Principles of Physics I (PHY111)

Lab

Experiment no: 5

Name of the experiment: Determination of the refractive index of a liquid using a plane mirror and a convex lens

Theory

For a certain couple of media and a ray of certain wave length the ratio of the trigonometric sine of angle of incident to the trigonometric sine of angle of refraction is always a constant which is said to be refractive index of the second medium (where the ray enters after refraction) with respect to the first medium (from where the ray comes before refraction) for that wave length of light.

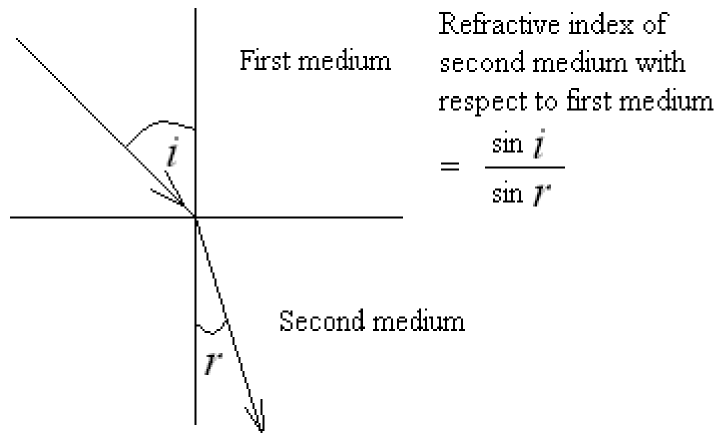

Figure 1: Refractive index

If a lens consists of a material of refractive index μ, its radius of curvature of first surface (the surface what a ray first encounters) is r_1 and that of second surface is r_2, then in air its focal length f satisfies the following equation:

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \qquad (1)$$

For a plane concave lens from equation (1) it can be shown that $\mu = 1 + \dfrac{r}{f}$

(2)

where r is the radius of curvature of its curved surface.

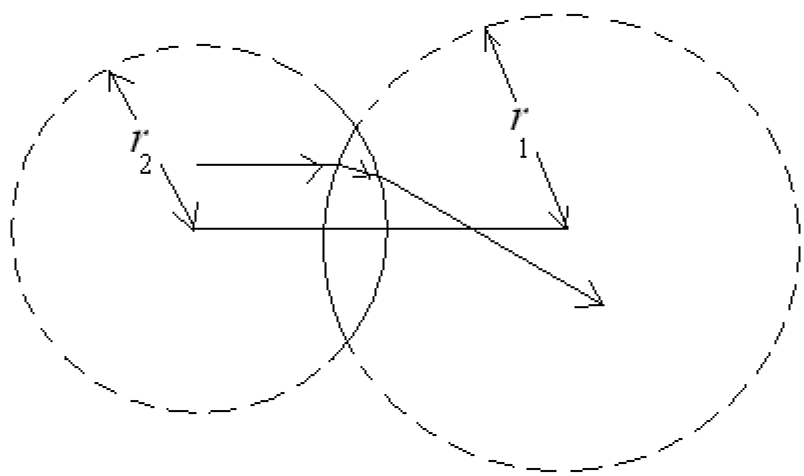

Figure 2: A lens having radii of curvature of r_1 and r_2

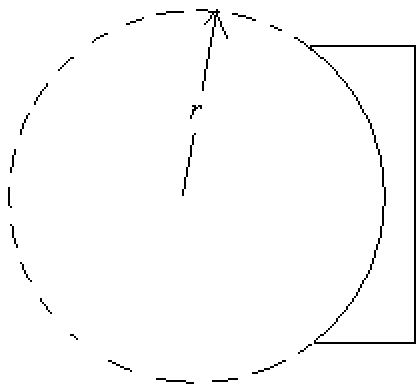

Figure 3: Plane concave lens

In this experiment we put some drops of liquid on a plane mirror. Then we place a convex lens on the liquid drops. Liquid drops trapped inside the convex lens and the plane mirror form a plano-concave lens.

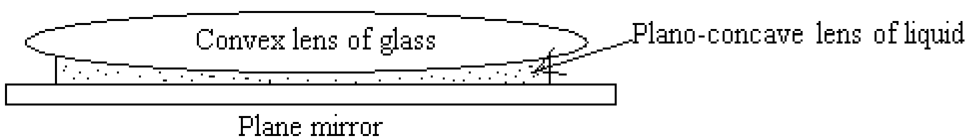

Figure 3: Plano concave lens is formed by water drops trapped between a convex lens and a plane mirror.

Radius of curvature of this plano-concave lens is equal to the radius of curvature of the bottom surface of the convex lens. By using a spherometer we can find out the radius of curvature, *r* of the convex lens. Now if we can find out *f* then by putting the values of *r* and f in equation (2) we can deduce μ .

