

Measurement in Science and Technology

We all make use of measurements in our daily life. A milkman measures milk, a shopkeeper measures rice or pulses, a farmer measures his field, a tailor measures the cloth before tailoring and so on. Everybody measures something or the other with different types of devices. It is seen that if we know what to measure and how to measure it, we can do many things well in life. Measurement is one of the basic life skills necessary for everyday life. It is also useful and essential in the learning of science and technology.

There is a constant need for measurement in our everyday life. Let us find out little more about the process of measurement. What does this process of measurement involve? Which tools are used for accurate and precise measurement? On which factors are measurement techniques based? This lesson will make you aware of several such aspects of measurement. In this lesson you will study about different measurement systems including the ancient system of measurement and the SI units. You will also learn about the methods of measurement of various physical quantities like length, mass, time, area and volume.

OBJECTIVES

After completing this lesson, you will be able to:

- cite examples of the uses of various parts of our body and senses to measure length;
- state the limitations of the use of body parts and senses for measurement and justify the need for a standard to measure anything exactly;
- describe the Indian and various other measurement systems used in the ancient times;
- define a physical quantity with examples;
- differentiate between fundamental and derived units;
- write S.I. units of different fundamental physical quantities;
- use multiples and submultiples of different units;
- define the least count of a measuring instrument;
- name the various devices and instruments used to measure length, mass and time stating the standard in each case;
- measure area of regular and irregular figures;
- measure volume of regular and irregular solids.

1.1 HISTORICAL BACKGROUND OF MEASUREMENT

1.1.1 Body parts and senses used for measurement

Since ancient times, people used their senses and body parts to measure various things. They did this because it became necessary for them in their daily life to deal with other people. Let us find out how senses and body parts help us in measurement.

(a) Use of our body parts and senses for measurement

We have five senses, which help us to find out about the things around us. These senses are seeing, hearing, smelling, tasting and touching. For example, if we see a tall and a short building or a tall and short person we can feel the difference in their heights. Similarly, if we touch a body we can feel the hotness or coldness of the body. Thus, our senses do help us to guess or estimate the height, length and hotness or coldness of a body and other things around us. *Here, estimation means a rough measurement made by our senses.*

(b) Use of body parts for measurement

In ancient days, long before measuring instruments were invented, people actually used different parts of their body to measure length. Figure 1.1 shows various parts of our body, which were used and can still be used to carry out various measurements. But since these measurements are dependent on the size of the person, they may vary from person to person. The length of the cubit, for example, depends on the arm length of the measurer. Thus, cubits had different lengths. To have a better understanding, let us perform an activity.

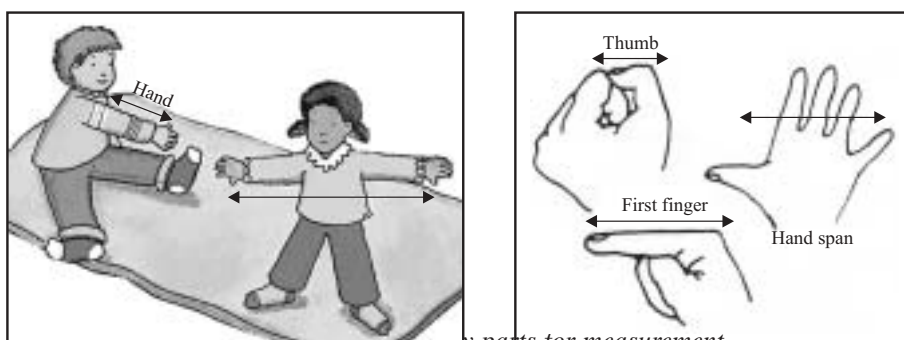


Fig. 1.1 Use of body parts for measurement

ACTIVITY 1.1

Aim : To understand the accuracy in the use of body parts for measurement.

What is required?

A ruler, a measuring tape.

What to do?

- With the help of a ruler, measure the length of various parts of your body like the arm or the palm, which are normally used for measurement.
- Repeat the measurements for your friend or for a younger brother and sister also. You can use a measuring tape also for this activity.
- Compare the measurements.

What do you observe?

You will find that there is a difference in the measurement of your body parts with those of your friends.

(c) Limitations of our senses and body parts

Though we use our senses and body parts for various measurements, we cannot trust them to measure exactly and accurately. Can you depend on your eyes to judge accurately the height or lengths of different objects? Look at figure 1.2a. Which circle is larger-A or B? Well, both are of the same size. Larger circles around the central one make it appear smaller. Small circles around the central circle make the other appear larger.

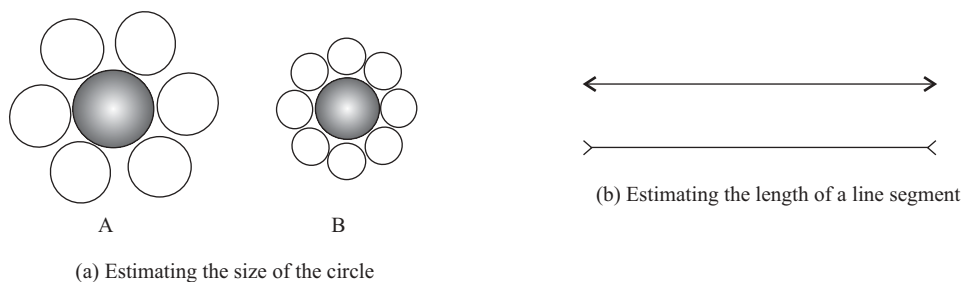


Fig. 1.2 Limitations of our senses and body parts in measurement

There are many more such instances where objects can fool our eyes. Now look at figure 1.2b and tell which line segment is larger. Verify your estimation by measuring each line segment with the help of a scale.

In the above mentioned cases we tried to guess the length or size by seeing i.e. tried to give an estimate, which may or may not be correct. Thus, the use of senses or body parts for measurement does not provide

- accuracy of measurement,
- reliability of measurement,
- uniformity of measurement,

The limitations of the use of senses and body parts have made us to develop some devices and instruments for accurate measurements.

1.1.2 Indian measurement system

a) Indian measurement system in the ancient period

Measurement plays an important role in our lives. We have been using measurement right from the pre-historic time. Let us have a brief look into the historical development of measurement system in India. In **ancient periods**, the lengths of the shadows of trees or other objects were used to know the **approximate time of the day**. Long time durations were expressed in terms of the lunar cycles, which even now is the basis of some calendars. In India, excellent examples of measurement practices in different historic periods are available. Our ancient literature reveals that in India different types of measurement practices were followed in different periods. For example, about 5000 years ago in the 'Mohenjodaro era', the size of bricks all over the region was same. The length, breadth and width of bricks were taken as a standard and were always in ratios of 4:2:1.

