

MEASUREMENT (II)

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Specific Objectives

By the end of this topic, the learner should be able to:

- a) measure length using vernier callipers and micrometer screw gauge
- b) express quantities in correct number of decimal places and correct number of significant figures
- c) express measurements in standard form
- d) estimate the diameter of a molecule of oil
- e) solve numerical problems in measurement.

(16 Lessons)

Content

1. Measurement of length using Vernier callipers and micrometer screw gauge
2. Decimal places, significant figures and standard form
3. Estimation of the diameter of the molecule of oil (relate to the size of the HIV virus, mention effects of oil spills on health and environment)
4. Problems in measurements
5. Project Work
6. Construct Vernier Calliper.

Connections

Building on...

- Measurement I
- Force

Arriving at ...

- Measuring lengths using vernier callipers and micrometer screw gauge.
- Expressing quantities in correct number of decimal places, significant figures and in standard form.
- Describing the oil drop experiment to estimate size of an oil molecule.

Looking forward to....

- Turning Effect of a Force
- Carrying out practicals and working out calculations in Physics.

MEASUREMENT (II)

Measurements of lengths such as diameter of a wire and that of a test-tube, which cannot be obtained directly using an ordinary ruler, are done using calipers and micrometer screw gauge.

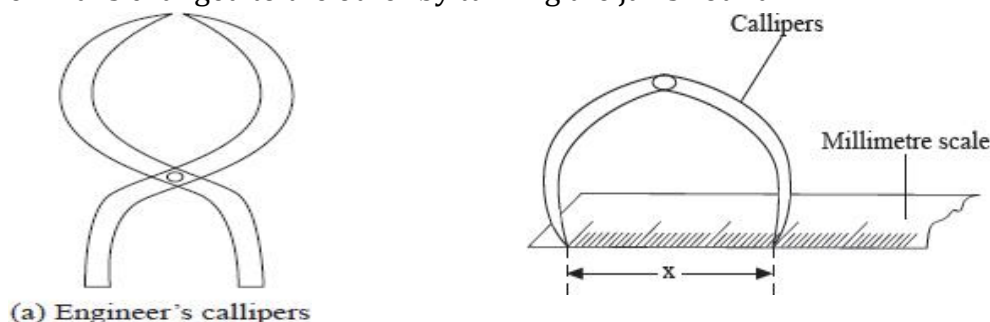
1. Callipers

The two types of callipers used are engineer's calipers and vernier calipers

(a) Engineer's Callipers

It consists of pair of hinged steel jaws which are closed until they touch the object at the desired position. Diameters of round objects can be measured using outside and inside calipers.

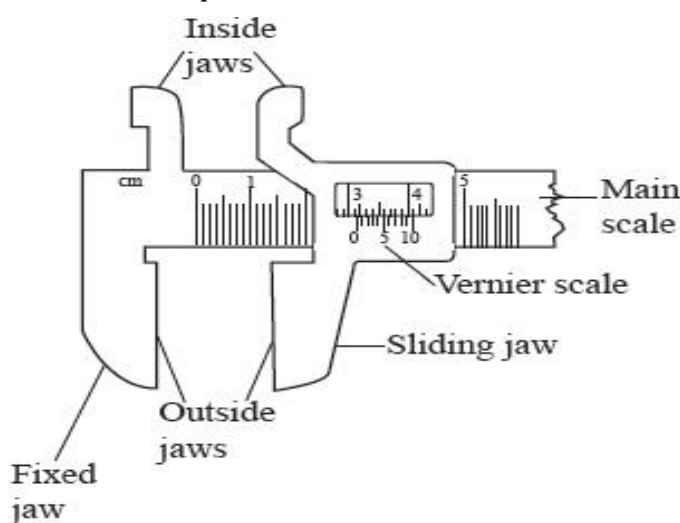
One kind is changed to the other by turning the jaws round.



When using the callipers, the jaws are opened just to slip past the cylinder or the widest part of the sphere. The distance between the jaws is then transferred and read on an ordinary millimetre scale, as shown above.

(b) Vernier Callipers

A vernier callipers consists of a steel frame with a fixed jaw and a sliding jaw, as shown [below](#).



The steel frame carries the main scale which is graduated in centimetres but also has millimetre divisions.

The sliding jaw carries the vernier scale, which has **ten equal divisions**.

