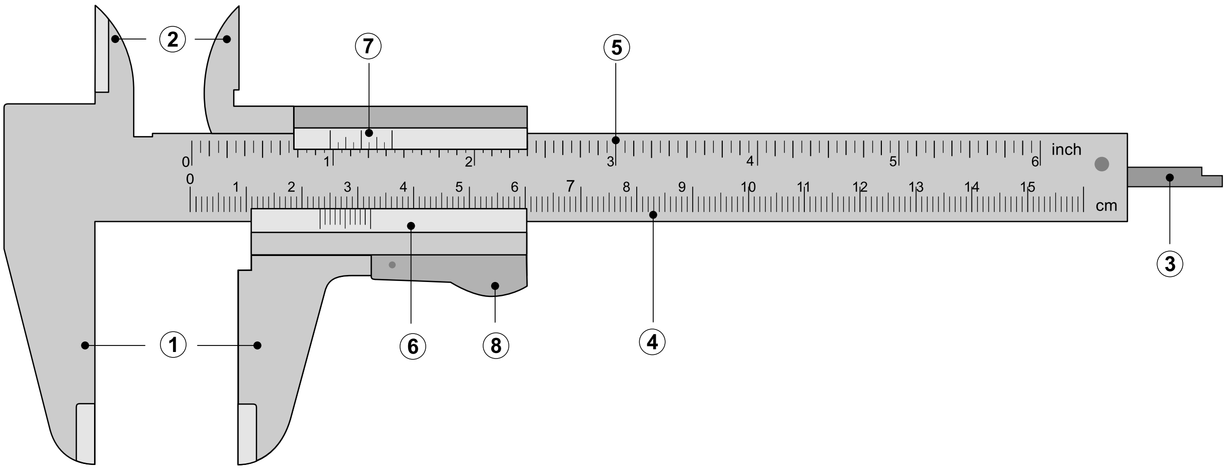
Vernier Calipers

Anant Kumar



(1) – Outside jaws: Used to measure external dimensions
(2) – Inside jaws: Used to measure internal dimensions
(3) – Depth probe: Used to measure depth of containers
(4) – Main scale (in cm)
(5) – Main scale (in inch)
(6) – vernier scale (in cm)
(7) – vernier scale (in inch)
(8) – Retainer: Used to block movable parts.

Contents

1 Introduction

Measurement is a fundamental aspect of any experimental science and Physics is no exception. Of the various measurable quantities, length is a quantity that we frequently require to measure. At one extreme, our vast universe extends this measuring exercise to light-years, the distances so vast that we cannot see them with our eyes. On the other extreme of the smallest distances, new discoveries are pushing it down to a *fermi* (which is 10^{-15} m) or even less. These distances are so small that, again, we cannot perceive them with our eyes. At every 1 to 2 order of magnitude change in distances, our instruments to measure them accurately can differ. When the distances that we want to measure, are in the range of 10^{-2} mm to 1 mm, we use Vernier calipers and Screw Gauge for precise measurement. In this handout, Vernier calipers and associated ideas are discussed.

2 Details of the Instrument

Vernier calipers, an instrument for making very accurate linear measurements was introduced in 1631 by Pierre Vernier of France. Vernier calipers are widely used in scientific laboratories and in manufacturing for quality control measurements.

2.1 Anatomy of the instrument

Its main parts are shown in the front page. There is a main scale which is graduated in cm (labeled by ④) on one side and in inch (labeled by ⑤) on the other side. Clamped on the main scale, there is a vernier scale (⑥ or ⑦) that can be moved along the main scale. There are two jaws. The outside jaws (①) which can be used to measure outer dimensions of objects, e.g. the length of a rod, the diameter of a cylindrical or spherical object, edge length of cube etc. and the inside jaws (②) that are useful in measuring internal diameter of hollow cylindrical objects or pipes. The depth probe or the depth strip (③) can be used to measure the depth of objects like beakers. The retainer (⑧) is spring loaded and is used to stop the movable parts from moving.