If the focal length of the convex lens is f1 and the focal length of the combined lens (Convex and plano-concave) lens is F, then

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f}$$

$$=> \quad f = \frac{Ff_1}{f_1 - F}$$

Since the lens is plano-concave *f* is negative. If we consider the absolute value of f, then

$$f = \frac{Ff_1}{|f_1 - F|} \qquad (3)$$

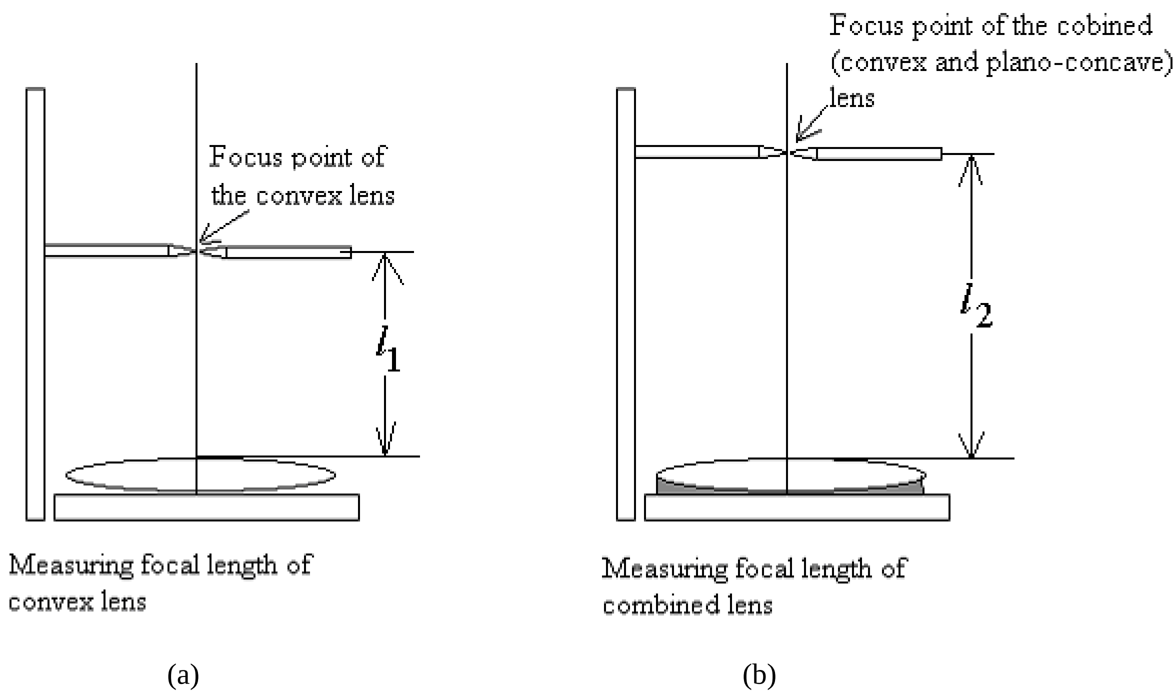

Figure 4: Measuring focal length using a plane mirror.

If we keep a mirror behind a lens and put an object on the focus point of the lens the image of the object will form at the same focus point where the object is. If it is an extended object, its image will be inverted and the size of the image will be as same as that of the object.

In this experiment at first we keep the convex lens on the plane mirror. Then gradually move an object (possibly a pen attached to a stand) along the principal axis of the lens until we see its image is inverted, equal size of the object and at the same position with the object. When the inverted image is of equal size of the object and at the same position, then we realize the object is at the focus point of the lens. By using a scale we measure the focal length, f_1 of the convex lens.

Next we pour some liquid drops on the mirror. Keep the convex lens on the drops to form a combined lens (convex lens and the plano-concave lens of liquid). In the same method we find out the focal length, F of the combined lens.

By using equation (3) we work out the focal length of the plano concave liquid lens, f.

Finally putting the values of r and f in equation (2) we deduce the refractive index of the liquid.

Apparatus

A spherometer, a biconvex lens, a plane mirror, liquid, a stand to hold the object (a pen), a meter scale and a slide calipers.

Procedure

1. Measure the radius of curvature of the surface of the bi-convex lens by using the spherometer. Please see appendix A (shown in the softcopy of this script available in the server) to know how to do so. Record the data in section A of the data sheet.

2. Place the mirror on the floor. Keep the convex lens on the mirror. Clamp the object (a pen) with the stand so that the nib of the pen is on the mid point of the lens. When the pen is close to the lens you should see a magnified erect image of the pen.

3. Move the pen gradually upward. You should notice that the image is getting more and more magnified. A time comes when the image is completely diminished. If you move the pen more upward, you should notice that again an image of the

object is created but this time it is inverted and still magnified. As you move the pen upward now, size of the image will get reduced.

4. Now move your head left and right to see whether the pen and its image are at the same position (that means whether the nib of the pen reaches at the focus point). If you see that they are not oscillating simultaneously (you see a gap between them which increases and decreases as you move your head left and right) with respect to your eye then the pen has not yet reached the focus point and still you have to move it gradually upward. When you see that the nib and the image are oscillating simultaneously and the gap between the nib and its image does not vary as you move your head left and right, then you realize that the nib has reached the focus point. At this position the size of the image will be equal to the size of the pen. Spin the screw of the clamp to fix it with the stand.

5. By using a meter scale measure the distance of the pen's nib from the mid point of the lens. This is the value of l_1. Write it down in the table-2 of section B of the data sheet.

6. By using a slide calipers measure the thickness, t of the lens. Please see appendix B (shown in the softcopy available in the server) to know how to do so.

7. Calculate the focal length, f_1 of the convex lens. It is given by, $f_1 = l_1 + \frac{t}{3}$

8. Now pour some liquid drops on the mirror. In the same way of steps 2 to 7 work out the focal length, F of the combined lens.