Similarly around 2400 years ago during the Chandragupta Maurya period there was a well-defined system of weights and measures. The government at that time ensured that everybody used the same weights and measures. According to this system, the smallest unit of length was 1 **Parmanu**. Small lengths were measured in **anguls**. For long distances **Yojana** was used. *One yojana is roughly equal to 10 kilometres.*

The Indian medicine system, Ayurveda, also had well-defined units for the measurement of the mass and volume. The measurement system was strongly followed to ensure the proper quantity of medicine for particular disease.

Different units of measurements used in the period of Chandragupta Maurya

8 Parmanus	=	1 Rajahkan (dust particle from the wheel of a chariot)
8 Rajahkans	=	1 Liksha (egg of lice)
8 Likshas	=	1 Yookamadhyas
8 Yookamadhyas	=	1 Yavamadhyas
8 Yavamadhyas	=	1 Angul
8 Anguls	=	1 Dhanurmushti

(Reference: Kautilaya's *Arthashastra*)

b) Indian measurement system in the medieval period

In the medieval period also the measurement system was in practice. As described in **Ain-i-Akbari** by **Abul Fazl-i-Allami**, during the period of Moghul Emperor **Akbar**, the **gaz** was used as the unit of measuring length. Each gaz was divided into 24 equal parts and each part was called **Tassuj**. This system was extensively used to measure land pieces, for construction of buildings, houses, wells, gardens and roads. You should know that, the gaz was widely used as a unit of length till the metric system was introduced in 1956. Even today in many parts of our country, particularly in the rural areas, gaz is being used as a unit of length.

c) Indian measurement system during British period

In order to bring about uniformity in the system of measurement and the weights used, a number of efforts were made during the British period. The British rulers wanted to connect Indian weights and measures to those being used in Great Britain at that time. During this period the **inch, foot, and yard** were used to measure length whereas **grain, ounce, pounds**, etc. were used to measure mass. These units and weights were used in India till the time of Independence in 1947. The essential units of mass used in India included **Ratti, Masha, Tola, Chhatank, Seer and Maund**. Raatti is a red seed whose mass is approximately 120 mg. It was widely used by goldsmiths and by practitioners of traditional medicine system in India.

Relation between various units of mass used during the British period

8 Ratti	=	1 Masha
12 Masha	=	1 Tola
5 Tola	=	1 Chhatank
16 Chhatank	=	1 Seer
40 Seer	=	1 Maund
1 Maund	=	100 Pounds troy (exact)

CHECK YOUR PROGRESS 1.1

1. Name the smallest unit of length during the Chandragupta Maurya period.
2. List out our body parts normally used for measurement.
3. In which period was 'gaz' used as a unit to measure length?

1.2 THE MODERN MEASUREMENT SYSTEM

In order to overcome the limitations of senses and body parts, and to bring about a worldwide uniformity in the measurement system, the need for exact measurement was felt. For this, a standard of measurements had to be developed which everybody everywhere accepts.

The problem of measuring lengths exactly was first solved by the Egyptians in 3000B.C. They did this by inventing the standard cubit. They realized that the length of the arm actually did not matter as long as people of Egypt were concerned. Then they made measuring sticks exactly of the same length as that of standard cubit. In this way they made sure that the cubit was the same length all over Egypt. That is really how measurement is carried out today. In fact, for each measurement a standard is chosen. Every measuring instrument has to be compared with that standard. The present measurement system, which is accepted world-over, has its origin in the French Revolution. You will study the details of the modern system of measurement, in the following sections.

1.2.1 Fundamental quantities and units

You have read that measurements are concerned with quantities like length, mass, time, density etc. Any quantity which can be measured is called a **physical quantity**. Out of the different physical quantities, there are seven physical quantities in terms of which other physical quantities can be measured. These fundamental physical quantities are length, mass, time, electric current, temperature, luminous intensity and amount of substance. Such quantities are considered to be the **basic** or **fundamental physical quantities**.

If you are asked to measure the quantity of a given amount of milk, you will express the volume of milk in some accepted units of volume. Likewise, if an engineer measures the length of a road that connects two cities, he should express the distance in an accepted unit of length. Such a procedure makes life more comfortable. If there were no common units accepted by all, life would be miserable. Such units are much more essential in scientific measurements to facilitate communication of information at international level.

Any measurement of a quantity includes a **reference standard or unit** in which the quantity is measured and the **number** of times the quantity contains that unit. Thus, when we say that the length of a rod is 4 metres, the rod is four times the metre, which is the **unit of length**. Metre is the standard length that is adopted as a standard for comparison while measuring length. *In the process of measurement the accepted reference standard which is used for comparison of a given quantity is called a **unit**.*

1.2.2 The SI units

Scientists have developed and used several systems for expressing the units of physical quantities. However, all measurements in any system are based on the units of the basic or fundamental physical quantities. The units of the fundamental or basic quantities that are independent of each other are called ***fundamental units***.

Keeping in view the importance of the proper units for measurement, there have been attempts over centuries in several developed civilizations to suggest standard units of measurements at international level. In the year 1967, the XIII General Conference on Weights and Measures rationalised the **MKSA (Metre, Kilogram, Second, Ampere) system** of units and adopted a system based on six basic units. It was called the **Système Internationale de unites** known as **SI units** in all languages. In 1971, the General Conference added another basic unit to the SI units i.e., **mole** for the amount of substance.

The fundamental units in different systems are different. The international system of units, known as SI units, are commonly used for all scientific purposes. This system has seven basic units for seven physical quantities, which are given in Table 1.1.

Table 1.1: SI units and their symbols

Physical quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Amount of substance	mole	mol
Electric current	ampere	A
Luminous intensity	candela	cd

Perhaps you may be confused by mass and amount of substance and also with luminous intensity as given in Table 1.1. The **mass** of a body is the amount of matter contained in the body, while a **mole** is the amount of any substance equal to its molecular mass.

$\begin{aligned} 1 \text{ mole of HCl} &= 36.46 \text{ g} \\ 2 \text{ moles of HCl} &= 36.46 \times 2 = 72.92 \text{ g} \end{aligned}$

Luminous intensity is the amount of light emitted by a point source per second in a particular direction.

The yard and mile as units of length are still in use in USA.

