SEMESTER-ONE

PERIOD–I

P10CH1

Topic

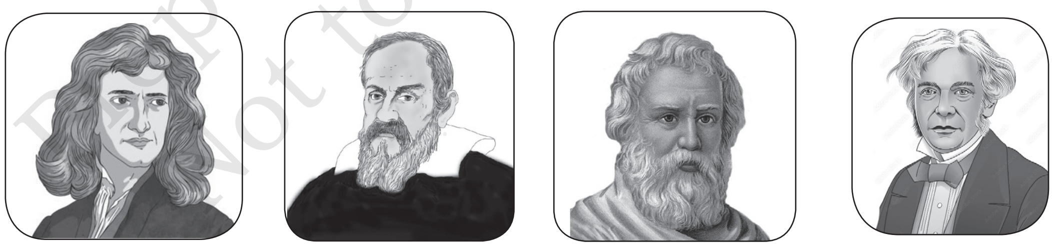
1

Introduction to Physics and Properties of Matter

1.1. DEVELOPMENT OF PHYSICS

Physics is a branch of science. The word 'Physics' has come from a Greek word meaning nature. Physics is the subject of studying nature and natural phenomena.

The development of Physics through a chain of discoveries has been very exciting. The fall of an apple on Newton's head led him to the idea of earth's gravity, the swings of a lamp hanging in a church led Galileo to a time-measuring device, while the rattling of the lid of a kettle caused the invention of the steam engine. The story of Archimedes is famous. He discovered his principle while taking bath in a tank and was so excited that he came out of the tank and ran into the street crying "*Eureka ! Eureka !*" (*I have found, I have found.*) Similarly, Faraday discovered electromagnetic induction accidently when the threw a magnet into a coil. This led to the designing of dynamos and motors.



Newton	Galileo	Archimedes	Faraday

Fig. 1.1.

The phenomenon of surface tension came into light by the simple observation that the rain drops are spherical. The sound produced on beating a drum gave idea of vibrations as source of sound. This led to the invention of gramophone and loudspeaker.

1.1.1. Importance of Physics

The practical application of physics and other branches of science has played important role in the development of various industries and in raising the standard of living of the society. Some applications of Physics are as follows:

(i) The Newton's laws of motion find application in the flight of rockets, and Bernoulli's theorem in the designing of aeroplane wings.

(ii) The principles of thermodynamics have been utilised in heat engines (steam, petrol and diesel) and in refrigerators and air-conditioners.

(iii) The electric bulbs, lamps and tubes are based on conversion of electric energy into light.

(iv) The electromagnetic induction, discovered by Faraday, has found application in electric generators, motors, furnaces, etc.

(v) At hydroelectric power stations generating electricity for homes and industries, the gravitational potential energy of water stored at a height in a dam is converted into electrical energy.

(vi) At thermal power stations, the chemical energy of burning coal is converted into electrical energy.

(vii) The energy released in nuclear fission process is utilised in nuclear reactors which produce electric power.

(viii) The tidal energy in the ocean and the solar energy (based on nuclear fusion process) are being converted into other forms of energy and used.

(ix) The properties and the theory of propagation of electromagnetic waves is applied in radio, television and wireless communication. An X-ray machine is used to identify internal diseases in the body. A geostationary satellite enables us to watch long-distance TV programs, to forecast weather and to make geophysical survey.

(x) Lasers covering an extremely wide field of practical applications make use of the phenomenon of population inversion.

(xi) The calculators and computers are based on digital electronics.

Thus, Physics plays an important role in technology and in our daily lives.

1.2. BRANCHES OF PHYSICS

The study of physics is divided into a number of branches. Though the classification is very wide, we limit our classification to a few major ones.

Fig. 1.2. Mechanics

Mechanics is one major branch of physics. This focuses on the behaviour of objects and the forces that act upon them.

Fig. 1.3. Heat and Thermodynamics

Heat and Thermodynamics is another branch which deals with the study of heat, temperature, and energy. The electric power plants and the engines of automobiles such as cars and bikes are based on the principles of thermodynamics.

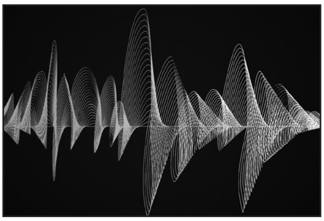


Fig. 1.4. Acoustics

Acoustics is study of sound and waves, and **optics** is the study of light and its properties. Both of these fields help describe how we interact with the world around us through two of our most important senses.

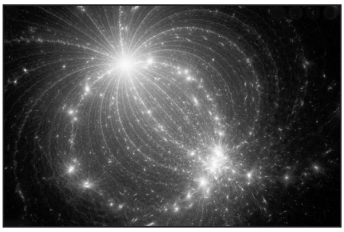


Fig. 1.5. Electromagnetism

Electromagnetism is the study of electrical and magnetic forces. Without this field of study we wouldn't have electricity to power our homes.

Astrophysics is the study of how celestial bodies such as stars, planets etc. are created.

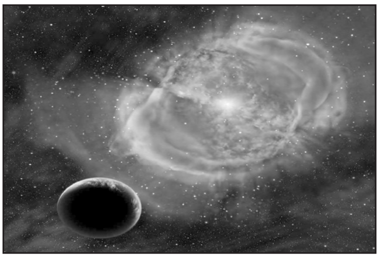


Fig. 1.6. Astrophysics

Space physics is the study of space which has lead to innovations such as use of satellites for communication and the invention of microwave ovens.

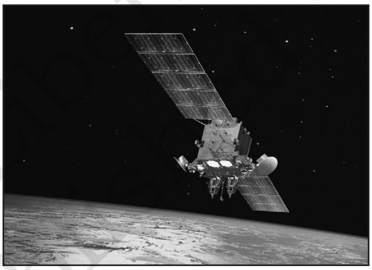


Fig. 1.7. Space physics

1.3. SYSTEMS OF MEASUREMENT

Any quantity that can be measured is called a physical quantity. The measurement of a physical quantity always involved the comparison of the quantity to be measured with a reference standard of the same kind. This reference standard used for the comparison is called the *unit* of the physical quantity.

1.3.1. The International System of Units

In earlier time scientists of different countries were using different systems of units for measurement. Three such systems, the CGS, the FPS (or British) system and the MKS system were in use extensively till recently.

The base units for length, mass and time in these systems were as follows :

- In CGS system they were centimetre, gram and second respectively.
- In FPS system they were foot, pound and second respectively.
- In MKS system they were metre, kilogram and second respectively.

The system of units which is at present internationally accepted for measurement is the *Système Internationale d' Unites* (French for International System of Units), abbreviated as SI. The SI, with standard scheme of symbols, units and abbreviations, was developed and recommended by General Conference on Weights and Measures in 1971.

1.4. FUNDAMENTAL QUANTITIES AND UNITS

There are certain physical quantities that cannot be explained in terms of other physical quantities. They are called *fundamental quantities*. They are the length, mass, time, electric current, temperature, luminous intensity and the amount of substance. The units used to measure the fundamental quantities are called *fundamental units* or *basic units*.

A summary of some fundamental quantities are shown below.

Table 1.1. SI Base Quantities and Units

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

1.5. DERIVED QUANTITIES AND UNITS

The quantities which are derived from fundamental quantities are called *derived quantities*. They are the *area*, *volume* and *speed* etc. The units of derived quantities are called *derived units* and are obtained from fundamental units.

Some common examples of derived units are shown below.

Table 1.2. Derived Quantities and Units

Physical quantity	Expression	Unit
Area	length × breadth	m^2
Volume	area × height	m^3
Velocity	displacement/time	$m\ s^{-1}$
Acceleration	velocity/time	$m\ s^{-2}$
Density	mass/volume	$kg\ m^{-3}$
Momentum	mass × velocity	$kg\ m\ s^{-1}$
Moment of inertia	mass × (distance)^2	$kg\ m^2$
Force	mass × acceleration	$kg\ m\ s^{-2}$ or N
Pressure	force/area	$N\ m^{-2}$ or Pa
Energy (work)	force × distance	N m or J
Surface tension	force/length	$N\ m^{-1}$

1.6. SCIENTIFIC NOTATION AND METRIC PREFIXES

Scientific notation helps us to represent the number which is very large or very small in a form of multiplication of single-digit numbers and 10 raised to the power of the respective exponent. The exponent is positive if the number is very large and it is negative if the number is very small.

Multiples of 10 and fractional numbers of 10 may be written by raising plus and minus powers respectively on 10. For example

1	$= 10^0$	1	$= 10^0$
10	$= 10^1$	0.1	$= 10^{-1}$
100	$= 10^2$	0.01	$= 10^{-2}$
1000	$= 10^3$	0.001	$= 10^{-3}$
10000	$= 10^4$	0.0001	$= 10^{-4}$
100000	$= 10^5$	0.00001	$= 10^{-5}$

On this basis, we can write any number in terms of powers of 10 in the following manner:

400	$= 4 \times 100$	$= 4 \times 10^{2}$
12000	$= 1.2 \times 10000$	$= 1.2 \times 10^{4}$
5610000	$= 5.61 \times 1000000$	$= 5.61 \times 10^{6}$
0.000121	$= 1.21 \times 0.0001$	$= 1.21 \times 10^{-4}$
0.0000095	$= 9.5 \times 0.000001$	$= 9.5 \times 10^{-6}$

Thus, any number, large or small, can be expressed in terms of plus or minus powers of 10 and multiplied by a number which is greater than 1, but less than 10 (in above examples these numbers are 4, 1.2, 5.61, 1.21 and 9.5). The magnitudes of very large and very small quantities are written compactly by using prefixes for powers of 10. The prefixes commonly used (for powers of 10) are listed in the following table:

Table 1.3. Prefixes used in SI system

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

For example, the average distance of sun from earth is 149600000000 m. It is much easier to write it as 1.496×10^{11} m or 1.496×10^{8} km (kilometre). Similarly, a time-interval of 0.000005 s can be expressed as 5×10^{-6} s or 5 μs (5 microseconds).

Another advantage of expressing quantities in powers of 10 is that their multiplication and division become very easy, because in multiplication powers are added and in division powers are subtracted. For example,

$$(8.91 \times 10^2) \times (1.10 \times 10^4) = 8.91 \times 1.10 \times 10^{2+4} = 9.801 \times 10^6$$

and

$$\frac{8.91 \times 10^2}{1.10 \times 10^4} = \frac{8.91}{1.10} \times 10^{2-4} = 8.10 \times 10^{-2}.$$

In adding or subtracting such quantities, it should be remembered that both the quantities be expressed in same powers of 10. For example, in order to add 1.20×10^2 and 5.63×10^3, we shall write both the quantities in the same power of 10. That is,

$$\begin{aligned} 1.20 \times 10^2 + 5.63 \times 10^3 &= 0.120 \times 10^3 + 5.63 \times 10^3 \\ &= (0.120 + 5.63) \times 10^3 = 5.75 \times 10^3. \end{aligned}$$

Example 1.1: *The diameter of the Earth is 12,756,000 metres. Write it in scientific notation form.*

Solution: As there is no decimal so, consider the decimal after the number and shift the decimal to left.