9. Using equation (3) deduce the focal length, f of the plano-concave lens of liquid.

10. By putting the value of r and f in equation (2) deduce the refractive index of the liquid.

Read carefully and follow the following instructions:

- **Please READ the theory carefully, TAKE printout of the 'Questions on Theory' and ANSWER the questions in the specified space BEFORE you go to the lab class.**
- **To get full marks for the 'Questions on Theory' portion, you must answer ALL of these questions CORRECTLY and with PROPER UNDERSTANDING, BEFORE you go to the lab class. However, to ATTEND the lab class you are REQUIRED to answer AT LEAST the questions with asterisk mark.**
- **Write down your NAME, ID, THEORY SECTION, GROUP, DATE, EXPERIMENT NO AND NAME OF THE EXPERIMENT on the top of the first paper.**
- **If you face difficulties to understand the theory, please meet us BEFORE the lab class. However, you must read the theory first.**
- **DO NOT PLAGIARIZE. Plagiarism will bring ZERO marks in this WHOLE EXPERIMENT. Be sure that you have understood the questions and the answers what you have written, and all of these are your own works. You WILL BE asked questions on these tasks in the class. If you plagiarize for more than once, WHOLE lab marks will be ZERO.**
- **After entering the class, please submit this portion before you start the experiment.**

Name: ______________________ ID: _______________ Sec: ___ Group: __ Date: ___________

Experiment no: ___

Name of the Experiment: ____

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Questions on Theory

*1) Define 'refractive index of a medium'. [1]

Ans:

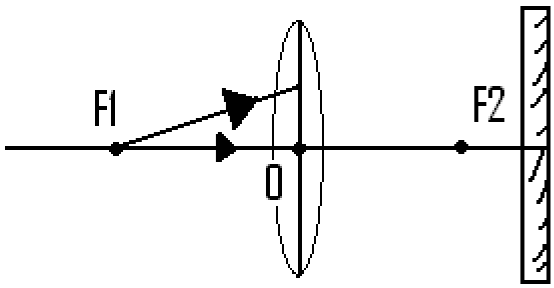
*2) Draw a lens having radii of curvature r_1 and r_2. If μ is the refractive index of the material of the lens with respect to air, then write down the formula of its focal length, f. [1]

Ans:

*3) Draw a plano-concave lens. You can consider that the plane surface of this lens is a portion of a huge sphere, hence its radius of curvature is ∞. For a plano-concave lens by using the equation of question 2 prove that, $\mu = 1 + \frac{r}{f}$. Here r is the radius of curvature of the concave surface of the lens. [1]

Ans:

4) Please see the figure where a point object is kept on one of the principal foci, **F1** and a mirror is kept on the other side of the lens, perpendicular to the principal axis. Where the image of the point object will form, explain with the help of ray diagrams. [Hints: Consider the two rays shown in the figure, then think how they will be refracted by the lens, then reflected by the mirror, next again refracted by the lens and finally where they meet each other.] [2]



Ans:

- **Draw the data table(s) and write down the variables to be measured shown below (in the 'Data' section), using pencil and ruler BEFORE you go to the lab class.**

- **Write down your NAME and ID on the top of the page.**
- **This part should be separated from your Answers of "Questions on Theory" part.**
- **Keep it with yourself after coming to the lab.**

Data:

A) Measurement of radius of curvature of the surface of lens:

Separation between two legs of the spherometer, a =

Pitch of the spherometer =

Least Count of the spheromenter, $L.C. =$

Number of full revolutions completed by the circular scale, N=

Number of extra divisions, F =

Displacement of the middle leg from the topmost point of the lens to the plane surface,

$$h = N \times \text{Pitch} + F \times \text{Least Count} =$$

Radius of curvature of the lens, $r = \frac{h}{2} + \frac{a^2}{6h} =$

B) Table 1: Measurement of the focal length of convex lens and the combined lens

Distance between the object and the top most point of convex lens (without liquid), l_1 (cm)	Focal length of the convex lens $f_1 = l_1 + \frac{t}{3}$ (cm)	Average value of f_1 (cm)	Distance between the object and the top most point of combined lens (with liquid), l_2 (cm)	Focal length of the combined lens $F = l_2 + \frac{t}{3}$ (cm)	Average value of F (cm)	Focal length of the plano-concave lens of liquid $f = \frac{Ff_1}{\lvert f_1 - F \rvert}$ (cm)

C) Thickness of the convex lens, t = _______________ cm

- **READ the PROCEDURE carefully and perform the experiment by YOURSELVES. If you need help to understand any specific point draw attention of the instructors.**
- **DO NOT PLAGIARIZE data from other group and/or DO NOT hand in your data to other group. It will bring ZERO mark in this experiment. Repetition of such activities will bring zero mark for the whole lab.**
- **Perform calculations by following the PROCEDURE . Show every step in the Calculations section.**
- **Write down the final result(s).**

Calculations

Result:

- **TAKE printout of the 'Questions for Discussions' BEFORE you go to the lab class. Keep this printout with you during the experiment. ANSWER the questions in the specified space AFTER you have performed the experiment.**
- **Attach Data, Calculations, Results and the Answers of 'Questions for Discussions' parts to your previously submitted Answers of 'Questions on Theory' part to make the whole lab report.**
- **Finally, submit the lab report before you leave the lab.**

