Model Textbook of

Physics 9

National Book Foundation
as
Federal Textbook Board
Islamabad

Based on National Curriculum of Pakistan 2022-23

Model Textbook of

Physics

Grade

9

National Curriculum Council
Ministry of Federal Education and Professional Training

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Model Textbook of **Physics**
for Grade 9

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PREFACE

This Model Textbook has been developed by NBF according to the National Curriculum of Pakistan 2022-2023. The aim of this textbook is to enhance learning abilities through inculcation of logical thinking in learners, and to develop higher order thinking processes by systematically building upon the foundation of learning from the previous grades. A key emphasis of the present textbook is on creating real life linkages of the concepts and methods introduced. This approach was devised with the intent of enabling students to solve daily life problems as they go up the learning curve and for them to fully grasp the conceptual basis that will be built upon in subsequent grades.

After amalgamation of the efforts of experts and experienced authors, this book was reviewed and finalized after extensive reviews by professional educationists. Efforts were made to make the contents student friendly and to develop the concepts in interesting ways.

The National Book Foundation is always striving for improvement in the quality of its books. The present book features an improved design, better illustration and interesting activities relating to real life to make it attractive for young learners. However, there is always room for improvement and the suggestions and feedback of students, teachers and the community are most welcome for further enriching the subsequent editions of this book.

May Allah guide and help us (Ameen).

بِسۡمِ اللّٰهِ الرَّحۡمٰنِ الرَّحِیۡمِ

اللہ کے نام سے شروع جو بڑا مہربان، نہایت رحم والا ہے

Contents

UNIT 1

PHYSICAL QUANTITIES AND MEASUREMENT

Which unit was used by ancient Egyptians while building pyramids?

Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-A-01] Differentiate between physical and non-physical quantities
- [SLO: P-09-A-02] Explain with examples that physics is based on physical quantities
- [SLO: P-09-A-03] Differentiate between base and derived physical quantities and units.
- [SLO: P-09-A-04] Apply the seven units of System International (SI)
- [SLO: P-09-A-05] Analyse and express numerical data using scientific notation
- [SLO: P-11-A-06] Analyse and express numerical data using prefixes.
- [SLO: P-09-A-07] Differentiate between scalar and vector quantities.
- [SLO: P-09-A-08] Justify that distance, speed, time, mass, energy, and temperature are scalar quantities.
- [SLO: P-09-A-09] Justify that displacement, force, weight, velocity, acceleration, momentum, electric field strength and gravitational field strength are vector quantities.
- [SLO: P-09-A-10] Determine, by calculation or graphically, the resultant of two vectors at right angles
- [SLO: P-09-A-11] Make reasonable estimates of physical quantities
- [SLO: P-09-A-12] Justify and illustrate the use of common lab instruments to measure length.
- [SLO: P-09-A-13] Justify and illustrate the use of measuring cylinders to measure volume.
- [SLO: P-09-A-14] Justify and illustrate how to measure time intervals using lab instruments.
- [SLO: P-09-A-15] Determine an average value for an empirical reading.
- [SLO: P-09-A-16] Round off and justify calculational estimates.
- [SLO: P-09-A-17] Critique and analyze experiments for sources of error.
- [SLO: P-11-A-09] Differentiate between precision and accuracy.
- [SLO: P-09-A-19] Determine the least count of a data collection instrument (analog) from its scale.

UNIT 1 PHYSICAL QUANTITIES AND MEASUREMENT

Measurements are not confined to science. They are part of our lives. They play an important role to describe and understand the physical world. Over the centuries, man has improved the methods of measurements. In this unit, we will study some of physical quantities and a few useful measuring instruments. We will also learn the measuring techniques that enable us to measure various quantities accurately.

1.1 INTRODUCTION TO PHYSICS

In the nineteenth century, physical sciences were divided into five distinct disciplines; physics, chemistry, astronomy, geology and meteorology. The most fundamental of these is the Physics. In Physics, we study matter, energy and their interaction. The laws and principles of Physics help us to understand nature.

Physics in Science: Physics is the most fundamental of all the sciences. In order to study biology, chemistry, or any other natural science, one should have a firm understanding of the principles of physics. For example, biology uses the physics principles of fluid movement to understand how the blood flows through the heart, arteries, and veins. Chemistry relies on the physics of subatomic particles to understand why chemical reactions take place.

FIGURE 1.1 PHYSICS AND TECHNOLOGY

(a) Robot is a machine that is designed to do tasks without the help of a person.

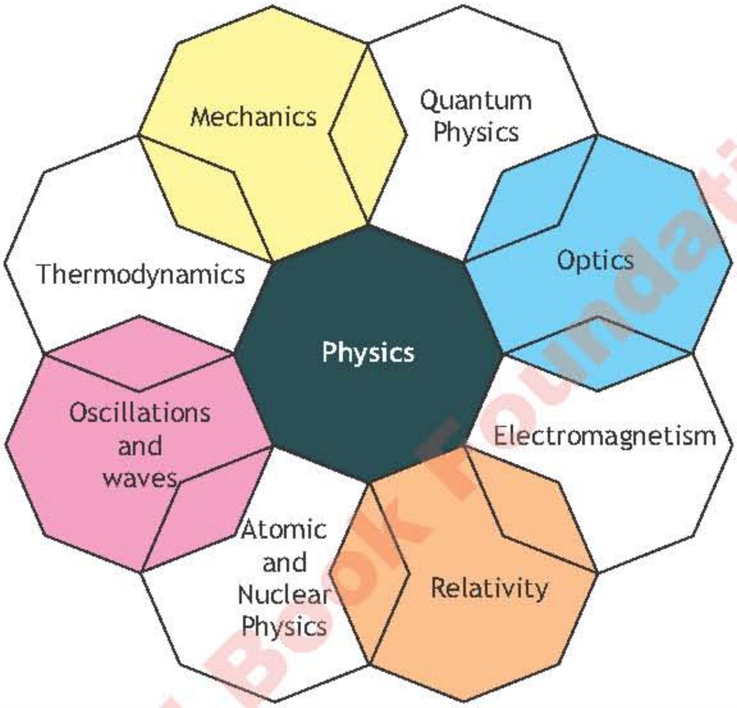
(b) Space shuttle being launched in to the space with rocket.

Physics and Technology: What are the technological devices that we use on a regular basis? Computers, smart phones, MP3 players, and internet come to our mind. What are technologies that you have only heard of? Rockets and space shuttles, Magnetically levitating trains, and microscopic robots that fight cancer cells in our bodies. All of these technologies, whether common place or exciting, are based on the principles of physics.

Physics is behind every technology and plays a key role in further development of these technologies, such as airplanes, computers, PET scans and nuclear weapons.

1.1.1 BRANCHES OF PHYSICS

Physics is vast and is therefore further subdivided in many other branches. These branches of physics are increasing as the technology is progressing, however the major branches of physics include mechanics, optics, oscillation and waves, thermodynamics, electromagnetism, astrophysics, quantum physics, atomic physics and nuclear physics.



DO YOU KNOW?

The cubit was the measurement unit used by Egyptians to build the pyramid.

The cubit is the measure from your elbow to the tip of your middle finger when your arm is extended.

Physics has strong connection with mathematics, to understand the nature physics we use mathematics as a tool. Therefore learning physics requires mathematical knowledge.

1.2 PHYSICAL AND NON-PHYSICAL QUANTITIES

"Physical quantities are those quantities which can be measured whereas non physical quantities are those quantities which can not be measured".

Quantities like length, mass, time, density, temperature, can be defined and measured, therefore they are termed physical quantities while taste, feeling and color can not be measured so they are non physical quantities

POINT TO PONDER

Measurement is a comparison between an unknown physical quantity (like length, mass, time etc) and standard to see how large or small it is compared to that standard.

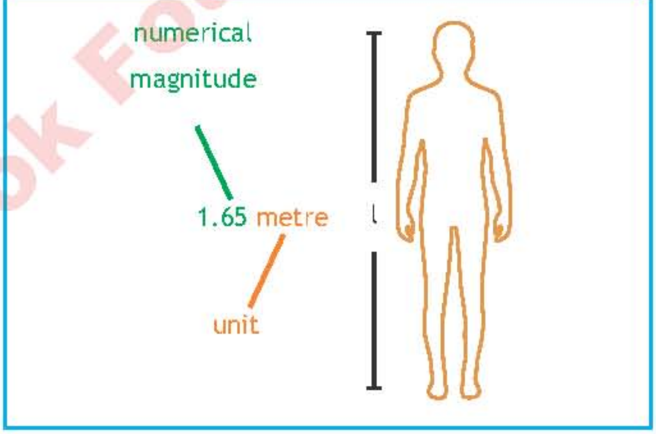
Unit is standard with which physical quantities are compared.

Measurement of a physical quantity consists of numerical magnitude (number representing the size of the quantity) and unit in which it is measured.

For example if the length of the person is 1.65 metres (5 foot and 5 inches), 1.65 is the numerical magnitude and meter is the unit as shown in figure 1.2.

To record a measurement, an appropriate unit is chosen and the size of quantity is then found with an instrument having a proper scale (like measuring tape).

FIGURE 1.2 LENGTH MEASUREMENT



1.2.1. BASE AND DERIVED PHYSICAL QUANTITIES

Base (or fundamental) physical quantities (like mass, length and time) are selected as the simplest form of physical quantities, such that all other physical quantities can be derived from them. The physical quantity obtained by multiplying or dividing base physical quantities are termed as the derived physical quantities.

1.3 INTERNATIONAL SYSTEM OF UNITS

'A complete set of units for all physical quantities is called system of units'.

The international system of units is termed as System International (abbreviated as SI), a short form of the French name 'System International d' Units' which means 'International System of Units'.

1.3.1. SYSTEM INTERNATIONAL (SI) BASE UNITS

In System International (SI) seven (07) physical quantities are chosen as base and their units are defined and standardized. These units are called base units. Each SI unit is defined carefully so that accurate and reproducible measurements can be made. The seven basic physical quantities, their SI base units and the symbols of SI units are given in the table 1.1.

TABLE 1.1 BASE UNITS FOR INTERNATIONAL SYSTEM OF UNITS

SI Base Quantity		SI Base Unit	
Name	**Symbol**	**Name**	**Symbol**
length	l	meter	m
mass	m	kilogram	kg
time	t	second	s
electric current	I	ampere	A
temperature	T	kelvin	K
amount of substance	n	mole	mol
light intensity	I_v	candela	cd

1.3.2. SYSTEM INTERNATIONAL (SI) DERIVED UNITS

Units of derived quantities are obtained by multiplying and/or dividing base quantities. In SI units all other physical quantities can be derived from the seven base units.

For example, the unit for area is 'm × m = m²', in this example base unit of length is used. Similarly the unit for velocity is 'm/s' and acceleration is 'm/s²'. Some derived units are given special names and symbols. For example force has derived units of 'kg m/s²' which is given special name as 'newton' and represented as 'N'. Some derived quantities with derived units in terms of base units are given in table 1.2.

EXPLORE

https://www.bipm.org/en/

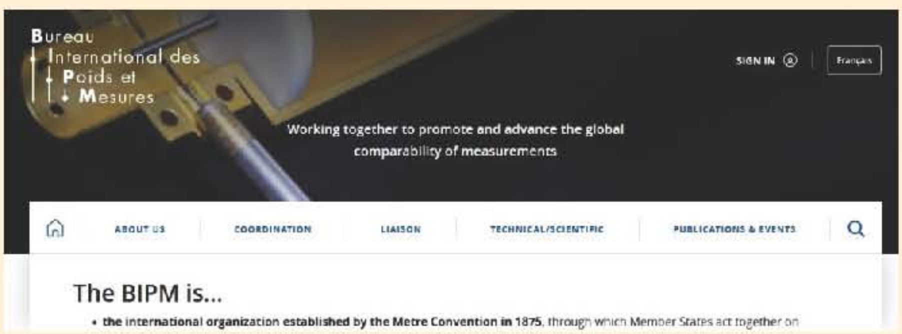


TABLE 1.2 DERIVED UNITS FOR 'INTERNATIONAL SYSTEM OF UNITS			
Derived Quantity		SI Derived Unit	
Name	Symbol	Name	Symbol
area	A	square meter	m^2
volume	V	cubic meter	m^3
speed, velocity	v	meter per second	ms^{-1}
acceleration	a	meter per second squared	ms^{-2}
density	ρ	kilogram per cubic meter	kgm^{-3}
force	F	newton (N)	$kgms^{-2}$
pressure	P	pascal (Pa)	$kgm^{-1}s^{-2}$
energy	E, U	joule (J)	kgm^2s^{-2}

1.4 STANDARD FORM / SCIENTIFIC NOTATION

In physics we deal with numbers that are either very small or very large, for example, the width of the observable universe is approximately 880,000,000,000,000,000,000,000,000 metres (88 with 25 zeros). If we use this number often, it is not only time consuming but there are chances of reporting it wrong.

