: Vernier calipers, rigid rod of uniform diameter, reading lens

Theory: One of the main basic measuring instruments in physics laboratory are the Vernier callipers that provide substantially (ten times) improved resolution that a simple ruler scale.
Before we make a measurement on the physical dimensions of objects using such an instrument, it's imperative on our part to ascertain the least count or the Vernier constant of that instrument.
The formula for the least count of a Vernier scale is:

$$L.C. = 1\ Main\ Scale\ (MS) - 1\ Vernier\ Scale\ (VS)$$

On our instrument, the smallest main scale division is $1\ mm$ and,

10 Vernier divisions coincide with 9 main scale divisions i.e., $9\ mm$

$\therefore$ 1 Vernier division $= \frac{9}{10}\ mm$

Hence, $L.C. = 1\ mm - 0.9\ mm = \ 0.1\ mm$

This is ten times better precision than the usual ruler scale that we use.

Diagrams

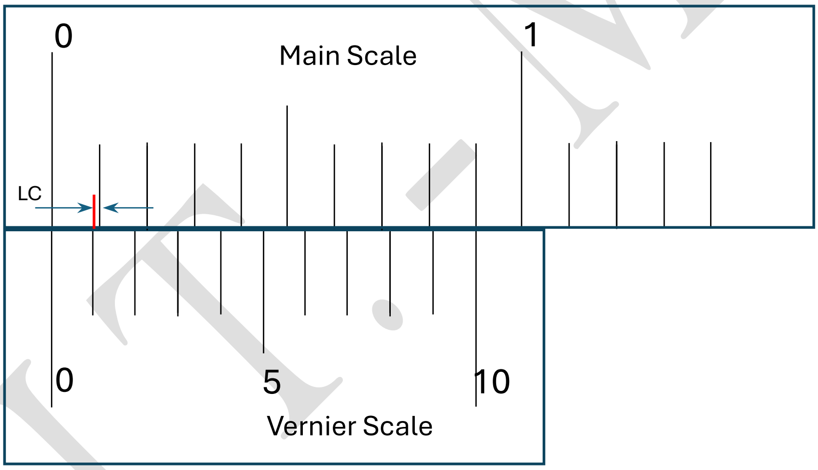

Fig.-1: Showing the main scale, the Vernier Scale and the physical meaning of LC as the difference of 1MS and 1 VS.

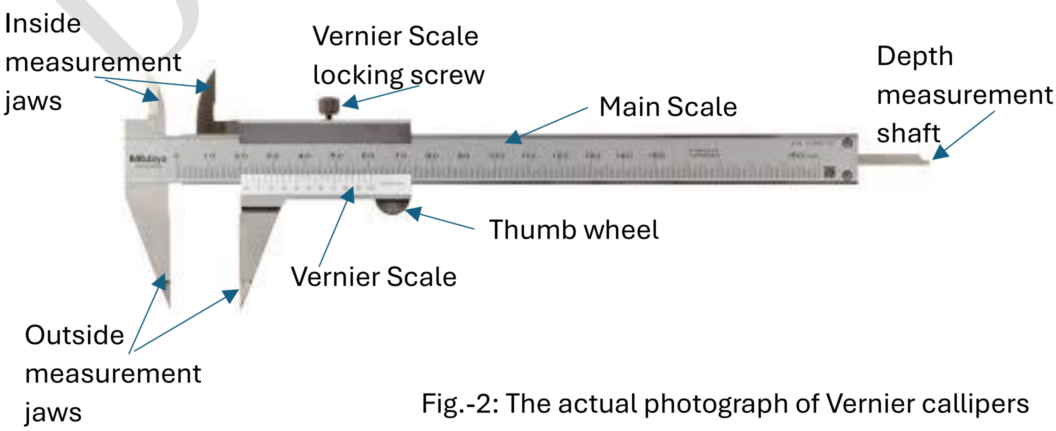

Fig.-2: The actual photograph of Vernier callipers showing all its components.