Name: ___________________________ ID: ___________________

Questions for Discussions

Discussions

1) What is the value of refractive index of the liquid found in the textbook? [0.5]

Ans:

2) What is the percentage of error you made while deducing the refractive index of the liquid? [0.5]

Ans:

3) If the object is placed within the principal focus of the lens what type of image will be formed? [0.5]

Ans:

4) Now, you know the refractive index of the given liquid (water). If you are given another liquid, how can you find out its refractive index without using a spherometer again? [Read the textbook] [0.5]

Ans:

Appendix A: How to use a spherometer to measure radius of curvature

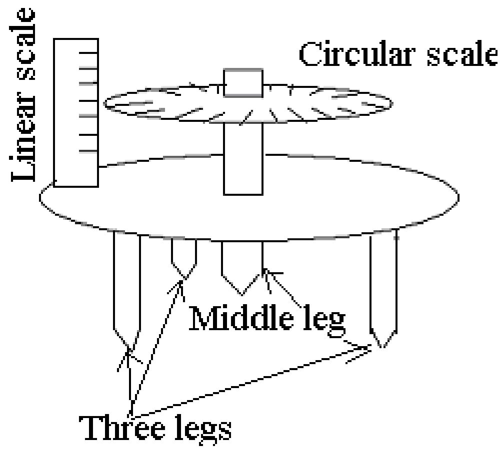


Figure A1: A typical spherometer

Principle: The spherometer is kept on the spherically curved surface so that each of the three legs touches the surface.

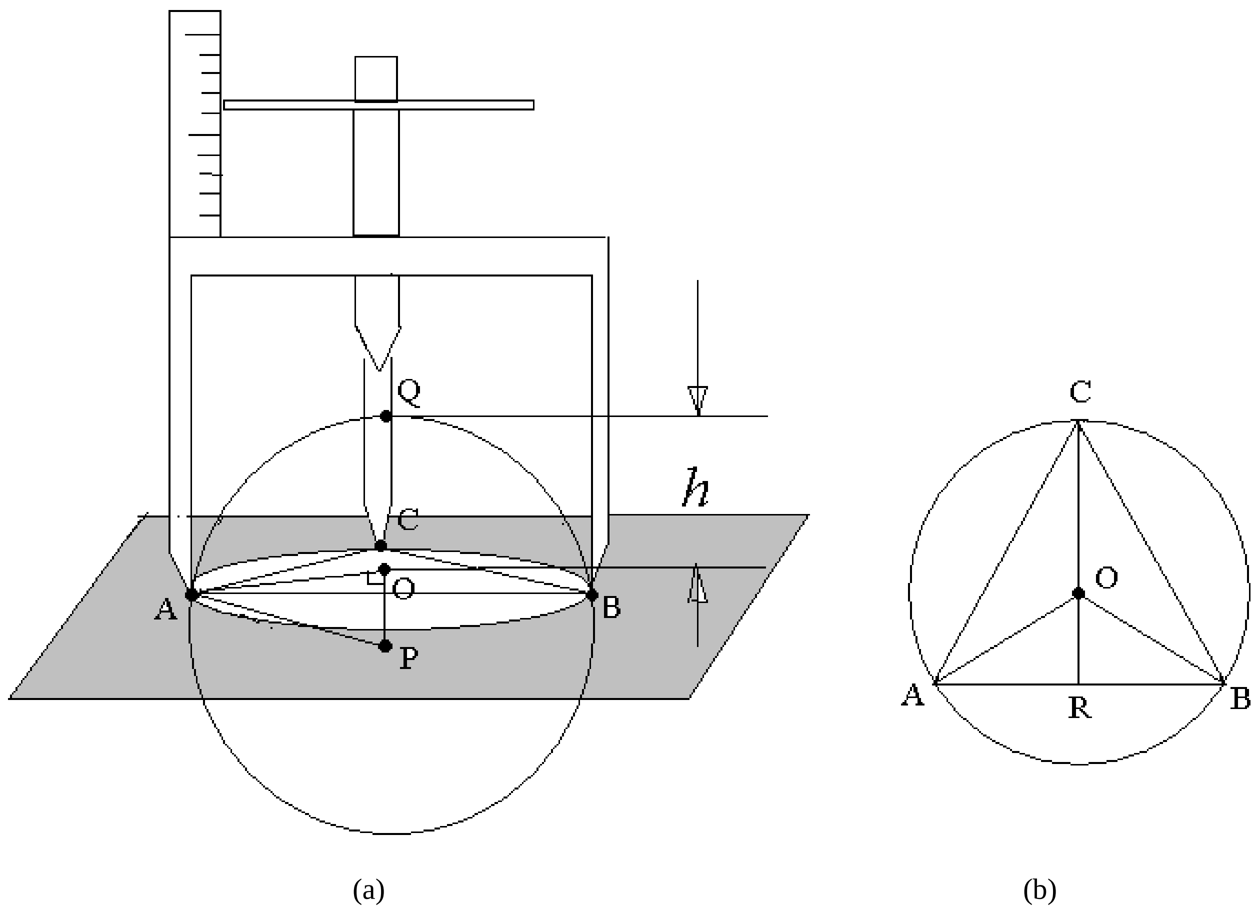


Figure A2: (a) A spherometer on a spherically curved surface. (b) Top view of the equilateral triangle ABC