Scientific notation is an easy method of writing very large or small numbers in power of ten.

DO YOU KNOW?

Standard form or scientific notation represents a number as the product of a number greater than 1 and less than 10 (called the mantissa) and a power of 10 (termed as exponent):

number = mantissa ×10exponent

Therefore the width of the observable universe can scientifically be written compactly as 8.8×10^{26} metres, where '8.8' is the mantissa and '26' is the exponent. Similarly the mass of earth is 5,980,000,000,000,000,000,000,000 kg which is written as 5.98×10^{24} kg and the diameter of hydrogen nucleus is about 0.0000000000000017 metres, which is 1.7×10^{-15} m.

1.5 PREFIXES TO POWER OF TEN

A mechanism through which numbers are expressed in power of ten that are given a proper name is called prefix.

Prefixes makes standard form or scientific notation further easier. Large numbers are simply written in more convenient prefix with units.

The thickness of a paper can be written conveniently in smaller units of millimetre instead of metre. Similarly the long distance between two cities may be expressed better in a bigger unit of distance, i.e., kilometre. Some prefixes in SI to replace powers of 10 are given in table 1.3.

TABLE 1.3 PREFIXES

Prefix	Decimal Multiplier	Symbol	Prefix	Decimal Sub-multiplier	Symbol
Exa	10^{18}	E	deci	10^{-1}	d
Peta	10^{15}	P	centi	10^{-2}	c
Tera	10^{12}	T	milli	10^{-3}	m
giga	10^{9}	G	micro	10^{-6}	μ
Mega	10^{6}	M	nano	10^{-9}	n
kilo	10^{3}	k	pico	10^{-12}	p
hecto	10^{2}	h	femto	10^{-15}	f
deca	10^{1}	da	atto	10^{-18}	a

For example

a. the number of seconds in a day are:

$86400\ s = 8.64 \times 10^4\ s = 86.4 \times 10^3\ s = 86.4\ ks.$

b. the distance to the nearest start alpha centauri is:

$4.132 \times 10^{16}\ m = 41.32 \times 10^{15}\ m = 41.23\ Pm$

c. the thickness of the page of the page of this book is about:

$4.0 \times 10^{-5}\ m = 40 \times 10^{-3}\ m = 40\ mm$

d. the mass of grain of salt is:

$1.0 \times 10^{-4}\ g = 100 \times 10^{-2}\ g = 100\ mg$

DO YOU KNOW?

Volume is a derived quantity

1 L = 1000 mL

1 L = 1 dm^3

= $(10\ cm)^3$

= 1000 cm^3

1 mL = 1 cm^3

CAN YOU TELL?

Can you write the number in power of ten and choose prefix to the following numbers

a). The mass of Sun is about 1,970,000,000,000,000,000,000,000,000,000 kg.

b). radius of a hydrogen atom, is about 0.00000000005 m.

c). The age of earth is about 143,300,000,000,000,000 s.

Can you express the following in terms of powers of 10.

a). The thickness of sheet of paper is about 100,000 nanometers.

b). Pakistan has a total installed power generation capacity of over 40,000 megawatt.

c). A single hard disk capacity of computers has exceeded 30 terabyte.

EXAMPLE 1.1: SCIENTIFIC NOTATION

Convert the following numbers in Standard form / scientific notation.

a) 149,530,000,000 m which is the average distance between earth and Sun.

b) 0.0008 g which is the average mass of human hair.

c) The number of seconds in a day.

SOLUTION

(a) For Standard form / scientific notation we can write the term as

$$\text{Distance} = 149530000000.0 \times 10^{0}\ \text{m}$$

For Standard form / scientific notation, in order to get mantissa (M), we have to move the decimal 11 digits towards left. Therefore, the power of 10 will be positive 11, that is

$$\boxed{\text{Distance} = 1.4953 \times 10^{11}\ \text{m}}$$ Answer

Which is the average distance between earth and sun in standard form / scientific notation

(b) In Standard form / scientific notation we can write the term as

$$\text{Mass of hair} = 0.0008 \times 10^{0}\ \text{g}$$

$$\boxed{\text{Mass of hair} = 8 \times 10^{-4}\ \text{g}}$$ Answer

(c) We know that there are 24 hours in a day, 60 minutes in an hour, and 60 s in a minute. These three relationships are conversion factors. As

$$1\ d = 86{,}400\ s$$

For Standard form/scientific notation we can write the term as:

$$1\ d = 86{,}400.0 \times 10^{0}\ s$$

$$\boxed{1\ d = 8.64 \times 10^{4}\ s}$$ Answer

EXAMPLE 1.2: PREFIXES

Write the numbers in standard/scientific notation and also represent using appropriate prefix.

(a) One ton of rice in gram

(b) The diameter of neutron is 0.0000000000000018 m.

SOLUTION

(a) One ton is equal to a mass of 1000 kilograms

1 ton = 1000 kg

As we know that: 1 kg = 1000 g, therefore 1 ton = 1000 × 1000 g

1 ton = 1,000,000 g = $1{,}000{,}000.0 \times 10^{0}$ g

In scientific form: For Standard form / scientific notation in order to get mantissa (M), we have to move the decimal 6 digits towards left.

Therefore, the power of 10 will be positive 6, given by:

$$\boxed{1\ \text{ton} = 1.0 \times 10^{6}\ g}$$ Answer

Using prefix: As 10^{6} = Mega, therefore

$$\boxed{1\ \text{ton} = 1.0\ \text{Mg}}$$ Answer

(b) The diameter of proton is 0.0000000000000017 m, which can be written as

Diameter of proton = $0.0000000000000018 \times 10^{0}$ m.

$$\boxed{\text{Diameter of proton} = 1.7 \times 10^{-15}\ m}$$ Answer

Using prefix: 10^{-15} = femto, therefore

$$\boxed{\text{Diameter of proton} = 1.7\ \text{fm}}$$ Answer

1.6 SCALARS AND VECTORS

Does direction of wind matter when you fly a kite? You need to know the direction in which the air is blowing; otherwise, it will be difficult for you to keep your kite flying. Some physical quantities require direction to be specified completely. Therefore these directional properties can be used to catagorize physical quantities as scalars and vectors.

1.6.1. SCALAR QUANTITIES OR SCALARS

Physical quantities which can be completely described only by its numerical magnitude (or size) with proper unit are termed as scalar quantities or simply scalars. Forexamples distance, speed, time, mass, energy, and temperature etc are scalar quantities.

consider a man travels a distance of 4.5km but its direction is not specified but only this magnitude is given so it is said to be scalar quantity similarly we say that time is a scalar quantity, because when we say that time measurement is 30 s, here '30' is the numerical magnitude and 's' is proper unit. We does not need to state the direction of time.

Scalar quantities can be added, subtracted and multiplied by using ordinary rules of algebra. For example if we took 5 s to reach the door of the classroom and another 20 s to reach the gate of school, the total time we took is (5 s + 20 s) 25 seconds.

1.6.2. VECTOR QUANTITIES OR VECTORS

Physical quantities which require not only numerical magnitude (or size) with proper unit, but also the direction are termed as vector quantities or simply vectors. Vector quantities, such as displacement, force, weight, velocity, acceleration, momentum, electric field strength, and gravitational field strength, require both numerical magnitude and direction. When we refer to a vector quantity, we not only mention its numerical magnitude and unit, but also its direction. To fully describe a vector, its direction must be specified.

Since vector quantities are associated with direction, they cannot be added, subtracted, or multiplied using the usual rules of algebra. They follow their own set of rules known as vector algebra.

POINT TO PONDER

A coordinate system is used to locate the position of any point and that point can be plotted as an ordered pair (x, y) known as Coordinates. The horizontal number line is called 'X-axis' and the vertical number line is called 'Y-axis' and the point of intersection of these two axes is known as the origin and it is denoted as 'O'. The reference frame is the coordinate system from which the positions of objects are described.

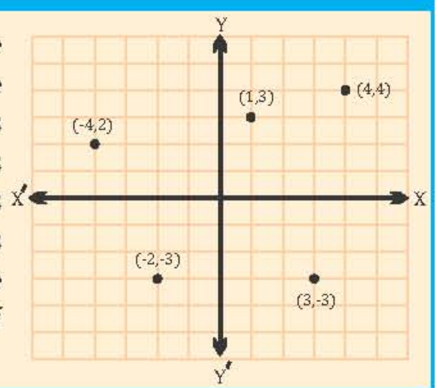
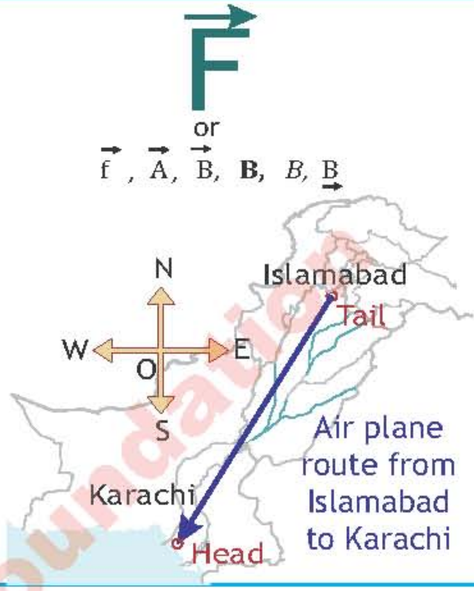


FIGURE 1.3 VECTOR REPRESENTATION

Symbolically a vector can be represented by a letter either capital or small. (e.g F and f or A and B) with an arrow over it.

Graphically a vector is represented by an arrow, the length of the arrow gives the magnitude with proper unit (under certain scale) and the arrow head points the direction of the vector. To use vectors we place them in coordinate axis.

Aeroplane route from Islamabad to Karachi is shown as a vector in figure. Here a Geographical Coordinate System having directions as North (N), East (E), West (W) and South (S) is used.



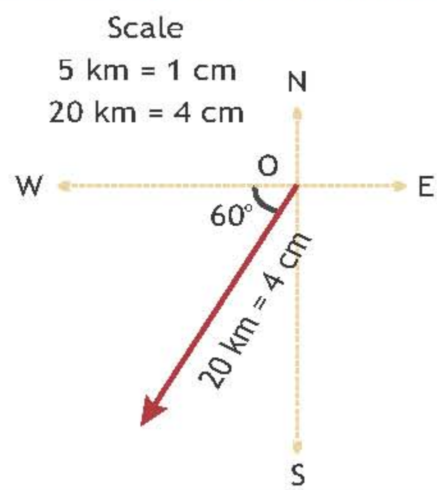
Steps to Represent a Vector in Coordinate System

The following method is used to represent a vector

1. Choose and draw a coordinate system.
2. Select a suitable scale.
3. Draw a line in the fixed direction. Cut the line equal to the magnitude of the vector according to the chosen scale.
4. Put an arrow along the direction of the vector.

For example the representation of helicopter as it moves to 20 km from origin towards 60° south of west is shown in the figure 1.4.

FIGURE 1.4 HELICOPTER MOTION

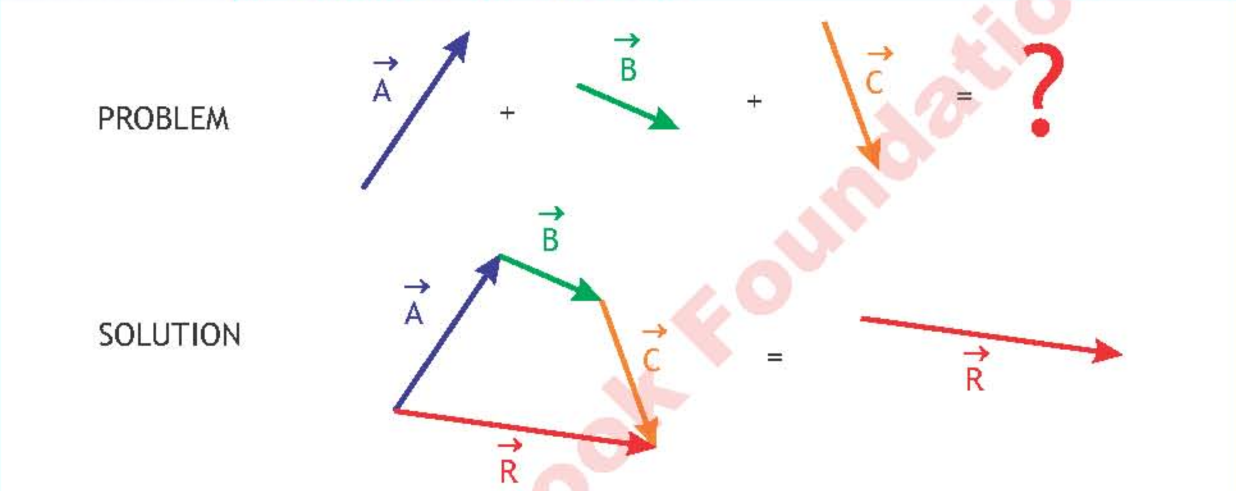


Since displacement, force, weight, velocity, acceleration, momentum, electric field strength, and gravitational field strength are vector quantities or vectors. They will require to follow the rules of vector addition. This means that when we combine two vectors, the resulting value must also result as a vector.

