بِسۡمِ اللّٰهِ الرَّحۡمٰنِ الرَّحِيۡمِ

IN THE NAME OF ALLAH, THE ALL-MERCIFUL, THE ALL-COMPASSIONATE

PHYSICS

9

PUNJAB CURRICULUM AND TEXTBOOK BOARD, LAHORE

Author

Professor (Rtd.) Muhammad Nisar

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About the Author

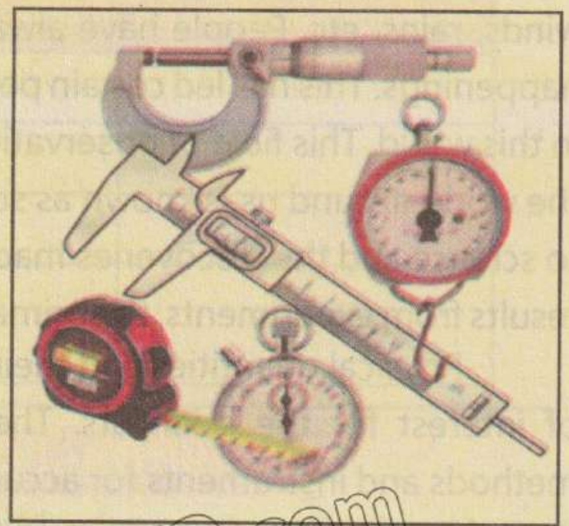
Professor (Rtd) Muhammad Nisar is an esteemed and experienced author, holds M.Sc. degree from University of the Punjab. He also attended a training program in Leeds University and Sheffield University UK under Columbo plan. He was a member of revision of Curricula, Textbooks and Teaching Aids Committee, constituted by the Government of the Punjab in 1999. He was awarded Governor's Education Gold Medal for developing National Curricula in General Science and Physics in 2001. He has been co-author and editor of more than 20 textbooks in Physics from class 9 – 12 and General Science from class 4 – 10 published by Punjab Textbook Board. He also developed Science Lesson Plans and Teacher's Guides at Directorate of Staff Development Punjab. He is also the author of Outsourced Science and General knowledge textbooks based on National Curriculum 2006. He has reviewed a number of Science and Physics textbooks and SRMs for PCTB. His reading material is a valuable resource for students and teachers.

Chapter 1

Physical Quantities and Measurements

Student Learning Outcomes

After completing this chapter, students will be able to:



- Differentiate between physical and non-physical quantities
- Explain with examples that physics is based on physical quantities [Including that these consist of a magnitude and a unit]
- Differentiate between base and derived physical quantities and units.
- Use the seven units of System International (SI) along with their symbols and physical quantities (standard definitions of SI units are not required)
- Analyse and express numerical data using scientific notation [in measurements and calculations.]
- Analyse and express numerical data using prefixes [interconverting the prefixes and their symbols to indicate multiple and submultiple for both base and derived units.]
- Justify and illustrate the use of common lab instruments to measure length [Including least count of instruments and how to measure a variety of lengths with appropriate precision using Tapes, Rulers and Vernier Callipers and Micrometres (including reading the scale on analogue and digital callipers and micrometres)]
- Justify and illustrate the use of measuring cylinders to measure volume [Including both measurement of volumes of liquids and determining the volume of a solid by displacement]
- Justify and illustrate how to measure time intervals using lab instruments [Including clocks and digital timers.
- Identify and explain the reason for common sources of human and systematic errors in experiments.
- Determine an average value for an empirical reading [Including small distance and for a short interval of time by measuring multiples (including the period of oscillation of a pendulum)] The uncertainty in measurements and describe the need using significant figures for recording and stating results of various measurements.

- Differentiate between precision and accuracy.
- Round off and justify measured estimates to make them reasonable. [Based on empirical data to an appropriate number of significant figures]
- Determine the least count of a data collection instrument (analogue) from its scale.

We are living in a physical world where we observe many natural phenomena and objects around us such as Sun, stars, moon, oceans, plants, winds, rains, etc. People have always been curious to know the reality of such happenings. This has led certain people to investigate the facts and laws working in this world. This field of observation and experimentation to understand about the world around us is known as science. Everything in our lives is closely linked to science and the discoveries made by the scientists. In order to obtain reliable results from experiments, the primary thing is to make accurate measurements.

Physical quantities and their measurements have always been the matter of interest for the scientists. They have been investigating to improve the methods and instruments for accurate measurements of the physical quantities. In this chapter, we will discuss physical quantities, their measurements and related contents.

1.1 Physical and Non-Physical Quantities

We describe various natural phenomenon, events and human behaviour using some of their features and terms such as love, affection, fear, wisdom, beauty, length, volume, density, time, temperature, etc. Some of these can be measured directly and indirectly using some tools and instruments such as length of an object using a ruler, time duration of an event using a clock, the temperature (the degree of hotness) of somebody using a thermometer. They are called physical quantities. The foundation of physics rests upon physical quantities through which the laws and principles of physics are expressed.

> **Quick Quiz**
> Is a non-physical quantity has dimensions?

Other quantities quoted above such as love, affection, fear, wisdom, and beauty cannot be measured using tools and instruments. They often pertain to the perception or interpretation of the observer. They can be described or qualitatively or compared using some pre-determined criteria, indices or through survey techniques. Non-physical quantities mostly help to understand and to analyse human behaviour, emotions and social interactions.

Table 1.1

Quick Quiz: Complete the following

Feature	Physical Quantity	Non-Physical Quantity
1. Measurement	Yes	No
2. Instrument used		
3. Numerical value and unit		
4. Examples	1. 2.	1. 2.

1.2 Base and Derived Physical Quantities

Physics is a science of physical world where we interact with many different types of material objects. These objects are exposed in terms of their measurable features known as physical quantities such as length, breadth, thickness, mass, volume, density, time, temperature, etc. Out of these, the scientists have selected arbitrarily some quantities to play a key role. They are called base quantities. All the quantities which can be described in terms of one or more base quantities are called derived physical quantities. For example, speed is a derived quantity which depends on distance and time which are base quantities whereas density of a material is described in terms of mass and volume.

Measurement of a Physical Quantity

A measurement is a process of comparison of an unknown quantity with a widely accepted standard quantity.

Activity 1.1

The teacher should facilitate this activity and initiate discussion as per direction.
One student should measure the length of a writing board with his hand. The same should be repeated by four or five students. Are all the measurements same? If they differ, then why? What is the solution to avoid confusion?

In the early days people used to measure length using hand or arm, foot or steps. This measurement may result in confusion as the measurement of different people may differ from each other because of different sizes of their hands, arms or steps. To avoid such confusion, there is a need of a standard so that measurement by any person may result the same. **This standard of measurement is known as a unit.**


The International Prototype kilogram

A measurement consists of two parts, a number and a unit. A measurement without unit is meaningless.