The length of the vernier scale is 0.9 cm., each division of the vernier scale is 0.09 cm. The difference in length between the main scale division and the vernier scale division is known as the least count.

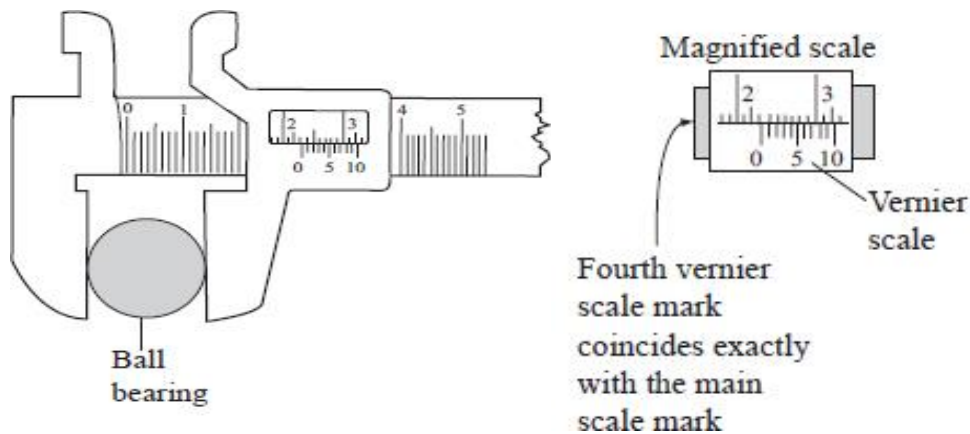
$$\begin{aligned}\text{Least count} &= (0.1 - 0.09) \text{ cm} \\ &= 0.01 \text{ cm}\end{aligned}$$

Most vernier callipers have both inside and outside jaws. The outside jaws are used to measure **external diameters** while the inside jaws are for measuring the **internal diameters**.

Vernier callipers have **small steel metal protruding at the back for measuring depths (depth probe)**

Using Vernier Callipers

- Place the object whose diameter is to be measured between the outside jaws. Close the jaws till they just grip the object.



- Record the reading on the main scale, **opposite and to the left of the zero mark of the vernier scale**. From above, it is 2.3 cm.
- Read the **vernier scale mark that coincides exactly with a main scale mark**.

The fourth mark of the vernier scale coincides exactly with a main scale mark. This gives a **reading of the least count**

$$= 4 \times 0.01$$

$$= 0.04 \text{ cm}$$

The sum of the vernier scale reading and the main scale reading gives the diameter of the ball bearing.

Therefore, the diameter of ball bearing

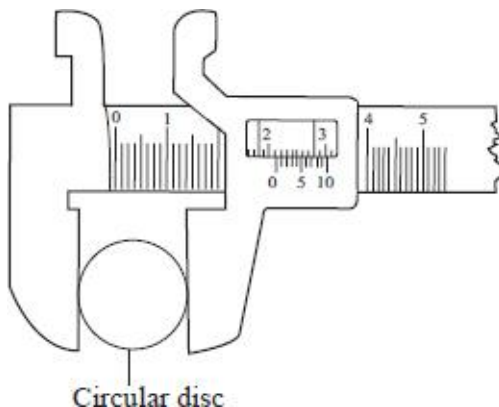
$$= (2.3 + 0.04) \text{ cm}$$

$$= 2.34 \text{ cm}$$

When the readings are taken in **centimetres**, the reading from the vernier scale gives the **second decimal place**.

Example 1

What is the diameter of the circular disc in the figure below?



Solution

Main scale reading = 2.1 cm

The vernier scale mark that coincides with main scale mark is the fourth one.

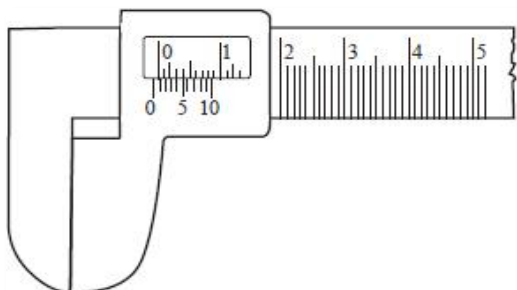
So, vernier scale reading = 0.02 cm

Diameter of the disc = $(2.1 + 0.02) \text{ cm}$
 $= 2.12 \text{ cm}.$

Zero Error

When the jaws of the vernier callipers are closed without an object between them, the zero mark of the main scale should coincide with the zero mark of the vernier scale, as shown below.