So, diameter of the Earth is 1.2756×10^7 m in scientific notation form.

Example 1.2: *The size of the bacteria is 0.0000085. Write it in scientific notation form.*

Solution: As there is decimal so, shift the decimal to right.

So, size of the bacteria is 8.5×10^{-6} in scientific notation form.

1.7. CONVERSION BETWEEN UNITS OF MEASUREMENT

Often while calculating, there is a need to convert units from one system to other.

Table 1.4. Conversion Table for Length and Mass

Length	10 millimetres (mm) = 1 centimetre (cm) 100 centimetres (cm) = 1 metre (m) 1000 metres (m) = 1 kilometre (km)
Mass	1000 milligrams (mg) = 1 gram (g) 1000 grams (g) = 1 kilogram (kg)

The method used to accomplish this is called **factor label method** or **unit factor method**. This is illustrated below.

Example 1.3: *A piece of metal is 3 inch (represented by in) long. What is its length in cm?*

Solution: We know that 1 in = 2.54 cm

From this equivalence, we can write

$$\frac{1\ \text{in}}{2.54\ \text{cm}} = 1 = \frac{2.54\ \text{cm}}{1\ \text{in}}$$

thus $\frac{1\ \text{in}}{2.54\ \text{cm}}$ equals 1 and $\frac{2.54\ \text{cm}}{1\ \text{in}}$ also equals 1. Both of these are called **unit factors**. If some number is multiplied by these unit factors (*i.e.*, 1), it will not be affected otherwise.

To convert 3 inch in cm, it is multiplied by the unit factor. So,

$$\begin{aligned} 3\ \text{inch} &= 3\ \text{inch} \times \frac{2.54\ \text{cm}}{1\ \text{inch}} \\ &= 3 \times 2.54\ \text{cm} \\ &= 7.62\ \text{cm} \end{aligned}$$

Now the unit factor by which multiplication is to be done is that unit factor ($\frac{2.54\ \text{cm}}{1\ \text{inch}}$ in the above case) which gives the desired units i.e., the numerator should have that part which is required in the desired result.

It should also be noted in the above example that units can be handled just like other numerical part. It can be cancelled, divided, multiplied, squared etc. Let us study some more examples.

Example 1.4: *A jug contains 2 L of milk. Calculate the volume of the milk in m^3.*

Solution:

Since 1 L = 1000 cm^3

and 1 m = 100 cm which gives

$$\frac{1\ \text{m}}{100\ \text{cm}} = 1 = \frac{100\ \text{cm}}{1\ \text{m}}$$

To get m^3 from the above unit factors, the first unit factor is taken and it is cubed.

$$\left(\frac{1\ \text{m}}{100\ \text{cm}}\right)^3 \Rightarrow \frac{1\ \text{m}^3}{10^6\ \text{cm}^3} = (1)^3 = 1$$

Now, 2 L = 2 × 1000 cm^3

The above is multiplied by the unit factor.

$$2 \times 1000\ \text{cm}^3 \times \frac{1\ \text{m}^3}{10^6\ \text{cm}^3} = \frac{2\ \text{m}^3}{10^3}$$

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

Example 1.5: *How many seconds are there in 2 days?*

Solution: Here, we know 1 day = 24 hours (h)

or $$\frac{1 \text{ day}}{24 \text{ h}} = 1 = \frac{24 \text{ h}}{1 \text{ day}}$$

then $$1 \text{ h} = 60 \text{ min}$$

or $$\frac{1 \text{ h}}{60 \text{ min}} = 1 = \frac{60 \text{ min}}{1 \text{ h}}$$

and $$1 \text{ min} = 60 \text{ s}$$

or $$\frac{1 \text{ min}}{60 \text{ s}} = 1 = \frac{60 \text{ s}}{1 \text{ min}}$$

The unit factors can be multiplied in series in one step only as follows:

$$2 \text{ day} \times \frac{24 \text{ h}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ h}} \times \frac{60 \text{ s}}{1 \text{ min}} = 2 \times 24 \times 60 \times 60 \text{ s} = 172800 \text{ s}$$

1.8. DEFINITION OF LENGTH, MASS AND TIME

1.8.1. Length

***Length** is defined as the straight-line distance between two points along an object.* It is denoted by [L]. Length is a physical quantity, which is independent of other physical quantities.

Thus, length is a fundamental physical quantity.

The CGS unit of length is centimetre, and SI unit is metre.

One metre is defined as the length of path covered by light, in vaccum, in a time interval of: $\frac{1}{299792458}$ of a second.

1.8.2. Mass

*The **mass** of an object is defined as the amount of matter present in it, and is denoted by M.*

Mass is a physical quantity, which is independent of other physical quantities. Thus, mass is a fundamental physical quantity.

The CGS unit of mass is gram, and SI unit is kilogram.

One kilogram is defined as the mass of a cylindrical piece of platinumiridium alloy kept in the International Bureau of Weights and Measures of Sevres near Paris.

1.8.3. Time

Time *is a measure in which events can be ordered from the past through the present into the future.* It is also the measure of durations of events and the intervals between them.

Time is a fundamental physical quantity. The CGS and SI unit of time is second.

1.9. THE MEASURING PROCESS

Measurement is basically a process of **'comparison'**. For measurement of any given physical quantity, we first need to choose a 'unit' or a 'standard' of that quantity. Then we 'compare' the given physical quantity with its unit and find a number that tells us as to how many times the 'unit' is 'contained' in the given physical quantity. Measurement thus basically involves two things: **'A unit'** and **'A number'**. A **'measurement'** is completely specified only when both the 'unit' and the 'number', associated with it, are clearly specified.

1.9.1. Accuracy and Precision of Measuring Instruments

All measurements are made with the help of instruments. The accuracy to which a measurement is made depends on several factors. For example, if length is measured using a metre scale which has graduations at 1 mm interval then all readings are good only upto this value. *The error is normally taken to be half of the smallest division on the scale of the instrument. Such an error is called* ***instrumental error***. In the case of a metre scale, this error is about 0.5 mm.

Precision of a number is often indicated by following it with ± symbol and a second number. This indicates the maximum error likely.

For example, if the length of a steel rod = (56.47 ± 3) mm then the true length will not be less than 56.44 mm or greater than 56.50 mm.

1.9.2. Significant Figures

The number of meaningful digits in a number is called the number of significant figures.

For example, 2.868 cm has four significant figures. But in different units, the same can be written as 0.02868 m or 28.68 mm or 28680 μm. All these numbers have the same four significant figures.

From the above example, we have the following rules.

(i) All the non-zero digits in a number are significant.

(ii) All the zeroes between two non-zeroes digits are significant, irrespective of the decimal point.

(iii) If the number is less than 1, the zeroes on the right of decimal point but to the left of the first non-zero digit are not significant. (In $\underline{0}.\underline{0}2868$ the underlined zeroes are not significant).

(iv) The zeroes at the end without a decimal point are not significant. (In 23080 μm, the trailing zero is not significant).

(v) The trailing zeroes in a number with a decimal point are significant. (The number 0.07100 has four significant digits).

Examples

(i) 30700 has three significant figures.

(ii) 132.73 has five significant figures.

(iii) 0.00345 has three and

(iv) 40.00 has four significant figures.

1.9.3. Rounding Off

The result of a calculation with number containing more than one uncertain digit, should be rounded off. The technique of rounding off is followed in applied areas of science.

A number $1.87\underline{6}$ rounded off to three significant digits is 1.88 while the number 1.872 would be 1.87. The rule is that if the insignificant digit (underlined) is more than 5, the preceeding digit is raised by 1, and is left unchanged if the former is less than 5.

Example 1.6: *Add 17.35 kg, 25.8 kg and 9.423 kg with due regard to significant figures.*

Solution: Of the three measurements given, 25.8 kg is the least accurately known.

$$\therefore \quad 17.35 + 25.8 + 9.423 = 52.573 \text{ kg}$$

Correct to three significant figures, 52.573 kg is written as 52.6 kg.

Example 1.7: *Multiply 3.8 and 0.125 with due regard to significant figures.*

$$3.8 \times 0.125 = 0.475$$

Solution: The least number of significant figure in the given quantities is 2. Therefore the result should have only two significant figures.

$$\therefore \quad 3.8 \times 0.125 = 0.475 = 0.48$$

1.9.4. Errors in Measurement

The **uncertainty** in the measurement of a physical quantity is called error. It is the difference between the true value and the measured value of the physical quantity. Errors may be classified into many categories.

(i) Constant errors: It is the same error repeated every time in a series of observations. Constant error is due to faulty calibration of the scale in the measuring instrument.

(ii) Systematic errors: These are errors which occur due to a certain pattern or system. Instrumental errors, personal errors due to individual traits and errors due to external sources are some of the systematic errors.

(iii) Gross errors: Gross errors arise due to one or more than one of the following reasons.

(a) Improper setting of the instrument.

(b) Wrong recordings of the observation.

(c) Not taking into account sources of error and precautions.

(d) Usage of wrong values in the calculation.

(iv) Random errors: It is very common that repeated measurements of a quantity give values which are slightly different from each other. **These errors have no set pattern and occur in a random manner.** Hence they are called random errors.

1.10. MEASURING INSTRUMENTS USED IN MEASURING LENGTH

The common instruments used to measure length are:

(a) Metre ruler (b) Vernier calliper (c) Screw gauge

(a) Metre Ruler

A metre ruler is one metre long (1 m).

The smallest marks on a metre ruler are millimetres (mm).

It takes 1,000 millimetres to equal one metre

$$1{,}000 \text{ mm} = 1 \text{ m}$$

or you could also say that a millimetre is one-thousandth of a metre.

$$0.001 \text{ m} = 1 \text{ mm}$$

Fig. 1.8. Metre Ruler

The longer lines that are numbered are centimetres (cm)

It takes 100 centimetres to equal one metre

$$100 \text{ cm} = 1 \text{ m}$$

Or you could say that a centimetre is one hundredth of a metre

$$1 \text{ cm} = 0.01 \text{ m}$$

Follow these steps to use a metre ruler:

1. Line up the zero line of the metre ruler up with the end of the object you are measuring.
2. Note the numbered line that is to the right edge of the object. In the picture below-the object is just to the right of the 41 mark.
3. Count the smaller lines after the numbered line (41 in this case) the object is 6 smaller lines past the 41.
4. Write down the measurement being sure to write the units you are measuring with. Your measurement for the object in this picture would be **41.6 cm**.

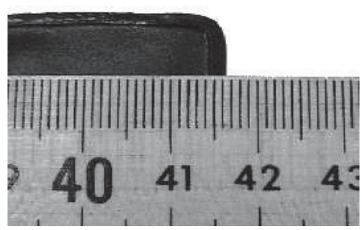


Fig. 1.9.