Not very far in the past, every country in the world had its own units of measurements. However, problems were faced when people of different countries exchanged scientific information or traded with other countries using different units. Eventually, people got the idea of standardizing the units of measurements which could be used by all countries for efficient working and growth of mutual trade, business and share scientific information.

1.3 International System of Units

The international committee on weights and measures in 1961 recommended the use of a system consisted of seven base units known as international system of units, abbreviated as SI. This system is in use all over the world.

Use of SI measurements helps all scientists to share and compare their observations and results easily. The seven base units are given in Table 1.2. Their values are fixed with reference to international standards.

Table 1.2

Sr. No.	Physical quantity	Unit	Symbol
1.	Length	metre	m
2.	Mass	kilogram	kg
3.	Time	second	s
4.	Temperature	kelvin	K
5.	Electric current	ampere	A
6.	Intensity of light	candela	cd
7.	Amount of substance	mole	mol

Derived Units

Base units cannot be derived from one another and neither can they be resolved into anything more basic. While the units of derived quantities such as speed, area, volume, force, pressure and electric charge can be derived using the base units. These units are called derived units.

The units which can be expressed in terms of base units are called derived units.

For example, Area = length × breadth
= metre × metre
= square metre
= $metre^2$ or m^2

Speed = Distance/Time = metre/second = $m\ s^{-1}$

A few derived units with specific names and symbols are given in Table 1.3.

Table 1.3

Sr. No.	Physical quantity	Unit	Symbol
1.	Area	square metre	m^2
2.	Volume	cubic metre	m^3
3.	Speed	metre per second	ms^{-1}
4.	Force	newton	N
5.	Pressure	pascal	Pa
6.	Electric charge	coulomb	C
7.	Plane angle	radian	rad

Quick Quiz

(a) Write the unit of charge in terms of base unit ampere and second.

(b) Express the unit of pressure "pascal" in some other units.

SI Prefixes

The SI is a decimal system. Prefixes are used to write units by powers of 10. The big quantities like 50000000 m and small quantities like 0.00004 m are not convenient to write down. The use of prefixes makes them simple. The quantity 50000000 m can be written as 5×10^7 m. Similarly, the quantity 0.00004 m can be written as 4×10^{-5} m.

Prefixes are the words or symbols added before SI unit such as milli, centi, kilo, mega, giga (Table1.4). The prefixes given in Table 1.4 should be known for use of SI units effectively. For example, one thousandth (1/1000) of a metre is millimetre. The thickness of a thin wire can be expressed conveniently in millimetres whereas a long distance is expressed in kilometres which is 1000 metres.

Multiples and sub-multiples of mass measurement are given in Table 1.5 whereas multiples and sub-multiples of length are given in Table 1.6. The following examples will explain the meaning of prefixes.

(I) 5000 mm $= \frac{5000}{1000}$ m = 5 m

(ii) 50000 cm = $\frac{50000}{100}$ m = 500 m

(iii) 3000g = $\frac{3000}{1000}$ kg = 3 kg

(iv) 2000 µs = 2000×10^{-6} s = 2×10^{-3} s
= 2 ms

1.4 Scientific Notation

It is short way of representing very large or very small numbers. Writing otherwise, the values of these quantities, take up much space They are difficult to read, their relative sizes are difficult to visualize and they are awkward to use in calculations. Their decimal places are more conveniently expressed as powers of 10. The numerical part of the quantity is written as a number from 1 to 9 multiplied by whole number powers of 10. To write numbers using scientific notation, move the decimal point until only one non-zero digit remains on the left. Then count the number of places through which the decimal point is moved and use this number as the power or exponents of 10. The average distance from the Sun to the Earth is 138,000,000 km. In scientific notation, this distance would be written as 1.38×10^8 km. The number of places, decimal moved to the left is expressed as a positive exponent of 10.

Diameter of hydrogen atom is about 0.000,000,000,052 m. To write this number in scientific notation, the decimal point is moved 11 places to the right. As a result, the diameter is written as 5.2×10^{-11} m. The number of places moved by the decimal to the right is expressed as a negative exponent of 10.

Table 1.4: Prefixes used with SI units

Prefix	Symbol	Powers of Ten
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	µ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}
peta	P	10^{15}
exa	E	10^{18}

Table 1.5

100 kg 10 quintal or 1000 kg	1 quintal 1 tonne

Table 1.6

1 m 1 cm 1 km	100 cm 10 mm 1000 m
1 mm 1 cm 1 km	10^{-3} m 10^{-2} m 10^{3} m

Quick Quiz

100 m is equal to:
(a) 1000 µm (b) 1000 cm
(c) 100,000 mm (d) 1 km

Do You Know?

The kilogram is the only base unit that has a prefix.

Example 1.1

Solve the following:

(a) 5.123×10^4 m $+ 3.28 \times 10^5$ m

(b) 2.57×10^{-2} mm $- 3.43 \times 10^{-3}$ mm

Solution

(a) $5.123 \times 10^4 \text{ m} + 3.28 \times 10^5 \text{ m}$

$= 5.123 \times 10^4 \text{ m} + 32.8 \times 10^4 \text{ m}$

$= (5.123 + 32.8)\, 10^4 \text{ m}$

$= 37.923 \times 10^4 \text{ m}$

$= 3.7923 \times 10^5 \text{ m}$

(b) $2.57 \times 10^{-2} \text{ mm} - 3.43 \times 10^{-3} \text{ mm}$

$= 2.57 \times 10^{-2} \text{ mm} - 0.343 \times 10^{-2} \text{ mm}$

$= (2.57 - 0.343)\, 10^{-2} \text{ mm}$

$= 2.227 \times 10^{-2}$ mm

$= 2.227 \times 10^{-2} \times 10^{-3}$ m

$= 2.227 \times 10^{-5}$ m .

Example 1.2

Find the value of each of the following quantities:

(a) $(4 \times 10^3 \text{ kg})\,(6 \times 10^6 \text{ m})$

(b) $\dfrac{6 \times 10^6 \text{ m}^3}{2 \times 10^{-2} \text{ m}^2}$

Solution

(a) $(4 \times 10^3 \text{ kg})\,(6 \times 10^6 \text{ m}) = (4 \times 6) \times 10^{3+6} \text{ kg m}$

$= 24 \times 10^9 \text{ kg m}$

$= 2.4 \times 10^{10} \text{ kg m}$

(b) $\dfrac{6 \times 10^6 \text{ m}^3}{2 \times 10^{-2} \text{ m}^2} = \dfrac{6}{2} \times 10^{6-(-2)} \text{ m}^{3-2}$

$= 3 \times 10^8$ m

1.5 Length Measuring Instruments

Metre Rule: Length is generally measured using a metre rule in the laboratory. The smallest division on a metre scale is 1 mm.

For Your Information!

The negative exponents have values less than one. For example, $1 \times 10^{-2} = 0.01$

Quick Quiz

Express the following into scientific notation:

(a) 0.00534 m (b) 2574.32 kg

(c) 0.45 m (d) 0.004 kg

(e) 186000 s

For Your Information!