However, sometimes this may not be the case. The vernier calipers are then said to have a zero error.

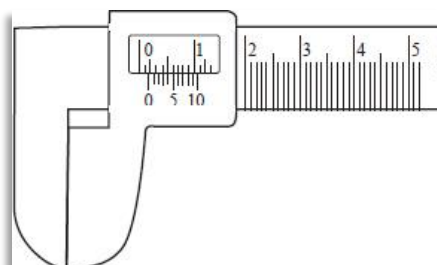


1. When the zero mark of the main scale is to the **right** of the zero mark of the vernier scale, the **zero error is negative**, hence the measured diameter is less than the actual diameter.

This is corrected by adding the zero error to the reading.

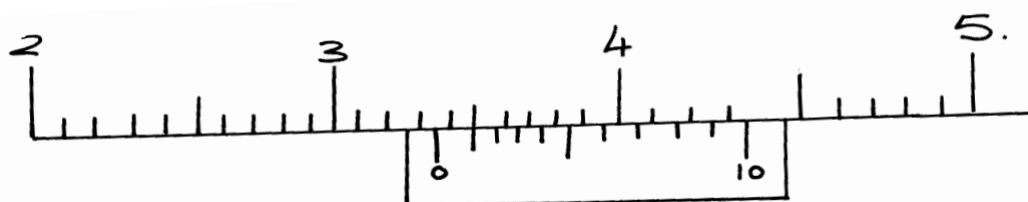
2. When the zero mark of the main scale is to the **left** of the zero mark of the vernier scale, the **Zero error is positive**. Therefore, the zero error is subtracted from the measured diameter to get the correct value of the diameter.

Measurements taken with such callipers are normally corrected by either adding or subtracting the zero error.



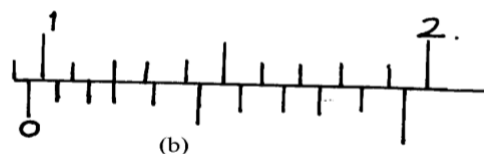
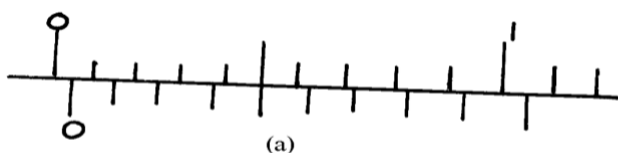
Review Exercise 1

1 The vernier calipers shown below has a zero error of -0.06 cm



State the actual reading on the instrument.

2. Figure (a) Shows vernier calipers with the jaws completely closed while (b) shows the same vernier calipers in use



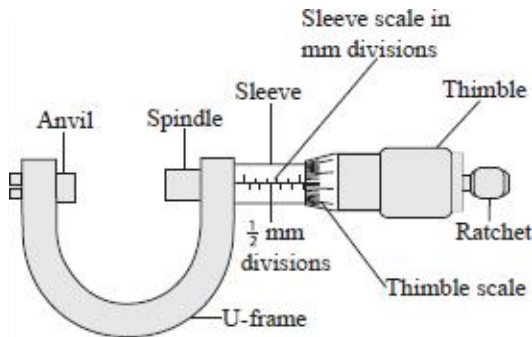
Determine the actual diameter of the coin

3. Sketch a vernier calipers scale reading 3.41 cm.

Micrometer Screw Gauge

The micrometer screw gauge is used to measure **small diameters** such as the diameter of a thin wire.

A micrometer screw gauge consists of a **U-frame** carrying an **anvil** at one end a **thimble** which carries a **circular rotating scale** known as the **thimble scale** and a **spindle** which can move forward and backwards when the thimble is rotated.



The **sleeve** has a **linear scale in millimeter's** and the **thimble** has a **circular scale of 50 equal divisions**.

The ratchet at the end of the thimble prevents the user from exerting undue pressure on an object when the micrometer screw gauge is in use. The **linear scale** has **half-millimetre marks**.

The distance moved by the spindle in one complete rotation of the thimble is known as the **pitch** of the micrometer.

In the figure above, since the spindle advances or retreats by 0.5 mm per complete rotation of the thimble, the pitch of micrometer is 0.5 mm.