ACTIVITY 1.1

Measuring length

1. Measure the length and width of your classroom blackboard using the metre ruler.
2. Copy the table 1.5 in your notebook and record all the readings on that table.

Table 1.5.

Person	Length of Blackboard
You	____________ m
Your classmate	____________ cm

(b) Vernier Calliper

It is another instrument used to measure length. A Vernier Calliper has two scales-one main scale and a vernier scale, which slides along the main scale. The main scale and vernier scale are divided into small divisions though of different magnitudes.

The main scale is graduated in cm and mm. It has two fixed jaws, A and C, projected at right angles to the scale. The sliding vernier scale has jaws (B, D) projecting at right angles to it and also the main scale and a metallic strip (N). The zero of main scale and vernier scale coincide when the jaws are made to touch each other. The jaws and metallic strip are designed to measure the distance/diameter of objects. Knob P is used to slide the vernier scale on the main scale. Screw S is used to fix the vernier scale at a desired position.

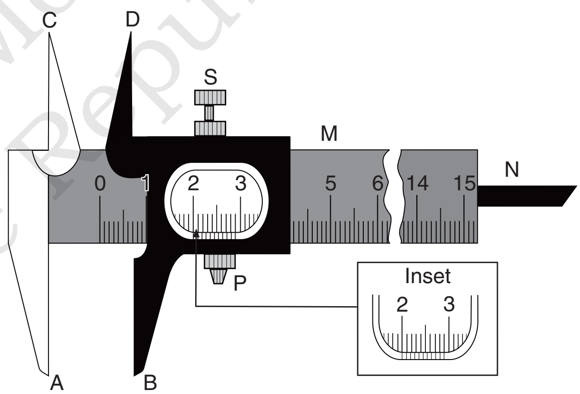


Fig. 1.10. Vernier Calliper

The least count of a common vernier scale is 0.1 mm.

Principle

The difference in the magnitude of one main scale division (M.S.D.) and one vernier scale division (V.S.D.) is called the least count of the instrument. It is the smallest distance that can be measured using the instrument.

$$n\text{V.S.D.} = (n - 1)\ \text{M.S.D.}$$

Formula Used

Least count of vernier callipers

$$= \frac{\textit{the magnitude of the smallest division on the main scale}}{\textit{the total number of small divisions on the vernier scale}}$$

Procedure

(i) Measuring the Length of an Object

1. Keep the jaws of Vernier Callipers closed. Observe the zero mark of the main scale. It must perfectly coincide with that of the vernier scale. If this is not so, account for the zero error for all observations to be made while using the instrument as explained later.
2. Use a magnifying glass, if available and note the number of division on the vernier scale that coincides with the one on the main scale. Position your eye directly over the division mark so as to avoid any parallax error.
3. Gently loosen the screw to release the movable jaw. Slide it enough to hold the object gently (without any undue pressure) in between the lower jaws AB. Now, gently tighten the screw so as to clamp the instrument in this position to the object.
4. Carefully note the position of the zero mark of the vernier scale against the main scale. Record the main scale division just to the left of the zero mark of the vernier scale.
5. Start looking for exact coincidence of a vernier scale division with that of a main scale division in the vernier window from left end (zero) to the right. Note its number (say) N, carefully.
6. Multiply 'N' by least count of the instrument and add the product to the main scale reading noted in step 4. Ensure that the product is converted into proper units (usually cm) for addition to be valid.
7. Repeat steps 3–6 to obtain the length of the object. Take three readings.
8. Prepare a table in your notebook as shown in table 1.2. Record the observations in the table with proper units. Apply zero correction, if need be.
9. Find the arithmetic mean of the corrected readings of the length of the object. Express the results in suitable units with appropriate number of significant figures.

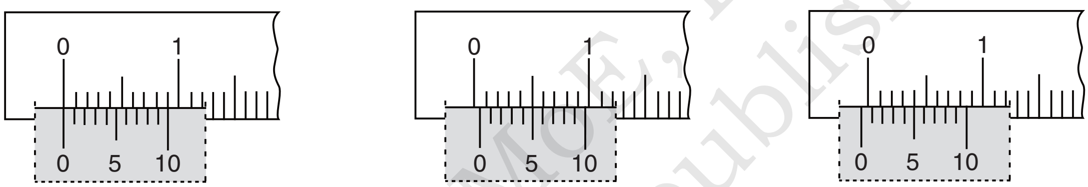
Least count of Vernier Callipers (Vernier Constant)

$$\text{Vernier constant} = \frac{1\text{MSD}}{\text{N}} = \frac{1\text{ mm}}{10}$$

$$\text{Vernier constant } (V_c) = 0.1 \text{ mm} = 0.01 \text{ cm.}$$

(ii) Zero Error and its Correction

When the jaws A and B touch each other, the zero of the Vernier should coincide with the zero of the main scale. If it is not so, the instrument is said to possess zero error (*e*). Zero error may be positive or negative, depending upon whether the zero of vernier scale lies to the right or to the left of the zero of the main scale. This is shown by the Fig. 1.11 (*a*) and (*b*). In this situation, a correction is required to the observed readings.



(*a*) (*b*) (*c*)

Fig. 1.11. Zero error (*a*) no zero error, (*b*) positive zero error, (*c*) negative zero error

(iii) Positive Zero Error

Figure 1.11 (*b*) shows an example of positive zero error. From the figure, one can see that when both jaws are touching each other, zero of the vernier scale is shifted to the right of zero of the main scale (This might have happened due to manufacturing defect or due to rough handling). This means that the reading taken will be more than the actual reading. Hence, a correction needs to be applied which is proportional to the right shift of zero of vernier scale.

In ideal case, zero of vernier scale should coincide with zero of main scale. But in Fig. 1.11 (*b*), 5$^{\text{th}}$ vernier division is coinciding with a main scale reading.

∴ Zero Error = + 5

Least Count = + 0.05 cm

Hence, the zero error is positive in this case. For any measurements done, the zero error (+ 0.05 cm in this example) should be 'subtracted' from the observed reading.

∴ True Reading = Observed reading – (+ Zero error)

(iv) Negative Zero Error

Figure 1.11 (*c*) shows an example of negative zero error. From this figure, one can see that zero of the vernier scale is shifted to the left of zero of the main scale. This means that the reading taken will be less than the actual reading. Hence, a correction needs to be applied which is proportional to the left shift of zero of vernier scale.

In Fig. 1.11 (*c*), 5^{th} vernier scale division is coinciding with a main scale reading.

∴ Zero Error = – 5 Least Count = – 0.05 cm

Note that the zero error in this case is considered to be negative. For any measurements done, the negative zero error, (– 0.05 cm in this example) is also subtracted 'from the observed reading'. Though it gets added to the observed value.

∴ True Reading = Observed Reading – (– Zero error)

Zero error, e = ± ... cm

Mean observed length = ... cm

Corrected length = Mean observed length – Zero error

Table 1.6. Measuring the Length of an Object

S. No.	Main scale reading, M (cm/mm)	Number of coinciding vernier division, N	Vernier scale reading, V = N Vc (cm/mm)	Measured length, M + V (cm/mm)
1.				
2.				
3.				
4.				

ACTIVITY 1.2

Measure the thickness of class room door or other boards using Vernier Calliper. Copy the table 1.6 in your notebook. Record your readings in the table.

(c) Screw Gauge

With Vernier Callipers, you are usually able to measure length accurately up to 0.1 mm. More accurate measurement of length, up to 0.01 mm or 0.005 mm, may be made by using a screw gauge. As such a Screw Gauge is an instrument of higher precision than a Vernier Callipers. You might have observed an ordinary screw [Fig. 1.12 (*a*)]. There are threads on a screw. The separation between any two consecutive threads is the same. The screw can be moved backward or forward in its nut by rotating it anticlockwise or clockwise [Fig. 1.12 (*b*)].

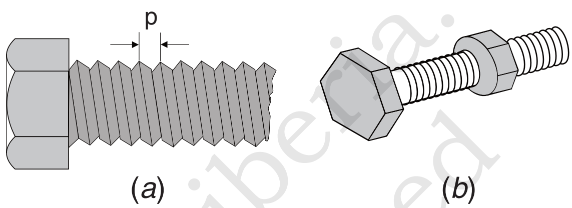


Fig. 1.12. A screw (a) without nut, (b) with nut

The distance advanced by the screw when it makes its one complete rotation is the separation between two consecutive threads. This distance is called the Pitch of the screw. Fig. 1.12 (*a*) shows the pitch (*p*) of the screw. It is usually 1 mm or 0.5 mm. Fig. 1.13 shows a screw gauge. It has a screw 'S' which advances forward or backward as one rotates the head C through rachet R. There is a linear scale 'LS' attached to limb D of the U frame. The smallest division on the linear scale is 1 mm (in one type of screw gauge). There is a circular scale CS on the head, which can be rotated. There are 100 divisions on the circular scale. When the end B of the screw touches the surface A of the stud ST, the zero marks on the main scale and the circular scale should coincide with each other.

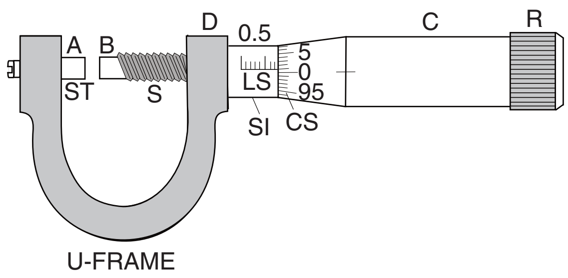


Fig. 1.13. View of a screw gauge.

Zero Error

When the end of the screw and the surface of the stud are in contact with each other, the linear scale and the circular scale reading should be zero. In case this is not so, the screw gauge is said to have an error called zero error.

Figure 1.14 shows an enlarged view of a screw gauge with its faces A and B in contact. Here, the zero mark of the LS and the CS are coinciding with each other.