2.2 Least Count of the instrument

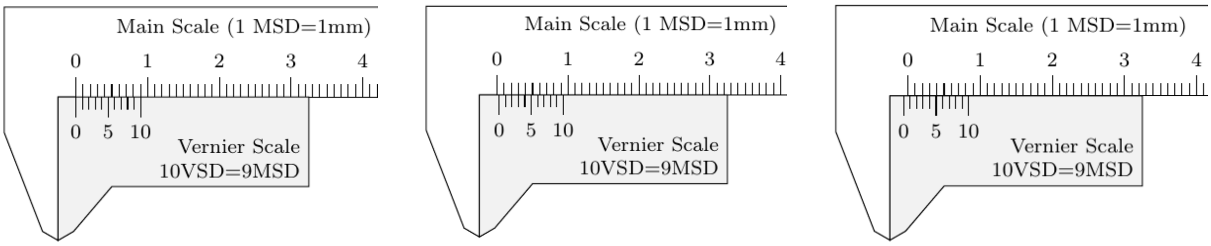
Observing carefully, we find that one main scale division (MSD) does not have the same length as one vernier scale division (VSD). In fact, with the 0^{th} mark of the main scale aligned with the 0^{th} mark of the vernier scale, the 9^{th} mark of the main scale coincides with the 10^{th} mark of the vernier scale. That is, 9 MSD = 10 VSD. This means that 1 VSD = $\frac{9}{10}$ MSD. Since one MSD is equal to 1 mm. This means that 1 VSD = 0.9 mm. The least count (LC for short) is defined as the difference between the length of one main scale division and the length of one vernier scale division, i.e.

$$\text{LC} = 1\text{ MSD} - 1\text{ VSD} = 1\text{ mm} - 0.9\text{ mm} = 0.1\text{ mm} = 0.01\text{ cm} \tag{2.1}$$

Hence, the least count of vernier calipers is 0.01 cm, i.e. it can measure upto a 100^{th} of a centimeter.

2.3 Zero Error

Normally, with the jaws closed the 0^{th} mark of the main scale should coincide with the 0^{th} mark of the vernier scale as has been shown in Figure 1a. However, due to various reasons, it might happen that with the two jaws closed, the 0^{th} marks of the two scale do not coincide. We then say that the vernier caliper has a *zero error*. If the 0^{th} mark the of vernier scale is slightly to the right of the 0^{th} mark of the main scale, as shown in Figure 1b, the zero error is *positive*. If, on the other hand, the 0^{th} mark of the vernier scale is to the left of the 0^{th} mark of the main scale, as shown in Figure 1c, the zero error is *negative*.



(a) No zero error (b) Positive zero error (c) Negative zero error

Figure 1: Zero error in a vernier caliper.

2.4 Using the device

In order to use the device for measuring the external dimensions of the object, grip the object using the external jaws as shown in Figure 2. Look at the mark on the main scale which lies just to the left of the 0^{th} marking of the vernier scale. This is the *main scale reading* (MSR). In

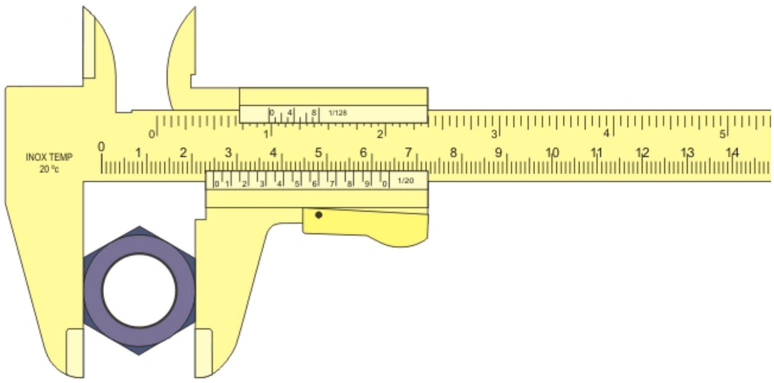


Figure 2: Grip the object using the jaws.

the example, shown in Figure 3, the MSR is 2.4. Next, look for one of the mark on the vernier scale, that coincides with any mark on the main scale. The division on the vernier scale that is coincident with any mark on the main scale is the *vernier scale reading* (VSR). In the example in Figure 3, VSR=7. Then the measured value is given by

$$\text{Meausred value} = \text{MSR cm} + \text{VSR} \times \text{LC cm} \tag{2.2}$$

For the example shown in Figure 3,

$$\text{measured value} = 2.4 \text{ cm} + 7 \times 0.01 \text{ cm} = 2.47 \text{ cm}$$

If the device has zero error, the required measurement is obtained by subtracting the zero error:

$$\text{Meausred value} = \text{MSR cm} + \text{VSR} \times \text{LC cm} - \text{Zero error (in cm)} \tag{2.3}$$

Note that Vernier calipers can be used to measure (1) outer dimensions like diameter of a sphere or edge of a cube (2) inner dimensions like inner diameter of a hollow cylinder and (3) depth of a hollow cylinder.