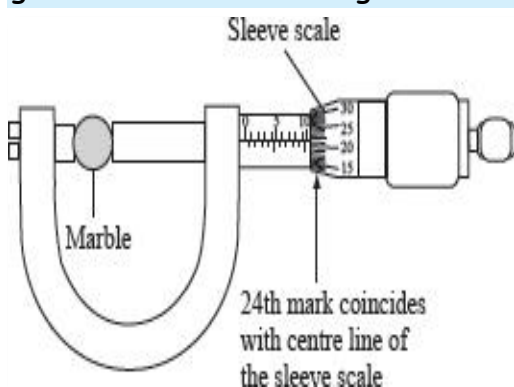
Thus, each division represents a spindle travel of $\frac{0.5}{50}$ mm = 0.01 mm.

Hence, if the thimble rotates through 1 division, the spindle advances by 0.01 mm or 0.001 cm.

Some micrometer screw gauges have a pitch of 1.0 mm and 100 divisions on the thimble.

Using a Micrometer Screw Gauge

The object whose diameter is to be found is held between the anvil and spindle (jaws). The micrometer is closed using the ratchet until the object is held gently between the anvil and the spindle. The ratchet will slip when the object is gripped firmly enough to give an accurate reading.



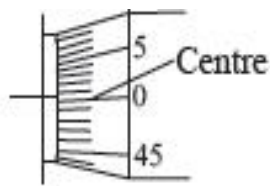
In the figure alongside, the sleeve reading is 10.5, mm and the thimble scale reading is : $\frac{24}{100}$ mm = 0.24 mm.

Thus, the diameter of the marble
 = sleeve reading + thimble reading
 = 10.5 mm + 0.24 mm
 = 10.74 mm

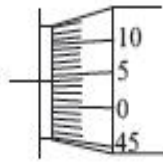
Zero Error

As in the case of vernier callipers, there occurs zero error in the micrometer screw gauge. It arises when the zero mark of the thimble scale does not coincide exactly with the centre line of the sleeve scale when the micrometer is closed.

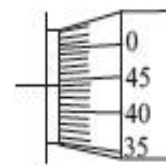
The **anvil** is usually used for the adjustment of the zero, so that the micrometer has no zero error.



(a) Zero mark of thimble scale coincides with the centre line of the sleeve scale



(b) Zero mark of thimble scale does not coincide with the centre line of the sleeve scale. Negative zero error add error to reading



(c) Zero mark of thimble scale does not coincide with the centre line of the sleeve scale. positive zero error subtract zero error from reading

The micrometer in (a) has no zero error while those in figures (b) and (c) have zero errors. Note the position of the zero mark in each case.

Example 2

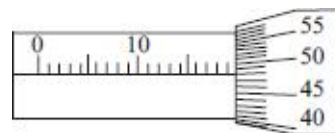
What is the reading of the micrometer screw gauge [below](#)?

Solution

Sleeve scale reading = 19 mm

Thimble scale reading = 0.48 mm

Hence, micrometer reading = $(19 + 0.48)$ mm
= 19.48 mm

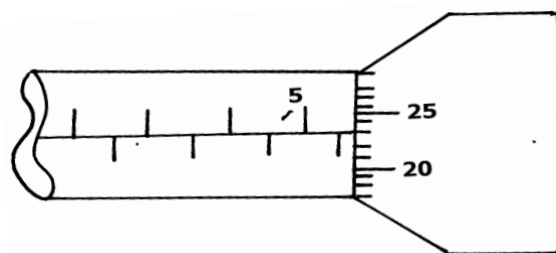


There are other measuring instruments which may also be used to measure smaller diameters, for example, the bore of a capillary tube. One such instrument is the **travelling microscope**. This is a microscope mounted on a heavy metallic base with a scale along which the microscope moves up, down and sideways.

Review Exercise 2

1. A micrometer screw gauge with zero error of -0.01mm is used to determine the diameter of a marble whose diameter is 2.32mm .
 - a) State the reading taken when the cylinder is grasped by the jaws
 - b) In the space below, sketch the scale that gives the reading in (a) above if it has a pitch of 0.5mm .
2. Draw a sketch of a micrometer screw gauge showing a reading of 8.53mm .
3. State the two limitations of the micrometer screw gauge?
4. List down the advantages and disadvantages of the micrometer screw gauge over the vernier callipers.