Procedure and Precautions:

Reading the Vernier scale: The marking on the main scale that appears just before the zero of the Vernier is the main scale reading (MSR) in millimeters.

One of the markings on the Vernier scale will be exactly in line with any one of the markings on the main scale. The number of that particular Vernier scale marking is the Vernier scale reading (VSR). VSR is just a number, when multiplied by the least count of the instrument it gets the unit same as that of the MSR. Thereafter, both may be added to get the complete reading.

Zero error: If the calipers are touching each other and the zero of the Vernier is after the zero of the main scale then the error is positive and it is to be subtracted from the subsequent readings. However, if the Vernier zero lands before the main scale zero, it is a negative zero error and will have to be added to the readings.

1. Make the jaws of the Vernier calipers touch each other. Do not keep anything in between.
2. Read the main scale and look for the Vernier coincidence. Record your observations in Table-1. This will be the zero error of the instrument. Good quality Vernier calipers seldom have zero errors. However, if they have; we must account for it.
3. While making measurements use a magnifying glass to read the scales.
4. Proceeding with the experiment, get a solid rod whose diameter is to be measured. The rod must be rigid enough not to deform when gripped firmly between the jaws of the Vernier calipers.
5. Measure the diameter of the rod at one specific location in one orientation only. Make at least 20 to 30 measurements and record your observations in Table-2.
6. Calculate and report your result, including the measurement uncertainty in an appropriate format.

Observations:

Table-1: Readings for the estimation of *zero error* of Vernier calipers.

S.No.	MSR	VSR	VSR × LC	Total
	(mm)		(mm)	(mm)
1				
2				
3				
$\cdots$	$\cdots$	$\cdots$	$\cdots$	
$\cdots$	$\cdots$	$\cdots$	$\cdots$	
n				
			Average zero error =	

We may choose to add or subtract the average zero error (depending upon, whether it is +ve or -ve) from each reading in Table-2, or it may be adjusted directly from the final value obtained.

Table-2: Readings for the measurement of diameter of a uniform rod using Vernier calipers of least count $0.1\ mm$.

S.No.	MSR	VSR	VSR × LC	Total	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
	(mm)		(mm)	(mm)	(mm)	$(mm)^2$
1	1.2	2	1.22	x_1	0.00	0.0000
2	1.2	1	1.21	x_2	-0.01	0.0001
3	1.1	9	1.19	x_3	-0.03	0.0009
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
i	1.2	0	1.20	x_i	-0.02	0.0004
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
n	1.2	3	1.23	x_n	+0.01	0.0001
				$\bar{x} = \frac{\sum_{i=1}^{n}(x_i)}{n}$		$\sum_{i=1}^{n}(x_i - \bar{x})^2$

Note: The values in the observation table are merely representative and have nothing to do with the actual values that you might record during experiments. These values are merely suggestive of the number of significant digits to be retained. By way of an example, in case you have 0.00047 in the right most column round it off to 0.0005 and enter it in the observation table.

Calculations

Calculate the average value of the diameter of the rod provided to you and compute the standard deviation and standard error.

$$\bar{\sigma} = \frac{\sigma}{\sqrt{n}} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n(n-1)}}$$

Results and discussion

The diameter d, of a rod provided is determined using Vernier calipers of Vernier constant 0.01 mm.

$$d = (\bar{x} \pm \bar{\sigma})\ mm$$

$$\%\ error\ in\ d = \frac{|d_{measured} - d_{standard}|}{d_{standard}} \times 100\%$$

It is always good to write a couple of lines discussing the result, its accuracy and precision. Also comment on why made measurements only at a single location of the rod and that too in one particular orientation, and not on the entire length of the rod.

EXPERIMENT – 0 B

Aim of the experiment: To measure the diameter of a thin wire using screw gauge and estimate the measurement uncertainty.