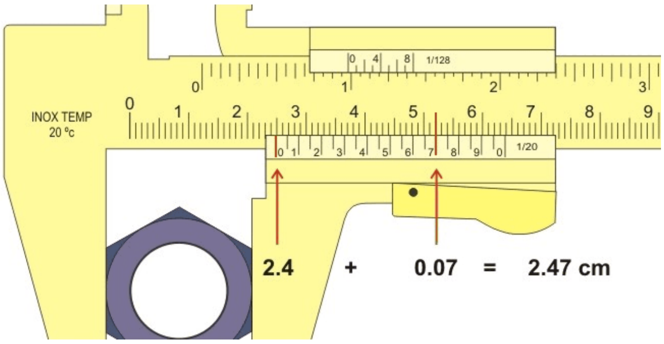


Figure 3: Reading the scale. In this caliper, the verier scale has twenty divisions.

3 Worked Out Examples

Example 1. The jaws of the Vernier calipers shown in Figure 4 are in contact with each other. Find the zero error of this Vernier calipers.

Solution: The least count of given Vernier calipers is

$$\text{LC} = \text{MSD} - \text{VSD} = 1 - (9/10) = 0.1 \text{ mm} = 0.01 \text{ cm}$$

The main scale reading is MSR = 0 cm and the vernier scale reading is VSR = 3. Thus,

$$\text{Zero error} = \text{MSR} + \text{VSR} \times \text{LC} = 0 + 3 \times 0.01 = 0.03 \text{ cm}$$

□

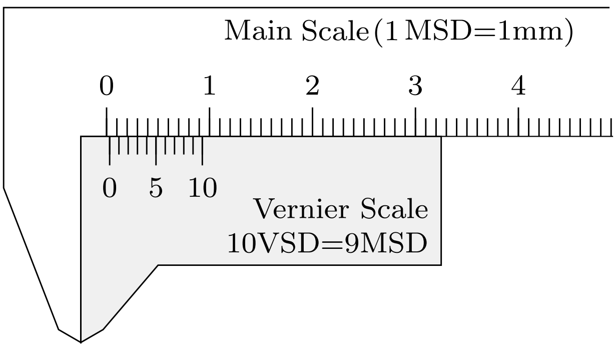


Figure 4: Example 1: Vernier calipers with positive zero error.

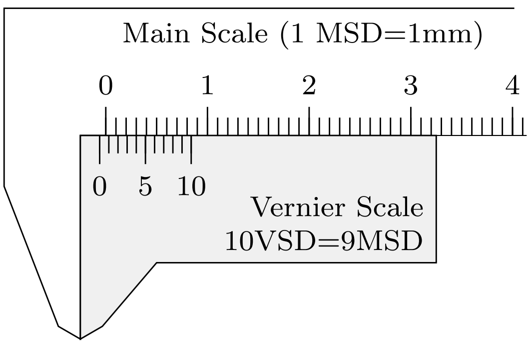


Figure 5: Example 2: Vernier calipers with negative zero error.

Example 2. The jaws of the Vernier calipers, shown in Figure 5, are in contact with each other. Find the zero error of this Vernier calipers.

Solution: This is an interesting problem. What is the MSR? Usually, it is the first reading of the mark on the main scale immediately to the left of the 0^{th} marking of the vernier scale. But in this case, there are no marks on the main scale to the left of the 0^{th} mark of the vernier scale. So we observe carefully to estimate the distance of the 0^{th} mark of the vernier scale and the 0^{th} mark of the main scale. In this case, it seems to be less than 1 mm, so we take MSR = -1 mm = -0.1 cm. The VSR = 4 and the least count LC = 0.01 cm. So we get

$$\text{Zero error} = \text{MSR} + \text{VSR} \times \text{LC} = -0.1 + 4 \times 0.01 = -0.06 \text{ cm}$$

□

Example 3. The Vernier calipers of Example 1 is used to measure the edge of a cube. The readings are shown in the Figure 6. Find the edge length of the cube.