1.6.3. ADDING VECTOR QUANTITIES

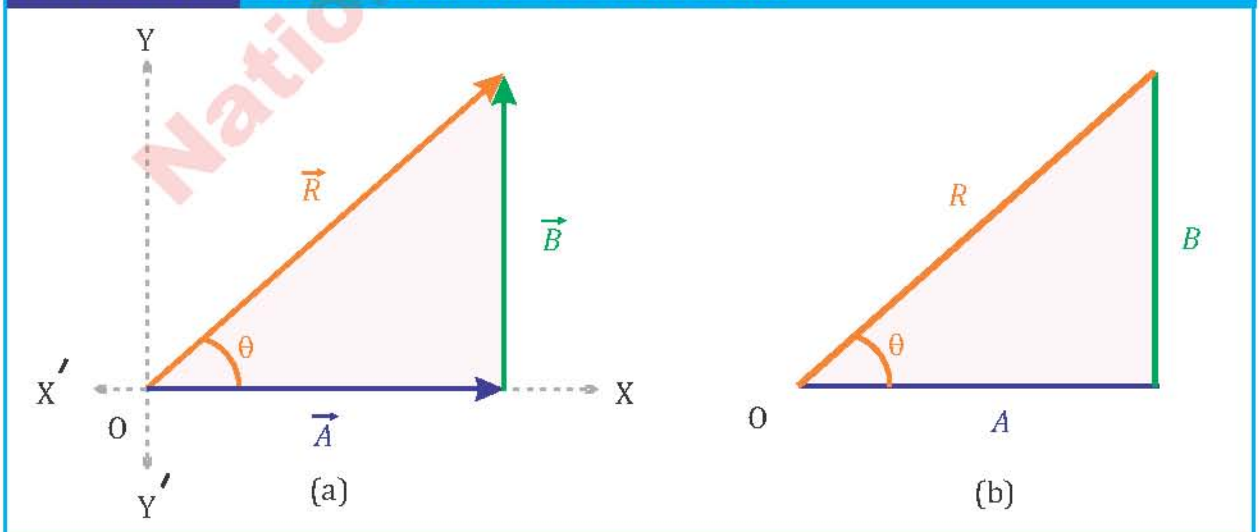
The process of combining two or more vectors to into a single vector (called as resultant vector) to determine their cumulated effect is termed as vector addition. In vector algebra, the resultant vector cannot be simply obtained by adding vector values. Vectors and may be added geometrically by drawing them to a common scale and placing them head to tail. Joining the tail of the first vector with the head of the last will give another vector which will be its **resultant vector.** For example, the addition of three vectors is shown in figure 1.5.

FIGURE 1.5 RESULTANT OF VECTORS



Consider two vectors ‘$\vec{A}$’ (along x-axis) and ‘$\vec{B}$’ (along y-axis), which are perpendicular to each other. We can add the two vectors by placing vector ‘$\vec{B}$’ on head of vector ‘$\vec{A}$’, the resultant vector ‘R’ will be obtained by joining tail of vector ‘$\vec{A}$’ with head of vector ‘$\vec{B}$’, as shown in figure 1.6.

FIGURE 1.6 RESULTANT OF TWO VECTORS



POINT TO PONDER

Does vector addition depends on the order? Will it make any difference if we add vector '$\vec{A}$' with vector '$\vec{B}$' or vector '$\vec{A}$' with vector '$\vec{B}$'.

1.7 MEASURING INSTRUMENTS

Physics is built on definitions that are expressed in terms of measurements. For measurements of physical quantities we need devices termed as measuring instruments. These range from simple objects such as rulers and stopwatches to Atomic Force Microscope (AFM) and Scanning Tunneling Electron Microscope (STEM).

All measuring instruments have some measuring limitations.

Least count is the minimum value that can be measured on the scale of measuring instrument. The measurement of every instrument is therefore limited to its least count.

1.7.1 METRE RULE AND MEASURING TAPE

We use ruler to draw margin lines on our notebooks. Have you ever used the scale on it to draw the lines with exact lengths? A meter rule is a physics laboratory tool, used to measure the length of objects.

Metre rules are one metre long (as compared to the standard metre). Metre Rulers usually have 1000 small divisions on them called millimetres. Such metre rulers have least count of 1 mm as shown in figure 1.7.

These instruments have similar scale on it as drawn on our rulers, principally rulers are shorter version of metre rule.

FIGURE 1.7 METRE RULE

A measuring tape is a flexible ruler used to measure larger distance or length. It consists of a ribbon of cloth, plastic, metal, or fiberglass with linear measurement markings on it. The tape is usually housed in a compact case, and it can be pulled out and locked in place to measure distances. The most common units of measurement on a measuring tape are inches and centimeters. Measuring tapes come in various lengths, typically ranging from a few feet to several meters.

POINT TO PONDER

Can you measure distances smaller than 1 mm on metre rule? Why?

CAN YOU TELL?

Some metre rulers like the one shown in the figure 1.7 are marked with inches and feet? What is the least count of metre rule on this scale? .

ACTIVITY

In this activity the students will determine their height in metres and millimetres by making a paper scale and pasting it on the wall. The paper scale should be 2 m large with marking in metre, centimetre and millimetre.

They can form pair to measure each other heights, with paper scale.

1.7.2 VERNIER CALIPER

In physics sometimes we need to measure a length smaller than 1 mm. A vernier calliper can help take smaller than a millimetre reading.

'Vernier caliper is a device used to measure a fraction of a smallest division on scale by sliding another scale over it'.

It can be used to measure the thickness, diameter or width of an object and the internal, external diameter of hollow cylinder.

FIGURE 1.8 VERNIER CALLIPERS

There are two scales on vernier callipers.

A main scale which has markings of usually of 1 mm each and it contains jaw on its left end.

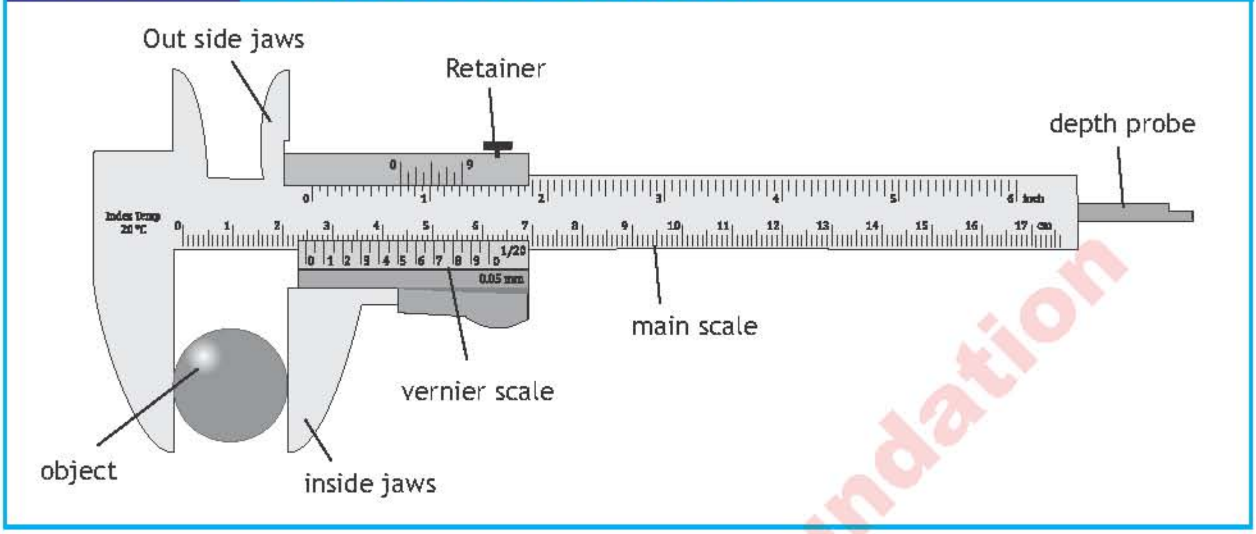
A sliding scale called vernier scale which has markings of some multiple of the marking on the main scale.

Minimum length which can be measured accurately with the help of a vernier callipers is called least count (vernier constant) of vernier callipers.

Least count can be obtained from dividing the value of smallest division on main scale by total number of divisions or vernier scale.

$$\text{Least Count} = \frac{\text{Smallest division on main scale}}{\text{Total number of divisions on vernier scale}}$$

FIGURE 1.9 VERNIER CALLIPER DIAGRAM



If the smallest main scale division is 1 mm and vernier scale division has 10 division on it then the least count of vernier caliper is:

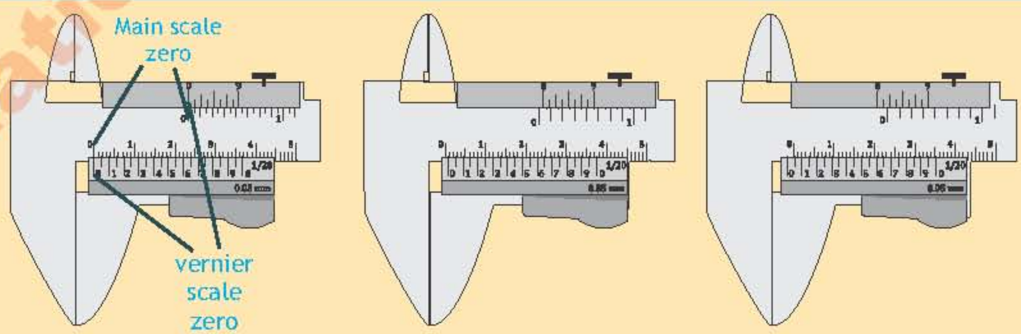
$$\text{Least Count} = \frac{1\,mm}{10} = 0.1\,mm$$

CAN YOU TELL?

What is the length of the object measured by metre rod if it is 20.14 cm measured by vernier callipers?

On closing the jaws of the vernier calipers, the zero of the vernier scale should coincide with the zero of the main scale. If their zeros does not coincide, there is an error in the instrument, called zero error. The zero error can be corrected which you will learn in laboratory work.

DO YOU KNOW?



(a) There is no zero error as the zero line of vernier scale is coinciding with the zero of vernier scale.

(b) Zero error is positive as vernier scale is towards the right of the zero of main scale.

(c) Zero error is negative as vernier scale is towards the left of the zero of main scale.

TAKING MEASUREMENT WITH VERNIER CALLIPERS

If we want to measure the diameter of an object (e.g. a small sphere) with vernier caliper, the following steps can be followed.

i. Note the least count of the vernier, (it is usually written on vernier caliper, or we can find it by method already learned). Determine and correct zero error if any.

ii. Fix the small sphere in the jaws and note the complete divisions of main scale past by the zero of vernier scale. This is main scale reading as shown in figure 1.6.

iii. Look for the division of vernier scale that is coinciding with any division on main scale. This is vernier scale reading.

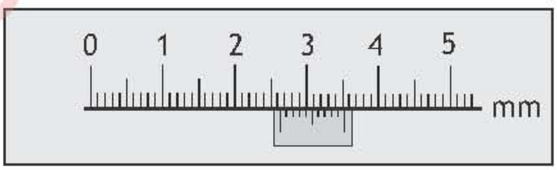
iv. Multiply the vernier scale reading with least count which is the fraction to be added with main scale reading. This fraction will be smaller than the main scale least count, thus vernier calliper measure the reading to the part of millimetre.

DIGITAL VERNIER CALLIPER

Digital Vernier Callipers has greater precision than mechanical vernier Callipers. Least count of Digital Vernier Callipers is 0.01 mm.

ACTIVITY

Read the following Vernier Caliper measurement, and answer the following questions.



If the main scale is in millimetre, what is the least count?________________

What is the main scale reading?__________________

What is the vernier scale reading?__________________

What is total reading of the measurement?__________________

1.7.3 SCREW GAUGE

Screw gauge is also length measuring device and is used for measurements even smaller than vernier callipers. 'Screw Gauge is a device used to measure a fraction of a smallest division on scale by rotating circular scale over it'.

The distance traveled by the circular scale on linear (or main) scale in one rotation is called the pitch of the screw gauge.

The minimum length which can be measured accurately by a screw gauge is called least count of the screw gauge. The least count of screw gauge is found by dividing its pitch by the number of circular scale divisions.