Suppose the centre of the spherically curved surface is P and the three legs touch the surface at points A, B and C. Imagine a plane passing through these three points. This plane will intersect the sphere at a circle ABC. The centre of the circle is O. The top most point of the curved surface is Q. The separation between O and Q is h. If we see the top view (figure A2 (b)), the triangle ABC is equilateral. So AB = BC =CA = *a*. O is the pericentre of ΔABC. OR$\perp$ AB. So, AR = $\frac{a}{2}$

$$\angle CAB = 60^\circ$$

$$\therefore \angle OAR = 30^\circ$$

From ΔOAR,

$$\cos\angle OAR = \cos 30^\circ = \frac{AR}{OA}$$

$$=> OA = \frac{AR}{\cos 30^\circ} = \frac{a/2}{\sqrt{3}/2} = \frac{a}{\sqrt{3}}$$

Now see figure A2 (a) :

AP = radius of curvature of the sphere = *r*

Applying Pythagoras theorem for ΔAOP,

$$AP^2 = OP^2 + OA^2$$

$$=> r^2 = (r-h)^2 + \left(a/\sqrt{3}\right)^2$$

$$=> r = \frac{h}{2} + \frac{a^2}{6h} \qquad \text{(A1)}$$

By using spherometer we measure *h*

Procedure

Step 1: By rotating the circular scale of the spherometer move the middle leg sufficiently upward. Put the spherometer on a white paper. Exert a little pressure on it so that you can see three marks of the three legs of the spherometer. Join the marked points. It should be an equilateral triangle if there is no mechanical error. Measure the length of each of the sides of the triangle. Take their average. It is the value of *a*.

Step 2: Rotate the circular scale for one complete revolution. See what the linear displacement of the circular scale is along the linear scale. This is the pitch of the spherometer. See how many numbers of divisions are there in the circular scale. Find out the least count by using following equation,

$$L.C. = \frac{Pitch}{Number\ \ of\ \ divisions\ \ of\ \ circular\ \ scale}$$

Step 3: Keep the spherometer on the surface of the lens so that each of the three legs touches the lens surface. Now gradually rotate the circular scale, until the middle leg of the spherometer touches the top most point of the lens surface.

Step 4: Notice which mark the circular scale coincides the linear scale. Record the reading of this mark (A) in the data table. In figure A3 the reading of this mark is 63

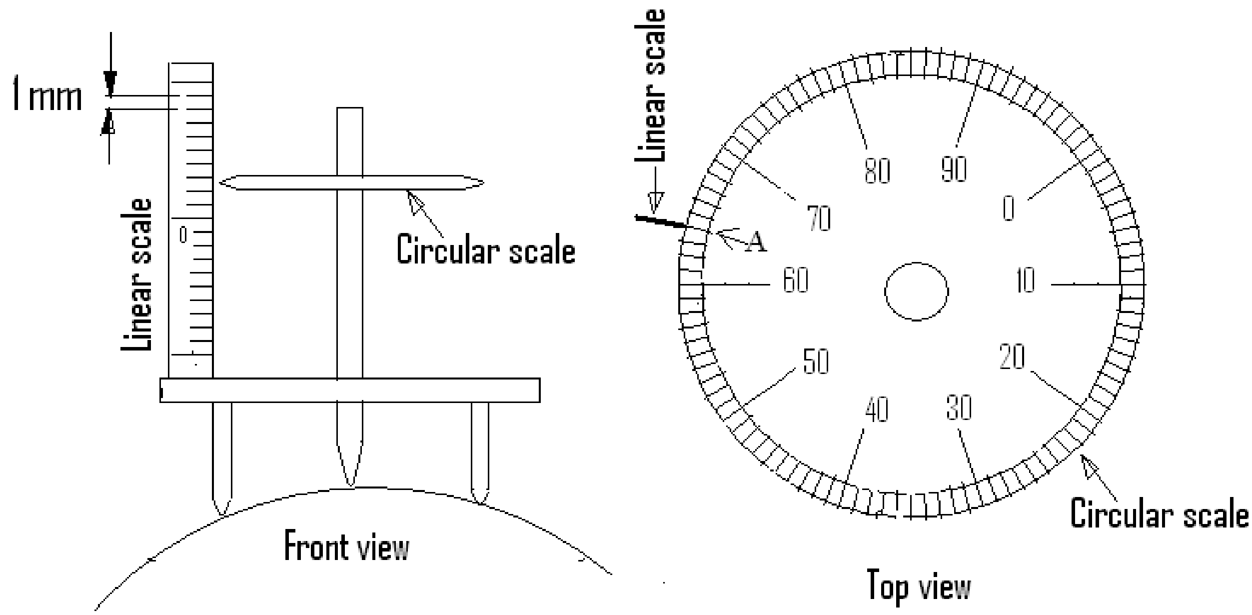


Figure A3: Front and top view of the system when the middle leg of the spherometer touches the topmost point of the lens.