Units of length still in use in USA		
1 mile	=	8 furlongs
1 furlong	=	220 yards
1 yard	=	3 feet
1 foot	=	12 inches
1 yard	=	0.9144 m (exactly)
1 inch	=	2.54 cm (exactly)
1 mile	=	1.61 km

The guiding principle in choosing a unit of measurement is to relate it to common man's life as far as possible. As an example, take the unit of mass as **kilogram** or the unit of

length as **metre**. In our day-to-day business we buy food articles in kg or tens of kg. We buy cloth in metres or tens of metres. If gram had been chosen as the unit of mass or millimetre as unit of length, we would be unnecessarily using big numbers in our daily life. It is for this reason that the basic units of measurements are very closely related to our daily life.

1.2.3 Standard units of fundamental quantities

Once we have chosen the fundamental units of the SI, we must decide on the set of standards for the fundamental quantities.

- a) **Mass:** The SI unit of mass is **kilogram**. *One kilogram is the mass of a particular cylinder made of Platinum–Iridium alloy, kept at the International Bureau of Weights and Measures in France.* This standard was established in 1887 and there has been no change because this is an unusually stable alloy. Prototype kilograms have been made out of this alloy and distributed to member states. The national prototype of India is the Kilogram no 57. This is preserved at the National Physical Laboratory, New Delhi.
 - b) **Length:** The SI unit of length is **metre**. Earlier the metre (also written as meter) was defined to be $1/10^7$ times the distance from the Equator to the North Pole through Paris. This standard was abandoned for practical reasons. In 1875, the new metre was defined *as the distance between two lines on a Platinum-Iridium bar stored under controlled conditions.* Such standards had to be kept under severe controlled conditions. Even then their safety against natural disasters is not guaranteed, and their accuracy is also limited for the present requirements of science and technology. In 1983 the metre was redefined as *the distance travelled by light in vacuum in a time interval of $1/299792458$ seconds.* This definition establishes that the speed of light in vacuum is 299792458 metres per second.
 - c) **Time:** The SI unit of time is **second**. The time interval second was originally defined in terms of the time of rotation of earth about its own axis. This time of rotation is divided in 24 parts, each part is called an hour. *An hour is divided into 60 minutes and each minute is subdivided into 60 seconds.* Thus, *one second is equal to $1/86400^{\text{th}}$ part of the solar day.* But it is known that the rotation of the earth varies substantially with time and therefore, the length of a day is a variable quantity, may be very slowly varying. The XIII General Conference on Weights and Measures in 1967 defined *one second as the time required for Cesium–133 atom to undergo 9192631770 vibrations.* The definition has its roots in a device, which is named as the **atomic clock**.
 - d) **Temperature:** The SI unit of temperature is **kelvin (K)**. The thermodynamic scale on which temperature is measured has its zero at absolute zero, and has its lower fixed point corresponding to 273.15 K at the triple point of water (0°C). *One unit of thermodynamic temperature (1K) is equal to $1/273.15$ of the thermodynamic temperature of the triple point of water.*
 - e) **Electric current:** The SI unit of electric current is the **ampere (A)**. One ampere is defined as *the magnitude of current that when flowing through two long parallel wires, each of length equal to 1 m , separated by 1 metre in free space, results in a force of $2 \times 10^{-7}\text{ N}$ between the two wires.*
 - f) **Amount of substance:** The SI unit of amount is **mole (mol)**. *One mole is defined as*
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the amount of any substance, which contains, as many elementary units, as there are atoms in exactly 0.012 kg of C-12.

- g) **Luminous intensity:** The SI unit of luminous intensity (I) is **candela (Cd)**. The candela is defined as *the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity of 1/683 watt per steradian in that direction.*

1.2.4 Derived units

The basic units or the fundamental units are independent of each other. The units of all other physical quantities can be expressed in terms of these **basic units**. Such units are called **derived units**. Thus, *the units, which are obtained by the combination of fundamental units, are known as derived units*. For example, area can be expressed in terms of the basic unit of length, as given below:

You know the area of a surface is the product of length and breadth. Therefore, the unit of area will be equal to the product of the unit of length and the unit of breadth (remember that breadth is also length).

$$\text{Unit of area} = \text{metre} \times \text{metre} = (\text{metre})^2$$

Thus, the **unit of area is m^2** .

Similarly, volume is equal to length \times breadth \times height of the object.

$$\begin{aligned}\text{Therefore, the unit of volume} &= \text{unit of length} \times \text{unit of breadth} \times \text{unit of height} \\ &= \text{metre} \times \text{metre} \times \text{metre} = (\text{metre})^3\end{aligned}$$

Thus, the **unit of volume is m^3** .

The derived units of other physical quantities are also found in the same way. Some of the commonly used derived units are given in Table 1.2.

Table 1.2 : SI units and symbols of some derived units

Physical quantity	SI Unit	Symbol
Area	square metre	m^2
Volume	cubic metre	m^3
Density	kilogram per cubic metre	kg/m^3
Velocity	metre per second	m/s
Acceleration	metre per square second	m/s^2
Force	kilogram metre per square second (also called Newton)	$\text{kg m}/\text{s}^2$ (called N)
Work	kilogram square metre per square second (also called Joule)	$\text{kg m}^2/\text{s}^2$ (called J)

There are some other commonly used derived units with special names. They are given in the Table 1.3.

Table 1.3: Some commonly used derived units

Physical quantity	Special name	Symbol	SI Unit
Force	Newton	N	kg m/s ²
Pressure	Pascal	Pa	N/m ²
Energy	joule	J	Nm
Power	watt	W	J/s

1.2.5 Multiples and sub-multiples of units

Sometimes the measurement of physical quantities can give very large or very small numbers. The smaller and larger units of the basic units are multiples of ten only. They strictly follow the decimal system. These multiples or submultiples are given special names. These are listed in Table 1.4.

For example, the mass of the earth and mass of the electron are found to be as follows:

$$\text{Mass of earth (M)} = 5,970,000,000,000,000,000,000 \text{ kg}$$

$$\text{Mass of an electron (m}_e\text{)} = 0.000,000,000,000,000,000,911 \text{ kg}$$

You will notice that it is not a convenient way to express the mass of earth or the mass of an electron. It takes up space and time to read it. Thus, for convenience, large numbers or very small decimals are expressed in an abbreviated form. The abbreviations in common use are based upon the powers of ten as given in the Table 1.4.