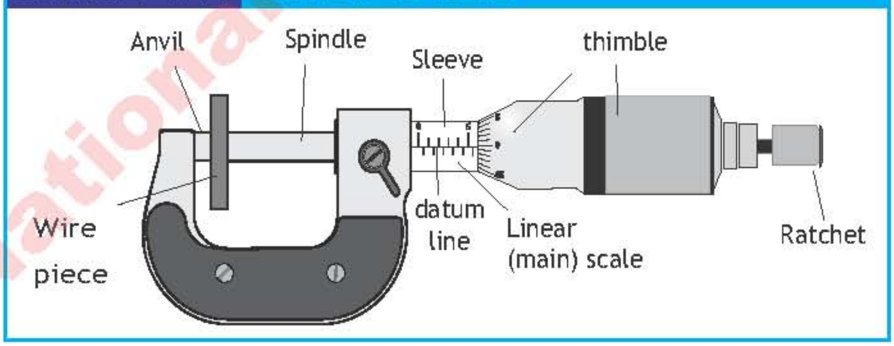
FIGURE 1.10 SCREW GAUGE

$$Least\ Count = \frac{\text{Pitch of Screw Guage}}{\text{Total Number of Divisions on Circular Scale}}$$

If the pitch of the screw gauge is 0.5 mm and the number of divisions on circular scale is 50 then

$$Least\ Count = \frac{0.5\ mm}{50} = 0.01\ mm$$

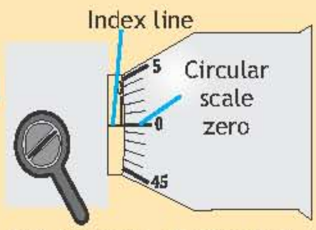
FIGURE 1.11 SCREW GAUGE



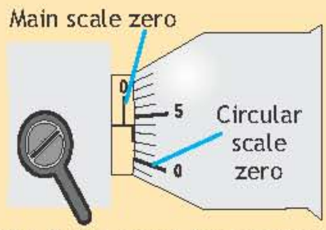
ZERO ERROR IN SCREW GAUGE

Turn the thimble until the anvil and spindle meet, datum line of the linear scale must meet with the zero on the thimble scale. If the zero mark on the thimble scale (or circular scale) does not lie directly opposite the datum line of the main scale we say that there is zero error. The zero error and its correction will be discussed in laboratory work.

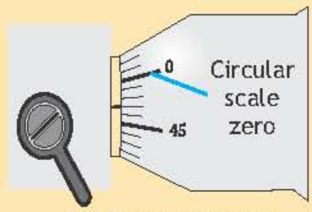
DO YOU KNOW?



(a) As zero of circular scale is exactly on the index line hence there is no zero error.



(b) Zero error is positive if zero of circular scale has not reached zero of main scale.



(c) Zero error is negative if zero of circular scale has passed zero of main scale.

TAKING MEASUREMENT WITH SCREW GAUGE

If we want to measure the diameter of an object (e.g a wire piece) with screw gauge, the following steps can be followed.

i. Note the pitch and least count of the screw gauge and determine the zero error (if any).

ii. Place the object (e.g a wire piece) between with spindle and anvil. Now gently close the gap between the spindle and the anvil by turning the ratchet.

iii. Turn the ratchet until it starts to click. The ratchet prevents the user from exerting too much pressure on the object.

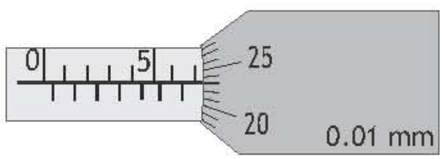
iv. Read the main scale reading, which is the reading shown (or unblocked) by circular scale as shown in figure 1.8.

v. Identify the line of circular scale aligned with datum line, now multiply the least count of screw gauge by this number. This is circular scale reading.

vi. Add linear (or main) scale reading and circular scale reading, which gives the total reading.

ACTIVITY

A screw gauge has a least count of 0.01 mm. Read the following screw gauge measurement, and answer the following questions.



What is the main scale reading? ____________________

What is the circular scale reading? ____________________

What is total reading of the measurement? ____________________

CAN YOU TELL?

You have to measure the thickness of page and internal diameter of a beaker which instrument would you use vernier calliper or screw gauge? Why?

FOR YOUR INFORMATION

Least count of ruler is 1mm. It is 0.1mm for Vernier Callipers and 0.01mm for micrometer screw gauge.

Thus measurements taken by micrometer screw gauge are the most precise than the other two.

1.7.4 PHYSICAL BALANCE

The balance (also balance scale, beam balance and laboratory balance) was the first mass measuring instrument invented. A physical balance as shown in figure 1.12 (a) is a very sensitive common balance which can measure weights in milligram order. It consist of a vertical pillar having a horizontal beam, resting on knife edge with two pans. A long pointer is attached to the middle of the beam.

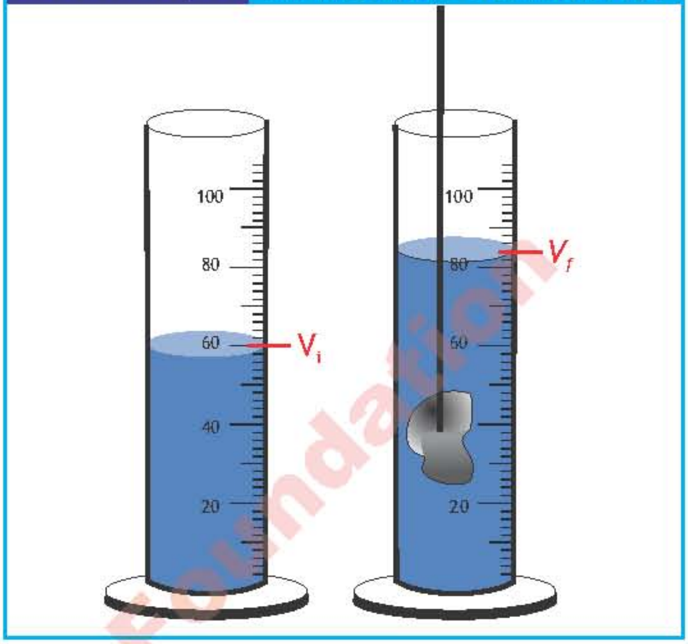
Leveling screws are used to level the physical balance, while the pointer is set at the center of the scale by adjusting screws. It is placed in a protective glass case so that even dust and wind can not affect the accuracy of the instrument. A weight box containing standard weights comes with the balance. The mass of a body is found by placing the body in one pan, placing some standard weights in the other, and then calculating it from the standard weights placed and the resting point of the pointer.

FIGURE 1.12 PHYSICAL BALANCE

1.7.5 MEASURING CYLINDER

A measuring cylinder is a tool used in laboratories to measure the volume of liquids, chemicals, or solutions. It is also known as a graduated cylinder. Measuring cylinders are typically made of transparent plastic or glass and have a vertical scale in milliliters (ml) or cubic centimeters (cm^3). The volume of a liquid can be determined by measuring the height of the liquid in the cylinder. The least count of a measuring cylinder is usually 1 cm^3, meaning that any volume change smaller than this cannot be measured. Measuring cylinders come in various sizes, ranging from small capacities of a few milliliters to larger capacities of several liters. The choice of cylinder size depends on the volume of the liquid being measured.

FIGURE 1.13 MEASURING CYLINDER



ACTIVITY

Measuring cylinder can be used for measuring the volume of an irregular solid body such as metallic bob as shown in figure. When the object is completely immersed the volume of the water is read again. The volume of the object is found by subtracting the first reading from the second.

1.7.6 STOP WATCH

The duration of specific interval of time is measured by a stop watch. Stop watch are of two main types i.e. mechanical stop watch and digital stop watch.

MECHANICAL / ANALOGUE STOP WATCH

It has two circular dials, a large circular dial in which a second hand of watch rotates and a small minute hand in which minute hand of watch rotates as shown in figure 1.14. The watch starts and stops by pressing the knob at top it, pressing it for some time will reset the watch back to zero.

FIGURE 1.14 MECHANICAL AND DIGITAL STOP WATCH

Generally the least count of analogue stop watch is 1 s and digital stop watch is 0.1 s

DIGITAL STOP WATCH

Digital stop watch are usually controlled by two buttons on the case as shown in the figure. Pressing the left button starts the timer and by pressing it again the time stops, thus the elapsed time is shown in the figure 1.14.

Pressing the right button resets the stopwatch to zero. The right button is also used to record split times or lap times.

1.8 ERRORS

Every measurement, no matter how careful, has a certain amount of doubt known as error. Error is simply the uncertainty that arises during measurement. This means that all measurements are only approximate due to the presence of errors.

There are two main types of errors in measurement: systematic errors and random errors.

1.8.1 SYSTEMATIC ERRORS

Systematic errors tend to occur consistently in one direction, either positive or negative. Some sources of systematic errors include:

(a) Instrumental errors, which result from imperfections in the design or calibration of the measuring instrument, as well as zero errors.

(b) Imperfections in the experimental technique or procedure, such as changes in external conditions like temperature, humidity, or wind velocity, which can systematically affect the measurement.

(c) Personal errors, which arise from an individual's bias, improper setup of the apparatus, or carelessness in taking observations without following proper precautions.

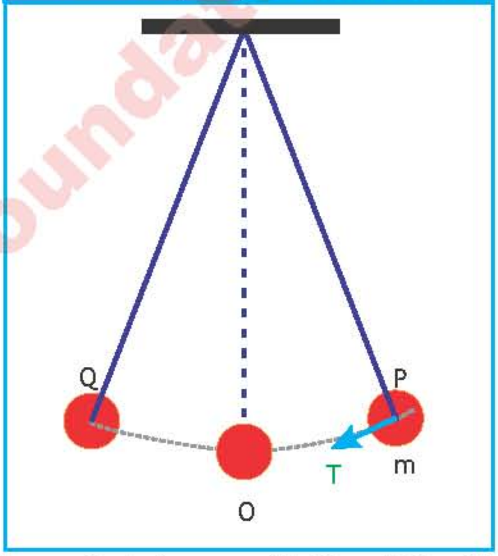
Systematic errors can be reduced by improving experimental techniques, choosing better instruments, and minimizing personal bias as much as possible. These errors can be estimated to some extent for a given setup, and the necessary adjustments can be made to the measurements.

1.8.2 RANDOM ERRORS

Random errors are unpredictable and uncontrollable errors that can happen irregularly. These errors can be caused by fluctuations in experimental conditions or imperfections in measuring instruments. The person conducting the measurements can also introduce variability due to factors like reaction time or technique. Because of this, if the same person repeats an observation multiple times, they are likely to get different readings each time. To minimize random errors, it is important to take repeated measurements and use statistical analysis to account for the variability.

During measurements, it is always a good idea to take multiple of the same measurement and find the mean, as it reduces errors. A simple pendulum is simply a mass that swings back and forth about a fixed point as shown in figure 1.15. One single oscillation of a pendulum is when it swings back to the exact same position and achieves the same state of motion that it started at. For example, if the pendulum started swinging from its right most point (from its position of maximum amplitude), the mass would have to swing towards the left and then come back all the way to the right to complete one oscillation. The time taken to complete a single oscillation is called a period. To measure the period of a pendulum, you usually measure the time taken for ten oscillations and then calculate the mean.

FIGURE 1.15 PENDULUM



That is, you divide the total length of time by 10, to get the period of one oscillation. This will reduce the error in measurement as human reflexes are usually too slow to be completely accurate, and that inaccuracy can have a major impact on something as small as a period.

1.9 PRECISION AND ACCURACY

Precision and accuracy are both important factors in determining the reliability and validity of measurements and experimental results. While precision focuses on the consistency and repeatability of results, accuracy is concerned with how close the measured values are to the true or accepted values.

Precision can be thought of as the degree of agreement between repeated measurements of the same quantity. If a set of measurements consistently yields similar results, with little variation or scatter, then it is considered to be precise. This indicates that the measurement process is reliable and consistent, and that the results can be reproduced under the same conditions. For example, a scale that always gives the same weight within a margin of 0.1 kg is precise, even if it consistently overestimates the true weight by 0.5 kg (not accurate).

Accuracy, on the other hand, refers to how close a measured value is to the true or accepted value. It is a measure of the absence of systematic errors or biases in the measurement process. An accurate measurement is one that is close to the true value, regardless of whether it is consistently reproducible. For example, thermometer that consistently reads 2 degrees Celsius higher than the actual temperature is not accurate, even if its readings are very precise (always 2 degrees above).

precision focuses on the consistency and reproducibility of measurements, while accuracy assesses how close the average of those measurements is to the true value.

Imagine throwing darts at a target as shown in figure 1.16. If your darts land close to the center of the target (hitting the bullseye is ideal) your aim will be referred as accurate. Your darts are grouped tightly together, even if they're not in the center (a tight cluster off-center) your aim will be termed as precise, therefore, it's possible for something to be:

Accurate and precise: Your darts hit the bullseye and are tightly grouped.

Accurate but not precise: Your darts land near the center, but they're scattered all over the place.

Precise but not accurate: Your darts are tightly grouped, but they're all off-center in the same direction.

FIGURE 1.16 PRECISION AND ACCURACY

High Precision and high accuracy | Low Precision and high accuracy | High Precision and low accuracy | Low Precision and low accuracy

CAN YOU TELL?