5. Give the reading on the micrometer screw gauge if it has a positive zero error of 0.01mm



3. Significant Figures

The digits 1 and 9 are significant when they appear in a number. The first digit from the left of the number is the first significant figure. The number of significant figures is determined by counting the number of the digits from the first significant figure on the left.

Zero is sometimes significant and at times it is merely used as a place holder. When a zero occurs at the left end of a number, it is not significant. For example, the zeros in 0.2 cm, 0.002 m are just place holders. Thus, in number 0.005734, the first significant figure is 5.

If zero occurs between non-zero digits, e.g, as in 7005, it is considered significant. Also, if zero occurs at the right hand end after the decimal point, it is always significant, e.g, 1.0 cm, 1.00 cm, 1.000cm.

If a zero occurs at the right hand end of an integer, it may or may not be significant. For example, the number 750000 could be correct to 2,3,4,5 or 6 significant figures. When the number is expressed to 2 significant figures, none of the zeros is significant. Conversely, to 6 significant figures all the zeros are significant. On the other hand, the number 995 can be written as 1000 to one significant figure or 1000 to 2 significant figures. None of the zeros in the first case is significant while in the second case, the first zero is significant but the last two are not.

Example

Find the area of a rectangle that measures 4.26 cm by 2.77 cm and write your answer correct to:

- Four significant figures.
- Two significant figures.

Solution

$$\begin{aligned}
 \text{Area} &= 4.26 \times 2.77 \text{ cm}^2 \\
 &= 11.8002 \text{ cm}^2 \\
 &= 11.80 \text{ cm}^2 \text{ to four s.f.} \\
 &= 12 \text{ cm}^2 \text{ to two s.f.}
 \end{aligned}$$

4. Standard Form

A positive number is said to be in standard form when written as $A \times 10^n$ where A is such that $1 \leq A < 10$ and index n is an integer.

For example, the number 9327 when written in standard form would be 9.327×10^3 .

Note that in this case, A is equivalent to 9.327 and the index $n = 3$ is positive because the decimal point after the last digit has been moved to the left.

However if the number lies between 0 and 1, then the index n becomes negative. For example, 0.009327 in standard form is 9.327×10^{-3} .

Example

Express each of the following numbers in standard form:

(a) 201

(a) $201 = 2.01 \times 10^2$

(b) 2670

(b) $2670 = 2.670 \times 10^3$

(c) 0.087

(c) $0.087 = 8.7 \times 10^{-2}$

(d) 0.0000009047

(d) $0.0000009047 = 9.047 \times 10^{-7}$

The use of standard form in expressing length, mass and time is a convenient means of writing large and small quantities. For example, the distance of the sun from the earth is estimated as 1.5×10^8 km and the mass of an electron is given as 9.1×10^{-31} kg.

5. The Oil Drop Experiment

This is an experiment to estimate the size of a molecule in an ordinary laboratory.

Theory

When an oil drop is carefully put in contact with the surface of water, it spreads out to form a very thin layer, which is almost circular. This is because the oil breaks the surface tension of the water, whose particles pull away from the oil. The thin layer can be approximated to be one molecule thick.

Estimating the Volume of an Oil Drop

Method 1

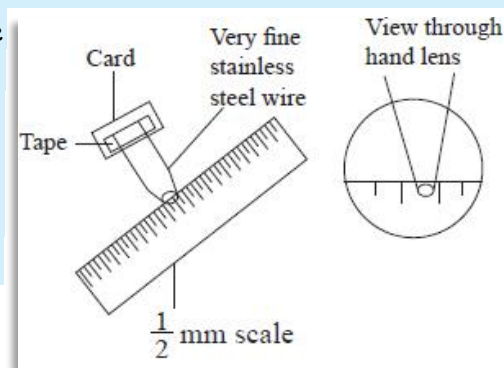
- Fill a 1cm^3 graduated burette with oil.
- Count the number of drops as they are squeezed out of the pipette. Let the number be y .

- If the number of drops is y , then the average volume occupied by the one drop is $\frac{1}{y} \text{ cm}^3$.