Apparatus required: Screw gauge, thin metal wire, reading lens

Principle: A screw gauge is a precision measuring instrument used for measuring small dimensions like, thickness, diameter, or length of an object, that is usually in millimeters or a fraction of it, with fair degree of accuracy. It utilizes a screw with precision thread for the purpose. The precision thread is crafted such that a thimble (fig-3) fitted with a counter thread (not shown in the diagram) advances a particular distance upon giving it a complete rotation. This distance is known as its pitch. A circular scale is marked on the thimble that effectively divides the pitch into equal parts. One part on the circular scale is its least count.

The least count of a screw gauge is given by,

$$L.C. = \frac{pitch}{number\ of\ circular\ scale\ divisions}$$

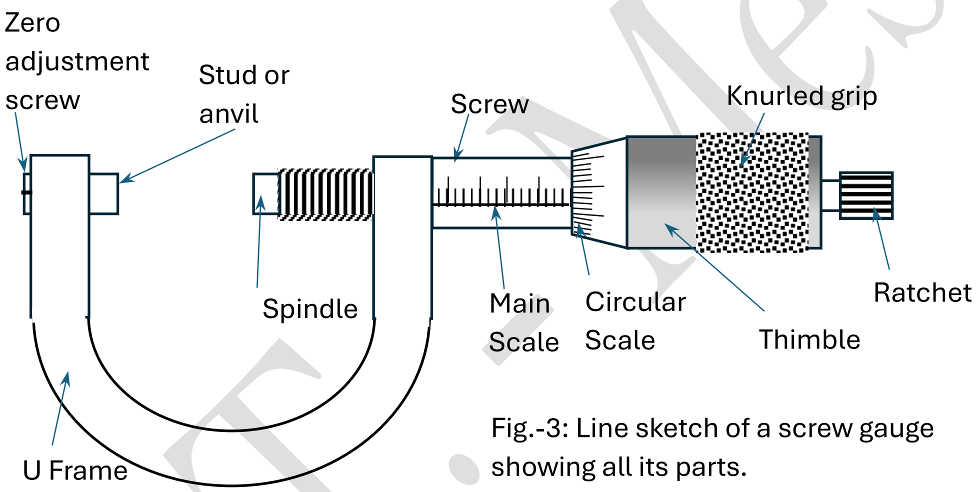

Fig.-3: Line sketch of a screw gauge showing all its parts.

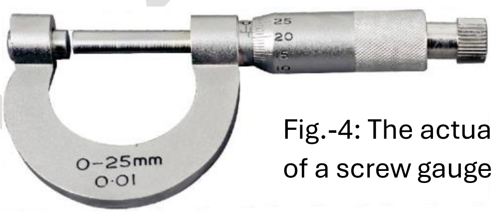

Fig.-4: The actual photograph of a screw gauge.

Preliminaries on reading the scales

<u>Reading the scales of a screw gauge</u>: Make the anvil and the spindle of the screw gauge touch each other. The thimble edge must be coinciding with zero of the main scale. If it doesn't then the total reading shown by the instrument is the zero error of that instrument in particular. Record the circular scale reading (CSR) that is against the horizontal line of the main scale. Multiply the CSR with LC and add it to the MSR, to get the initial reading.

Next, clamp an object between the anvil and the spindle of the screw gauge. See the number of main scale divisions the thimble edge has traversed in the process. Also note the circular scale reading (CSR) against the horizontal line of the main scale. Multiply the CSR with LC and add it to the MSR, to get the final reading. Take the difference of the final and the initial readings. Make sure to compensate the readings for zero error.

A better idea however, is to start the experiment by clamping the wire between the anvil and the spindle and record the CSR only (example value 23). Then gently loosen the spindle a bit to remove the wire and again rotate the thimble with the help of the ratchet so that the spindle hits the anvil. While doing this make sure to count the number of complete rotations through which the thimble has rotated. That is from 23 (example value) to next 23 after one complete rotation is 1 MSR. Now, suppose it has taken 5 complete rotations and 37 divisions more to come to a stop. So, the MSR in this case is 5 and the CSR is 37.

The size of 1 MSR may be either 0.5 mm or 1 mm depending upon the instrument that we are using. Let us assume 1 MSR to be 0.5 mm on our instrument. In this case MSR = 5 x 0.5 = 2.5 mm.