Books in a library were counted one by one. There were a total of 57,000 books in the library. How many significant digits are there in the result? Will the result change if the books are measured in the packets of 10?

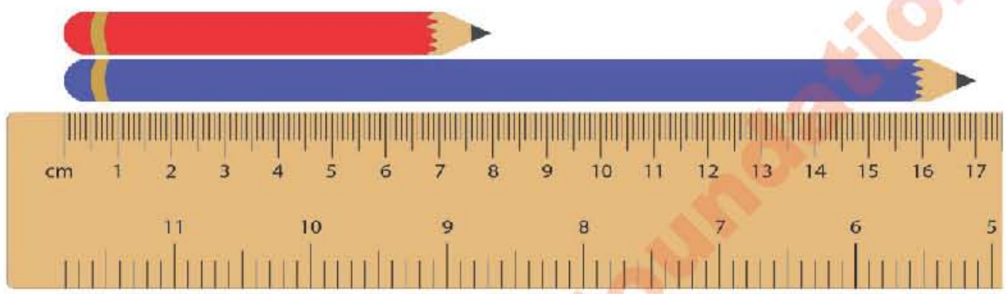
In practice, both precision and accuracy are desirable qualities in measurements. A measurement can be precise but not accurate, or accurate but not precise. Ideally, measurements should be both precise and accurate, meaning that they are both consistent and close to the true value. Achieving both precision and accuracy often requires careful calibration of instruments, control of experimental conditions, and consideration of sources of error.

1.10 SIGNIFICANT FIGURES

There are two types of values, exact and measured. Exact values are those that are counted clearly. For example while reporting 3 pencils or 2 books, we can indicate the exact number of these items.

The numerical value of any measurement will always contain some uncertainty. Suppose, for example, that you are measuring the length of two pencils as shown in figure 1.17.

FIGURE 1.17 LENGTH OF PENCILS



It seems clear that the length of blue pencil is greater than 17 cm but shorter than 17.1 cm, similarly the length of red pencil is greater than 8 cm but shorter than 8.1 cm. But how much longer or shorter? You cannot be certain about the length. As your best estimate, you might say that the pencils are 17.05 cm and 8.05 cm long.

Everyone would agree that you can be certain about the first numbers 17.0 and 8.0 for blue and red pencils respectively. The last number 0.05 has been estimated and is not certain. The two certain numbers, together with one uncertain number, represent the greatest accuracy possible with the ruler being used. Thus the pencils are said to be 17.05 cm and 8.05 cm wide respectively.

A significant figure is a number that is believed to be correct with some uncertainty only in the last digit. 'All the accurately known figures and the first doubtful figure are termed as significant figures'.

MINI-LAB

Measure the length, width and thickness of physics textbook and report your observations in significant figures. Does your reading depends upon the instrument you used for measurement?

1.10.1 GENERAL RULES FOR WRITING SIGNIFICANT FIGURES

There are a few simple rules that help us determine how many significant figures are contained in a reported measurement:

1. All digits reported as a direct result of a measurement are significant.

2. The reported NONZERO digits (all digits from 1 to 9) are always significant. For example the number of significant figures in 23.457 is 5.
3. In figures reported as larger than the digit 1, the digit 0 is not significant when it follows a nonzero digit to indicate place. For example, in a report that '29,000 spectators watched a cricket match'. The digits 2 and 9 are significant but the zeros are not significant. In this situation, the 29 is the measured part of the figure, and the three zeros tell you an estimate of how many watched the match. If this figure is a measurement rather than an estimate, then to avoid confusion it is written in scientific notation with exact number of significant figures as in measurement e.g 2.90×10^5 showing three significant figures or 2.900×10^5 showing four significant figures or even 2.9000×10^5 showing 5 significant figures.
4. In figures reported as smaller than the digit 1, zeros after a decimal point that come before nonzero digits are not significant and serve only as place holders. For example, 0.0029 has two significant figures: 2 and 9. The zeros after a nonzero digit indicate a measurement, so these zeros are significant. The figure 0.00290, for example, has three significant figures.

EXAMPLE 1.3: SIGNIFICANT FIGURE

Find the number of significant figures in each of the following values. Also express them in scientific notations.

a) 100.8 s b) 0.00580 km c) 210.0 g

SOLUTION

a) All the four digits are significant. The zeros between the two significant figures 1 and 8 are significant. To write the quantity in scientific notation, we move the decimal point two places to the left, thus

$$100.8 \text{ s} = 1.008 \times 10^2 \text{ s}$$

b) The first two zeros are not significant. They are used to space the decimal point. The digit 5,8 and the final zero are significant. Thus there are three significant figures. In scientific notation, it can be written as

$$5.80 \text{x} 10^{-3} \text{ km}.$$

c) The final zero is significant since it comes after the decimal point. The zero between last zero and 1 is also significant because it comes between the significant figures. Thus the number of significant figures in this case is four. In scientific notation, it can be written as

$$210.0 \text{ g} = 2.100 \times 10^2 \text{g}$$

1.10.2 ROUNDING OFF NUMBERS AND SIGNIFICANT FIGURES

Rounding off numbers is an essential practice in scientific and quantitative contexts as it allows for the presentation of numbers with the appropriate level of precision. In these fields, accuracy and precision are crucial, and rounding off numbers helps to achieve this.

When dealing with measurements or calculations, it is often necessary to express the result in a more manageable or meaningful form. Rounding off numbers allows scientists and researchers to simplify complex figures without sacrificing the overall accuracy of the data.

Significant figures play a vital role in determining which digits in a number are reliable and meaningful. They indicate the precision of a measurement or calculation by identifying the digits that are known with certainty. By using significant figures, scientists can convey the level of uncertainty associated with a particular value. For example, consider a scientific experiment that measures the length of an object to be 3.5678 centimeters. While this measurement may be precise, it is not practical to report it with such detail. Rounding off the number to three significant figures, we can express it as 3.57 centimeters, which provides a more concise representation without compromising the accuracy of the measurement.

Rounding numbers is the act of approximating a number to a simpler value that is easier to use, understand, or work with. It includes reducing the number of digits while maintaining an appropriate level of accuracy for the situation.

A. Rounding rules for whole numbers: When rounding to a specific whole number of significant figures, we follow these steps:

1. Always choose the smaller place value for an accurate final result. Find the next smaller place to the right of the number being rounded off. For example, if rounding off a digit from the tens place, look at the digit in the ones place.
2. If the digit in the smallest place is less than 5, leave it as it is. Any digits after that become zero, which is called rounding down.
3. If the digit in the smallest place is greater than or equal to 5, add +1 to that digit. Any digits after that become zero, which is called rounding up.

B. Rounding rules for decimal numbers: The rules for rounding decimal numbers are as follows:

1. Find the digit you want to round and look at the digit to its right.
2. If the digits to the right are less than 5, treat them as zero.
3. If the digits to the right are 5 or greater, add 1 to that digit and treat all other digits as zero.

EXAMPLE 1.4: ROUNDING OFF

Round off the following numbers to

(a)	Two decimal points	i) 3.876	ii) 657.873	iii) 0.0857
(b)	Three significant digits	i) 24.68	ii) 0.07683	iii) 7,847

SOLUTION

a) In order to round off a number to two decimal points, we will drop all digits after the decimal except two.

i) 3.876: Here the dropping digit is 6, which is greater than 5, so, it will be dropped by increasing the next digit 7. So, the answer is 3.88.

ii) 657.873: Here the dropping digit is 3, which is smaller than 5, so, it will be dropped without any change to the next digit. So, the answer is 657.87.

iii) 0.0857: Here the dropping digits are 5 and 7. After dropping 7 (which is greater than 5), the next digit will become 6 to get 0.086. Now by dropping 6, the next digit will become 9. So, the answer is 0.09.

b) In order to round off a number to three significant digits, we will drop or replace with zero all digits except three significant digits.

i) 24.68: Here we will drop the digit 8, which is greater than 5, so it will increase the next digit to 7. So, the answer is 24.7.

ii) 0.07683: Here we will drop the digit 3, which is smaller than 5, so it will not change the next digit. So, the answer is 0.0768.

iii) 7,847: As this is a whole number so, the digit 7 is replaced by zero. As it is greater than 5, so it will increase the next digit to 5. So, the answer is 7,850

SUMMARY

- **Physics** is the branch of science which deals with the study of matter and energy.
- **Physical quantities** are measurable quantities
- **System International (SI)** is the system of units which consists of seven base units and a number of derived units.
- **Seven Base SI Units** are metre (length), kilogram (mass), second (time), ampere (current), candela (luminous intensity), Kelvin (temperature) and mole (amount of substance).
- **Scientific Notation** is an internationally accepted way of writing numbers in which numbers are recorded using the power of ten and there is only one non zero digit before the decimal.
- **Vernier calliper** is a device used to measure a fraction of smallest scale division by sliding another scale over it.
- **Screw Gauge** is a device used to measure a fraction of smallest scale division by rotatory motion of circular scale over it.
- **Stop Watch** is an instrument used for measurement of time interval
- **Significant Figures** are the accurately known digits and first doubt full digit in any measurement.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option.

1. Which one of the following unit is not a derived unit?
   A. pascal B. kilogram C. newton D. watt
2. Amount of a substance in terms of numbers is measured in:
   A. gram B. kilogram C. newton D. mole
3. The number of significant figures in 0.00650 s are:
   A. . 2 B. . 3 C.5 D. 6
4. Which of the following numbers show 4 significant digits?
   A . 9000.8 B. 4 C. 5174.00 D. 0.001248
5. Which of following prefix represents a largest value?
   A. mega B. pico C. peta D. kilo
6. Micrometer can be used to measure:
   A. current B. force C. length D. mass
7. The instrument best measures the internal diameter of a pipe is:
   A. screw gauge B. vernier caliper C. metre rule D. measuring tape
8. Least count of screw gauge is 0.01 mm. If main scale reading of screw gauge is zero and third line of its circular scale coincides with datum line then the measurement on the screw gauge is:
   A. 0 mm B. 3 mm C. 0.03 mm D. 0.3 mm
9. 9.483×10^3 m is the standard form of
   A. 94.83 m B. 9.483 m C. 948.3 m D. 9483 m
10. Which of the following is a base unit?
    A. pascal B. coulomb C. meter per second D. mole
11. The numbers having one significant digit is:
    A. 1.1 B. 6.0 C. 7.1 D. 6×10^2
12 Ratio of millimetre to micrometre is:
    A. 1000 metre B. 0.001 metre C. 1000 D. 0.001
13. 0.2 mm in units of meters is:
    A. 0.0002 m B. 2×10^{-4} m C. both A and B D. none

SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

1. How physics plays an important role in our life?
2 Estimate your age in minutes and seconds
3. What base quantities are involved in these derived physical quantities; force, pressure, power and charge.
4. Show that prefix micro is thousand times smaller than prefix milli.
5. Justify that displacement is a vector quantity while energy is a scalar quantity.
6. Screw gauge can give more precise length than vernier calipers. Briefly explain why?
7. Differentiate between mechanical stop watch and digital stop watch.
8. How measuring cylinder is used to measure volume of an irregular shaped stone?
9. What precaution should be kept in mind while taking measurement using measuring cylinder?
10. Why do we need to consider significant digits in measurements?
11. How random error can be reduced?
12. Differentiate between precision and accuracy.

LONG RESPONSE QUESTIONS

QIII. Give a detailed response to questions below.

1. Define Physics. Describe its revolutionary role in technology.
2. List with brief description of different branches of physics.
3. What are physical quantities? Distinguish between base physical quantities and derived physical quantities. Give at least three examples to show that derived physical quantities are derived from base physical quantities.
4. What do you mean by unit of a physical quantities? Define base units and derived units.
5. What are prefixes? What is their use in measurements?
6. What is scientific notation or standard form of noting down a measurement? Give at least five examples.
7. Describe construction and working of vernier calipers in detail.
8. What is screw gauge? What is its pitch and least count? How is it used to measure thickness of thin copper wire?
9. Define error. Differentiate between random and systematic error. How can these errors be reduced?
10. Differentiate between scalars and vectors. Justify that distance, speed, mass and energy are scalars while displacement, velocity, acceleration and force are vectors.
11. Justify and illustrate the use of a measuring cylinder to measure the volume of a liquid.
12. Differentiate between precision and accuracy.

NUMERICAL RESPONSE QUESTIONS

QIV. Solve the questions given below.

1. Write the following numbers in scientific notations

   a. 1234 m b. 0.000023 s c. 469.3×10^5 m d. 0.00985×10^7 s

2. Express the followings measurements using prefixes

   a. 27.5×10^{-10} m b. 0.00023×10^{-2} s

3. If a boy has age of 15 years 2 months and 10 days, convert his age in

   a. seconds b. milli seconds c. mega seconds

4. How many kilometers are there in 25 micrometers?

5. What is pitch and least count of:

   a. Vernier calipers if smallest division on main scale is 1mm and total divisions on vernier scale are 20.