Addition and subtraction of numbers is only possible if they have the same exponents. If they do not have the same exponents, make them equal by the displacement of the position of the decimal point.

For Your Information!

Use of SI units require special care, particularly in writing prefixes.

- Each unit is represented by a symbol not by an abbreviation. For example, for SI not S.I., for second s not sec, for ampere A not amp, for gram g not gm.
- Symbols do not take plural form. For example, 10 mN, 100 N, 5 kg, 60 s.
- Full name of unit does not begin with capital letter. For example, metre, second, newton except Celsius.
- Symbols appear in lower case, m for metre, s for second, exception is only L for litre.
- Symbols named after scientist's name have initial letters capital. For example, N for newton, K for kelvin and Pa for pascal.
- Prefix is written before and close to SI unit. Examples: ms, mm, mN, not m s, m m, m N.
- Units are written one space apart. For example, N m, N s.
- Compound prefixes are not allowed. For example,

(i) 7 μμs should be written as 7 ps.

(ii) 5×10^4 cm should be written as 5×10^2 m.

The smallest measurement that can be taken with a metre rule is 1 mm. One millimetre is known as least count of the metre rule.

Least count is the smallest measurement that can be taken accurately with an instrument.

To measure the length of an object, the metre rule is placed in such a way that its zero coincides one edge of the object and then the reading in front of the other edge is the length of the object. One common source of error comes from the angle at which an instrument is read. Metre ruler should either be tipped on its edge or read when the person's eye is directly above the ruler as shown in Fig. 1.1 at point B. If the metre ruler is read from an angle, such as from point A or C, the object will appear to be of different length. This is known as parallax error.

Measuring Tape: It can measure 1 mm to several metres. Its least count is 1 mm. It is used to measure longer distances.

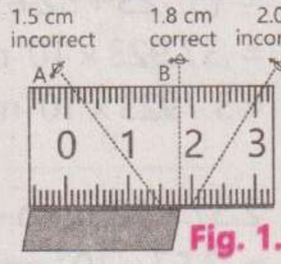


Fig. 1.1

Vernier Callipers

It is an instrument used to measure small lengths down to 1/10th of a millimetre. It can be used to measure the thickness, diameter, width or depth of an object. The two scales on it are:

(a) A main scale which has marking of 1mm each.

(b) A Vernier (sliding) scale of length 9 mm and it is divided into 10 equal parts.

Least count of a Vernier Callipers is the difference between one main scale division (M.S) and one Vernier scale (V.S) division.

Hence, Least count = 1 M.S div − 1 V.S div

= 1 mm − 0.9 mm = 0.1 mm

Usually, the least count is found by dividing the length of one small division on main scale by the

For Your Information!

Parallax error is due to incorrect position of eye when taking measurements. It can be avoided by keeping eye perpendicular to the scale reading.

Do You Know?

Some specific lengths in (m)	
Football ground	9.1×10^{1}
Man	1.8×10^{0}
Thickness of book page	1.0×10^{-4}
Diameter of pencil	7.0×10^{-3}

Do You Know?

Vernier Callipers was invented by a French Scientist Pierre Vernier in 1631.

total number of divisions on the Vernier scale which is again 1 mm/10 = 0.1 mm. The parts of the Vernier Callipers are shown in Fig. 1.2.

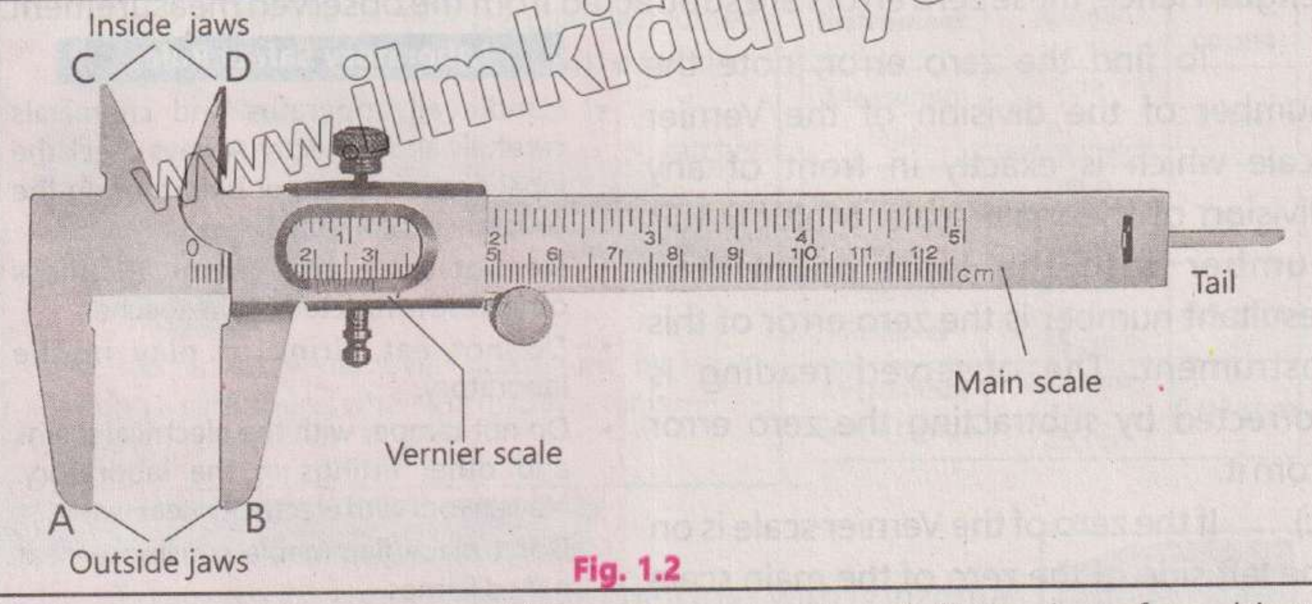


Fig. 1.2

There are two Jaws A and B to measure external dimension of an object whereas jaws C and D are used to measure internal dimension of an object. A narrow strip that projects from behind the main scale known as tail or depth gauge is used to measure the depths of a hollow object.

Measurement Using Vernier Callipers

Suppose an object is placed between the two jaws, the position of the Vernier scale on the main scale is shown in Fig. 1.3.

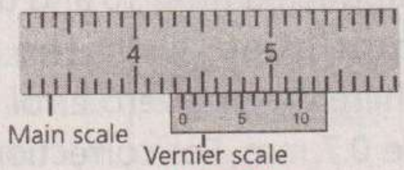


Fig. 1.3

1. Read the main scale marking just infront of zero of the Vernier scale. It shows 4.3 cm.
2. Find the Vernier scale marking or division which is in line with any of the main scale marking. This shows:

Length of object = Main scale reading + (Least count × Vernier scale reading).