CSR is 37; we multiply it with LC, i.e., 0.01 mm (for our instrument, say), getting 0.37 mm

Adding 2.5 mm and 0.37 mm gives a total of 2.87 mm

With a little care, this technique offers a great deal of simplicity and avoids the reckoning of zero error altogether.

The choice of technique however rests with the experimenter.

Zero error: If no object is present between the anvil and the spindle, the main scale must read zero. The circular scale however, may show a small value. If the circular scale zero crosses the reading mark, it has a positive zero error and needs to be subtracted from the reading. On the other hand, if it did not cross the reading mark then the number of divisions before zero that remained from crossing is the negative error and needs to be added to get the correct final value.

Procedure and Precautions:

1. Give the thimble a few rotations to ascertain the pitch of the instrument and divide it by the total number of circular scale divisions (CSD) to get the least count (LC) of the instrument.
2. Make the stud and the spindle of the screw gauge touch each other without keeping anything in between.
3. Read the main scale and the circular scale. Record your observations in Table-3. This will be the zero error of the screw gauge.
4. If we haven't placed any object for measurement and the screw gauge shows a value other than zero, this is an error known as zero error or the bias error. We need to account and suitably adjust our reading for this error.
5. Ideally the zero of the circular scale should coincide with the zero of the main scale. In such a case the zero error has a null value.
6. While making measurements use a magnifying glass to read the scales.
7. Get a thin wire whose diameter is to be measured.
8. Measure the diameter of the wire at one specific location where it is uniform. Make at least 20 to 30 measurements and record your observations in Table-2.
9. Calculate and report your result, including the measurement uncertainty in an appropriate format.

Table-3: Readings for the estimation of *zero error* of a screw gauge.

S.No.	MSR	CSR	CSR × LC	Total
	(mm)		(mm)	(mm)
1				
2				
3				
$\dots$	$\dots$	$\dots$	$\dots$	
$\dots$	$\dots$	$\dots$	$\dots$	
n				
			Average zero error =	

We may choose to add or subtract the average zero error (depending upon, whether it is +ve or -ve) from each reading in Table-3, or it may be adjusted directly from the final value obtained.

Table-4: Readings for the measurement of diameter of a thin wire using a screw gauge of least count $0.01\ mm$.

S.No.	MSR	CSR	CSR × LC	Total	Corrected Total	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
	(mm)		(mm)	(mm)	(mm)	(mm)	$(mm)^2$
1					x_1		
2					x_2		
3					x_3		
$\dots$					$\dots$		
$\dots$					$\dots$		
i					x_i		
$\dots$					$\dots$		
$\dots$					$\dots$		
n					x_n		
				$\bar{x} = \frac{\sum_{i=1}^{n}(x_i)}{n}$			$\sum_{i=1}^{n}(x_i - \bar{x})^2$

Calculations

Calculate the average value of the diameter of the rod provided to you and compute the standard deviation and standard error.

$$\bar{\sigma} = \frac{\sigma}{\sqrt{n}} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n(n-1)}}$$

Results and discussion

A thin wire of 22 SWG has been provided. Its diameter ($d_{standard}$) according to the standard wire-gauge (SWG) table is 0.7112 mm.

Note these values are representative. Ensure the SWG of the wire provided to you.

The diameter of the provided wire as determined using the screw gauge is

$$d = (\bar{x} \pm \bar{\sigma})\ mm$$

$$\%\ error\ in\ d = \frac{|d_{measured} - d_{standard}|}{d_{standard}} \times 100\%$$

It is always good to write a couple of lines discussing the result, its accuracy and precision. Also comment on why we made measurements only at a single point on the wire and that too in one particular orientation, and not on the entire length of the wire. Mention what information we gain from it and what we couldn't.

EXPERIMENT – 0 C

Aim of the experiment: To measure the radius of curvature of a lens using a spherometer and estimate the measurement uncertainty.