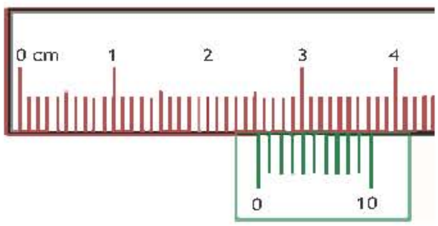
   b. Screw gauge if smallest division on its main scale is 0.5 mm and its movable scale has 50 divisions.

6. Look at the measurement of vernier calipers:

   a. What is its main scale reading?

   b. What is its coinciding division on vernier scale?

   c. Calculate total reading on the vernier calipers?

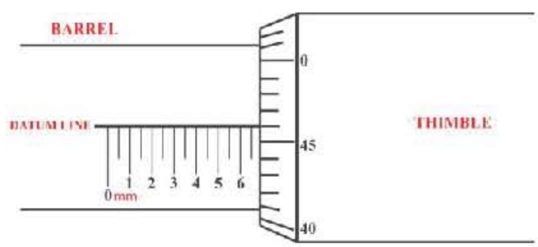


7. Look at the figure of screw gauge, let a small steel ball is place between its thimble and anvil then:

   a. What is its main scale reading?

   b. What is coinciding division of circular scale?

   c. Calculate the total diameter of the ball?



KINEMATICS

UNIT
2

How fast the bullet move?

Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-B-01] Differentiate between different types of motion.
- [SLO: P-09-B-02] Differentiate between distance and displacement, speed and velocity.
- [SLO: P-09-B-03] Define and calculate speed.
- [SLO: P-09-B-04] Define and calculate average speed.
- [SLO: P-09-B-05] Differentiate between average and instantaneous speed.
- [SLO: P-09-B-06] Differentiate between uniform velocity and non-uniform velocity.
- [SLO: P-09-B-07] Define and calculate acceleration.
- [SLO: P-09-B-08] Differentiate between uniform acceleration and non-uniform acceleration.
- [SLO: P-09-B-9] Sketch, plot and interpret distance-time and speed-time graphs.
- [SLO: P-09-B-10] Use the approximate value 9.8m/s2 for free fall acceleration near Earth to solve problems.
- [SLO: P-09-B-11] Justify how the gradient of a distance vs time graph gives the speed.
- [SLO: P-09-B-12] Analyse the distance traveled in speed vs time graphs.
- [SLO: P-09-B-13] Derive how the area beneath a speed vs time graph gives the distance traveled.
- [SLO: P-09-B-14] Calculate acceleration from the gradient of a speed-time graph.
- [SLO: P-09-B-15] Justify how the gradient of the speed vs time graph gives the acceleration.
- [SLO: P-09-B-16] State that there is a universal speed limit for any object in the universe that is approximately 3×108 ms-1.

Mechanics is the study of motion. Everywhere we look, objects are moving. We see people moving on roads, some using vehicles. Actually, everything we know is constantly in motion. Celestial objects and our Earth are always moving. Even objects that appear to be still have atoms and molecules that vibrate in continuous motion.

Our formal study of physics starts with kinematics, which is the study of motion without considering its causes. The term "kinematics" comes from Greek and means motion. In this unit, we will only focus on the motion of objects, without concerning ourselves with the forces that cause or change their motion.

2.1 REST AND MOTION

If with passage of time an object does not change its position then it is at rest with respect to an observer and if it is changing its position then it is in motion.

When we look around us, we observe that many objects do not change their position. Thus we consider them at the state of rest. For example a bench in a park fixed under a tree is at rest as there is no change in its position with respect to us while standing near it with the passage of time. On the other hand we also observe that many objects do change their position from one place to another. Hence we consider them to be in the state of motion. For example a car is in motion if there is change in its position with time.

POINT TO PONDER

Interestingly objects can be at rest and in motion at same time. It looks simple to distinguish the rest from motion, for example a car starts, it changes its position with reference to its surrounding, we say that car is moving.

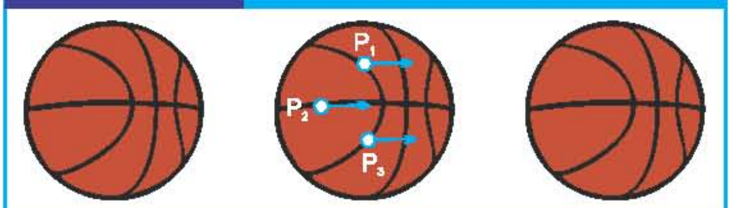
However, we know that Earth is spinning on its axis, so the car along with its road is also in motion. Not only this but Earth is also moving around the sun and the sun along with the rest of the solar system are also moving through our milky way galaxy. Apart from this our galaxy is also traveling through space. How can we say that our car is at rest? This is why when we state an object to be at rest or motion, we specify it reference to some observer.

2.1.1 TYPES OF MOTION

Looking at the motion of object we see that objects move differently. These different types of motion can be broadly categorized in three types translatory motion, rotatory motion and vibratory motion.

A. Translatory motion: If all points of a moving object move uniformly in the same direction, such that there is no change in the object's orientation the object is said to be undergoing translatory motion (also termed as translational motion).

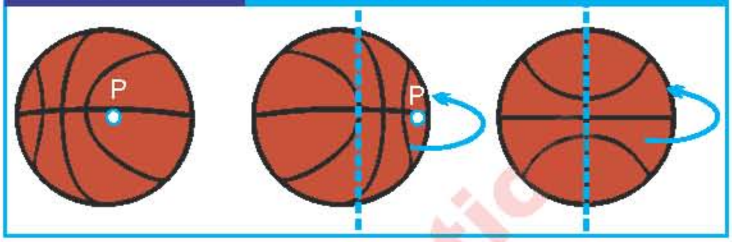
FIGURE 2.1 TRANSLATORY MOTION



A basketball is shown in figure 2.1 as an example of translatory motion. All the three points 'P_1', 'P_2' and 'P_3' moves parallel to each other and there is no change in its orientation relative to a fixed point.

B. Rotatory motion: When an object rotates on its own axis (a line passing through the object), the object is said to be undergoing rotatory motion (also termed as rotational motion). A basketball in figure 2.2 is again shown as an illustration of rotational motion.

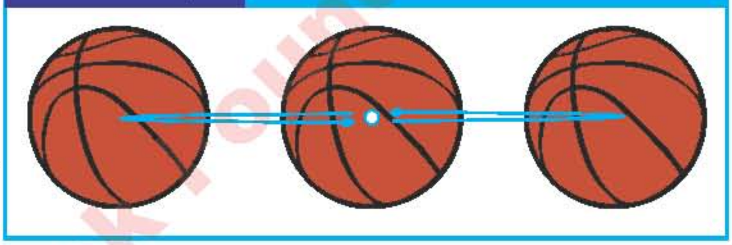
FIGURE 2.2 ROTATORY MOTION



The point '*P*' is rotated around an axis of rotation passing through the center of it.

C. Vibratory motion: When an object is moving forward and backward repeatedly about mean position (certain fixed position), the object is said to be undergoing vibratory motion (also termed as vibrational motion) . A basketball in figure 2.3 is shown as an example of vibrational motion.

FIGURE 2.3 VIBRATORY MOTION



The basketball moves back and forth about the mean position. Figure 2.4 shows some daily life examples of types of motion.

FIGURE 2.4 TYPES OF MOTION

Translatory motion | Rotatory motion | Vibratory motion.

Translatory motion is further divided into three types.

- **Rectilinear motion** is the translatory motion of the object in straight line path. For example the motion of train on track, motion of gun shot and motion falling apple.
- **Circular motion** is the translatory motion of an object in which it moves in a curved path. For example the motion of a football when kicked, the motion of roller coaster and the motion of a vehicle in a turn are examples of curvilinear motion. Circular motion is a special case of curvilinear motion in which the radius of rotation remains constant and object moves along a circular path.

Types of Motion

Translatory motion

Change in position of a body as a whole. The line or path of motion could be straight, curved or random.

Examples are motion of ball, car, flying birds, airplane etc.

Rotatory motion

Rotation of a body around a fixed rotation axis. The particles of the object in rotation moves in a circle.

Examples are motion of helicopter rotors, blades of fan etc.

Vibratory motion

The to and fro motion of an object about its mean position. The object in vibration repeats its motion.

Examples are motion of swing, strings of sitar, guitar, etc.

Translatory motion is further divided into three types

Rectilinear motion

Straight line motion

Example is motion of free falling body

Curvilinear motion

Circular or curved path motion

Example is motion of cars around a turn

Random motion

Irregular motion

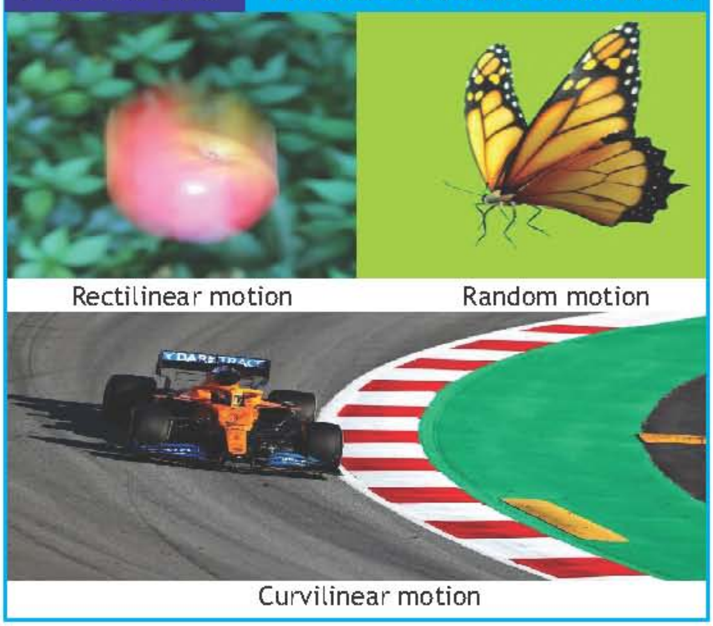
Example is motion of butterfly

An object can have any combination of these types of motion.

- **Random Motion** is the translatory motion of an object with no specific path. For example kites flying through sky, motion of clouds and the motion of butterfly.

Translational motion is seen in various scenarios, covering a wide range of situations. Whether in engineering, physics, or everyday life, objects frequently display this type of motion. It is crucial to comprehend the specific motion type in order to accurately analyze and describe the behavior of moving objects.

FIGURE 2.5 TRANSLATIONAL MOTION



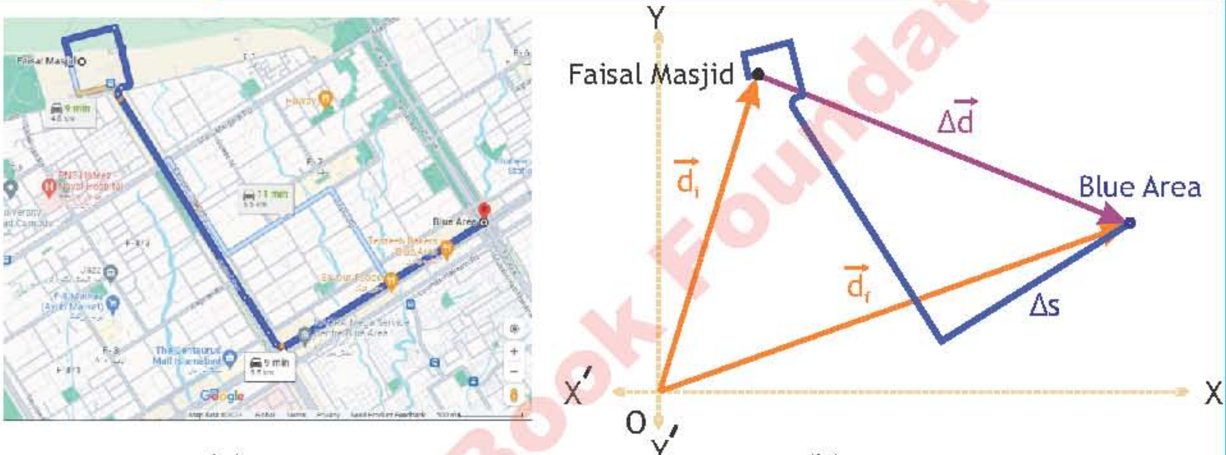
2.2 DISTANCE AND DISPLACEMENT

If we are at Faisal Masjid, Islamabad and we want to move to Blue area, Islamabad by searching on google map as shown in figure 2.5 (a), we get a twisted path, showing us the way to reach our destination. However, the straight path as shown in figure 2.5 (b) can be shorter.

'The length of path traveled between two positions is called distance'.

Distance has no direction and therefore it is a scalar quantity. Distance is usually denoted by Δx, Δr, Δs, Δd or Δl, and has SI unit as metre (m).

FIGURE 2.6 DISTANCE AND DISPLACEMENT



(a) (b)

'The shortest distance from initial position to final position (or straight directed distance) is called displacement'.