Table 1.4: Representation of large and small quantities in powers of ten

Large quantities	Small quantities
$10^0 = 1$	$1 = 10^0$
$10 = 10^1$	$0.1 = 10^{-1}$
$100 = 10^2$	$0.01 = 10^{-2}$
$1,000 = 10^3$	$0.001 = 10^{-3}$
$10,000 = 10^4$	$0.0001 = 10^{-4}$
$100,000 = 10^5$	$0.00001 = 10^{-5}$
$1,000,000 = 10^6$	$0.000001 = 10^{-6}$
Thus, $10^3 = 10 \times 10 \times 10 = 1000$	

$$\text{and, } 10^{-3} = \frac{1}{10^3} = \frac{1}{1000} = 0.001$$

Example 1.1: Suppose a large ship has a mass of nine hundred thousand kilograms. Express it in powers of ten.

Solution: Given, mass of ship = 900,000 kg

Thus, in powers of ten, the mass of ship = 9×10^5 kg

Example 1.2: Express the number 0.00034 in terms of powers of ten.

Solution: $0.00034 = 3.4 \times 10^{-4}$

This concept has been used to express multiples and submultiples of basic units of

measurement – again for the purpose of convenience. For example, let us take the SI unit of length, i.e. metre. Its *multiples and submultiples would be*:

<i>Multiple</i>
1000 metres = 1 kilometre or $10^3 \text{ m} = 1 \text{ km}$

<i>Sub-multiple</i>
$1/1000 \text{ metres} = 1 \text{ millimetre}$ or $10^{-3} \text{ m} = 1 \text{ mm}$

As the metric system uses the base 10, the change from one unit to the another is very easy and it uses simple prefixes to denote multiples or submultiples of the basic units. For example, prefix *kilo* always means 1000 whether it is kilometre (1000 m) or kilogram (1000 g), kilowatt (1000 W) or whatever. Similarly, the prefix *centi* always means 1/100 while the prefix *milli* always denotes 1/1000. A list of prefixes for multiples and submultiples is given in Table 1.5.

Table 1.5: Prefixes for multiples and submultiples

Name	Symbol	Equivalent
deca	da	10^1
hecta	h	10^2
kilo	k	10^3
mega	M	10^6
giga	G	10^9
terra	T	10^{12}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

CHECK YOUR PROGRESS 1.2

1. What are the characteristics of a physical quantity?
2. Differentiate between fundamental and derived units.
3. What is the difference between mass and amount of a substance?
4. Derive the unit of the following quantities:
 - (i) Force = Mass \times acceleration
 - (ii) Pressure = Force/Area
5. Represent 237 nm in metres.

1.3 MEASUREMENT OF QUANTITIES

We use measurements of different types in our daily life. For example, while buying cloth, we measure its length and while buying milk or kerosene we measure its volume. But for accurate and precise measurement, we have to follow certain methods. Let us study some of them.

Let us consider a physical quantity, say length. We know that its standard of measurement is metre. Measuring sticks with the same length as the standard metre have been made which we commonly call as the **metre stick**. This one metre long stick is divided into 100 equal parts, i.e. into 100 centimetres. Each centimetre is further divided into 10 millimetres. Thus, the smallest division on a metre scale is 1 millimetre. This is the least count of the

metre scale. Thus, *the minimum or the least quantity that can be measured by a given instrument is called its **least count***. For example, the least count of a metre scale is 1 mm or 0.1 cm. A metre scale cannot measure lengths less than 1 mm. The least count of any measuring instrument is, thus, very important. We must always quote the result of a measurement only up to the least count of the measuring instrument used. Besides, the method and the selection of proper measuring device for a particular measurement are also very important.

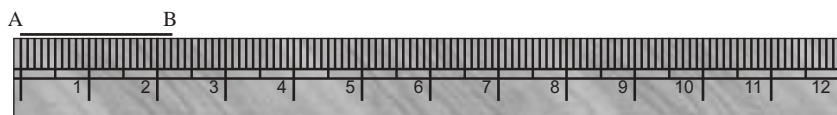
1.4.1 Length and its measurement

As we have studied in the last section, length is the distance between two points and it is measured in terms of metres. Different types of devices are used to measure lengths. For example to measure the length of your table, you will use a ruler or measuring tape. But to measure the diameter (thickness) of a wire, you will require a **screw gauge**. These devices had been made by comparing them with a standard length called standard metre. The standard metre is a fixed length decided by scientists and accepted by all.

a) Using a scale to measure length

To measure the length of a given line segment AB (Fig 1.3), the metre scale is kept along the line segment with its graduations parallel to it. The metre scale must be so placed that its divisions are as close as possible to the line segment to be measured. Its zero end is made coincident with one end of the line segment. Note the point where the other end of the line segment lies. Suppose, it lies beyond the 2 cm mark and is coincident with the second small division after it. Since each of these marks is 1 mm, the total length of the line segment is

$$2 \text{ cm} + 2 \text{ mm} = 2 \text{ cm} + 0.2 \text{ cm} = 2.2 \text{ cm}$$



Remember that while looking at the reading on a scale, we must keep our eyes in front of and in line with the reading to be taken. In case of a metre scale, it is not always possible to make the zero mark on the scale coincident with one end of the line to be measured. With repeated use, the ends of measuring scale get somewhat worn-out and ill defined. In such cases, we keep the metre-scale with any of its divisions other than zero coincident with one end of the line. Suppose we place the scale (ruler) in such a way that the two ends of the line segment coincides with 2.0 cm and 4.2 cm marks, respectively (Fig 1.4). Then, the length of the line segment is

$$4.2 \text{ cm} - 2.0 \text{ cm} = 2.2 \text{ cm}$$

That is, it is the difference between the readings on a scale at its two ends.

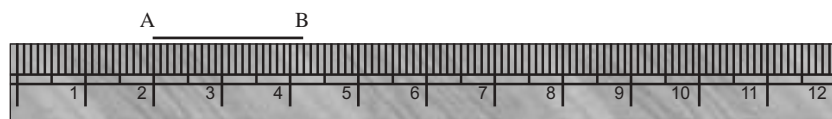


Fig. 1.4 The length of a line segment is the difference between the readings on a scale at its two ends.

If we have to measure a larger length, such as length of a playground, we use a measuring

tape that may be 10 m, 15 m or 50 m long.

Sometimes, we are required to measure very small lengths, say (less than 1 mm) like the diameter of a thin wire, the dimensions of fine machine parts, etc. We cannot use a metre scale for such measurements. For such distances, measuring instruments like the **vernier callipers** and the **screw gauge** are used. Vernier callipers, as shown in Fig 1.5, is an instrument used to measure the length or thickness of a solid body up to 0.01 cm accurately. A screw gauge as shown in Fig. 1.6, is an instrument used to measure the length or thickness of a solid body up to 0.001 cm. accurately However, each measuring instrument is limited to a certain accuracy of measurement which depends on its graduation. To measure the thickness of a wire or a metallic sheet we require screw gauge.