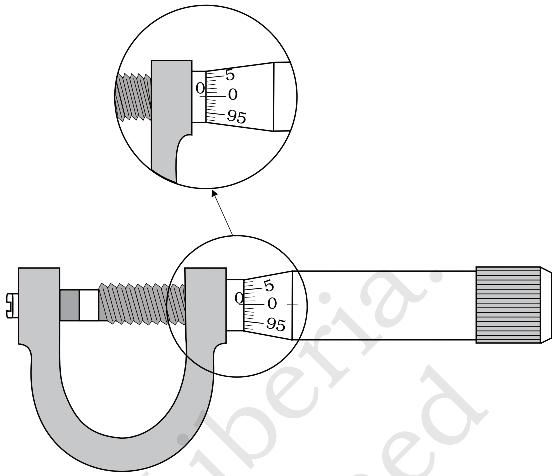
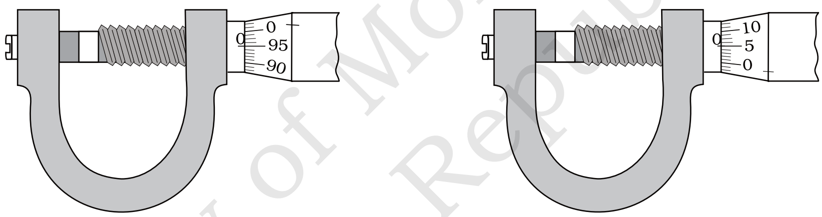


Fig. 1.14. A screw gauge with no zero error

When the reading on the circular scale across the linear scale is more than zero (or positive), the instrument has **positive zero error** as shown in Fig. 1.15 (*a*). When the reading of the circular scale across the linear scale is less than zero (or negative), the instrument is said to have **negative zero error** as shown in Fig. 1.15 (*b*).



(*a*) (*b*)

Fig. 1.15. (a) Showing a positive zero error, (b) Showing a negative zero error

Taking the Linear Scale Reading

The mark on the linear scale which lies close to the left edge of the circular scale is the linear scale reading. For example, the linear scale reading as shown in Fig. 1.16, is 0.5 cm.

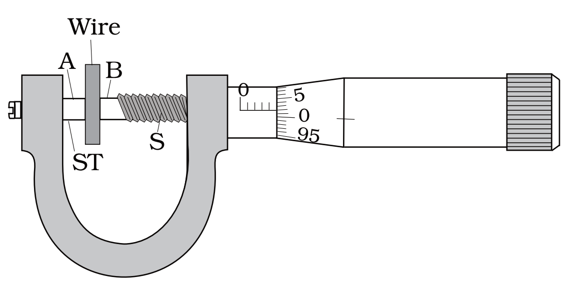


Fig. 1.16. Measuring thickness with a screw guage

Taking Circular Scale Reading

The division of circular scale which coincides with the main scale line is the reading of circular scale. For example, in the Fig. 1.16, the circular scale reading is 2.

Total Reading

Total reading = linear scale reading + circular scale reading × least count

= 0.5 + 2 × 0.001 = 0.502 cm

Principle

The linear distance moved by the screw is directly proportional to the rotation given to it. The linear distance moved by the screw when it is rotated by one division of the circular scale, is the least distance that can be measured accurately by the instrument. It is called the least count of the instrument.

$$\text{Least count} = \frac{\text{pitch}}{\text{No. of divisions on circular scale}}$$

For example for a screw gauge with a pitch of 1 mm and 100 divisions on the circular scale. The least count is

$$1\ \text{mm}/100 = 0.01\ \text{mm}$$

This is the smallest length one can measure with this screw gauge.

Note: A screw gauge can also be used to measure diameter of a wire.

Activity 1.3

Measure thickness of the metal sheet of your geometry box using a screw gauge. Copy the table 1.7 in your notebook and record your observations.

Procedure

1. Insert the given sheet between the studs of the screw gauge and determine the thickness at five different positions.
2. Find the average thickness and calculate the correct thickness by applying zero error following the steps followed earlier.

Observations and Calculation

Least count of screw gauge = ... mm

Zero error of screw gauge = ... mm

Table 1.7. Measurement of Thickness of Sheet

S. No.	Linear scale reading M (mm)	Circular scale reading n	Thickness $t = M + n \times L.C.$ (mm)
1.			
2.			
3.			
4.			
5.			

Mean thickness of the given sheet = ... mm

Mean corrected thickness of the given sheet

= observed mean thickness – (zero error with sign) = ... mm

Result

The thickness of the given sheet is ... m.

1.11. MEASURING INSTRUMENTS USED IN MEASURING MASS

Mass is the basic property of matter. The SI unit of mass is the kilogram (kg). Mass is measured using different kinds of balances.

A balance is a device that measures the mass of an object by comparing it with a standard mass.

(a) Beam Balance

The common beam balance consists of a horizontal beam with a pointer in the middle.

The beam is free to tilt about its centre point, which is the fulcrum.

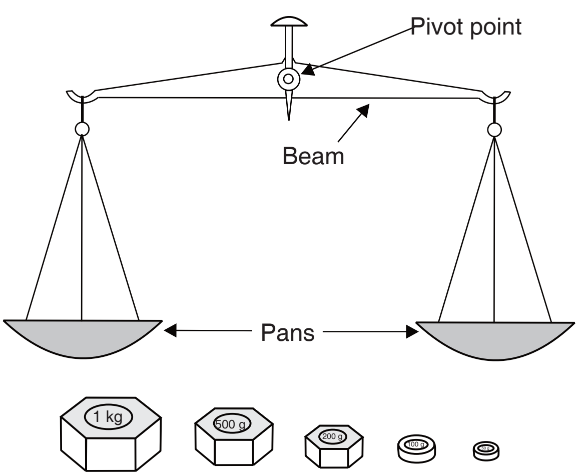


Fig. 1.17. A beam balance and set of weights

Two pans are suspended on either side of the pointer at equal distances.

The body whose mass is to be determined is placed in the left pan, and the standard masses are added to the right pan until the pointer comes to the centre and the beam remains horizontal. In such a situation, the sum of the standard masses gives the mass of the object.

For an accurate measure of mass in a laboratory, a common balance is not useful.

Fig. 1.18. A Physical balance

In such cases, a physical balance is used, which can measure mass up to one milligram accurately.

Now-a-days, electronic balances are used to measure mass. These display readings up to one milligram accurately.

Fig. 1.19. Electronic Balances

(b) Spring Balance

It is used to measure the weight or gravitational mass of a body.

It consists of a helical spring fixed to a rigid support and connected to a pointer P at the other end. The pointer P is connected to the hook H by means of a rigid rod R. The balance is suspended by means of a hook provided at the top of the balance. The body to be weighed is loaded at H. Due to the load, the spring gets extended. As a result of this, the pointer P moves down on a scale calibrated in kg. Thus, the reading of the pointer on the scale directly gives the weight of the body.

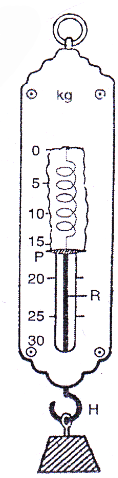


Fig. 1.20. Spring Balance

1.12. MEASURING INSTRUMENTS USED IN MEASURING TIME

Since the beginning of civilization, humans have been fascinated by time. During ancient period, people measured time by simply looking at the sun and the moon. Then came early clocks. Some of the clocks of historical importance are sundials, water clocks, sand clocks. Nowadays, time is measured by modern and advanced clocks and watches such as wrist watch, stopwatch, digital watch and pendulum clocks.

Sand clock Stopwatch Pendulum clock

Fig. 1.21. Different Types of Time Measuring Instruments

Stopwatch

A stopwatch is used to measure the time interval of an event. It is a kind of watch that stands out for the accuracy and precision with which it can measure the time of an event. It works by pressing a start button and then stopping it.

Let us perform Activity 1.4 to understand the use of a stopwatch.

ACTIVITY 1.4

To measure the time by using stopwatch

Note: In the laboratory, in races, and many other game events, we are required to measure short time intervals.

Materials Required

A stopwatch, a whistle.

Procedure

1. Take a stopwatch and bring it to the zero position.
2. Ask one of your friends to run a race across the football ground when you blow the whistle.

3. When your friend starts running, start the stopwatch.
4. When he/she reaches the other end of the ground, stop the watch. Note the time he/she takes to complete the race.
5. Ask all your friends one by one and repeat the steps 1 to 4.
6. Copy the table 1.8 in your notebook and record the time in that table.

Table 1.8.

S. No.	Name of Friend	Time Taken to Complete the Race
1.		
2.		
3.		
4.		

1.13. MEASURING INSTRUMENT USED IN MEASURING TEMPERATURE—THERMOMETER

Thermometer is an instrument which is used to measure the temperature of a body or an object.

Many physical properties of materials change sufficiently with temperature to be used as basis for constructing thermometers. The commonly used property is variation of the volume of a liquid with temperature. For example, a common thermometer (the liquid in glass type). Mercury and alcohol are the liquids used in most liquid in glass thermometers.

Thermometers are calibrated so that a numerical value may be assigned to a given temperature. The three most common units of measurement for temperature are celsius, fahrenheit and kelvin.

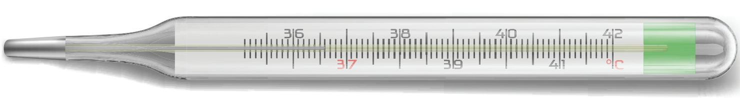


Fig. 1.22. Thermometer

1.14. FINDING VOLUME, AREA AND DENSITY

Volume, area and density are derived quantities as they are obtained from fundamental physical quantities.

1.14.1. Volume

It is defined as the amount of space that a substance or object occupies, or that is enclosed within a container. Objects can be regular or irregular in shape.

1.14.1.1. Volume of Regular Objects

Regular objects are solid bodies with well known geometrical shapes like rectangular block, right cylinder and sphere. You know that regular objects occupy space.

The space occupied by a regular body is known as its volume. It is denoted by V. It can be determined from the corresponding formulae that relate their volume to certain measured quantities. For example, volume of rectangular block can be expressed as follows:

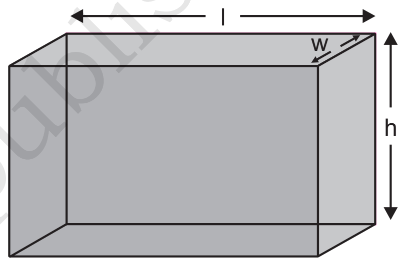


Fig. 1.23. Rectangular Block

Volume = length × width × height

i.e., $V = l \times w \times h$

Volume units are cubic units, since they are the result of multiplying three units of length.

So, unit of volume $= l \times w \times h = \text{m} \times \text{m} \times \text{m} = \text{m}^3$

Where l = length of object

w = width of object

h = height of object

In SI, the unit of volume is cubic metre (m^3).

A common unit, litre (L) which is not an SI unit, is used for measurement of volume of liquids.

$$1 \text{ L} = 1000 \text{ mL},$$

$$1000 \text{ cm}^3 = 1 \text{ dm}^3$$

Fig. 1.24 helps to visualise these relations.