Displacement has direction and therefore it is a vector quantity. Displacement has SI unit as metre (same as length).

If an object moves then the object's position changes. This change in position vector '$\Delta\vec{d}$' of an object, from initial position '$\vec{d}_i$' to final position '$\vec{d}_f$' is known as displacement as shown in figure 2.6 (b). Mathematically:

$$\Delta\vec{d} = \vec{d}_f - \vec{d}_i$$

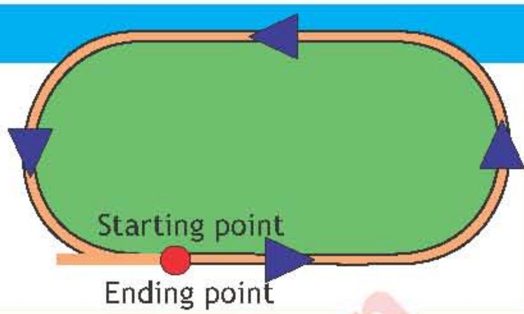
POINT TO PONDER

Here we used symbol Δ (Greek letter delta) for change in position; however, it is used to represent a 'change in' any quantity. For example elapsed time Δt is the change in (or the difference between) the ending time t_f and beginning time t_i.

$$\Delta t = t_f - t_i$$

CAN YOU TELL?

If on a 400 m running track your starting point and ending point is same. How much distance you have covered? What is your displacement?



CAN YOU TELL?

Can displacement be greater than distance?

Can distance and displacement be equal?

2.3 SPEED AND VELOCITY

Speed is the measure of how fast an object is moving, whereas velocity describes the speed as well as the direction of a moving object.

2.3.1 SPEED

Speed tells us how fast an object is moving. Suppose we are in a car that is moving over a straight road. How could we describe our speed? We need at least two measurements:

- the distance we have traveled, and
- the time that has elapsed while we covered this distance.

'Measure of the distance covered (Δs) with passage of time (Δt) is called speed (denoted by v)'. Mathematically:

$$speed = \frac{\text{distance}}{\text{elapsed time}} \quad \text{or} \quad v = \frac{\Delta d}{\Delta t} \quad \text{or} \quad v = \frac{s_f - s_i}{t_f - t_i} \qquad (2.1)$$

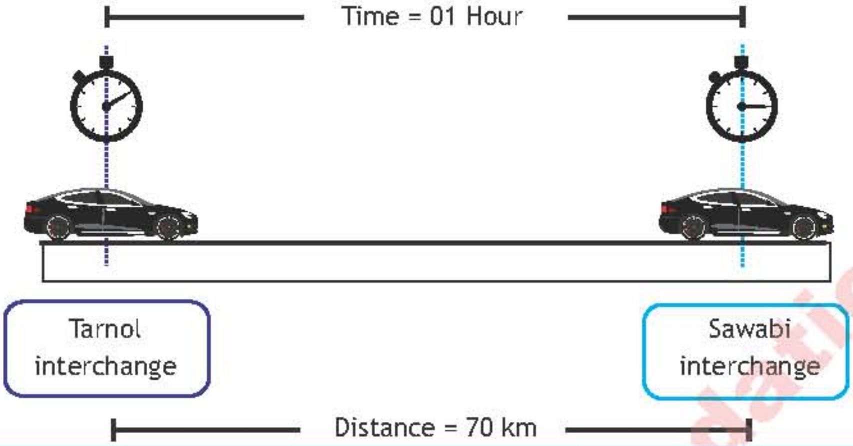
Speed of an object show us the rate at which the object is moving. Speed is a scalar quantity having SI unit of metre per second (m/s or ms^{-1}). The speed will be one 'metre per second' if *an object cover one metre distance in one second.*

Speed tells us how fast an object is moving. An object is fast if it cover large distance in a short time. For example while going from Islamabad to Peshawar through motor-way M1, we leave at Tarnol interchange at 2:00 pm and cross Sawabi interchange at 3:00 pm as shown in figure 2.7. Since Sawabi interchange is about 70 km from Tarnol interchange and it took us one hour therefore our speed can be obtained as:

$$v = \frac{70\,km}{1hr} = 70\, {}^{km}/_{hr}$$

A fast-moving object covers a relatively large distance in a given amount of time and thus has a high speed. Whereas a slow-moving object covers a relatively small amount of distance in the same amount of time and therefore has a low speed.

FIGURE 2.7 SPEED OF A CAR



POINT TO PONDER

SOME INTERESTING SPEED FACTS

Who is the fastest man on earth? Yes, Usain Bolt. He finished a 100-metre sprint in just 9.58 seconds back in 2009. In that instance, his speed was 10.44 m/s or 37.58 km/h.

The slowest animal in the world, the crown goes to the 3-toed sloth. And, the average speed of them is about 0.00134112 m/s or 0.0048 km/h. You would have seen garden snails or turtles moves which is faster than this rate.

The fastest animal in the world is Peregrine Falcon, it can attain a maximum speed of up to 108.333 m/s or 390 km/h. Cheetah is the fastest animal in the land can reach a fastest speed of 33.33 m/s or 120 km/h.

This means that our car is moving at 70 km/hr neither speeding up nor slowing down. However, it is usually difficult to maintain a same speed. Other cars and distractions can cause us to reduce speed or at times we have to increase speed of our car.

A. AVERAGE SPEED

If we calculate our speed over an entire trip, we are considering a large distance between two places and the total time that elapsed. The increases and decreases in speed would be averaged.

The average speed is the total distance (s) covered in total time (t). Mathematically,

$$v_{ave} = \frac{\text{total distance}}{\text{total time}} = \frac{s}{t} \qquad (2.2)$$

Interchangeably this equation can also be written as $$s = v_{ave}\, t \qquad (2.3)$$

ACTIVITY

MEASURE YOUR BOWLING SPEED

How the speed of bowler in cricket game is calculated? You can also roughly calculate your bowling speed. First carefully measure the length of the cricket pitch in metres from bowlers delivery stride mark to where the batter is standing. Now give a stop watch to your friend and ask him to start the stopwatch as you release the ball and stop it once it reaches the batter. To get the speed in m/s divide the length of the pitch by the time in the stop watch. For comparison with speed of international bowlers, we would require to convert this speed to kph or pmh.

B. INSTANTANEOUS SPEED

We see sign boards on road reading, sharp turn ahead reduce speed 'speed limit 70 km/hr'.Certainly this sign board does not refer to our average speed, but the speed at which we are moving at that particular instant of time. The speed at any specific instant of time is called the instantaneous speed.

If we are not looking at the speedometer of car we only have a rough idea of how fast we are moving, and how much we should reduce speed. However, looking at the speedometer, on the other hand, we will know exactly how fast we are going at that instant of time.

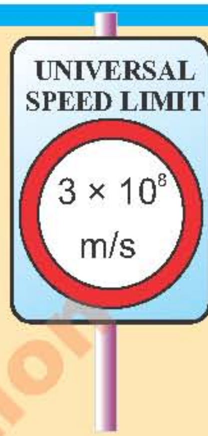
FIGURE 2.8 SPEEDOMETER OF A CAR

C. UNIFORM AND VARIABLE SPEED

'If an object covers equal distances in equal intervals of time we say that the object is moving with uniform speed'. In uniform speed object does not get slower or faster and maintains the same speed.

DO YOU KNOW?

When it comes to fastest measured speed, the limit is set by the laws of physics themselves as the 'speed of light'. Albert Einstein realized that, a light ray appears to move at the same speed, regardless of whether it's moving towards us or away from us. No matter how fast you travel or in what direction, all light always moves at the same speed. Moreover, anything that's made of matter can only approach, but never reach, the speed of light. If you don't have mass, you must move at the speed of light; if you do have mass, you can never reach it.



The speed of light is in a vacuum is about 299,792,458 m/s or 299,792 km/s (which is approximately 3×10^{8} ms^{-1}). At this speed, you can revolve around the Earth 7.5 times in a second. In comparison the speed of sound in the air is roughly 343 m/s or 767 mph or 1235 km/h. That means the speed of light is so much faster than the speed of sound.

EXAMPLE 2.1: REACTION TIME OF BATSMAN

Shoaib Akhtar made a record in Word cup 2003 against England by bowling at a speed of 161.3 km/h. If the batsman is at a displacement of 17.5 m from the bowler, what should be the reaction time for the batsman to play such a delivery?

GIVEN

Speed of ball $v = 161.3\ \text{km/h} = \dfrac{161.3 \times 1000\ \text{m}}{3600\ \text{s}} = 44.8\ \text{m/s}$

Distance covered by ball $s = 17.5$ m

REQUIRED

time $t = ?$

SOLUTION

From the definition of average speed, equation 2.2 we have $\quad v_{ave} = \dfrac{\text{total distance}}{\text{total time}} = \dfrac{s}{t}$

$$t = \frac{s}{v_{ave}} \qquad \text{Putting values} \qquad t = \frac{17.5m}{44.8\,{}^{m}\!/_{s}}$$

Hence $\boxed{t = 0.39\ s}$ — Answer

The batsman should react in just 0.39 seconds to play this delivery. These are typical reaction times player deal in game of cricket.

DO YOU KNOW?

Pakistani Cricketer Shoaib Akhtar bowled the fastest recorded ball in the history of cricket in the World Cup match at Newlands South Africa. This match was played between Pakistan and England and the ball was faced by Nick Knight (former England opener).

EXAMPLE 2.2: FASTEST TRAIN IN THE WORLD

Shanghai's Maglev, the fastest train, travelled a distance of 30 kilometres in 7 minutes and 30 seconds. What is its speed? Convert the speed to km/h.

GIVEN

Distance travelled 'Ds' = 30 km = 30 × 1000 m = 30,000 m

Time taken 'Dt' = 7 min 30 s = (7 × 60) s + 30 s = 420 s + 30 s = 450 s

REQUIRED

speed v = ?

SOLUTION

From the definition of speed, equation 2.1 we have: $v = \frac{\Delta s}{\Delta t}$

Putting values $v = \frac{30{,}000\, m}{450\, s}$

Hence $\boxed{v = 66.67\, m/s}$ — Answer

Conversion in km/h

Converting m to km and s to h

$$v = \left[66.67 \frac{m}{s}\right] \times \left[\frac{3600}{1} \frac{s}{h}\right] \times \left[\frac{1}{1000} \frac{km}{m}\right] = 240.01\, km/h$$

$\boxed{v = 240.01\, km/h}$ — Answer

This is a much greater speed as compared to the speed limits on motor ways (120 km/h)

Maglev is a system of train transportation that uses two sets of electromagnets: one set to repel and push the train up off the track, and another set to move the elevated train ahead, taking advantage of the lack of friction.

2.3.2 VELOCITY

Velocity is similar to speed, but a direction is needed for the description of velocity. 'Measure of displacement ($\Delta \vec{d}$) with passage of time (Δt) is called velocity (denoted by $\vec{v}$)'. Mathematically

$$velocity = \frac{\text{displacement}}{\text{elapsed time}} \quad \text{or} \quad \vec{v} = \frac{\Delta \vec{d}}{\Delta t} \quad \text{or} \quad \vec{v} = \frac{\vec{d}_f - \vec{d}_i}{t_f - t_i} \qquad (2.4)$$

Velocity is a vector quantity having same direction as displacement vector. The SI unit of velocity is metre per second (m/s). When we know both the speed and the direction of an object, we simply call it as velocity.

For straight-line motion in one direction, speed and velocity have same magnitudes because the lengths of the distance and the displacement are the same. The distinction between them in this case is that a displacement direction must be specified for the velocity.

A. AVERAGE VELOCITY

The average velocity is the total displacement ($\vec{d}$) covered in total time (t). Mathematically,

$$\vec{v} = \frac{\vec{d}}{t} \quad (2.5)$$

B. INSTANTANEOUS VELOCITY

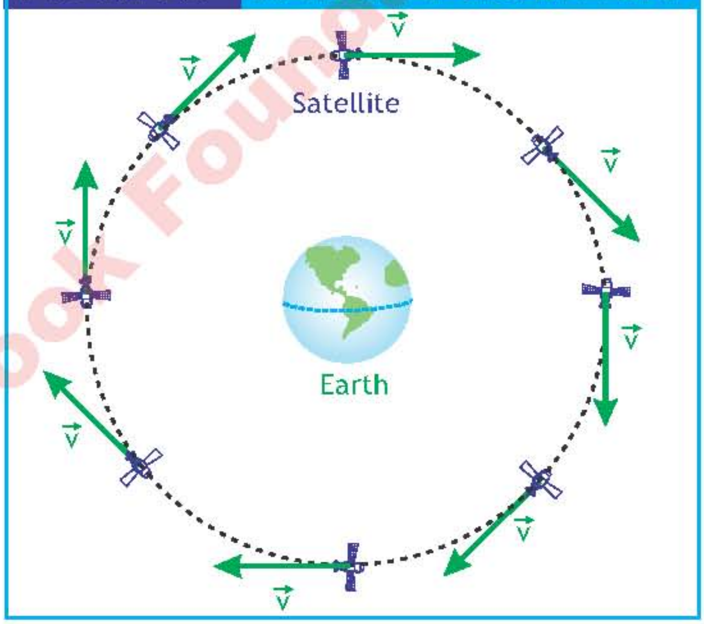
If velocity is measured by keeping the time interval small, such velocity is termed as instantaneous velocity. To calculate velocity both the speed and direction for that moment of time need to be specified.