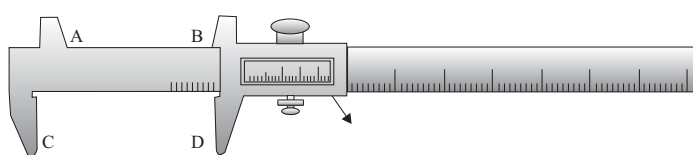


Fig.1.5 Vernier callipers

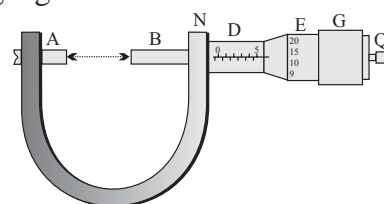


Fig.1.6 Screw gauge

To measure large distances like the distance of your school from your house, or distance between two cities or the distance between the earth and moon, we use **indirect methods of measurement**. For example, to measure the distance between two cities, we will measure the average speed of certain vehicle, say a car, and the time taken by it to cover that distance. The product of the speed and time will give the required distance.

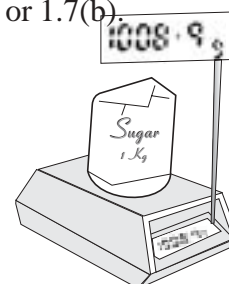
1.3.2 Mass and its measurement

Like length there are many other measurements, which we make in our daily life by using different measuring standards and instruments. For any object, say this book, if some body asks you to answer the question, “How much stuff is there in it”? It means he is trying to find out the mass of the object. As you have studied earlier in this lesson, *mass of a body is defined as the amount of matter contained in the body*. The standard mass chosen by the scientists is called **kilogram**. This standard is used to compare the masses of unknown bodies.

In order to measure the mass of different bodies different types of balances or scales are used. The most common is the one we see with the shopkeepers and vendors. What standard masses are used by shopkeepers to measure quantities? What do their balance look like? Have you seen a balance like the one in figure 1.7(a) or 1.7(b).



(a)



(b)

ACTIVITY 1.2

Fig. 1.7 (a) The shopkeeper's balance (b) A modern balance

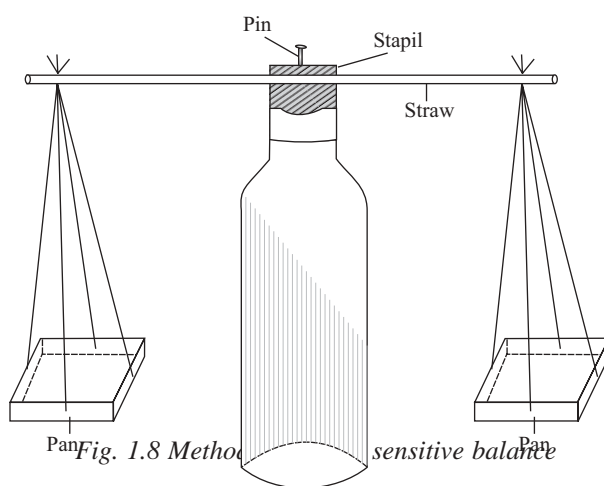
Aim : To make a sensitive balance to compare the masses of light objects.

What is required?

A tall bottle like a squash bottle or an oil bottle, two square pieces having each side about 15 cm in length cut from a sheet of a chart paper, a few drinking straws, pins, sewing thread, gum, plasticine (or wet *atta*)

What to do?

- Use the square papers to make pans as shown in Fig.1.8.
- Draw a small square at a distance of 2 cm from the edges.
- Fold the paper along the outline of the inner square.
- Fold again along dotted lines and fix the paper to outer side of the scale pan with gum.
- Pass lengths of sewing thread through the centre of the four sides. Make a knot so that four stands are of the same length.
- Measure the drinking straw and find its mid-point. Pass a pin through this point.
- Balance the pin on a piece of small rubber (eraser) which is glued or fixed with cello tape to the bottle cap.
- Tie the pans near the two ends of the straw in such a way that they are at equal distances from the mid-point, i.e. the pin.
- Check to see if they are balanced, otherwise use little bits of *atta* or plasticine on the pans.
- This balance can be used to compare the weights of small objects like paper clips and buttons.
- Try and find out the amount of water loss when leaves dry up by weighing them when green and drying them on a hot plate and re-weighing.



A shopkeeper's balance, however, does not provide accurate measurement of masses that is needed. In some cases, for example, to find the mass of a piece of gold or the

composition of chemicals required to make aspirin, etc. For accurate measurement of masses a **physical balance** is used. Figure 1.9 shows a physical balance. Known masses from a standard box are used with this balance.

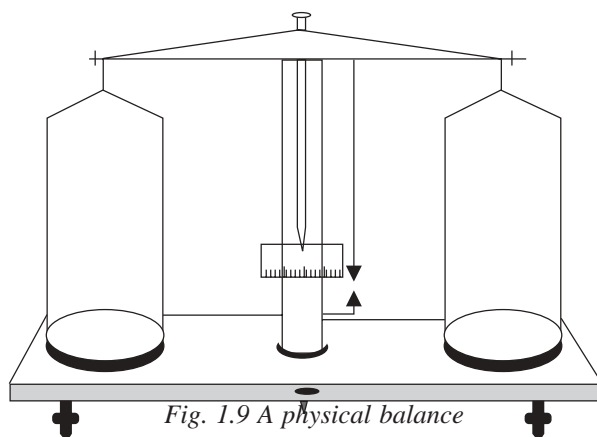


Fig. 1.9 A physical balance

1.3.3 Time and its measurement

Time is measured when you answer questions like, how long does it take to reach Delhi from Bombay? How long do the fruits last? When does the school start?

All these questions relate to happenings of two events with a gap between them. For example, if someone says, “It took me 17 hours to travel by train from Delhi to Bombay”, she is thinking of a measurement of the time interval between a first event (i.e. leaving Delhi) and a second event (i.e. arriving Bombay). She may have measured this interval which is a time interval by looking at her watch when she departed and when she arrived. **Thus, when we measure time we measure the interval of time between two events.**

Sundial

Long long ago, people noticed that shadows were long in the morning and evening, and were the shortest when the sun was directly overhead at noon. From these observations they learnt to tell the hour of the day. Based on it, *the world’s first timepiece – the sundial* was made. The sundial was a hemispherical opening in a block of stone or wood. It had an upright rod, called **gnamon** fixed in the center of the opening (Fig. 1.10). The shadow of the gnamon travelled over the day, telling the time of the day. But the sundial had certain limitations. Can you think of them?