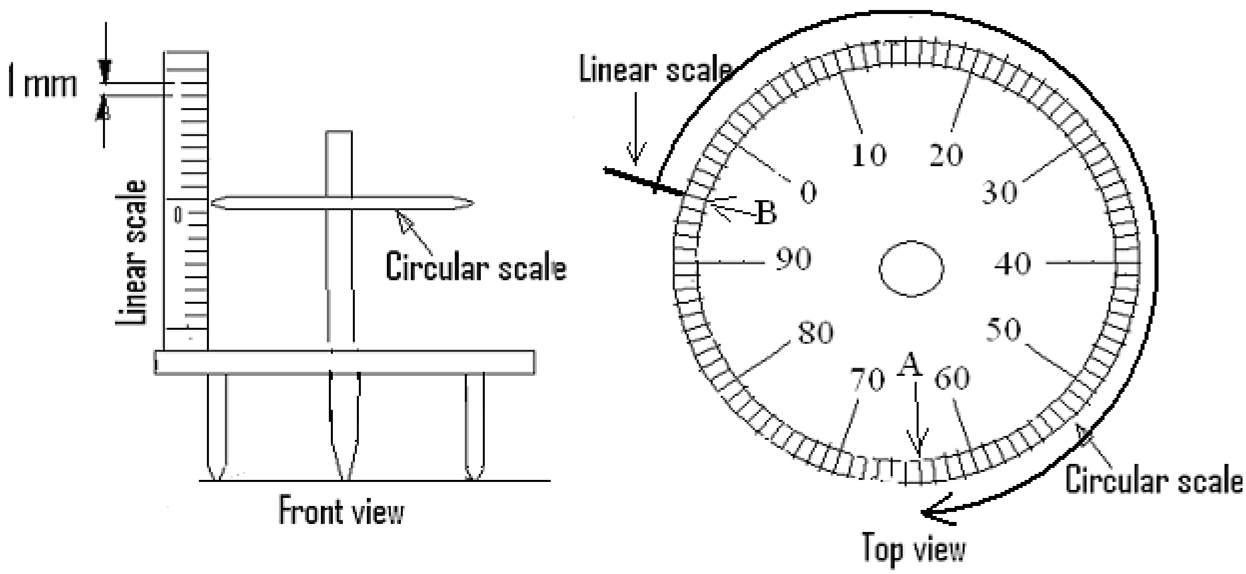


Figure A4: Front and top view of the system when the middle leg of the spherometer touches the plane surface.

<u>Step 5</u>: Now keep the lens on the plane surface (the plane mirror what is provided to you). Until the middle leg touches plane surface, spin the circular scale CLOCKWISE and notice how many number of times the mark A makes complete revolutions (when the mark A crosses the linear scale, A makes a complete revolution). Clearly the displacement of the middle leg from the topmost point of the lens to the plane surface is the value of *h* (=OQ of figure A2)

<u>Step 6</u>: Notice which mark of the circular scale coincides the linear scale when the middle leg touches the plane surface. Record the reading of this mark (B) in the data table. As for example in figure A4 it is 95

<u>Step 7</u>: Count how many number of circular scale divisions are there from B to A along clockwise order that is *F*. In figure A4 this is 69. Then F times least count is the fractional revolution made by the mark A.

<u>Step 8</u>: Finally calculate the value of h by using the following formula,

$$h = N \times \text{Pitch} + F \times \text{Least Count}$$

APPENDIX B: How to measure length with a slide calipers

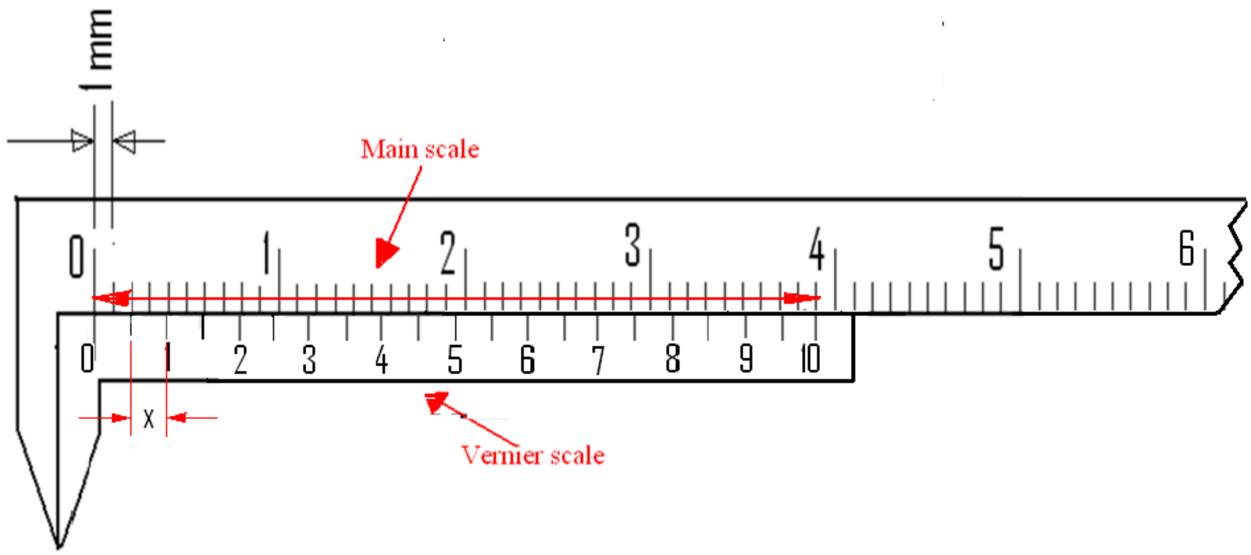


Figure 1: A slide calipers when its two jaws touch each other.