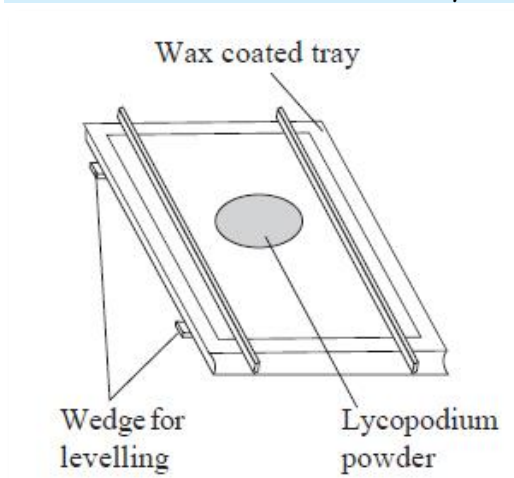
Method 2

- Hold a drop of the oil in front of a fine millimetre scale using a fine wire and view it through a magnifying glass.
- Read off the diameter of the oil drop.
- Assuming that it is spherical, its volume is given by

$$V = \frac{4}{3} \pi \left(\frac{d}{2} \right)^3$$

**To obtain a Mono Layer of Oil Patch**

- Fill a level tray with water until it overflows.
- Clean the surface of water by moving a wax-coated rod across it.
- Place two waxed beams at the centre of the tray and slide them towards the edges of the tray. They will be used to estimate the diameter of the spread.
- Sprinkle lycopodium powder lightly on the water surface.
- Touch the surface of the water with the drop until it spreads on the surface. The area covered by the oil is seen as a clear circular patch of oil left as the water particles pull away from it.
- Adjust the rods and use a metre rule to estimate the diameter of the patch, say d_1 . Repeat the same steps three or four times and get the average diameter.

**Data Analysis**

Average diameter of the patch, $d_{av} = \frac{d_1 + d_2 + d_3}{3}$

Area of the patch $= \pi r^2 = \pi \left(\frac{d_{av}}{2} \right)^2$

Volume of the oil drop = area of the patch (A) $\times$ thickness of the patch (h)

Thus, $V = \pi \left(\frac{d_{av}}{2} \right)^2 \times h$

Therefore, $h = \frac{4V}{\pi (d_{av})^2}$

The oil drop experiment can be used to determine the **extent of environmental damage caused by oil spillage from ships.**

Example 5

In an experiment to estimate the size of a molecule of olive oil, a drop of oil volume 0.12 mm^3 was placed on a clean water surface. The oil spread into a patch of area $6.0 \times 10^4 \text{ mm}^2$. Estimate the size of a molecule of olive oil.

Solution

Volume of the drop = 0.12 mm^3

Area of the patch = $6.0 \times 10^4 \text{ mm}^2$

$$\begin{aligned}\text{Thickness, } t, \text{ of patch} &= \frac{V}{A} \\ &= 0.12 \\ &= \frac{0.12}{6.0 \times 10^4} \\ &= 2.0 \times 10^{-6} \text{ mm}\end{aligned}$$

Thus, thickness, $t = 2.0 \times 10^{-9} \text{ m}$

This is the thickness of an oil molecule in a mono layer of olive oil.

6. Prefixes used with SI Units

The table below shows the multiples and sub-multiples used with SI units, their prefixes and symbols for these prefixes.

Sub-multiple/multiple	Prefix	Symbol for prefix
10 ⁻¹	deci	d
10 ⁻²	centi	c
10 ⁻³	milli	m
10 ⁻⁶	micro	μ
10 ⁻⁹	nano	n
10 ⁻¹²	pico	p
10 ⁻¹⁵	femto	f
10 ⁻¹⁸	atto	a
10 ¹	deca	da
10 ²	hecto	h
10 ³	kilo	k
10 ⁶	mega	M
10 ⁹	giga	G
10 ¹²	tera	T
10 ¹⁵	peta	P
10 ¹⁸	exa	E

$$1 \mu\text{s} = 10^{-6} \text{ s}$$

$$1 \text{ s} = 10^6 \mu\text{s}$$

$$5 \text{ kg} = 5 \times 10^3 \text{ g}$$

7. Decimal Places

The number of digits to the right of the decimal point determine the accuracy of the number given. For example, if the number is given as 6.0234, it is said to be accurate to four decimal places. The same number could be written as:

6.023 to 3 decimal places.

6.02 to 2 decimal places.

6.0 to 1 decimal place.

6 to the nearest whole number.

The number 6.0234 represents the highest degree of accuracy, followed by 6.023. If written as 6, it has the least degree of accuracy.