= 4.3 + 0.01 × 4 = 4.34 cm

3. Checking for zero error. Following are some important points to keep in mind before checking zero error:

(a) If on joining the jaws A and B, the zeros of the main scale and Vernier scale do not exactly coincide with each other then there is an error in the instrument called zero error.

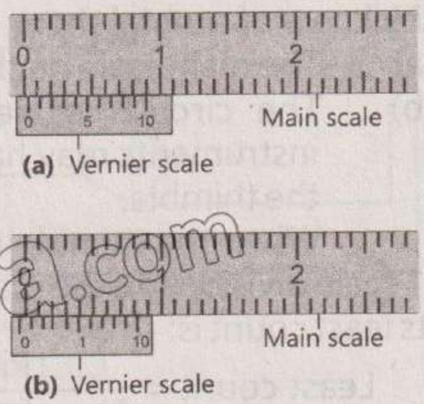


Fig. 1.4

(b) If the zero of the Vernier scale is on the right side of the zero of the main scale (Fig. 1.4-a) then this instrument will show slightly more than the actual length. Hence, these zero errors are subtracted from the observed measurement.

To find the zero error, note the number of the division of the Vernier scale which is exactly in front of any division of the main scale. Multiply this number with the least count. The resultant number is the zero error of this instrument. The observed reading is corrected by subtracting the zero error from it.

(c) If the zero of the Vernier scale is on the left side of the zero of the main scale (Fig. 1.4b), then instrument will show slightly less than the actual length.

Hence, the zero error is added in the observed measurement. For example, if 3 is the number of divisions coinciding with any main scale division then 3 is subtracted from 10 and the result is then multiplied with the least count. Therefore, the zero error in this case will be 0.7 mm. For correction, it is added in the observed reading.

Laboratory Safety Rules

- Handle all apparatus and chemicals carefully and correctly. Always check the label on the container before using the substance it contains.
- Do not taste any chemical unless otherwise instructed by the teacher.
- Do not eat, drink or play in the laboratory.
- Do not tamper with the electrical mains and other fittings in the laboratory. Never work with electricity near water.
- Don't place flammable substance near naked flames.
- Wash your hands after all laboratory work.

Activity 1.2

The teacher should facilitate to perform this activity by making groups. Each group should place ten coins one above the other. Record their total height using a metre rule. Divide by 10.

What is the thickness of one coin?

Now find the thickness of one coin using Vernier Callipers.

What is the result?

Each group should comment on the measurement using the two instruments.

Micrometer Screw Gauge

It is used to measure very small lengths such as diameter of a wire or thickness of a metal sheet. It has two scales:

(a) The main scale on the sleeve which has markings of 0.5 mm each.

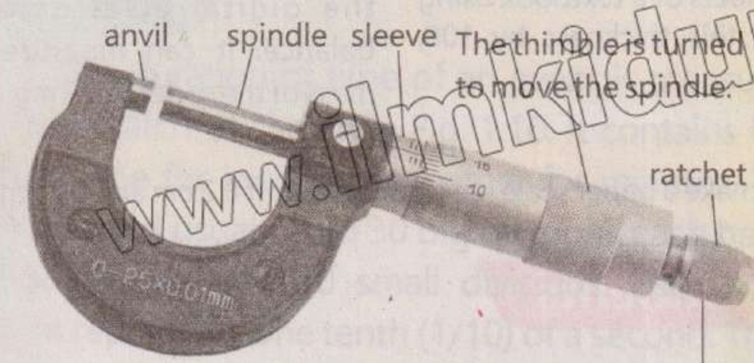
(b) The circular scale on the thimble which has 50 divisions. Some instruments may have main scale marking of 1 mm and 100 divisions on the thimble.

When the thimble makes one complete turn, the spindle moves 0.5 mm (1 scale division) on the main scale which is called pitch of the screw gauge. Thus, its least count is:

$$\text{Least count} = \frac{\text{Pitch of the screw gauge}}{\text{No. of divisions on the circular scale}} = \frac{0.5\text{ mm}}{50} = 0.01\text{ mm}$$

The parts of the screw gauge are shown in Fig. 1.5.

The object that is to be measured is placed between the anvil and the spindle.



The ratchet prevents over tightening by making a click sound when the micrometer is ready to be read.

Fig. 1.5

Limitations of measuring Instruments		
Instrument	**Range**	**Least count**
Measuring Tape	1 cm to several metres	1 mm
Metre rule	1 mm to 1 m	1 mm
Vernier Callipers	0.1 mm to 15 cm	0.1 mm
Micrometer Screw gauge	0.01 mm to 2.5 cm	0.01 mm

Checking for Zero Error

If the zero of the circular scale coincides with horizontal line, there is no zero error (Fig. 1.6-a).

If it is not exactly in front of the horizontal line of the main scale on joining the anvil and spindle then there is a zero error in the screw gauge (Fig. 1.6-b). If zero of the circular scale is below the horizontal line then it will measure slightly more than the actual thickness and hence, zero error will be subtracted from the observed measurement.

If the zero of the circular scale is above the horizontal line (Fig. 1.6-c), then it will show slightly less than the actual thickness and hence, the zero error will be added to the observed measurement.

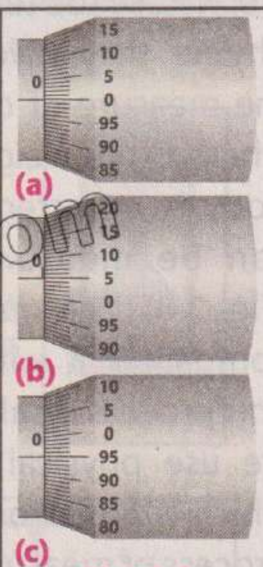


Fig. 1.6

Measurement Using Screw Gauge

Suppose when a steel sheet is placed in between the anvil and spindle, the position of circular scale is shown in Fig.1.7.

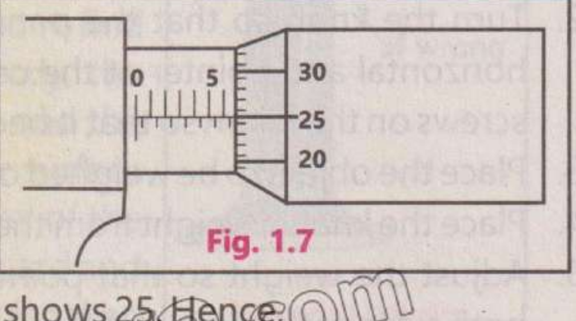


Fig. 1.7

(a) Read the marking on the sleeve just before the thimble. It shows 6.5 mm.

(b) Read the circular scale marking which is in line with the main scale. This shows 25. Hence,

Thickness = main scale reading + (circular scale reading × L.C.)