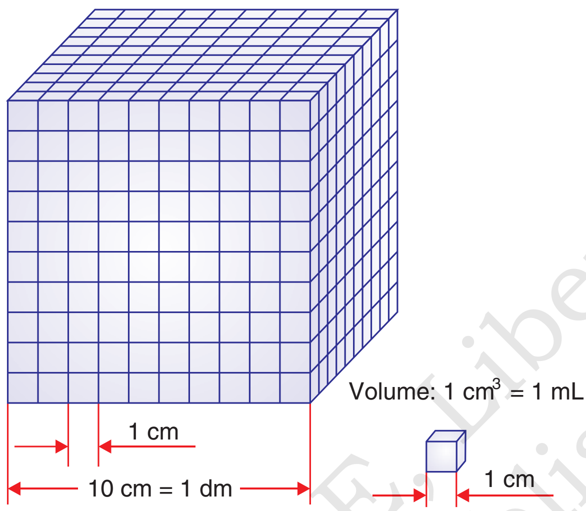


Fig. 1.24. Different units used to express volume

Example 1.8: *Find the volume of a water tank having 2 m length, 150 cm width and 1 m height.*

Solution:

Given:

$$l = 2\text{ m},\ w = 1.5\text{ m},$$
$$h = 1\text{ m}$$
$$V = l \times w \times h$$
$$= 2\text{ m} \times 1.5\text{ m} \times 1\text{ m} = 3\text{ m}^3$$

Note: The unit of the length, the width and the height must be the same when they are used in the expression $V = l \times w \times h$.

1.14.1.2. Reading Volumes of Liquids in Graduated Containers

We know that liquids are fluids and do not have definite shape. To measure the volume of a liquid, it has to be placed in graduated containers such as a measuring cylinder. Graduated measuring cylinder is a container used in laboratory to measure volume of liquids. When liquid is poured into the cylinder, it forms a meniscus (*i.e.*, a curved surface). The volume of liquid is measured in litre. The smaller unit of volume is millilitre (ml).

ACTIVITY 1.5

Measuring the Volume of a Liquid Using Measuring Cylinder

Materials Required

A measuring cylinder and water.

Procedure

1. Pour liquid into the graduated cylinder.
2. Hold the graduated cylinder with the meniscus at eye level as shown in the Fig. 1.25.
3. Read the level of liquid at the bottom of the meniscus.
4. Note your reading.
5. Repeat the activity by using different volumes of water.

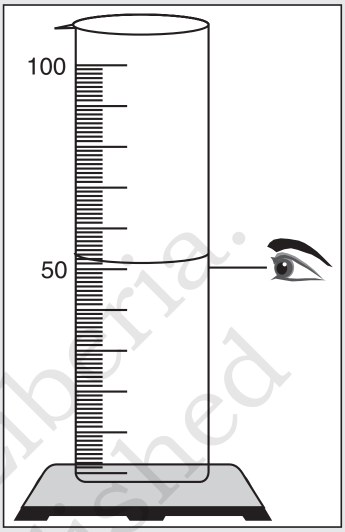


Fig. 1.25. Measuring volume at eye level

Note: Measuring volume of water using measuring cylinder is more accurate.

1.14.1.3. Determining the Volume of Irregular Solids

Look at the figure 1.26 of some irregular solids.

It is difficult to obtain the volume of such irregular objects from mathematical formula. The volume of irregular objects is measured by displacement method. Let us perform the following activity to determine the volume of irregular solids.

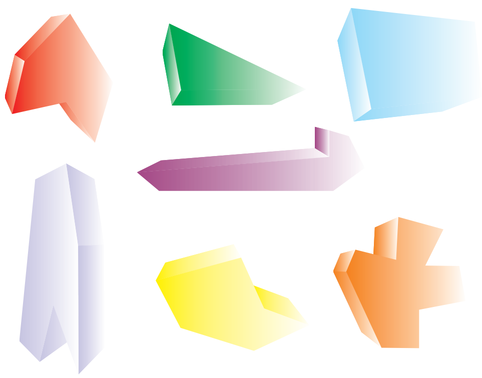


Fig. 1.26. Some Irregular solids

Activity 1.6

Determination of Volume of an Irregular Object Using a Graduated Cylinder

Materials Required

A small stone, a thread, a graduated measuring cylinder and water.

Procedure

1. Take a graduated measuring cylinder and fill it half with water.
2. Note the reading of water level correctly.
3. Tie the stone with a strong thread and lower it gently into the graduated measuring cylinder so that it is completely immersed into the water.
4. What do you observe? Does the level of water rise up?
5. Note the reading of water level in the graduated measuring cylinder.

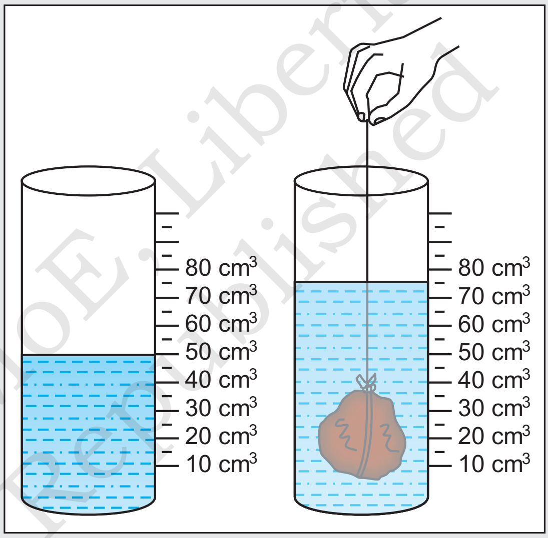


Fig. 1.27. Measuring volume of a irregular body

Observation

When we immerse the stone into the water, the water level rises in the cylinder, because the stone displaces water equal to its volume.

Calculation (To be done in your notebook)

First reading = ________ cm^3

Second reading = ________ cm^3

Volume of the stone

= Second reading – First reading

= ________ cm^3 – ________ cm^3

= ________ cm^3

1.14.2. Area

Area is a derived quantity which is described in terms of two lengths. Area units are square units since they are the result of multiplying two units of length. In SI, the unit of area is the square meter (m^2).

The area of an object is the multiplication of its length and breadth.

$$\text{Unit of area} = l \times b = \text{m} \times \text{m} = \text{m}^2$$

where l = length of object

b = breadth of object

1.14.2.1. Area of regular two Dimensional Figures

The area of a figure is the space it encloses within it. It can be calculated by measuring the length of the sides of the object.

Area of Square

Square is a two dimensional figure with equal sides.

The area of a **square** can be calculated by multiplying its sides, hence

$$\text{Area of square} = \text{side} \times \text{side} = (\text{side})^2$$

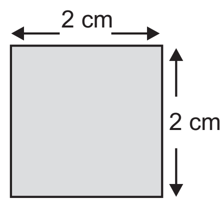


Fig. 1.28. Square

Area of Rectangle

Rectangle is a two dimensional figure with opposite sides equal.

The area of a **rectangle** can be calculated by multiplying its length and width, hence

$$\text{Area of rectangle} = \text{length} \times \text{width} = l \times w$$

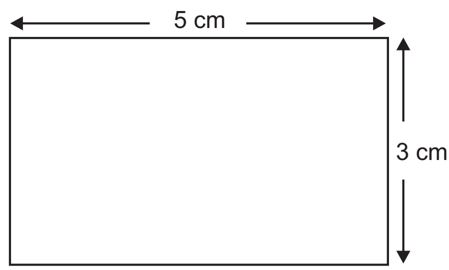


Fig. 1.29 Rectangle

It must be noted that when we find the area of a rectangular surface we have to multiply the numbers and the units describing its length and width.

Example 1.9: *Find the area of the following rectangular surfaces.*

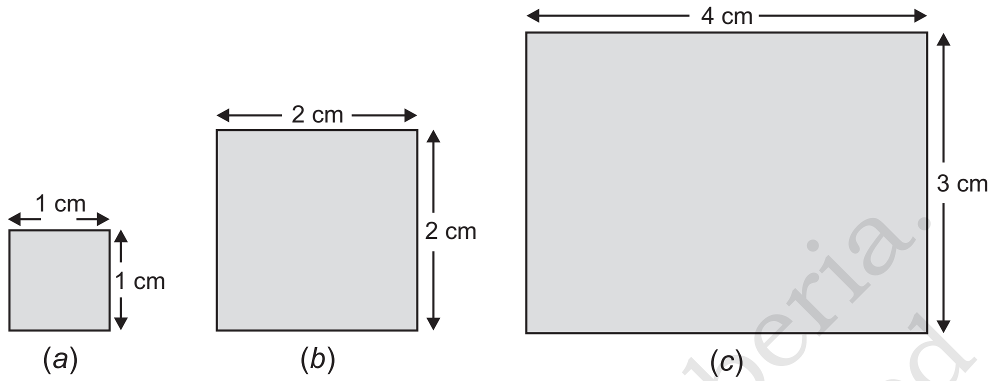


Fig. 1.30. Rectangular surfaces

Solution:

(a) A = $l \times b$ = 1 cm × 1 cm = 1 cm^2

(b) A = $l \times b$ = 2 cm × 2 cm = 4 cm^2

(c) A = $l \times b$ = 4 cm × 3 cm = 12 cm^2

Area of Triangle

The area of a **triangle** of height h and base b is given by half of the product of its base and its height, *i.e.*,

$$A = \frac{1}{2} bh$$

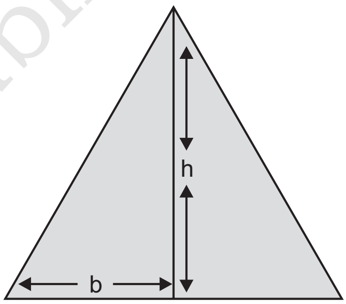


Fig. 1.31. Triangle

Example 1.10: *Find the area of a triangle of height 40 cm and base 140 cm.*

Solution:

Given: Height (h) = 0.4 m,

Base (b) = 1.4 m

Area $A = \frac{1}{2} bh = \frac{1}{2} \times 0.4 \text{ m} \times 1.4 \text{ m} = 0.28 \text{ m}^2$

Area of Circle

The area of a **circle** of radius r is given by the product of π and the square of the radius, i.e.

$$A = \pi r^2$$

where π stands for 3.14.

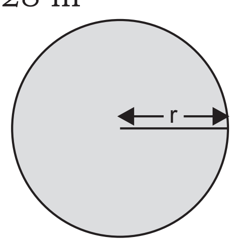


Fig. 1.32. Circle

Example 1.11: *Find the area of a circular field of diameter 4 metres.*

Solution:

Given:

$$\text{Radius } (r) = 2 \text{ m},$$
$$\pi = 3.14$$
$$\text{Area (A)} = \pi r^2$$
$$= 3.14 \times 2 \text{ m} \times 2 \text{ m} = 12.56 \text{ m}^2$$

1.14.3. Density

You have observed that some objects float on the surface of water while other sink. Can you explain why? It is due to the density of the substances. Let us perform Activity 1.7 to understand it.

ACTIVITY 1.7

To Demonstrate Why Objects Sink in Water

Materials Required

A nail, a beaker and water

Procedure

1. Take a beaker and fill it with water.
2. Take an iron nail and place it on the surface of the water.
3. Observe what happens?