Equipment and devices required: Spherometer, a glass lens (of focal length greater than 15 cm), a reading lens

Preliminaries on reading the scales

<u>Reading the scales of a spherometer</u>: Place the spherometer on a flat glass plate and make the central pin touch it's surface. The disc edge must be coinciding with zero of the main scale. Note the circular scale reading (CSR) that is against the main scale. Multiply the CSR with LC and add it to the main scale reading (MSR), to get the initial reading.

Lift the central pin quite a bit and place the spherometer on a curved surface such that its outer three pins are on that surface itself. Gradually lower the central pin and make it touch the surface. Note the MSR and the CSR. Multiply the CSR with LC and add it to the MSR, to get the final reading. Take the difference of the final and the initial readings.

<u>A better idea however</u>, is to start the experiment by placing the spherometer on the curved surface such that all the pins touch the surface. Record the CSR only (example value 57). Then place the spherometer on a flat glass plate and lower the central pin making it touch the glass surface. While doing this make sure to count the number of complete rotations through which the reading disc has rotated. That is, from 57 (example value) to next 57 after one complete rotation is 1 MSR. Now, suppose it has taken 3 complete rotations and 26 divisions more to come to a stop. So, the MSR in this case is 3 and the CSR is 26.

The size of 1 MSR may be either 0.5 mm or 1 mm depending upon the instrument that we are using. Let us assume 1 MSR to be 0.5 mm on our instrument. In this case MSR = 3 x 0.5 = 1.5 mm.

CSR is 26; we multiply it with LC, i.e., 0.01 mm (for our instrument, say), getting 0.26 mm

Adding 1.5 mm and 0.26 mm gives a total of 1.76 mm

With a little care, this technique offers a great deal of simplicity and avoids the reckoning of zero error altogether.

The choice of technique however rests with the experimenter.

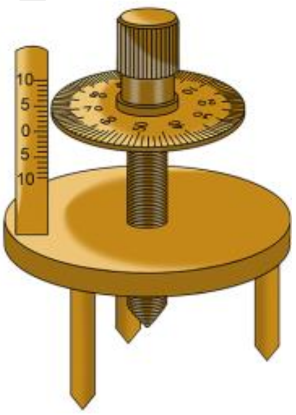

Fig.-5: The actual picture of a spherometer.

Principle:

A spherometer is a precision measuring instrument used for determining the radius of curvature of spheres or its small part / portion. It is especially designed to

The least count of a spherometer is:

$$L.C. = \frac{pitch}{number\ of\ circular\ scale\ divisions}$$

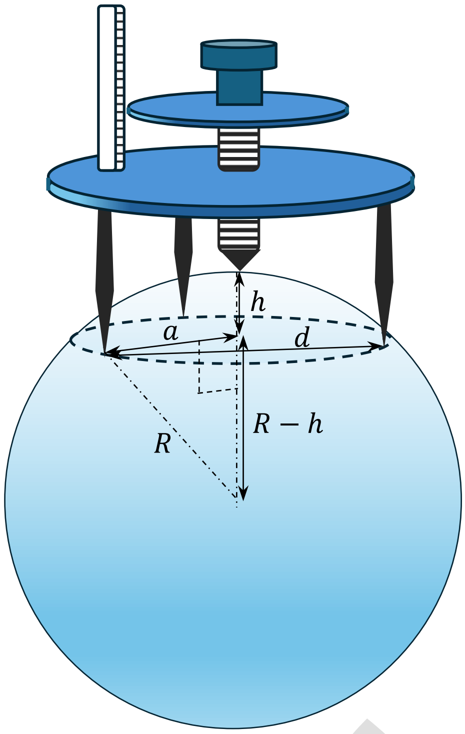

Fig.-6: Geometry of spherometer pin tips when placed on a hemisphere.