= 6.5 mm + 25 × 0.01 mm

= 6.5 mm + 0.25 mm = 6.75 mm

Activity 1.3

The teacher should facilitate the activity by making groups and ask them to find the thickness of 100 sheets of a textbook using a micrometre screw gauge. Dividing this thickness by 100, estimate the thickness of one sheet.

For Your Information!

The most precise balance is the digital electronic balance. It can measure mass of the order of 0.1mg

Activity 1.4

The teacher should help each group to make a paper scale having least count 0.2 cm and 0.5 cm.

1.6 Mass Measuring Instruments

Physical Balance

There are many kinds of balances used for measuring mass of an object. In our daily life, we use the term weight instead of mass. In Physics, they have different meanings. Mass is the measure of quantity of matter in a body whereas the weight is the force by which the body is attracted towards the Earth. Weight can be measured using spring balance (Fig. 1.8). The mass of an object is found by comparing it with known standard masses. This process is called weighing. In laboratories, we use physical balance shown in Fig. 1.9 which is based on the principle of levers. The process of measurement is given below:

Fig. 1.8

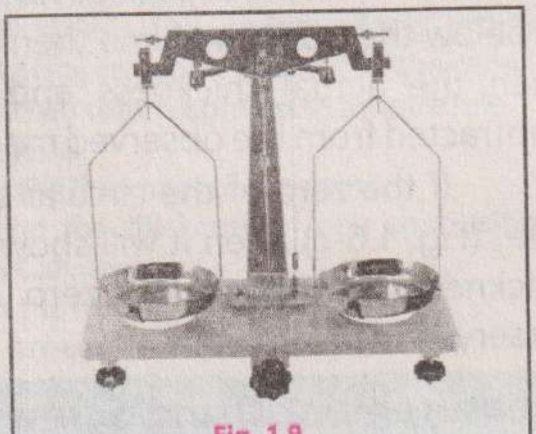


Fig. 1.9

1. Level base of the balance using levelling screws until the plumb line is exactly above the pointed mark.
2. Turn the knob so that the pans of the balance are raised up. Is the beam horizontal and pointer at the centre of the scale? If not, turn the balancing screws on the beam so that it becomes horizontal.
3. Place the object to be weighed on the left pan.
4. Place the known weight from the weight box in the right pan using forceps.
5. Adjust the weight so that pointer remains on zero or oscillates equally on both sides of the zero of the scale.
6. The total of standard masses (weights) is a measure of the mass of the object in the left pan.

1.7 Time Measuring Instruments

Stopwatch

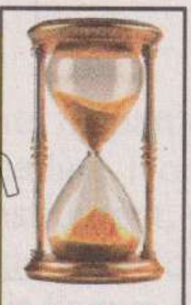
Fig. 1.10 Mechanical Stopwatch

Fig. 1.11 Digital Stopwatch

The duration of time of an event is measured by a stopwatch as shown in Fig. 1.10. It contains two needles, one for seconds and other for minutes. The dial is divided usually into 30 big divisions each being further divided into 10 small divisions. Each small division represents one tenth (1/10) of a second. Thus, one tenth of a second is the least count of this stopwatch. While using, a knob present on the top of the device is pressed. This results in the starting of the watch. The same knob is again pushed to stop it. After noting the reading, the same knob is again pressed to bring back the needles to the zero position. Now-a-days, electronic/digital watches (Fig. 1.11) are also available which can measure one hundredth part of a second.

Activity 1.5 Model of a sandclock

The teacher should arrange the required articles and help students to make a model of a sandclock as shown in the figure. Using two glass funnels, adhesive tape, two lids, and dry sand. Observe how much time it takes for the sand to flow down once completely. Make a paper scale from this and paste on the glass funnels along straight side.



Sandclock

1.8 Volume Measuring Instruments

Measuring Cylinder

It is a cylinder made of glass or transparent plastic with a scale divided in cubic centimetres (cm^3 or cc) or millilitres (mL) marked on it. It is used to find the volume of liquids and non-dissolvable solids.

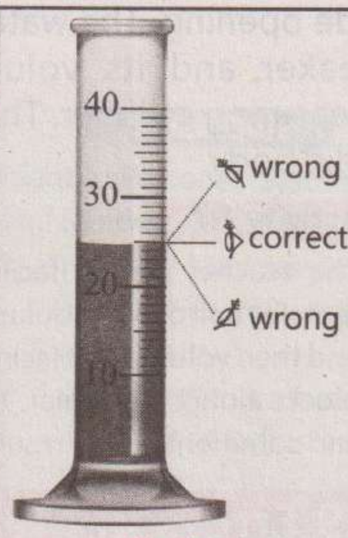
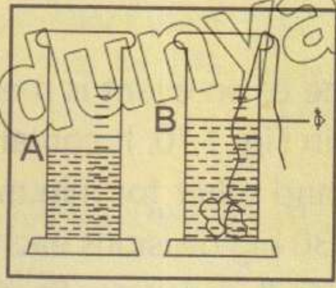


Fig. 1.12
Measuring cylinder

The level of liquids in the cylinder is marked to find the volume. In order to read the volume correctly, the cylinder must be placed on a horizontal surface and the eye shall be kept in level with meniscus of water surface as shown in Fig. 1.12. The meniscus is the top level of the liquid surface. Water in the cylinder curves downward and its surface is called concave surface. The reading is taken corresponding to the bottom edge of the surface. The mercury in the cylinder curves upward. Its surface is convex and the reading is taken corresponding to the top edge. The cylinder can be used to find the volume of solids.

Activity 1.6

The teacher should facilitate the groups to perform this activity following the given instructions.



1. Take a liquid in which the given solid does not dissolve.
2. Note the initial position of liquid surface.
3. Put the solid in the cylinder containing liquid.
4. Note again the position of liquid surface in the cylinder which rises due to solid.
5. The difference of the two readings is the volume of the solid.

Caution: While taking a reading, keep your eye in front and in line with the lower meniscus of the water.

Do You Know?

Ancient Chinese used to estimate the volume of grains by sounding their containing vessels.

Displacement Can Method

If the body does not fit into the measuring cylinder, then an overflow can or displacement can of wide opening is used as shown in Fig. 1.13. Place the displacement can on the horizontal table. Pour water in it until it starts overflowing through its opening. Now tie a piece of thread to the solid body and

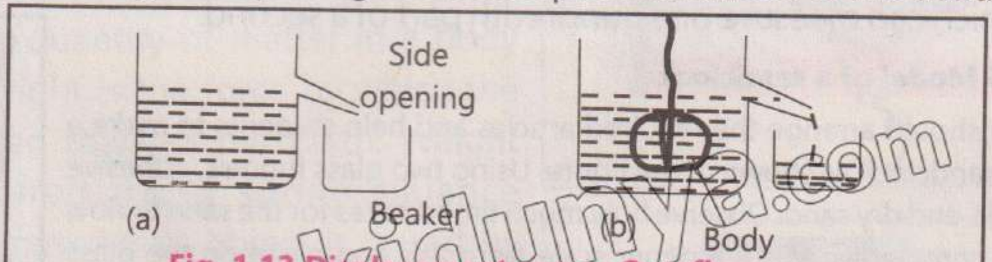


Fig. 1.13 Displacement can or Overflow can

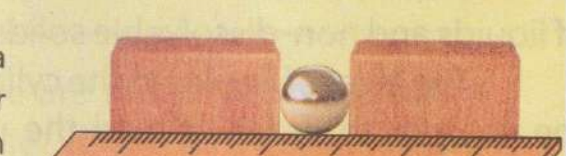
lower it gently into the displacement can. The body displaces water which overflows through the side opening. The water or liquid is collected in a beaker and its volume is measured by the measuring cylinder. This is equal to the volume of solid body.