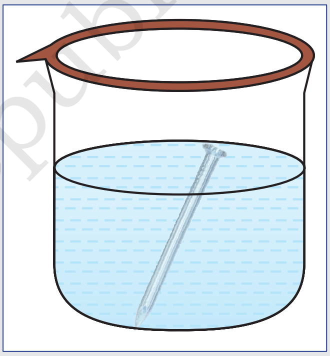


Fig. 1.33.

You will observe that the nail sinks. Can you explain why? The density of nail is more as compared to water.

Some objects float on the water surface. Let us perform the following activity to understand it.

ACTIVITY 1.8

To Demonstrate that Objects Float on Water Surface

Materials Required

A cork, an iron nail, a beaker and water

Procedure

1. Take a beaker and fill it with water.
2. Take a piece of cork and an iron nail of equal mass.
3. Place them on the surface of water.
4. Observe what happens?

You will observe that the cork floats while the nail sinks. This happens because of the difference in their densities. The density of the cork is less than the density of water. Therefore, objects of density less than that of a liquid float on the liquid. The objects of density greater than that of a liquid sink in the liquid.

Density is a derived physical quantity that relates to the mass and volume of a body. Density of a substance is its amount of mass per unit volume.

$$\rho = \frac{m}{V}$$

SI unit of density

= SI unit of mass/SI unit of volume

= $Kg.m^{-3}$.

This unit is quite large, so often density is expressed in $g.\ cm^{-3}$, where mass is expressed in gram and volume is expressed in cm^3.

If there are several bodies of the same volume but different mass, it is said that their densities are different. Similarly, if you have several bodies of the same mass but different volume, then we say that their densities are different.

Density is a characteristic property of each substance. For example, pure iron objects made of any mass or volume always have the same density.

Relation between density, mass and volume is as follows.

1. Density = $\frac{\text{Mass}}{\text{Volume}}$ *i.e.*, $\rho = \frac{M}{V}$
2. Mass = Density × Volume *i.e.*, $M = \rho \times V$
3. Volume = $\frac{\text{Mass}}{\text{Density}}$ *i.e.*, $V = \frac{M}{\rho}$

Example 1.12: *A piece of wood weighs 72 g. What is its density if its volume is 20 cm^3?*

Solution:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{72}{20}$$

$$= 3.6 \text{ g cm}^{-3}$$

Example 1.13: *A lump of gold has a density of 6 g cm^{-3} and volume of 24 cm^3. Calculate the mass of the gold.*

Solution:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Hence, Mass} = \text{density} \times \text{volume}$$
$$= 6 \text{ g cm}^{-3} \times 24 \text{ cm}^3$$
$$= 144 \text{ g}$$

Example 1.14: *A piece of stone weighs 90 g. When put in a measuring cylinder, the water level rose from 48 cm^3 mark to the 78 cm^3 mark. Find the density of the stone.*

Solution:

Initial volume (level) of water,

$$V = 48 \text{ cm}^3$$

Final volume (level) of water,

$$V_1 = 78 \text{ cm}^3$$

Volume of stone

= Volume of water displaced

$= V_1 - V = (78 - 48) \text{ cm}^3 = 30 \text{ cm}^3$

Mass of stone

$$M = 90 \text{ g}$$

Density of stone

$$= \frac{\text{Mass}}{\text{Volume}} = \frac{M}{V_1 - V} = \frac{90}{30} = 3 \text{ g cm}^{-3}$$

1.14.3.1. Relative Density or Specific Gravity

The ratio of the density of a substance to the density of water 4°C, is called ***relative density (R.D.)*** *or* ***specific gravity (S.G.)*** *of that substance i.e.,*

$$\text{Relative density} = \frac{\text{Density of a substance}}{\text{Density of water}}$$

It is a pure number having no unit.

As density of water at 4°C = 1 g cm^{-3} hence in C.G.S. units relative density of a substance becomes **numerically equal to its density**.

Example 1.15: *Relative density of silver is 10.8. The density of water is 10^3 kg m^{-3}. What is the density of silver in SI units?*

Solution: Here:

Density of water, $\rho_W = 10^3 \text{ kg m}^{-3}$

Relative density of silver, R.D. = 10.8

Density of silver, $\rho_{Ag} = ?$

From relation, relative density

$$\text{R.D.} = \frac{\text{Density of the substance}}{\text{Density of water}}$$

We have,

$$\text{density of silver} = \text{R.D. of silver} \times \text{Density of water}$$

Substituting various values, we get,

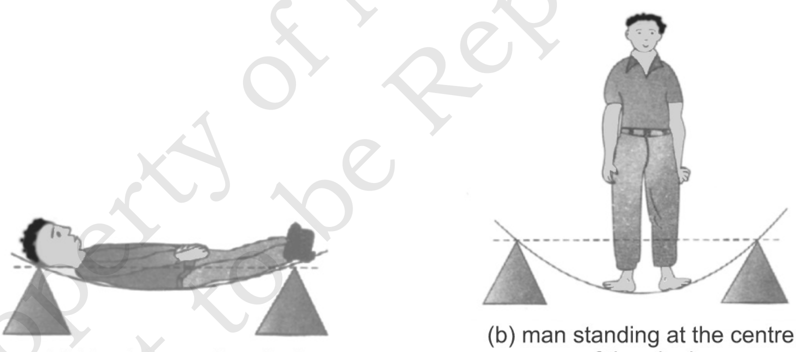
$$\rho_{Ag} = 10.8 \times 10^3 \text{ kg m}^{-3}$$

$$\text{Density of silver} = 10.8 \times 10^3 \text{ kg m}^{-3}$$

1.14.4. Thrust and Pressure

Suppose a thin wooden plank is lying horizontally, supported at its end on two wooden wedges (Fig. 1.34).

When a man lies flat over it, the plank is bent in the middle slightly. [Fig. 1.34 (*a*)] and there is no fear of breaking of the plank. But when the same man stands vertical in the middle of the plank, the plank bends more [Fig. 1.34 (*b*)]. A slight jerk may break the plank.



(a) Man lying on the plank

(b) man standing at the centre of the plank

Fig. 1.34. Man and Wooden plank.

While lying, the weight of the man is spread over more area of the plank, causing less depression.

While standing, the same weight falls over a small area under his feet, causing more depression. Thus, we see that effect of force depends on the area of the object on which it acts. Weight of the body is also force and it always act in the downward direction.

Though total weight is same in both cases, weight per unit area is more in second case. Total weight measures ***thrust*** and the weight per unit area measures ***pressure***.

Thus, *thrust is the total force applied normally on a surface.* It is represented by the symbol $\vec{F}$. Being a force, it is a vector quantity. It has units of force.

Pressure is the thrust per unit area of a surface. It is represented by the symbol *P*. It is a scalar quantity.

i.e.,
$$\text{Pressure} = \frac{\text{Total force (normally)}}{\text{Area}}$$

or
$$\text{Pressure} = \frac{\text{Thrust}}{\text{Area}}$$

$\therefore$
$$\text{Thrust} = \text{Pressure} \times \text{Area}$$

or
$$F = PA$$

The C.G.S. unit of pressure is dyne per square cm (dyn cm^{-2}).

The SI unit of pressure is newton per square metre (N m^{-2}) or Pascal (Pa).

$$1\ \text{Nm}^{-2} = 10\ \text{dyne cm}^{-2} = 1\ \text{Pa}$$

Example 1.16: *A block of wood is kept on table top. The mass of wooden block is 5 kg and its dimension are 40 cm × 20 cm × 10 cm. Find the pressure exerted by the wooden block on the table top, if it is made to lie on the table top with its sides of dimensions (a) 20 cm × 10 cm and (b) 40 cm × 20 cm.*

Solution: Here: Mass of the wooden block, M = 5 kg

Thrust due to wooden block,

$$Mg = 5\ \text{kg} \times 9.8\ \text{m s}^{-2} = 49\ \text{N}$$

(a) Surface area of 20 cm × 10 cm surface,

$$A = (20 \times 10)\ \text{cm}^2 = (0.2 \times 0.1)\ \text{cm}^2 = 0.02\ \text{m}^2$$

From relation,

$$\text{pressure} = \frac{\text{thrust}}{\text{area}}$$

we have, $P = \dfrac{Mg}{A}$

Substituting various values, we get

$$P = \frac{49\ \text{N}}{0.02\ \text{m}^2} = \frac{49}{0.02}\ \text{N m}^{-2}$$

or Pressure, $P = 2450\ \text{N m}^{-2}$

(b) Surface area of 40 cm × 20 cm surface,

$$A = (40 \times 20)\ \text{cm}^2 = (0.4 \times 0.2)\ \text{m}^2 = 0.08\ \text{m}^2$$

$$P = \frac{Mg}{A} = \frac{49\ \text{N}}{0.08\ \text{m}^2} = \frac{49}{0.08}\ \text{N m}^{-2}$$

or Pressure, $P = 612.5\ \text{N m}^{-2}$

1.14.4.1. Fluid Pressure

A substance which can flow easily is called a fluid. The term fluid includes both liquids as well as gases.

The pressure at any point in a fluid is defined as the normal force (or thrust) acting on unit area surrounding that point.

Let a vessel with vertical walls, having bottom area A, have some liquid of density ρ up to a height *h* (Fig. 1.35).

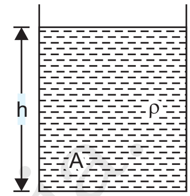


Fig. 1.35. Pressure due to liquid column.

Then,

Volume of liquid in the vessel = Ah

Mass of liquid in the vessel = $Ah\rho$

Weight of liquid in the vessel = $Ah\rho g$

Thrust at the bottom of the vessel = Total weight of the liquid in the vessel = $Ah\rho g$

Area of the bottom (on which this thrust acts) = A

$$\text{Hence, pressure at the bottom} = \frac{\text{Thrust}}{\text{Area}}$$

$$\text{or} \qquad \rho = \frac{Ah\rho g}{A}$$

$$\text{or} \qquad \rho = h\rho g$$

This pressure is independent of the area of the bottom of the vessel (container) and varies directly as the height (*h*) of the liquid column in the vessel and the density (ρ) of the liquid.

1.15. DIMENSIONAL ANALYSIS

The study of the relationship between physical quantities with the help of dimensions and units of measurement is termed as dimensional analysis. Dimensional analysis is essential because it keeps the units the same, helping us perform mathematical calculations smoothly.

All the physical quantities represented by derived units can be expressed in terms of some combination of seven fundamental or base quantities are denoted with square brackets [ ].

For examples:

(i) Length as [L]
(ii) Mass as [M]
(iii) Time as [T]
(iv) Electric current as [A]
(v) Temperature as [K]
(vi) Luminous intensity as [cd]
(vii) Amount of substance as [mol].

1.15.1. Dimensions of Physical Quantities

The unit of a physical quantity can be written in different ways. For example, velocity can be expressed in metre/second, km/hour or km/minute, but in every case we divide the unit of length by the unit of time, that is,

$$\text{unit of velocity} = \frac{\text{unit of length}}{\text{unit of time}} = (\text{unit of length})^1 \times (\text{unit of time})^{-1}.$$

Thus, in order to get the unit of velocity, we raise the unit of length to the power 1 and the unit of time to the power –1. These powers are called the 'dimensions of velocity'.