Figure 1 shows you the magnified view of the slide calipers what you are using in the laboratory. When the two jaws touch each other the 0 mark of main scale coincides the 0 mark of the Vernier scale, if the slide calipers is free from mechanical error.

Step 1: Notice what the length of smallest division of the main scale is.

It is 1 mm, for the slide calipers shown above

Step 2: Count the number of the smallest divisions of the Vernier scale.

Here, it is 20.

Step 3: Measure the length of the all 20 divisions of the Vernier scale by using the main scale (If your vernier scale had 40 divisions instead of 20, then you would measure the length of all 40 divisions in this step).

Here, it is 39 mm.

Step 4: Work out the length of the smallest division of the Vernier scale.

If x is the length of the smallest division of the Vernier scale then we can write,

$20\,x = 39$ mm
So, $x = (39/\,20)$ mm $= 1.95$ mm

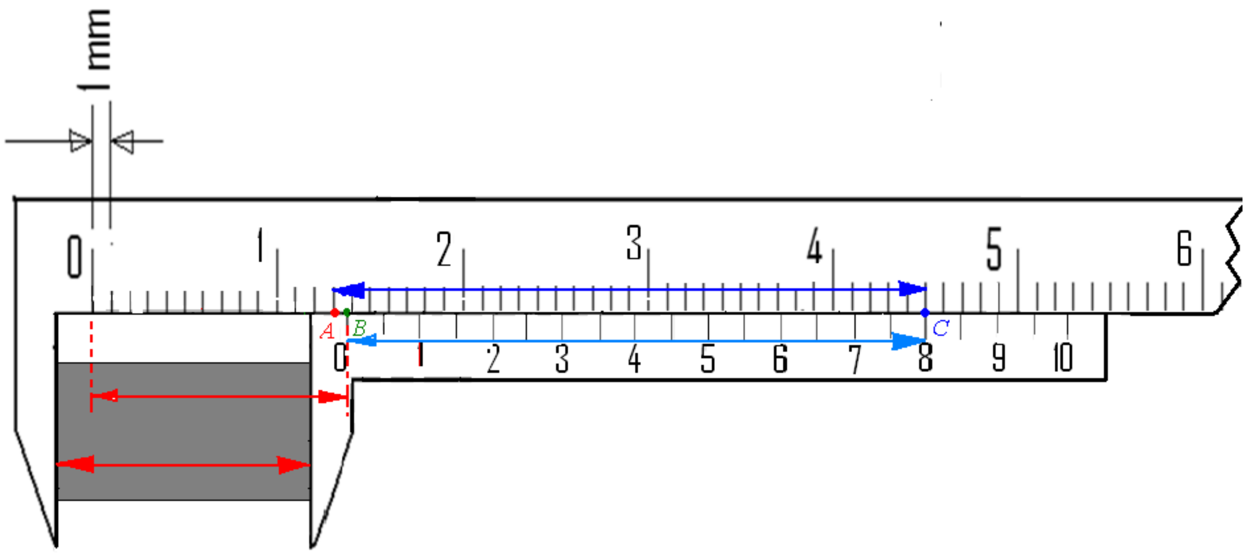


Figure 2: Same slide calipers containing a body between its two jaws.

Step 5: Now keep the body between the jaws of the slide calipers. So the 0 mark of the Vernier scale is displaced. Separation between the 0 mark of the main scale and the 0 mark of the Verinier scale is equal to the length of the body. Which mark of the main scale does the 0 of Vernier scale (B) just cross?

We can see, for this body it the mark of 13 mm. Let's denote it by A (figure 2)and the 0 of Vernier by B.

So, the length of the body = 13 mm + AB

Main scale reading = 13 mm

Step 6: Now, see which mark of the Vernier scale coincides with any mark of the main scale.

We can see it is the mark of 16th division of the Vernier scale. In the Vernier scale this mark is denoted by 8. Let's call it point C.

Step 7: Measure AC by using main scale.

AC = 32 mm

Step 8: Measure BC by using Vernier scale.

BC = 16 x = 16×1.95 mm = 31.2 mm

Step 9: Find AB.

AB = AC – BC = (32-31.2) mm = 0.8 mm
So Vernier scale reading = 0.8 mm

Step 10: Now find the total length of the body

Length of the body = Main scale reading + Vernier scale reading
= (13 + 0.8) mm

Vernier constant:

Go back at step 9. Look how we find AB (Excess by Vernier scale)

AB = (32 – 31.2) = 16 (2-1.95) mm = 16 × 0.05 mm

Here 16 was the mark-number of Vernier which coincided with a mark of main scale. This is called "vernier coincident". By multiplying it by 0.05 mm we get the Vernier scale reading.

We say 0.05 mm is the Vernier constant of the slide calipers. You must have noticed that 0.05 mm is written at the top left corner of the Vernier scale of the slide calipers what you are using.

So, to find the Vernier scale reading, you can just notice the Vernier scale division which coincides with a mark of main scale and then multiply it by Vernier constant.