Do You Know?

Despite the use of SI in most countries, the old measure is still in use, such as printers type is measured in point. One point is 1/72 of an inch equivalent to 0.35 mm.

Activity 1.7

The teacher should facilitate the groups to take a metallic ball or a pendulum bob. Measure its diameter and then volume by placing it in between two wooden blocks alongside a ruler. Then use measuring cylinder and comment on the result of this two onset activities.



1.9 Errors in Measurements

Measurements using tools and instruments are never perfect. They inherit some errors and differ from their true values. The best we shall do is to ensure that the errors are as small as reasonably possible. A scientific

For Your Information!

The symbol of the base units are universal independent of the language used in the written text.

measurement should indicate the estimated error in the measured values. Usually, there are three types of experimental errors affecting the measurements.

(i) Human Errors **(ii) Systematic Errors** **(iii) Random Errors**

(i) Human Errors

They occur due to personal performance. The limitation of the human perception such as the inability to perfectly estimate the position of the pointer on a scale. Personal errors can also arise due to faulty procedure to read the scale. The correct measurement needs to line up your eye right in front of the level. In timing experiments, the reaction time of an individual to start or stop clock also affects the measured value. Human error can be reduced by ensuring proper training, techniques and procedure to handle the instruments and avoiding environmental distraction or disturbance for proper focusing. The best way is to use automated or digital instruments to reduce the impact of human errors.

(ii) Systematic Errors

They refer to an effect that influences all measurements of particular measurements equally. It produces a consistence difference in reading. It occurs due to some definite rule. It may occur due to zero error of instrument, poor calibration of instrument or incorrect marking. The eff ct of this kind of error can be reduced by comparing the instrument with another which is known to be more accurate. Thus, a correction factor can be applied.

(iii) Random Errors

It is said to occur when repeated measurements of a quantity give different values under the same conditions. It is due to some unknown causes which are unpredictable.

The experimenter have a little or no control over it. Random error arise due to sudden fluctuation or variation in the environmental conditions. For example, changes in temperature, pressure, humidity, voltage, etc. The effect of random errors can be reduced using several or multiple readings and then taking their average or mean value. Similarly, for the measuring time period of oscillating pendulum, the time of several oscillations, say 30 oscillations is noted and then mean or average value of one oscillation is determined.

Quick Quiz

Identify Personal, Systematic and Random errors:

1. Your eye level may move a bit while reading the meniscus.
2. Air current may cause the balance to fluctuate.
3. The balance may not be properly calibrated.
4. Some of the liquid may have evaporated while it is being measured.

1.10 Uncertainty in a Measurement

There is no such thing as a perfect measurement. Whenever a physical quantity is measured except counting, there is inevitably some uncertainty about its determined value due to some instrument. This uncertainty may be due to use of a number of reasons. One reason is the type of instrument being used. We know that every measuring instrument is calibrated to a certain smallest division and this fact puts a limit to the degree of accuracy which can be achieved while measuring with it. Suppose that we want to measure the length of a straight line with the help of a metre rule calibrated in millimetres. Let the end point of the line lies between 10.3 cm and 10.4 cm marks. By convention, if the end of the line does not touch or cross the midpoint of the smallest division, the reading is confined to the previous division. In case the end of the line seems to be touching or have crossed the midpoint, the reading is extended to the next division. Thus, in this example, the maximum uncertainty is ± 0.05 cm. It is, infact, equivalent to an uncertainty of 0.1 cm equal to the least count of the instrument divided into two parts, half above and half below the recorded reading.

Uncertainty in Digital Instruments

Some modern measuring instruments have a digital scale. We usually estimate one digit beyond what is certain. With digital scale, this is reflected in fluctuation of the last digit.

The uncertainty in small length such as diameter of a wire and short interval of time can be reduced further by taking multiple readings and then finding average value. For example, the average time of one oscillation of a simple pendulum is usually found by measuring the time for thirty oscillations.

The uncertainty or accuracy in the value of a measured quantity can be indicated conveniently by using significant figures.

1.11 Significant Figures

We can count the number of candies in a jar and know it exactly by counting but we cannot measure the height of the jar exactly. All measurements include uncertainties depending upon the refinement of the instrument which is used for measurement.

It is important to reflect the degree of uncertainty in a measurement by recording the observation in significant figures.

The significant figures or digits are the digits of a measurement which are reliably known.

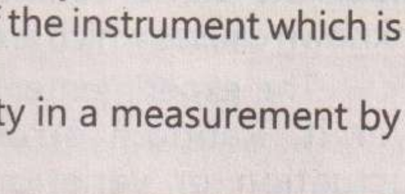


Fig. 1.14

Figure 1.14 shows a rod whose length is measured with a ruler. The measurement shows the length in between 4.6 cm and 4.7 cm. Since the length of the rod is slightly more than 4.6 cm but less than 4.7 cm, so the first student estimates it to be 4.6 cm whereas the second student takes it as 4.7 cm. The first student thinks that the edge is nearer to 6 mm mark whereas the second student considers the edge of the rod nearer to 7 mm mark. It is difficult to decide what is the true length.

Both students agree on digit 4 but the next digit is doubtful which has been determined by estimation only and has a probability of error. Therefore, it is known as a doubtful digit. In any measurement, the accurately known digits and the first doubtful digit are known-as significant figures.

Quick Quiz

Name some repetitive processes occuring in nature which could serve as reasonable time standard.

The following points are to be kept in mind while determining the number of significant figures in any data. All digits from 1 to 9 are significant. However, zeros may or may not be significant. In case of zeros, the following rules apply:

(a) A zero between two digits is considered significant. For example in 5.06m, the number of significant figures is 3.

(b) Zeros on the left side of the measured value are not significant. For example, in 0.0034 m, the number of significant figures is 2.

(c) Zeros on the right side of a decimal are considered significant. For example, in 2.40 mm the significant digits are 3.

(d) If numbers are recorded in scientific notation, then all the digits before the exponent are significant. For example, in 3.50×10^4 m, the significant figures are 3.