To express the dimensions of physical quantities in mechanics, the length, mass, and time are denoted by [L], [M] and [T]. If the dimensions of a physical quantity are a in length, b in mass, and c in time, then the dimensions of that physical quantity shall be written in the following manner :

$$[L^a \ M^b \ T^c].$$

This is the **'dimensional formula'** of that quantity.

1.15.2. Dimensional Formulae of some Physical Quantities

In order to get dimensional formula of a physical quantity, the quantity is described in terms of other simple quantities of known dimensions. Dimensional formulae of certain physical quantities and their S.I. units are given as follows:

Table 1.9.

S. No.	Physical Quantity	Relation with other Physical Quantity	Dimensional Formula	S.I. Unit
1.	**Area**	length × breadth	$[L \times L] = [L^2] = [M^0 L^2 T^0]$	m^2
2.	**Volume**	length × breadth × height	$[L \times L \times L] = [L^3] = [M^0 L^3 T^0]$	m^3
3.	**Density**	$\frac{\text{mass}}{\text{volume}}$	$\frac{[M]}{[L^3]} = [M L^{-3}] = [M L^{-3} T^0]$	$kg\ m^{-3}$
4.	**Velocity (or Speed)**	$\frac{\text{displacement (or distance)}}{\text{time}}$	$\frac{[L]}{[T]} = [L T^{-1}] = [M^0 L T^{-1}]$	$m\ s^{-1}$
5.	**Acceleration**	$\frac{\text{change in velocity}}{\text{time}}$	$\frac{[L T^{-1}]}{[T]} = [L T^{-2}] = [M^0 L T^{-2}]$	$m\ s^{-2}$
6.	**Force**	mass × acceleration	$[M] [L T^{-2}] = [M L T^{-2}]$	$kg\ ms^{-2}$ or N (newton)
7.	**Work**	force × displacement	$[M L T^{-2}] [L] = [ML^2 T^{-2}]$	$kg\ m^2\ s^{-2}$ or J (joule)
8.	**Acceleration due to gravity (g)**	$\frac{\text{weight (force)}}{\text{mass}}$	$\frac{[M L T^{-2}]}{[M]} = [M^0 L T^{-2}]$	$m\ s^{-2}$
9.	**Power**	$\frac{\text{work}}{\text{time}}$	$\frac{[M L^2 T^{-2}]}{[T]} = [ML^2 T^{-3}]$	$J\ s^{-1}$ or W (watt)
10.	**Pressure**	$\frac{\text{force}}{\text{area}}$	$\frac{[M L T^{-2}]}{[L^2]} = [M L^{-1} T^{-2}]$	$N\ m^{-2}$

1.15.3. Uses of Dimensional Equations

1. **To Convert Units of one System into the Units of other System:** The product of the numerical value of a physical quantity and its corresponding unit is a constant.

   Consider the physical quantity 'force', its unit in MKS (or SI) system is 'newton' and in CGS system is 'dyne'. Let us convert 1 newton into dynes.

   The dimensional formula of force is $[M L T^{-2}]$. Suppose, M_1, L_1, T_1 represent kilogram (kg), metre (m), second (s) and M_2, L_2, T_2 represent gram (g), centimetre (cm), second (s) respectively. Then, the units of force in MKS and CGS systems will be $(M_1L_1T^{-2})$ and $(M_2 L_2 T_2^{-2})$ respectively. If the numerical values of force are n_1 and n_2 respectively, then

   $$n_1 (M_1L_1T_1^{-2}) = n_2 (M_2 L_2 T_2^{-2})$$

   or
   $$n_2 = n_1\left(\frac{M_1}{M_2}\right)\left(\frac{L_1}{L_2}\right)\left(\frac{T_1}{T_2}\right)^{-2}$$

   Here, $n_1 = 1$.

   $$\therefore \quad n_2 = 1\left(\frac{kg}{g}\right)\left(\frac{m}{cm}\right)\left(\frac{s}{s}\right)^{-2}$$

   $$= 1\left(\frac{10^3 g}{g}\right)\left(\frac{10^2 \text{ cm}}{cm}\right)\left(\frac{s}{s}\right)^{-2}$$

   $$= 1 \times 10^3 \times 10^2 \times 1 = 10^5.$$

   Thus, $\quad 1 \text{ newton} = 10^5 \text{ dynes}.$

2. **To Check the Correctness of an Equation:** Every equation relating physical quantities should be in dimensional balance. It means that *the dimensions of all the terms on both sides of a physical equation must be the same.* This is called the *principle of homogeneity of dimensions.*

   Suppose, we have to check the correctness of the equation $\frac{1}{2} m v^2 = mgh$, where m is the mass of a body, v its velocity, g is acceleration due to gravity and h is the height. The dimensional formulae of the various quantities in the equation are :

   $$\text{mass, } m = [M]$$

$$\text{velocity, } v = [\mathrm{L\,T^{-1}}]$$
$$\text{acceleration due to gravity, } g = [\mathrm{L\,T^{-2}}]$$
$$\text{height, } h = [\mathrm{L}].$$

$\frac{1}{2}$ is a pure ratio, having no dimensions. Substituting these dimensional formulae in the equation

$\frac{1}{2}$ m $v^2 = mgh$, we have

$$[\mathrm{M}]\,[\mathrm{L\,T^{-1}}]^2 = [\mathrm{M}]\,[\mathrm{L\,T^{-2}}]\,[\mathrm{L}]$$

or $$[\mathrm{M\,L^2\,T^{-2}}] = [\mathrm{M\,L^2\,T^{-2}}].$$

The dimensions on both the sides are same. Hence, the given equation is correct.

3. **To Establish the Relation Among Various Physical Quantities:** If we know the factors on which a given physical quantity may possibly depend, then, using dimensions, we can find a formula relating the quantity with those factors.

   Let us find the expression for the time period of a simple pendulum. The time-period T of a simple pendulum may depend on the following :

   (a) mass (m) of the bob,

   (b) length (l) of the thread

   and (c) acceleration due to gravity (g)

   To establish the relation among these, let us suppose that the time-period T depends on mass raised to the power a, on length raised to the power b and on acceleration due to gravity raised to the power c. That is,

$$T \propto (m)^a\,(l)^b\,(g)^c$$

or $$T = k\,(m)^a\,(l)^b\,(g)^c, \qquad \text{...(1)}$$

   where k is a dimensionless constant. Writing the dimensions of both the sides, we have

$$[\mathrm{T}] = [\mathrm{M}]^a\,[\mathrm{L}]^b\,[\mathrm{L\,T^{-2}}]^c$$

or $$[\mathrm{M^0\,L^0\,T^1}] = [\mathrm{M}^a\,\mathrm{L}^{b+c}\,\mathrm{T}^{-2c}].$$

   By the principle of homogeneity of dimensions, the dimensions on the two sides of this equation must be the same. That is

$$a = 0$$
$$b + c = 0$$

and $-2c = 1.$

Solving these three equations, we get

$$a = 0,\ c = -\frac{1}{2} \quad \text{and} \quad b = \frac{1}{2}.$$

Putting these values in eq. (1), we get

$$T = k\,(m)^0\,(l)^{1/2}\,(g)^{-1/2}$$

or $$T = k\sqrt{\frac{l}{g}}.$$

This is the formula for the period of a simple pendulum. It is clear that time-period does not depend upon the mass of the bob. From the dimensional equation, the value of k cannot be known. However, on the basis of experiments the value of $k = 2\pi$,

$$\therefore \quad T = 2\pi\sqrt{\frac{l}{g}}.$$

Example 1.17: *Velocity* $= \sqrt{\dfrac{\text{pressure}}{x}}$*, then write the dimensions of x.*

Solution: Dimensions of velocity $= [LT^{-1}]$, dimensions of pressure $= [ML^{-1}\,T^{-2}]$.

Substituting the dimensions in the given equation, we have

$$x = \frac{\text{pressure}}{\text{velocity}^2} = \frac{[ML^{-1}T^{-2}]}{[LT^{-1}]^2} = [M\,L^{-3}]$$

Example 1.18: *A body has a uniform acceleration of 45 km min*$^{-2}$*. Find its value in m s*$^{-2}$ *(SI system).*

Solution: The dimensional formula of acceleration is $[L\,T^{-2}]$. Let L_1, T_1 denote km and min, and L_2, T_2 denote m (metre) and s (second) respectively. If the numerical values are n_1 and n_2 respectively, then

$$n_1\,(L_1\,T_1^{-2}) = n_2\,(L_2\,T_2^{-2})$$

or $$n_2 = n_1\left(\frac{L_1}{L_2}\right)\left(\frac{T_1}{T_2}\right)^{-2}.$$

Here, $n_1 = 45.$

$$\therefore \quad n_2 = 45\left(\frac{\text{km}}{\text{m}}\right)\left(\frac{\text{min}}{\text{s}}\right)^{-2}$$

$$= 45\left(\frac{10^3\ \text{m}}{\text{m}}\right)\left(\frac{60\ \text{s}}{\text{s}}\right)^{-2}$$

$$= \frac{45\times10^3}{60\times60} = 12.5.$$

Thus, the acceleration of the body is 12.5 m s^{-2}.

Example 1.19: *Check the correctness of the relation $v^2 - u^2 = 2as$, where u is the initial velocity of a particle and v is its final velocity after travelling a distance under uniform acceleration a.*

Solution:

$$v^2 - u^2 = 2as \qquad ...(1)$$

The dimensional formulae of the various quantities in this equation are:

velocity, v or u = $[L\ T^{-1}]$

acceleration, a = $[L\ T^{-2}]$

distance, s = $[L]$.

The number 2 is dimensionless. Substituting these formula in the given equation (1), we have

$$[L\ T^{-1}]^2 - [L\ T^{-1}]^2 = [L\ T^{-2}]\ [L]$$

or $[L^2\ T^{-2}] - [L^2\ T^{-2}] = [L^2\ T^{-2}]$.

The dimensions of each term on the left-hand side are the same as those on the right-hand side. Hence, the given relation is dimensionally correct.

Example 1.20: *A student writes the Einstein's mass-energy equivalence relation as $E = c^2/m$, where m is mass and c is the speed of light in free space. Is the relation correct? If not, establish the correct relation.*

Solution: A relation is dimensionally consistent if the dimensions of both sides of the relation are the same. The dimensions of the quantities involved in the given relation $E = c^2/m$ are as below:

dimensions of E = $[M\ L^2\ T^{-2}]$

$$\text{dimensions of } \frac{c^2}{m} = \frac{[LT^{-1}]^2}{[M]} = [M^{-1}\ L^2\ T^{-2}]$$

Since, the dimensions of the two sides are not the same, the given relation is incorrect.