Mechanical Error:

If 0 of Vernier scale does not coincide with the 0 of main scale when the two jaws touch each other, then there is mechanical error.

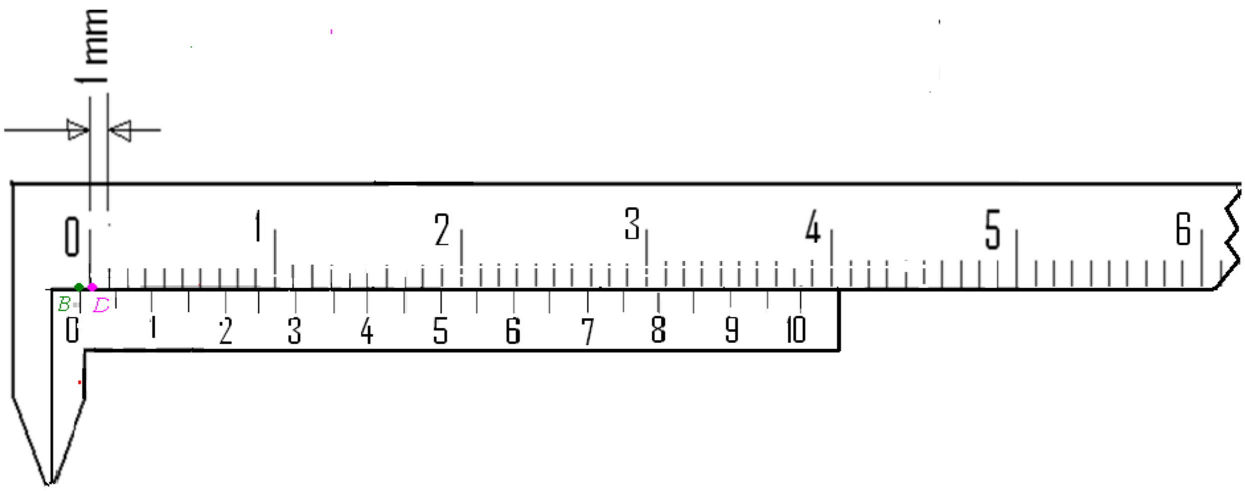


Figure 3: A slide calipers with mechanical error, where 0 of Vernier scale lies at left of the 0 or main scale.

In figure 3 we see the 0 of Vernier scale (B) lies at left of the 0 of main scale (D). We have to add this distance BD with the measured length of any body to correct it.

We can see the mark of 8^{th} division (denoted by 4 in the Vernier scale) coincides with a line of the main scale.

So BD = 8 × 0.05 mm = 0.40 mm

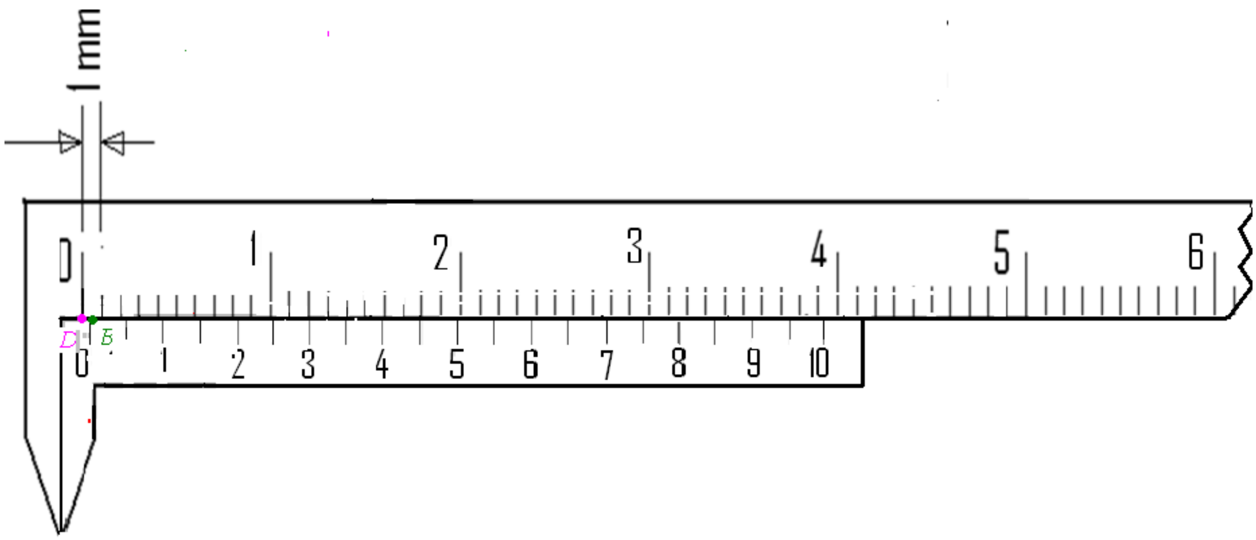


Figure 4: A slide calipers with mechanical error, where 0 of Vernier scale lies at right of the 0 or main scale.

In figure 4 we see the 0 of Vernier scale (B) lies at left of the 0 of main scale (D). We have to subtract this distance BD from the measured length of any body to correct it.

We can see the mark of 6^{th} division (denoted by 3) in the Vernier scale coincides with a line of the main scale.

So BD $= 6 \times 0.05$ mm $= 0.30$ mm