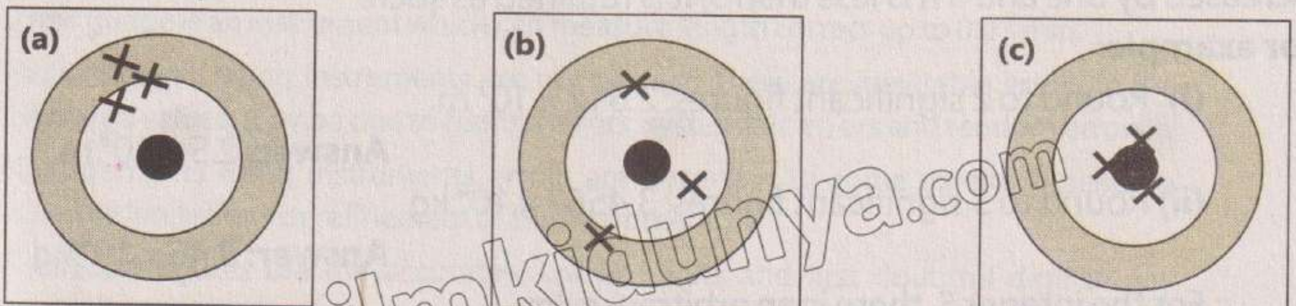
Quick Quiz

How many significant figures are there in each of the following?

(a) 1.25×10^2 m (b) 12.5 cm (c) 0.125 m (d) 0.000125 km

1.12 Precision and Accuracy

A physical measurements should be precise as well as accurate. These are two separate concepts and need clear distinction. Generally, precision of a measurement refers to how close together a group of measurements actually are to each other. Accuracy of a measurement refers how close the measured value is to some accepted or true value.



Precise not accurate Accurate not precise Accurate and precise

Fig. 1.15

A classic illustration is helpful to distinguish the two concepts. Consider a target or bullseye hit by arrows in Fig. 1.15. To be precise, arrows must hit near each other (Fig.1.15-a) and to be accurate, arrows must hit near the bullseye

(Fig. 1.15-b). Consistently hitting near the centre of bullseye indicates both precision and accuracy (Fig. 1.15-c). When these concepts are applied to measurements, the precision is determined by the instrument being used for measurement. The smaller the least count, the more precise is the measurement. A measurement is accurate if it correctly reflects the size of the object being measured. Accuracy depends on fractional uncertainty in the measurement. Infact, it is relative measurement which is important. The smaller the size of physical quantity, the more precise instrument is needed to be used. The accuracy of measurement is reflected by the number of significant figures, the larger is the number of significant figures, the higher is the accuracy.

Table 1.7 Some Timing Devices

Type of clock/watch	Use and accuracy
Atomic clock	Measures very short time intervals of about 10^{-10} seconds.
Digital stopwatch	Measures short time intervals (in minutes and seconds) to an accuracy to ±0.01 s.
Analogue stopwatch	Measures short time intervals (in minutes and seconds) to an accuracy to ±0.1 s.
Ticker-tape timer	Measures short time intervals of 0.02 s.
Watch/Clock	Measures longer time intervals in hours, minutes and seconds.
Pendulum clock	Measures longer time intervals in hours, minutes and seconds.
Radioactive decay clock	Measures (in years) the age of remains from thousands of years ago.

1.13 Rounding off the Digits

When rounding off numbers to a certain number of significant figures, do so to the nearest value. If the last digit is more than 5, the retained digit is increased by one and if it is less than 5, it is retained as such.

For example:

(i) Round to 2 significant figures: 2.512×10^3 m.

Answer: 2.5×10^3 m

(ii) Round to 3 significant figures: 3.4567×10^4 kg.

Answer: 3.46×10^4 kg

For the integer 5, there is an arbitrary rule:

If the number before the 5 is odd, one is added to the last digit retained.

If the number before the 5 is even, it remains the same:

For example:

(i) Round to 2 significant figures: 4.45×10^2 m.
(ii) Round to 2 significant figures: 4.55×10^2 m.

Answer: 4.4×10^2 m
Answer: 4.6×10^2 m

Sometimes, logic is applied to decide the fate of a digit. If we round to 2 significant figures 4.452×10^2 m, the answer should be 4.5×10^2 m since 4.452×10^2 m is more closer to 4.5×10^2 m than 4.4×10^2 m.

Do You Know?

An Electronic timer can measure time intervals as short as one-ten thousands (1/10,000) of a second.

KEY POINTS

- A physical quantity can be measured directly or indirectly using some instruments.
- Non-physical quantity is not measurable using an instrument. It qualitatively depends on the perception of the observer and estimated only.
- Base quantities are length, mass, time, temperature, electric current, etc.
- Derived quantities are all those quantities which can be defined with reference to base quantities. For example, speed, area, volume, etc.
- Standard unit does not vary from person to person and understood by all the scientists.
- Base units of system international are: metre, kilogram, second, ampere, candela, kelvin and mole.
- The units which can be expressed in terms of base units are called derived units.
- Scientific notation is an internationally accepted way of writing numbers in which numbers are recorded using the powers of ten or prefixes and there is only one non-zero digit before the decimal.
- Least count is the least measurement recorded by an instrument.
- Vernier Callipers is an instrument which can measure length correct up to 0.1 mm.
- Screw guage is an instrument which can measure length correct up to 0.01 mm.
- Measurements using instruments are not perfect. There are inevitable errors in the measured values, may be due to human errors, systematic errors and random errors.
- Measurements using instruments errors are uncertain to some extent depending upon the limitations or refinement of the instrument.
- Significant figures are the accurately known digits and first doubtful digit in any measurement.
- The precision is detemined by the instrument being used for measurement whereas the accuracy depends on relative measurement reflected by the number of significant figures.

EXERCISE

A Multiple Choice Questions

Tick (✓) the correct answer.

1.1. The instrument that is most suitable for measuring the thickness of a few sheets of cardboard is a:
(a) metre rule (b) measuring tape
(c) Vernier Callipers (d) micrometer screw gauge

1.2. One femtometre is equal to:
(a) 10^{-9} m (b) 10^{-15} m
(c) 10^{9} m (d) 10^{15} m

1.3. A light year is a unit of:
(a) light (b) time
(c) distance (d) speed

1.4. Which one is a non-physical quantity?
(a) distance (b) density
(c) colour (d) temperature

1.5. When using a measuring cylinder, one precaution to take is to:
(a) check for the zero error
(b) look at the meniscus from below the level of the water surface
(c) take several readings by looking from more than one direction
(d) position the eye in line with the bottom of the meniscus

1.6. Volume of water consumed by you per day is estimated in:
(a) millilitre (b) litre
(c) kilogram (d) cubic metre

1.7. A displacement can is used to measure:
(a) mass of a liquid (b) mass of a solid
(c) volume of a liquid (d) volume of a solid

1.8. Two rods with lengths 12.321 cm and 10.3 cm are placed side by side, the difference in their lengths is:
(a) 2.02 cm (b) 2.0 cm (c) 2 cm (d) 2.021 cm