Fig. 1.10 A sundial

Time is measured in seconds (s), minutes (m), hours and days with stop watches and clocks. Our early ancestors used the alternation of the day and night as a clock. They did

this because this phenomenon repeats itself at regular intervals of time. As such, they considered this as a standard with which they used to compare an unknown time interval. *Such a system, which repeats itself at regular intervals of time, is called **periodic system**.*

The measurement of time is really the comparison of an unknown time interval with the standard time interval of a periodic system. Based on this, instruments like sundials, water and sand clocks were used in early times to measure time intervals.

In fact, water clock was the ancestor of our mechanical clocks. Let us perform an activity to understand the working of a water clock.

ACTIVITY 1.3

Aim : To use a water clock to measure your pulse or your friend's pulse

What is required?

Water, beaker, a paper cup and a pin

What to do?

- With the help of a pin make a very small hole in the bottom of the cup.
- Place your finger over the hole and fill the cup with water.
- Hold the cup over a sink or a larger beaker and remove your finger from the hole. The water should drip from the hole and you should be able to count the drops easily. If water runs out instead of dripping, get another cup and try to make a smaller hole.
- After preparing the water clock (Fig. 1.11), use your middle finger and lightly feel your pulse.
- You start counting your pulse, you tell your friend to start counting the drops from the cup at the same time. Both of you have to start and stop at the same time.
- Record the time taken by the heart to beat 15 times in terms of 'drops'.
- Repeat this with your friend. Is there a difference in the pulse rate between you and your friend?



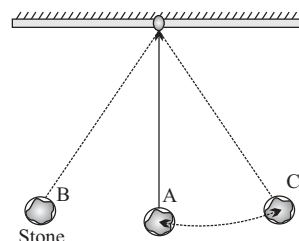
Fig. 1.11 Working of a water clock

These clocks of early times however, were inconvenient to use because the sundial could not be moved from one place to another place and sand and water clocks had to be attended regularly.

The real advancement in the construction of clocks came with the introduction of the pendulum. Let us see how pendulum helped us in measuring time.

The pendulum—A tool to measure time

Tie a small stone to one end of a long string and hang it with the help of the other end to a firm support. This may be used as **simple pendulum**. Pull stone gently to one side and let it go. The stone begins move to and fro, i.e. oscillates (Fig. 1.12). Make sure does not move in circles.



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When the pendulum was at rest, it was at A. This position is called the **mean position**. When it swings, it moves from A to B, back to A, from A to C and back to A. In this way it completes one full swing. Each swing is called one **oscillation**. The distance from A to B or from A to C is called **amplitude** of the oscillation. *Amplitude of a pendulum is the maximum distance the pendulum moves away from the mean position while it is oscillating. The time taken for one oscillation is called the **time period** of the pendulum.*

Fig. 1.12 A simple pendulum

Once your pendulum has started swinging steadily you can use your stopwatch or a wristwatch with seconds hand to find out your pendulum's time period. For this, you may count how long your pendulum takes to make 20 oscillations and then from it, the time for one oscillation can be calculated.

Pendulum clock

The pendulum was used as a time controller in clocks. 1656, **Christian Huygens**, a Dutch scientist, made first pendulum clock, which was regulated by a mechanism using a 'natural' period of oscillation. Although, **Galileo** had invented the pendulum and noticed that the time taken by the weights hanging from a chain or rod to swing back and forth is exactly same amount of time. The whole system was enclosed in a case and thus became the grandfather clock. The length of pendulum and the acceleration to gravity at a place determined the time taken in oscillation.

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Fig. 1.13 A pendulum clock

Though with the discovery of pendulum clocks, time keeping became almost accurate, but it had certain limitations like acquiring large space, and difficulty in movement from one place to the other. Therefore, spring watches were discovered. Such watches have a flat steel-bound spring, which is coiled tight by winding the spring. As the time passes the spring uncoils moving the hour and minutes hands attached to it. Thus, it tells us the time.

With the advancement of science and technology and to meet the need of more accurate time measurement, quartz clocks and atomic clocks came into existence.



(a) Stop Watch



(b) Electronic Watch



(c) Quartz Clock

Fig. 1.14 Different types of clocks

Quartz clocks

Quartz clocks came into existence in 1929 when quartz crystal rings were used in the mechanical clock. But they became popular in 1970. The rings were connected to an electrode in a circuit. When a current is passed through the circuit, the crystal vibrates at a regular frequency. This helps us to measure time. The quartz clocks lose one second in every 10 years.

CHECK YOUR PROGRESS 1.3

- You are given some words like *pans, beam, pointer, weights, objects*. Use these words to fill up blanks in the following paragraph, which gives a general description of a balance.
 “A balance has two _____ supported from a rigid _____. At the center of the support there is a _____ which is free to move. In one pan the _____ to be measured are placed. In the other pan _____ are placed one by one to balance both the pans.
- Estimate the length of this page of your book in the following ways:
 - by just looking at it (i.e., seeing)
 - with the help of your fingers
 - by using your ruler (in cm)
- Why were the clocks of early times inconvenient to use?

1.4 MEASUREMENT OF AREA

The concept of area finds considerable use in our day to day life. For example, we have to consider the area of the top of the table while buying glass or mica for it. Similarly, the farmer has to consider the area of his field while estimating about the crop yield and so on. Now, the question arises what ‘area’ is?

In fact, the area of a figure can be defined as the surface enclosed by the figure or the extent of the surface of the figure. Like every other physical quantity, we need a unit of area also, for its measurement. *The area of a square of side 1m is taken as SI unit of area, which is one square metre*, and it is abbreviated as 1 m^2 . To measure areas, we often use the units cm^2 , mm^2 , km^2 , etc. Also knowing that $100 \text{ cm} = 1 \text{ m}$, we have

$$10^4 \text{ cm}^2 = 1 \text{ m}^2$$

$$\text{and } 1 \text{ km}^2 = 10^6 \text{ m}^2, 1 \text{ m}^2 = 10^{-6} \text{ km}^2$$

Now, let us see, how the areas of different types of figures are measured.