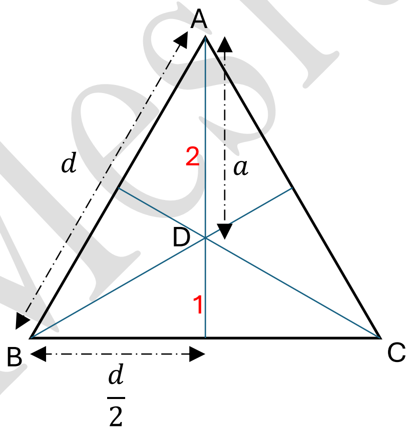

Fig.-7: Geometry of spherometer pin tips when placed on a flat surface

Placing the three pins A, B and C of the spherometer on a plane, the central pin lies at the centroid, D of the equilateral triangle ABC. From the geometry of fig-7 we may write,

$$a = \frac{2}{3}\sqrt{d^2 - \frac{d^2}{4}}$$

or,
$$a = \frac{d}{\sqrt{3}}$$

When the spherometer is placed on a curved surface of radius R, such that all the four pins touch the surface then, again from the geometry (Pythagoras) of fig-6 we may write,

$$or, \qquad R^2 = a^2 + (R - h)^2$$

$$or, \qquad R^2 = a^2 + R^2 + h^2 - 2hR$$

$$or, \qquad a^2 = 2hR - h^2$$

Substituting a in the above equation we get

$$\frac{d^2}{3} = 2hR - h^2$$

$$or, \qquad R = \frac{d^2}{6h} + \frac{h}{2}$$

The above relation may be used to determine the radius of curvature of the curved surface using a spherometer.

In case we are using a biconvex lens to experimentally determine its radius of curvature, we may consider verifying the same using a simple technique in which we try to focus the image of a window of our lab on the wall on the other side, while keeping a long ruler scale just under it measure its focal length. Remember that for a biconvex lens, $Radius\ of\ curvature\ (R_{optical}) = focal\ length$. This value may be used to estimate the percent error in our final result for R.

Procedure and Precautions:

1. Lift the central pin of the spherometer sufficiently. Put the spherometer on the biconvex lens, so that the three pins rest fully on the bulged portion.
2. Lower the central pin gently by rotating the screw-head, so that the pin just touches the lens surface. *Note that at this point the pin and its image reflected from the lens surface just appear to touch each other.*
3. Note the main scale and the circular scale readings.
4. Now, put the spherometer on a flat glass plate and gradually lower the central pin to make it touch the glass surface.
5. Again, note the main scale and the circular scale readings. The difference in the two noted readings will give you the value for h.
6. Now, lift the central pin of the spherometer sufficiently. Put the spherometer on a free page of your rough notebook and apply a force on its frame so that the three pins leave their mark on it. Measure the separation between any of the two marks. This is d, as shown in fig-7.
7. Populate table-5, calculate and report your results, including the measurement uncertainty in an appropriate format.
8. Also report the percent error in your determination.

Table-5: Readings for the measurement of radius of curvature of a lens using a spherometer of least count $0.01\ mm$.

S.No.	MSR	CSR	CSR × LC	Total	Corrected Total	$R = \frac{d^2}{6h} + \frac{h}{2}$	$(x_i - \bar{x})^2$
	(mm)		(mm)	(mm)	(mm)	(mm)	$(mm)^2$
1						x_1	
2						x_2	
3						x_3	
...						...	
...						...	
i						x_i	
...						...	
...						...	
n						x_n	
						$\bar{x} = \frac{\sum_{i=1}^{n}(x_i)}{n}$	$\sum_{i=1}^{n}(x_i - \bar{x})^2$

Calculations

Average value of the radius of curvature of the biconvex lens, the standard deviation and standard error in its determination are all calculated.

Standard error is given by, $\bar{\sigma} = \frac{\sigma}{\sqrt{n}} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n(n-1)}}$

Results and discussion

The radius of curvature of the lens

$$R = (\bar{x} \pm \bar{\sigma})\ mm$$

$$\%\ error\ in\ R = \frac{|R_{spherometer} - R_{optical}|}{R_{optical}} \times 100\%$$

A couple of lines discussing the result, its accuracy and precision viz-a-viz the radius of curvature of the biconvex lens determined by optical technique, would fetch credit to the experimenter.