1.9. Four students measure the diameter of a cylinder with Vernier Callipers. Which of the following readings is correct?
(a) 3.4 cm (b) 3.475 cm (c) 3.47 cm (d) 3.5 cm

1.10. Which of the following measures are likely to represent the thickness of a sheet of this book?
(a) 6×10^{-25} m (b) 1×10^{-4} m
(c) 1.2×10^{-15} m (d) 4×10^{-7} m

1.11. In a Vernier Callipers ten smallest divisions of the Vernier scale are equal to nine smallest divisions of the main scale. If the smallest division of the main scale is half millimetre, the Vernier constant is equal to:
(a) 0.5 mm (b) 0.1 mm
(c) 0.05 mm (d) 0.001 mm

B Short Answer Questions

1.1. Can a non-physical quantity be measured? If yes, then how?

1.2. What is measurement? Name its two parts.

1.3. Why do we need a standard unit for measurements?

1.4. Write the name of 3 base quantities and 3 derived quantities.

1.5. Which SI unit will you use to express the height of your desk?

1.6. Write the name and symbols of all SI base units.

1.7. Why prefix is used? Name three sub-multiples and three multiple prefixes with their symbols.

1.8. What is meant by:

(a) 5 pm

(b) 15 ns

(c) 6 μm

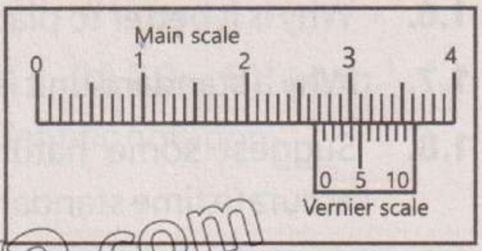
(d) 5 fs

1.9. (a) For what purpose, a Vernier Callipers is used?

(b) Name its two main parts.

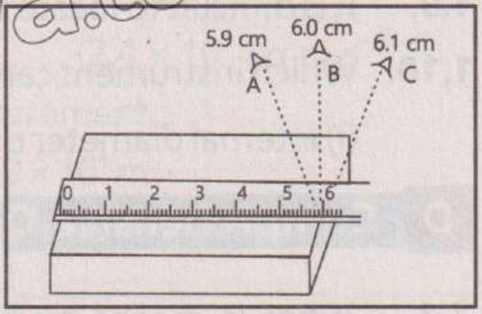
(c) How is least count found?

(d) What is meant by zero error?



1.10. State least count and Vernier scale reading as shown in the figure and hence, find the length.

1.11. Which reading out of A, B and C shows the correct length and why?



C Constructed Response Questions

1.1. In what unit will you express each of the following?

(a) Thickness of a five-rupee coin: ______

(b) Length of a book: ______

(c) Length of football field: ______

(d) The distance between two cities: ______

(e) Mass of five-rupee coin: ______

(f) Mass of your school bag: ______

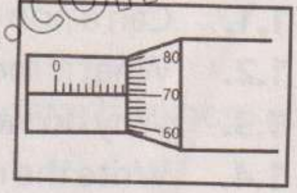
(g) Duration of your class period: ______

(h) Volume of petrol filled in the tank of a car: ______

(i) Time to boil one litre milk: ______

1.2. Why might a standard system of measurement be helpful to a tailor?

1.3. The minimum main scale reading of a micrometer screw gauge is 1 mm and there are 100 divisions on the circular scale. When thimble is rotated once, 1 mm is its measurement on the main scale. What is the least count of the instrument? The reading for thickness of a steel rod as shown in the figure. What is the thickness of the rod?



1.4. You are provided a metre scale and a bundle of pencils; how can the diameter of a pencil be measured using the metre scale with the same precision as that of Vernier Callipers? Describe briefly.

1.5. The end of a metre scale is worn out. Where will you place a pencil to find the length?

1.6. Why is it better to place the object close to the metre scale?

1.7. Why a standard unit is needed to measure a quantity correctly?

1.8. Suggest some natural phenomena that could serve as a reasonably accurate time standard.

1.9. It is difficult to locate the meniscus in a wider vessel. Why?

1.10. Which instrument can be used to measure:

(i) internal diameter of a test tube (ii) depth of a beaker?

D Comprehensive Questions

1.1. What is meant by base and derived quantities? Give the names and symbols of SI base units.

1.2. Give three examples of derived unit in SI. How are they derived from base units? Describe briefly.

1.3. State the similarities and differences between Vernier Callipers and micrometer screw gauge.

1.4. Identity and explain the reasons for human errors, random errors and systematic errors in experiments.

1.5. Differentiate between precision and accuracy of a measurement with examples.

E Numerical Problems

1.1 Calculate the number of seconds in a (a) day (b) week (c) month and state your answers using SI prefixes. (86.4 ks, 604.8 ks, 2.592 Ms)

1.2 State the answers of problem 1.1 in scientific notation.

[8.64×10^4 s, 6.048×10^5 s, 2.592×10^6 s]

1.3 Solve the following addition or subtraction. State your answers in scientific notation.

(a) 4×10^{-4} kg + 3×10^{-5} kg (b) 5.4×10^{-6} m − 3.2×10^{-5} m

[(a) 4.3×10^{-4} kg (b) -2.66×10^{-5} m]

1.4 Solve the following multiplication or division. State your answers in scientific notation.

(a) $(5 \times 10^4\ \text{m}) \times (3 \times 10^{-2}\ \text{m})$ (b) $\dfrac{6 \times 10^8\ \text{kg}}{3 \times 10^4\ \text{m}^3}$

(a) $1.5 \times 10^3\ \text{m}^2$ (b) $2.0 \times 10^4\ \text{kg m}^{-3}$

1.5 Calculate the following and state your answer in scientific notation.

$$\frac{(3 \times 10^2\ \text{kg}) \times (4.0\ \text{km})}{5 \times 10^2\ \text{s}^2}$$

(2.4×10^3 kg m s^{-2})

1.6 State the number of significant digits in each measurement.

(a) 0.0045 m (b) 2.047 m (c) 3.40 m (d) 3.420×10^4 m

[(a) 2 (b) 4 (c) 3 (d) 4]

1.7 Write in scientific notation:

(a) 0.0035 m (b) 206.4×10^2 m

[(a) 3.5×10^{-3} m, (b) 2.064×10^4 m)]

1.8 Write using correct prefixes:

(a) 5.0×10^4 cm (b) 580×10^2 g (c) 45×10^{-4} s [(0.5 km, 58 kg, 4.5 ms)]

1.9 Light year is a unit of distance used in Astronomy. It is the distance covered by light in one year. Taking the speed of light as 3.0×10^8 m s^{-1}, calculate the distance.

(9.46×10^{15} m)

1.10 Express the density of mercury given as 13.6 g cm^{-3} in kg m^{-3}.

(1.36×10^4 kg m^{-3})