1.4.1 Areas of regular figures

To measure the areas of regular geometrical figures like a rectangle, a triangle, or a circle,

we have well-known formulae. Some of these are given in

Table 1.6

Table 1.6: Formulae to calculate the areas of some geometrical figures	
Figure	Area
Rectangle	length \times breadth

Triangle	$\frac{1}{2} \times \text{base} \times \text{height}$
Circle	$\pi \times (\text{radius})^2$
Parallelogram	$\text{base} \times \text{altitude}$

Using these formulae, we can calculate the required area. For example, if you are asked to find the area of a rectangular playground whose sides are given as 50 m and 60 m, you can easily calculate the area by finding the product of the two sides of the playground.

1.4.2 Area of irregular figures

You can easily find the areas of regular figures by using formulae. But the problem arises in the case of irregular figures. Because, an irregular figure does not have any defined length, breadth, etc. We cannot, therefore, use any formulae to calculate its area. In such cases, we make use of graph papers having squares of side 1 cm each as shown in Fig. 1.15. First, we draw the outline of the given figure of irregular shape on that graph paper. Then we count the number of complete squares in it and the number of incomplete squares. While counting the incomplete squares, we count only those squares that lie half or more within the figure; the other incomplete squares are neglected. The total number of squares thus counted gives the approximate area of the given irregular surface in cm^2 .

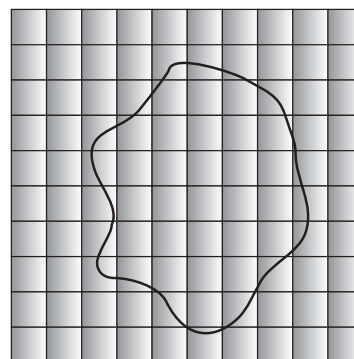


Fig. 1.15 Method to find the area of an irregular figure

In order to measure the areas of the irregular figures of very big size like field or playground, we split them into regular-shaped figures. Then the area of each figure is calculated and added to find the total area.

CHECK YOUR PROGRESS 1.4

1. By what factor will the area of a rectangle increase if all its sides are increased 3 times?
2. A circular tabletop has a radius of 1.4 m. What is the area of mica needed to cover it?
3. How will you measure the area of the leaf of a plant?
4. The area of a figure is 60 m^2 , what is its value in cm^2 ?

1.6 MEASUREMENT OF VOLUME

You would have seen that all the materials occupy certain space. The total space occupied by any piece of matter is referred to as its **volume**. The SI unit used for volume measurement is the volume of a cube of side 1m each. We call this unit as one cubic metre, abbreviated as 1m^3 . To measure smaller or larger volumes, we use other appropriate units like cm^3 , mm^3 , or km^3 .

Now, let us study how to measure the volume of different types of bodies.

Table 1.7: Volume of regular solids	
Solids	Volume
Cube	$(\text{side})^3$
Cuboid	$\text{Length} \times \text{breadth} \times \text{height}$
Sphere	$(4\pi/3) \times (\text{radius})^3$
Cylinder	$\pi(\text{radius})^2 \times \text{height}$

1.6.1 Volumes of regular solids

To measure the volumes of regular solids like cube, sphere or cylinder etc., we have well known formulae. Some of such formulae these are given in Table 1.7.

You would have seen a milkman or a kerosene dealer using volume-measuring vessels as shown in Fig. 1.15 These are generally cylindrical or conical in shape and have their capacity in litres. A litre is one-thousandth part of the SI unit of volume, i.e. m^3 .

$$1 \text{ litre} = 10^{-3} \text{m}^3$$

a) Taking a reading of liquid level in a measuring cylinder

It is observed that liquids like water form a concave meniscus as shown in Fig. 1.17a, while

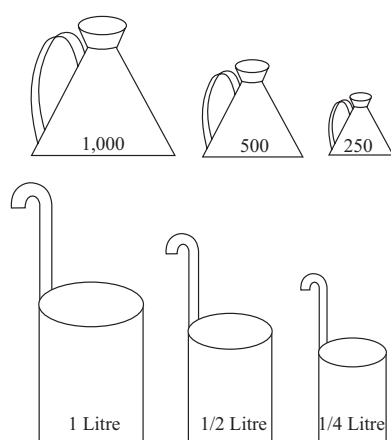


Fig. 1.16 Volume measuring vessels

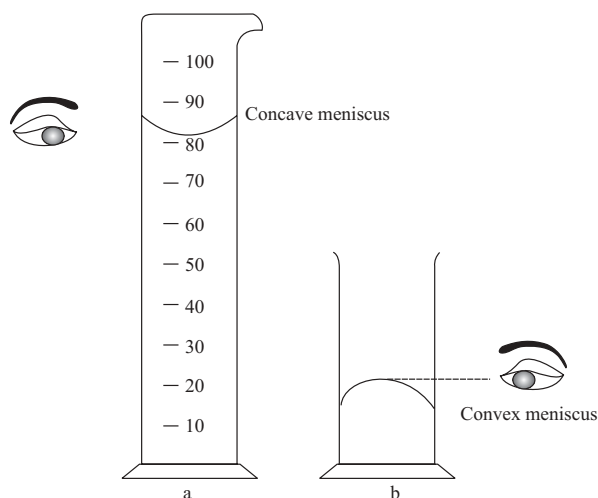


Fig. 1.17 (a) Liquid with concave meniscus (b) Liquid with convex meniscus

those like mercury form a convex meniscus Fig. 1.17b. Now, question arises how to take correct readings of the liquids in such cases. We must keep our eyes in line with the flat middle part of the liquid while taking a reading. If we just look at the measuring cylinder and water level we will get a wrong reading.

1.6.2 Volume of irregular solids

In order to measure the volume of irregular solids, we follow an indirect way of measurement. For this purpose, we use a graduated cylinder or an overflow can. Let us see, how?

a) Using graduated cylinder

For small solids, we half-fill the given graduated cylinder with water and note the reading. Now, dip the solid in it after tying it with a thread as shown in Fig. 1.17. You will notice that the water level rises in the cylinder. Note this reading also. Thus, the difference in the readings of the water level before and after insertion of the solid gives the

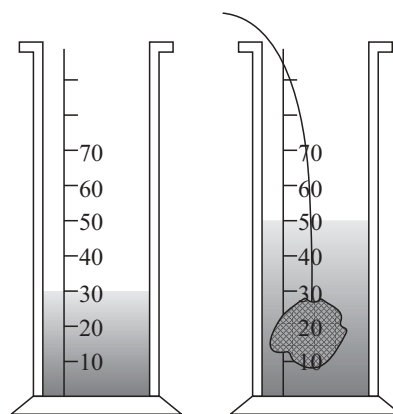


Fig. 1.18 Measuring the volume of a solid using graduated cylinder

volume of the solid.