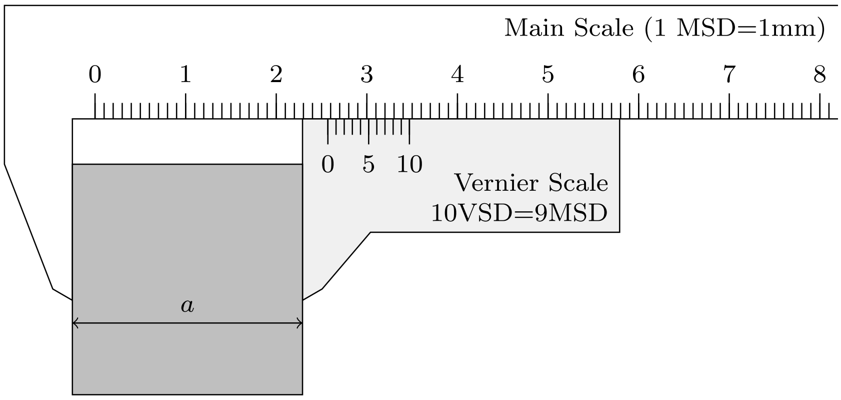


Figure 6: Example 3: Measuring the edge of a cube with the Vernier caliper of Example 1.

Solution: The reading are MSR = 2.5 cm and VSR = 7. Thus

$$a = \text{MSR} + \text{VSR} \times \text{LC} - \text{Zero error} = 2.5 + 7 \times 0.01 - 0.03 = 2.54 \text{ cm}$$

□

Example 4. The Vernier calipers of Example 2 is used to measure the edge of a cube. The readings are shown in the figure 6. Find the edge length of the cube.

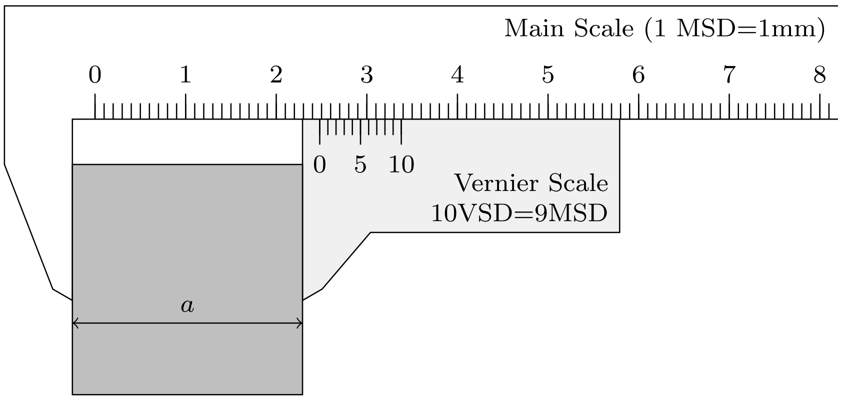


Figure 7: Example 3: Measuring the edge of a cube with the Vernier caliper of Example 2.

Solution: The readings are MSR = 2.4 cm and VSR = 8. Thus,

$$a = \text{MSR} + \text{VSR} \times \text{LC} - \text{Zero error} = 2.4 + 8 \times 0.01 - (-0.06) = 2.54 \text{ cm}$$

□

Example 5. N divisions on the main scale of a Vernier calipers coincide with $(N + 1)$ divisions on its Vernier scale. If each division on the main scale is of a units, determine the least count of the instrument.

Solution: Since $(N+1)$ VSD $= N$ MSD. Therefore, 1 VSD $= \dfrac{N}{N+1}$ MSD $= \dfrac{Na}{N+1}$ units. So the least count

$$\text{LC} = 1\ \text{MSD} - 1\ \text{VSD} = a - \frac{Na}{N+1} = \frac{a}{N+1}\ \text{units.}$$

□

Example 6. The edge of a cube is measured using a Vernier calipers (9 divisions of the main scale are equal to 10 divisions of Vernier scale and 1 main scale division is 1 mm). The main scale division reading is 10 and first division of Vernier scale was found to be coinciding with the main scale. The mass of the cube is 2.736 g. Calculate the density in g/cm^3 up to correct significant figures.

Solution: Given: 1 MSD = 1 mm. Since 10 VSD = 9 MSD, we get 1 VSD = (9/10) MSD = 0.9 mm. So the least count LC = 1 MSD − 1 VSD = 1.0 − 0.9 = 0.1 mm = 0.01 cm.