Similarly, $\pi = 3.1415926$. This is accurate to 7 decimal places. When expressed as 3.142, it is correct (to 3 decimal places). For working purposes π is given as 3.142 correct to 3 decimal places. While using a millimetre scale, a reading of 5.4 cm would be accurately measured. However, a reading of 5.47 cm can only be given by making an estimate of the second decimal. Therefore, the reading given by an ordinary ruler is **only accurate to the first decimal place (d.p)**.

Example 6

Find the area of the rectangle measuring 3.93 cm by 5.35 cm. Express your answer correct to 2 d.p.

Solution

$$\text{Area} = 3.93 \times 5.35 \text{ cm}^2$$

$$= 21.0255 \text{ cm}^2$$

$$= 21.03 \text{ cm}^2$$

Review Exercise 3

1. When a drop of olive oil of radius 1.36mm is placed on the surface of water, it spreads out to form a circular film of diameter 40cm. Calculate;

- The volume of the olive oil drop in m^3 (Take $\pi = \frac{22}{7}$)
- Using the value of (a) above, estimate the thickness of the film.
- Explain why lycopodium powder is sprinkled on the surface of water before the oil is dropped on it.
- State **two** assumptions made when finding the thickness of the film formed.

Recently.....

1. State two environmental hazards that may occur when oil spills over a large surface area of the sea.
2. **Figure 1** shows part of the main scale and vernier scale of a vernier calipers.

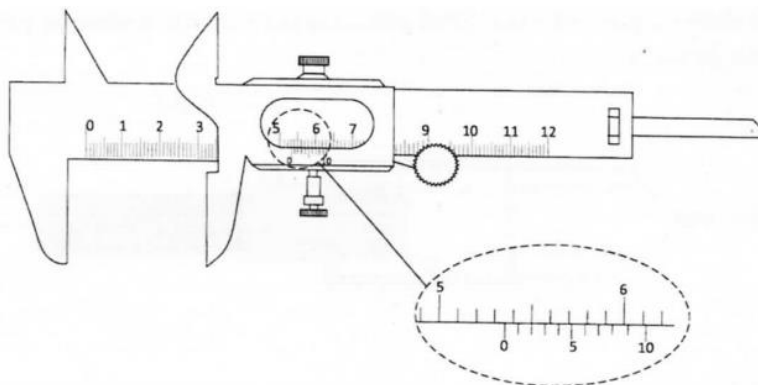


Figure 1

Record the reading indicated.

3. An oil drop of volume $V \text{ m}^3$ introduced on the surface of water spreads to form a patch whose area is $A \text{ m}^2$. Derive an expression for obtaining the diameter, d of a molecule of oil. (2 mks)
4. Figure 1 shows part of the main scale of a vernier Calipers.



Figure 1

5. Insert the vernier scale to the main scale, to show a reading of 3.14 cm (1mk)
6. When a drop of an organic acid of known volume is dropped on the surface of water in a large trough, it spreads to form a large circular patch. State one assumption made when the size of the molecule of the acid is estimated by determining the area of the patch. (1 mk)
7. In order to determine the size of an oil molecule, a student performed an experiment using five oil drops to make a circular patch of the oil on the surface of water in a waterbath. State two assumptions made by the student during the calculations. (2 marks)
8. (a) In an experiment to determine the size of an oil molecule, oil is placed on the surface of water after sprinkling lycopodium powder on it.
 - (i) State **two** reasons why oil is used. (2 marks)
 - (ii) State the function of the lycopodium powder. (1 mark)
 - (iii) State **any two** assumptions that are made in this experiment. (2 marks)
 - (iv) Explain why the oil spreads on the surface of water. (2 marks)

(b) The following data was obtained from an experiment to determine the size of a palm oil molecule.

- Volume of 100 drops of palm oil = 15.0mm^3
- Area of a patch from one drop of oil = $8.0 \times 10^4\text{mm}^2$

Determine the size of a palm oil molecule. (3 marks)

9. Describe how the knowledge of the oil drop experiment may be used to estimate the area of oil spillage from a ship in the sea assuming the surface water is not disturbed. (3 marks)
10. A micrometer screw gauge has a -0.03mm error. State the reading that is observed on the instrument when used to measure the diameter of a wire whose actual diameter is 0.38mm