We cannot use water if the given solid is a piece of water soluble material, such as rock salt. In such a case, we must use a liquid in which the given solid neither dissolves nor reacts chemically.

b) Using an overflow can

If the given solid is so large that it cannot be dipped in a graduated cylinder, then we use a large overflow can with a spout. We fill the overflow can with water till it starts overflowing as shown in Fig 1.19.

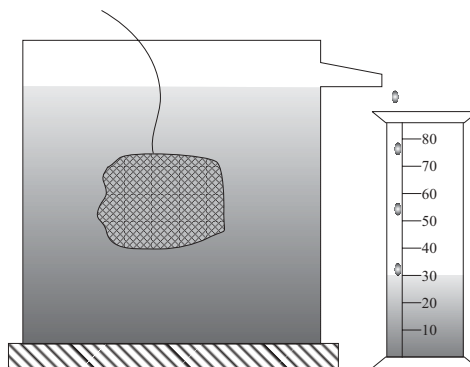


Fig. 1.19 Measuring the volume of a solid using an overflow can

We wait till no more drops overflow. We then place a clean graduated cylinder below the nozzle of the overflow can and dip the given solid in it. Some water overflows and collects in the graduated cylinder. The volume of water overflowed is carefully noted. This is equal to the volume of the given solid.

CHECK YOUR PROGRESS 1.5

1. Why do we need a suitable oil while determining the volume of a piece of rock salt using a graduated cylinder?
2. How many cm^3 will be there in one litre?
3. What is the shape of the meniscus of milk in a cylinder?
4. What is the volume of a sphere of radius 7 cm?

LET US REVISE

- Measurement is basically a process of comparison and involves two things: a number and a unit.
- The unit of physical quantity is a standard value of it in terms of which other quantities of that kind are expressed.
- There are seven fundamental quantities amount of substances namely length, mass, time, temperature, amount of substances light intensity and electric current.
- There are seven SI units and a number of derived units.
- A metre scale is used to measure large lengths. To measure small lengths, we use vernier callipers or screw gauge.
- Area is measured in square metre (m^2) and graph papers are used for estimating the areas of irregular figures.
- The total space occupied by any piece of matter is called its volume. It is measured in cubic metres (m^3). The unit 'litre' is also used to measure the volume of liquids.
- Standard measuring vessels are used to measure volumes of liquids like milk, kerosene oil, mobile oil at petrol pumps, etc.
- In the laboratory, we use graduated cylinder and an overflow can to measure the volume of large irregular bodies.

TERMINAL EXERCISES

A. Multiple choice type questions.

- Which of the following is not an SI unit?
(a) Metre (b) Pound
(c) Kilogram (d) Second
- If the mass of a solution is $10\mu\text{g}$, it is the same as
(a) 10^{-6}g (b) 10^{-12}g
(c) 10^{-9}g (d) 10^{-3}g
- A line segment was measured using a scale. One end of the line segment coincided with the 1.3cm mark on the scale. The other end coincided with 7.2 cm mark. The length of the line segment is
(a) 1.3cm (b) 7.2cm
(c) 8.5cm (d) 5.9cm
- Rajesh travelled from city A to city B by car. The average speed of the car was 70 km/h. It took 4h 30min to cover the distance. The distance between the two cities is
(a) 315km (b) 280km
(c) 2100km (d) 17.5km

B. Descriptive type questions.

- What are the limitations of using our senses and body parts for measurement?
 - Define the following key concepts
(i) Estimation
(ii) Standard of measurement
(iii) Standard metre
(iv) Time interval
(v) Pendulum
 - Name the SI units used to measure length, mass, time and temperature.
 - Give four examples of periodic systems?
 - Define amplitude and time period of a pendulum.
 - Airplane pilot cannot use his senses to guide his plane through thick clouds. He must depend on the plane's instruments. Why?
 - In a village 100 acres of land was distributed among ten farmers. The farmers were very happy because all of them got equal-sized plot of land. How did the Head of the Panchayat manage to do this?
 - Goldsmith uses a balance to measure gold ornaments. Why does he use an instrument for this purpose?
 - In 100 metre race, you must have seen that for each athlete the judge looks at a stop watch to measure the 'time' required by the athlete to complete 100 metres. What does this 'time' mean?
 - Describe the method for finding out the area of a leaf.
 - Measure the diameter of a glass marble by using a scale and two wooden blocks. Which other instrument can be used for finding it more accurately? Why?
 - A thin wire is closely wound on a pencil with its successive turns in contact with each
-

other. If turns of the wire occupy a total distance 2 cm, what is the diameter of the wire.

Which other instrument can be used for more accurate result?

13. How much volume of petrol is needed to fill a spherical tank of radius 2.1 m?

14. Why a standard reference is taken as a unit?

ANSWERS TO CHECK YOUR PROGRESS

1.1

1. Parmanu
2. Arm, angul, cubit, etc.
3. During the period of Moghul emperor Akbar.

1.2

1. It can be measured and is a subject of study through our five senses.
2. a) Fundamental units are only seven in number whereas derived units are very large in number.
b) Fundamental units are independent of each other but derived units are obtained from fundamental units.
3. Mass of a body is the amount of matter contained in a body while the amount of substance is equal to its molecular mass.
4. Unit of force = Unit of mass x Unit of acceleration = kg ms^{-2}
5. Unit of pressure = Unit of force/Unit of area = $\text{kg ms}^{-2} / \text{m}^2 = \text{kg m}^{-1}\text{s}^{-2}$
6. $237\text{nm} = 237 \times 10^{-9}\text{m} = 2.37 \times 10^{-7}\text{m}$

1.3

1. pans – beam – pointer – objects – weight
2. Do as in section 1.3.1.
3. They were heavy and bulky and could not be taken from one place to another.

1.4

1. 9 times
2. 6.16 m^2
3. refer section 1.4.2
4. 600000cm^2

1.5

1. We cannot use water because rock salt will dissolve in water but not in oil.
2. 1000 cm^3
3. concave
4. 1437.33 cm^3

GLOSSARY

Area of a figure: the surface enclosed by a figure or the extent of the surface of a figure.

Derived units: Units that are obtained by the combination of fundamental units.

Fundamental units: The units of fundamental or basic quantities that are independent of each other.

Least count: The minimum or least quantity that can be measured by a given instrument.

~~**Physical quantity:** Any quantity that can be measured.~~

Periodic system: A system that repeats itself at regular intervals of time.

Unit: The accepted reference standard which is used for comparison of a given quantity.

Volume: The total space occupied by any piece of matter.