Since the main scale reading is 10, it equals 10 mm or 1.0 cm. Also the vernier scale reading is 1, so the edge of the cube

$$a = \text{MSR} + \text{VSR} \times \text{LC} = 1.0 + 1 \times 0.01 = 1.01\ \text{cm}$$

The measured value of a has three significant digits. The volume of the cube is $V = a^3 = 1.03\ \text{cm}^3$ and the density is

$$\frac{\text{mass}}{\text{volume}} = \frac{2.736}{1.03} = 2.6563 = 2.66\text{g/cm}^3$$

after rounding off to three significant digits. □

Example 7. The diameter of a cylinder is measured using a Vernier calipers with no zero error. It is found that the zero of the Vernier scale lies between 5.10 cm and 5.15 cm of the main scale. The Vernier scale has 50 divisions equivalent to 2.45 cm. The 24$^{\text{th}}$ division of the Vernier scale coincides exactly with one of the main scale divisions. Find the diameter of the cylinder.

Solution: From the given data, one main scale division (MSD) and one Vernier scale division (VSD) are

$$1\ \text{MSD} = 5.15\ \text{cm} - 5.10\ \text{cm} = 0.05\ \text{cm}$$

and

$$1\ \text{VSD} = \frac{2.45}{50}\ \text{cm} = 0.049\ \text{cm}$$

So the least count (LC) of this Vernier calipers is

$$\text{LC} = 1\ \text{MSD} - 1\ \text{VSD} = 0.001\ \text{cm}$$

For the given measurement, main scale reading (MSR) is 5.10 cm and the vernier scale reading (VSR) is 24. Hence, the diameter D of the cylinder is

$$D = \text{MSR} + \text{VSR} \times \text{LC} = 5.10 + 24 \times 0.001 = 5.124\ \text{cm}$$

□

4 Exercise Problems

Problem 1. The jaws of the Vernier calipers shown in Figure 8 are in contact with each other. Find the zero error of this Vernier calipers. (*Ans:* 0.19 cm)

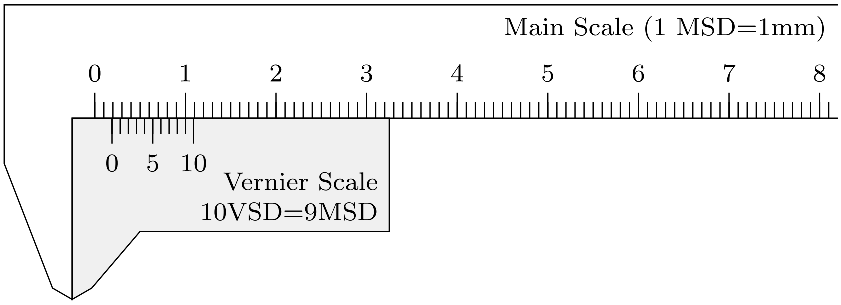


Figure 8: Problem 1.

Problem 2. The jaws of the Vernier calipers shown in Figure 9 are in contact with each other. Find the zero error of this Vernier calipers. (*Ans:* −0.12 cm)

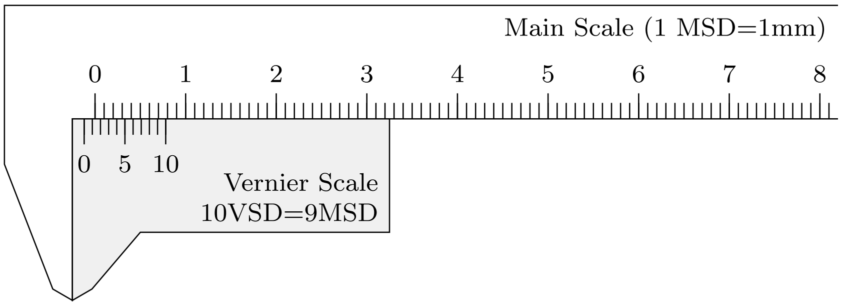


Figure 9: Problem 2.

Problem 3. The zero error of the Vernier calipers shown in Figure 10 is 0.09 cm. What is the diameter of the sphere being measured in the figure. (*Ans:* 3.14 cm)