To get the correct form of the relation, let us suppose that the energy (E) depends upon the mass (m) raised to the power a and upon the speed of light c raised to the power b. Then

$$E = m^a\ c^b, \qquad ...(1)$$

Writing the dimension formulae of both sides, we have

$$[M\ L^2\ T^{-2}] = [M]^a\ [LT^{-1}]^b$$

or $[M\ L^2\ T^{-2}] = [M^a\ L^b\ T^{-b}]$.

Equating the dimensions of both the sides, we have

$$a = 1 \quad \text{and} \quad b = 2$$

Substituting these values in eq. (1), we have

$$E = mc^2$$

This is the famous mass – energy equivalence relation.

1.16. SCALAR AND VECTOR QUANTITIES

All those quantities which can be measured are known as physical quantities. These quantities can be broadly classified into two categories—scalar quantities and vector quantities.

Scalar quantities: Scalar quantities are those physical quantities which have only magnitude and no direction.

These directionless quantities are briefly called scalars. These obey the ordinary laws of Algebra. A scalar quantity is completely specified by merely stating a number. A few examples of scalars are volume, mass, speed, density, number of moles, angular frequency, temperature, pressure, time, power, total path length, energy, gravitational potential, coefficient of friction, charge and specific heat.

Vector quantities: Vector quantities are those physical quantities which have both magnitude and direction.

These quantities are briefly called vectors. A vector is specified not by merely stating a number but a direction as well. Since the concept of vectors involves the idea of direction, therefore, vectors do not follow the ordinary laws of Algebra. A few examples of vectors are : displacement, velocity, angular velocity, acceleration, impulse, force, angular momentum, linear momentum, electric field, magnetic moment and magnetic field.

The differences between scalars and vectors are given here in a tabular form.

Table 1.10. Difference between Scalars and Vectors

S. No.	Scalars	Vectors
1.	These possess only magnitude.	These possess both magnitude and direction.
2.	These obey the ordinary laws of Algebra.	These do not obey the ordinary laws of Algebra.
3.	These change if magnitude changes.	These change if either magnitude or direction or both change.
4.	These are represented by ordinary letters.	These are represented by bold-faced letters or letters having arrow over them.

GLOSSARY

Accuracy: the degree to which the result of a measurement, calculation, or specification conforms to the correct value or a standard.

Area: Area of a figure is the space it encloses with in it.

Density: It is the mass per unit volume of the substance.

Derived quantities: The quantities which are defined in terms of other physical quantities.

Error: The uncertainty in the measurement of a physical quantity is called error.

Force: It is defined as the product of mass and acceleration.

Fundamental quantities: The physical quantities which are independent and are not defined in terms of other physical quantities.

Kilogram: It is standard unit for measuring mass.

Length: It is the distance from one end of something to the other end.

Mass: The amount of matter present in an object.

Measurement: It is comparison of an unknown quantity with some fixed quantity of the same kind.

Metre: It is the standard unit for measuring length.

Physical quantities: These are the quantities such as length, mass, time and temperature.

Precision: The quality, condition, or fact of being exact and accurate.

Second: It is the standard unit for measuring time.

Significant figures: The number of meaningful digits in a number is called the number of significant figures.

Time: It is a measure of distance of events and the intervals between them.

Unit: It is a fixed quantity with respect to which a physical quantity is measured.

Volume: Amount of space that an object occupies.

Weight: It is the product of mass and the local gravitational acceleration (g).

REVIEW EXERCISES

Do the review exercises in your notebook.

A. Multiple Choice Questions.

1. Which of the following branch of Physics is related to the study of sound and waves?

(a) Mechanics (b) Acoustics
(c) Astrophysics (d) Space Physics

2. Which of the following is a derived quantity?

(a) Length (b) Electric Current
(c) Density (d) Time

3. The SI unit of length is

(a) Centimetre (b) metre
(c) kilometre (d) Foot

4. The SI unit of mass is

(a) gram (b) kilogram
(c) pound (d) milligram

5. A ruler can measure length accurately upto

(a) 0.1 mm (b) 1 mm
(c) 0.01 mm (d) 1 cm

6. A vernier calliper can measure length accurate upto

(a) 0.1 mm (b) 1 mm
(c) 0.01 mm (d) 1 cm

7. Which of the following instrument is appropriate for measuring short time intervals

(a) Analog clock (b) Pendulum clock
(c) Stopwatch (d) None of these

8. In scientific notation 0.000121 can be written as:

(a) 1.21×10^{-3} (b) 12.1×10^{-4}
(c) 0.121×10^{-3} (d) 1.21×10^{-4}

9. The number of significant figures in 0.06900 is

(a) 5 (b) 4
(c) 2 (d) 3

10. The sum of the numbers 436.32, 227.2 and 0.301 in appropriate significant figures is

(a) 663.821 (b) 664

(c) 663.8 (d) 663.82

11. The mass and volume of a body are 4.237 g and 2.5 cm^3, respectively. The density of the material of the body in correct significant figures is

(a) 1.6048 g cm^{-3} (b) 1.69 g cm^{-3}

(c) 1.7 g cm^{-3} (d) 1.695 g cm^{-3}

12. If momentum (P), area (A) and time (T) are taken to be fundamental quantities, then energy has the dimensional formula

(a) $(P^1 A^{-1} T^1)$ (b) $(P^2 A^1 T^1)$

(c) $(P^1 A^{-1/2} T^1)$ (d) $(P^1 A^{1/2} T^{-1})$

13. Which of the following ratios expresses pressure?

(a) Force/Area (b) $\frac{\text{Area}}{\text{Force}}$

(c) Energy/Area (d) Force/Volume.

14. Which of the following is a scalar quantity?

(a) Displacement (b) Velocity

(c) Speed (d) Force

B. Match the following Prefixes with their Multiples.

	Prefixes		**Multiples**
1.	micro	(a)	10^6
2.	deca	(b)	10^9
3.	mega	(c)	10^{-6}
4.	giga	(d)	10^{-15}
5.	femto	(e)	10

C. Fill the following Table in Your Notebook.

S. No.	Quantity	mm^2	cm^2	m^2
1	40 mm^2			
2	25 cm^2			
3	1 m^2			

D. Fill in the Blanks.

1. __________ is the study of space which has lead to innovations.
2. The quantities that cannot be explained in terms of other physical quantities are called __________ .
3. The quantities which are derived from fundamental quantities are called __________ .
4. The number of meaningful digits in a number is called the number of __________ .
5. The ratio of the density of a substance to the density of water at 4°C is called __________ .
6. __________ is the thrust per unit area of a surface.
7. The dimension formula of force is __________ .
8. Physical quantities which have both magnitude and direction are called __________ .

E. State Whether the following Statement are True or False.

1. Centimeter is SI unit of length.
2. Velocity is a derived quantity.
3. $0.0000095 = 9.5 \times 10^{-6}$
4. One metre is defined as the length of path covered by light, in vacuum, in a time interval of $\frac{1}{299792458}$ of a second.
5. Screw gauge is usually able to measure length accurately up to 0.1 mm.
6. A stopwatch is used to measure the time interval of an event.
7. Mercury and alcohol are the liquids used in most liquid in glass thermometers.
8. The dimensional formula of density is $[M^0 L T^{-2}]$.

F. Answer the Following Questions.

1. Explain physics as a science subject and discuss its importance.
2. Discuss the branches of physics.
3. Explain the basic fundamental physical quantities.
4. Differentiate between derived and fundamental physical quantities.
5. Introduce International System (SI) of measurement units.
6. Write short notes on
   (a) Vernier calliper (b) Screw gauge
   (c) Stopwatch (d) Spring balance

7. Describe how you find the density of
   (a) Rectangular wooden block (b) A stone
8. What is dimensional analysis? Write the dimensional formula of density.
9. Write the uses of dimensional equations.
10. What are scalar and vector quantities? Distinguish between scalars and vectors.

G. Numericals.

1. The distance of Earth to Sun is 150,000,000,000 metres. Write it in scientific notation form.
2. The diameter of a cell is 0.000001 metres. Write it in scientific notation form.
3. Add 18.36 kg, 12.5 kg and 8.821 kg with due regard to significant figures.
4. Albert and Lisa live 2000 m from each other. Express the distance between their houses in kilometres (km.)
5. Convert the length measures and complete the following table in your notebook.

S. No.	Quantity	mm	cm	m	km
1.	32 mm				
2.	479 mm				
3.	88 cm				
4.	1728 cm				
5.	34 m				
6.	1500 m				
7.	4 km				
8.	25 km				

6. Find the volume of a cuboid having 3 m length, 200 cm width and 2 m height.
7. Find the area of a triangle of height 20 cm and base 70 cm.
8. Find the area of a circular field of diameter 2 metres.
9. Find the area of the figures shown below:
   (a) 7 cm × 9 cm rectangle (b) A circle of radius 10 cm

(c) A triangle of base 15 cm and height 24 cm

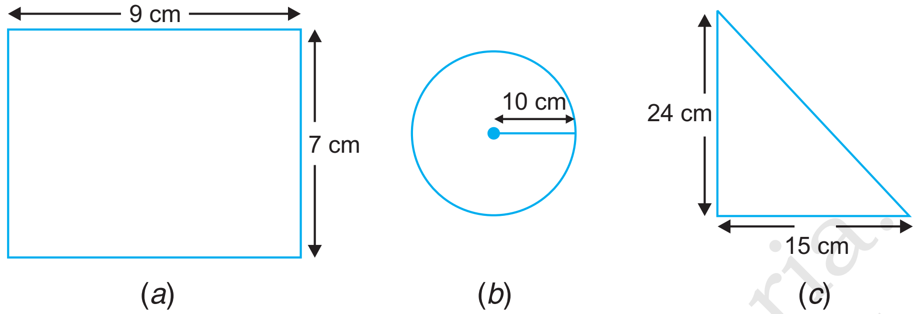


Fig. 1.36.

10. A rectangular field has a length of 120 m and a width of 80 m. Calculate the area of the field.

11. When 6 g of a given substance is completely submerged in water, 5 ml of water is displaced. What is the density of the substance in g/cm^3?

12. Relative density of gold is 19.3. The density of water is 1000 kg/m^3. What is the density of gold in SI units?

13. Which will exert more pressure, 100 kg mass on 10 m^3 or 50 kg mass on 4 m^2? Given reason.

14. If the density of mercury is 13.6 g cm^{-3}, convert its value into kg m^{-3}, using dimensional equation.

15. Find the value of 60 joule/minute on a system which has 100 g, 100 cm and 1 min as fundamental units.

H. Questions based on Higher Order Thinking Skills (HOTS).

1. Why do some objects float while others sink?

2. The level of water in a measuring cylinder was 72 ml and it raised to 78 ml when a piece of metal was dropped in it.

(a) Why is the level raised?

(b) Is it possible to tell the volume of the metal from the given information?