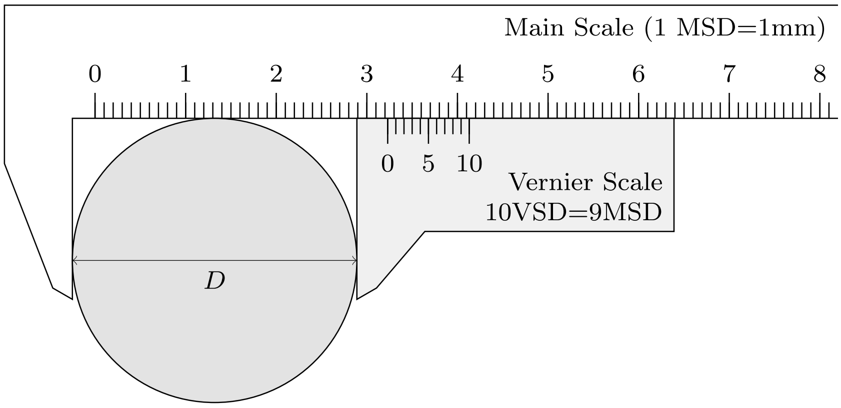


Figure 10: Problem 3.

Problem 4. The zero error of the Vernier calipers shown in Figure 11 is -0.5 mm. What is the diameter of the sphere being measured in the figure. (*Ans:* 3.14 cm)

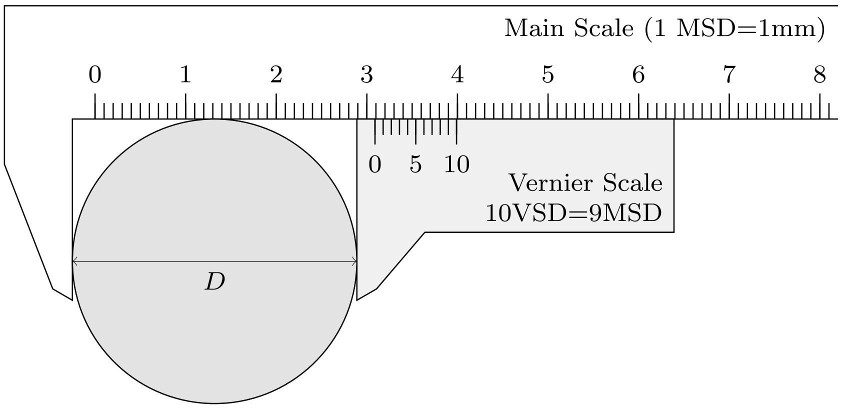


Figure 11: Problem 4.

Problem 5. The smallest division on main scale of a Vernier calipers is 1 mm and 10 vernier scale division coincide with 9 main scale divisions. While measuring the length of a line, the zero mark of the Vernier scale lies between 10.2 cm and 10.3 cm and the third division of Vernier scale coincide with a main scale division. Determine (a) the least count of the Vernier calipers, and (b) the length of the line. (*Ans:* 0.01 cm, 10.23 cm)

Problem 6. The main scale of a Vernier calipers is calibrated in mm and 19 divisions of main scale are equal in length to 20 divisions of vernier scale. In measuring the diameter of a cylinder by this instrument, the main scale reads 35 divisions and 4^{th} division of vernier scale coincides with a main scale division. Find (a) least count of the Vernier calipers and (b) radius of the cylinder. (*Ans:* 0.005 cm, 1.76 cm)

Problem 7. Least count of a Vernier calipers is 0.01 cm. When the two jaws of the instrument touch each other the 5^{th} division of the vernier scale coincides with a main scale division and the zero of the vernier scale lies to the left of the zero of the main scale. Furthermore while measuring the diameter of a sphere, the zero mark of the Vernier scale lies between 2.4 cm and 2.5 cm and the 6^{th} vernier division coincides with a main scale division. Calculate the diameter of the sphere. (*Ans:* 2.51 cm)

Problem 8. The jaws of a Vernier calipers touch the inner wall of calorimeter without any undue pressure. The position of zero of vernier scale on the main scale reads 3.48 cm. The 6^{th} division of the vernier scale coincides with a main scale division. Vernier constant of calipers is 0.01 cm. Find actual internal diameter of calorimeter, when it is observed that the instrument has a zero error of -0.03 cm. (*Ans:* 3.57 cm)

Problem 9. The thin metallic strip of the Vernier calipers moves downward from top to bottom in such a way that it just touches the surface of a beaker. Main scale reading of calipers is 6.4 cm whereas its Vernier constant is 0.1 mm. The 4^{th} division of the vernier scale coincides with a main scale division. If the instrument has no zero error, determine the depth of the beaker. (*Ans:* 6.44 cm)

Problem 10. In an instrument, there are 25 divisions on the vernier scale which coincides with 24 divisions of the main scale. 1 cm on main scale is divided into 20 equal parts. Find the least count of the instrument. (*Ans:* 0.002 cm)