C. UNIFORM AND VARIABLE VELOCITY

'If an object covers equal displacements in equal intervals of time we say that the object is moving with uniform velocity. **Uniform velocity is the velocity that does not change otherwise it is called variable velocity.**

To produce variable velocity (a change in velocity), either the speed or the direction is changed (or both are changed). A satellite moving with a constant speed in a circular orbit around Earth does not have a constant velocity since its direction of movement is constantly changing as shown in figure 2.9.

FIGURE 2.9 MOTION OF A SATELLITE



EXAMPLE 2.3: VELOCITY OF A CAR

A car travels a curvy track of length 800 metres in 40 seconds. The straight path is about 600 metres between starting point and ending point, which the same car travels in 36 seconds.

What is the car's (a) average speed and (b) average velocity?

GIVEN

Length of curvy track = Distance Δd = 800 m

Time taken 'Δt' = 40 s

Length of straight path = Displacement Δd = 600 m

Time taken 'Δt' = 40 s

REQUIRED

(a). Average speed v = ?

(b). Average Velocity Δv = ?

SOLUTION

From the definition of speed and velocity, we have

(a). Average Speed= $v_{ave} = \dfrac{\text{Total distance}}{\text{Total time}} \Rightarrow v_{ave} = \dfrac{s}{t}$

Putting vales: $v_{ave} = \dfrac{800\ \text{m}}{40\ \text{s}} \Rightarrow \boxed{v_{ave} = 20\ \text{m/s}}$ Answer

(b). Average Velocity= $\vec{v}_{ave} = \dfrac{\text{Total displacement}}{\text{Total time}} \Rightarrow \vec{v}_{ave} = \dfrac{\vec{d}}{t}$

Putting values: $\vec{v}_{ave} = \dfrac{600\text{m}}{36\text{s}} \Rightarrow \boxed{\vec{v}_{ave} = 16.67\ \text{m/s}}$ Answer

2.4 ACCELERATION

Can we measure the change in velocity? Velocity is changed by changing speed, direction or both, we would need one additional measurement to measure change in velocity, which is how much time elapsed while the change was taking place. **'The measure of change in velocity '$\Delta\vec{v}$' with the passage of time 'Δt' is called acceleration $\vec{a}$.** (or) Time rate of change in velocity '$\Delta\vec{v}$' is called acceleration '$\vec{a}$'. Mathematically:

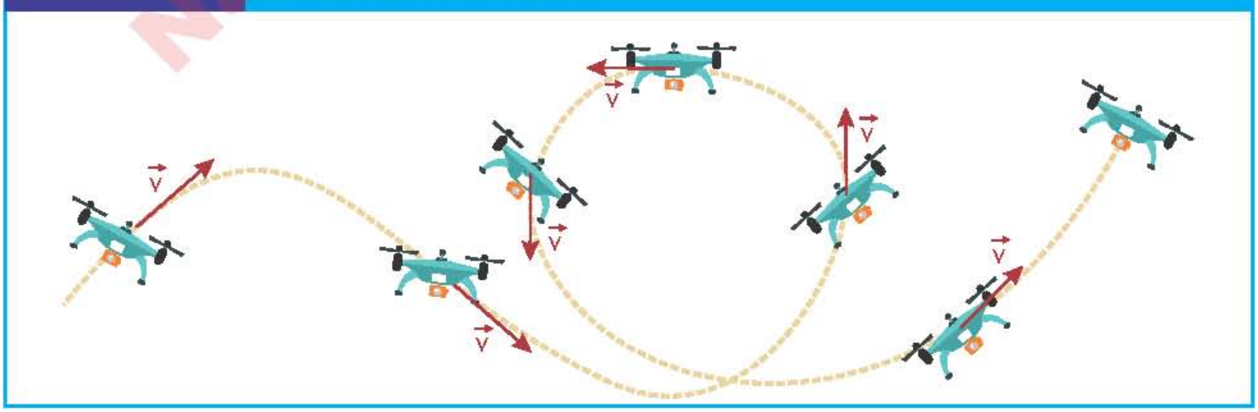
$$\text{acceleration} = \frac{\text{change in velocity}}{\text{elapsed time}} \quad \text{or} \quad \vec{a} = \frac{\Delta\vec{v}}{\Delta t} \quad \text{or} \quad \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} \qquad (2.6)$$

Acceleration is a vector quantity with same direction as change in velocity. SI Unit of acceleration is metre per second per second or metre per square second (m/s^2). Acceleration is a measure of how rapidly the velocity is changing.

A positive acceleration means an increase in velocity with time, whereas the negative acceleration (deceleration) means a decrease in velocity with time.

Since velocity is a vector quantity, therefore only the change in direction of velocity can also produce acceleration. The drone in the figure 2.10 is accelerating because it is changing directions.

FIGURE 2.10 MOTION OF DRONE

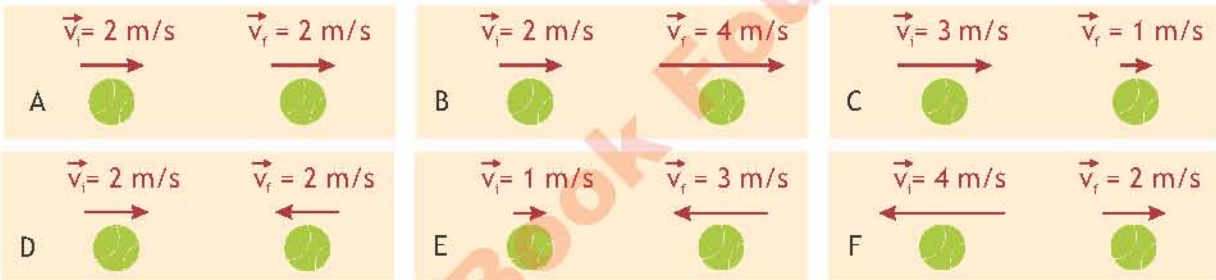


Uniform and Non-uniform Acceleration: When an object is changing its velocity at the same rate each second we call it uniform acceleration. A body has uniform acceleration if it has equal changes in velocity in equal intervals of time.

Non-uniform acceleration occurs when an object's velocity changes, but this change is not steady over time. In simple terms, the rate at which the object's velocity changes is not the same throughout its movement. Acceleration, which is the measure of velocity change, is therefore not constant in non-uniform acceleration. Understanding non-uniform acceleration is important in physics to explain the movement of objects affected by changing forces. This is a common and practical situation since many real-life scenarios involve forces that vary over time, resulting in non-uniform acceleration.

CAN YOU TELL?

The initial velocity v_i and final velocity v_f of a tennis ball at two different points in time is shown below. The direction of the ball is indicated by the arrow. For each case, indicate if there is an acceleration and show the direction of acceleration.



EXAMPLE 2.4: ACCELERATION OF CHEETAH

Cheetah (fastest land animal) can accelerate its speed from zero to 26.8 m/s in just three seconds. Suppose the Cheetah has started running towards East, find its acceleration.

GIVEN

Initial velocity v_i = 0 m/s (East)

Final velocity v_f = 26.8 m/s (East)

Time taken Δt = 3 s

REQUIRED

acceleration a = ?

SOLUTION

From the definition of acceleration, equation 2.6 we have $\vec{a} = \dfrac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$

Putting values $\vec{a} = \dfrac{26.8\ m/s - 0\ m/s}{3\,s}$

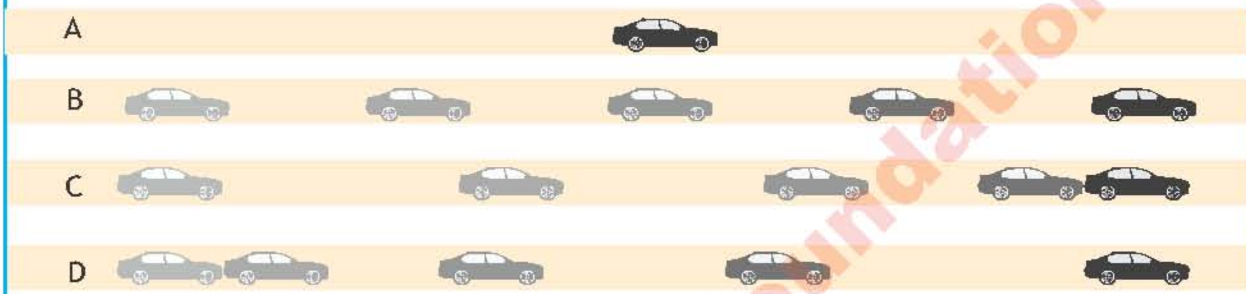
$$\boxed{\vec{a} = 9.93\ m/s^2}$$ Answer

That is a big value, as typical cars have accelerations of only 3 to 4 m/s^2

CAN YOU TELL?

The car is depicted after equal time intervals, can you determine that in which picture A, B, C and D, the car is

at rest	☐	speeding up	☐
moving at a constant speed	☐	slowing down	☐



POINT TO PONDER

The first scientist to measure speed as distance over time was Galileo. He dropped various objects of different masses from the leaning tower of Pisa. He found that all of them reach the ground at the same time. The acceleration of freely falling bodies is called gravitational acceleration or acceleration due to gravity denoted by 'g'.

2.5 MOTION DUE TO GRAVITY

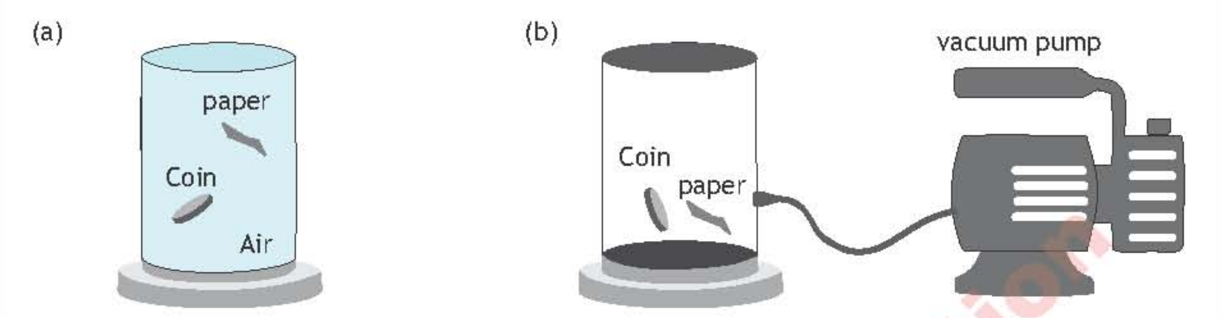
If you drop a ball and large stone from the roof of your school building, which of them will reach the bottom first? All the freely falling objects have the same acceleration called the acceleration due to gravity (g) and is independent of their masses.

The acceleration due to gravity is directed downward, toward the center of the earth. Near the earth's surface, g is approximately

$$g = 9.80 \text{ m/s}^2 \text{ or } 32.2 \text{ ft/s}^2$$

For large object the presence of air resistance is neglected, however if we drop a small piece of paper and coin. The coin will fall faster than a sheet of paper due to air resistance as in Figure 2.11 (a). However, when air is removed, as in Figure 2.11 (b), the coin and the paper will experience the same acceleration due to gravity, and both the coin and the paper will fall at same rate.

FIGURE 2.11 FREE FALL EXPERIMENT



When an object moves with the gravity acceleration due to gravity is taken as positive (+g) and when object moves against gravity (like an object thrown up), acceleration due to gravity is taken as negative (-g).

EXAMPLE 2.5 ACCELERATION DUE TO GRAVITY

A block of mass 2 kg is left from the top of a building. How much time will the block take to reach the ground if it strikes the ground with a speed of 78.5 m/s? (Ignore air resistance).

GIVEN

Mass of the block 'm' = 2 kg

Initial speed 'v_i' = 0 m/s

Final velocity 'v_f' = 78.5 m/s

Acceleration due to gravity 'g' = 9.8 m/s^2

REQUIRED

Time to reach the ground 'Δt' = ?

SOLUTION

From the definition of acceleration, acceleration due to gravity can also be written as

$$g = \frac{v_f - v_i}{\Delta t} \quad \text{rearranging for time} \quad \Delta t = \frac{v_f - v_i}{g}$$

Putting values $$\Delta t = \frac{78.5m/s - 0m/s}{9.8m/s^2}$$

Therefore, $\boxed{\Delta t = 8s}$ Answer

So, the block will reach the ground in 8 seconds.

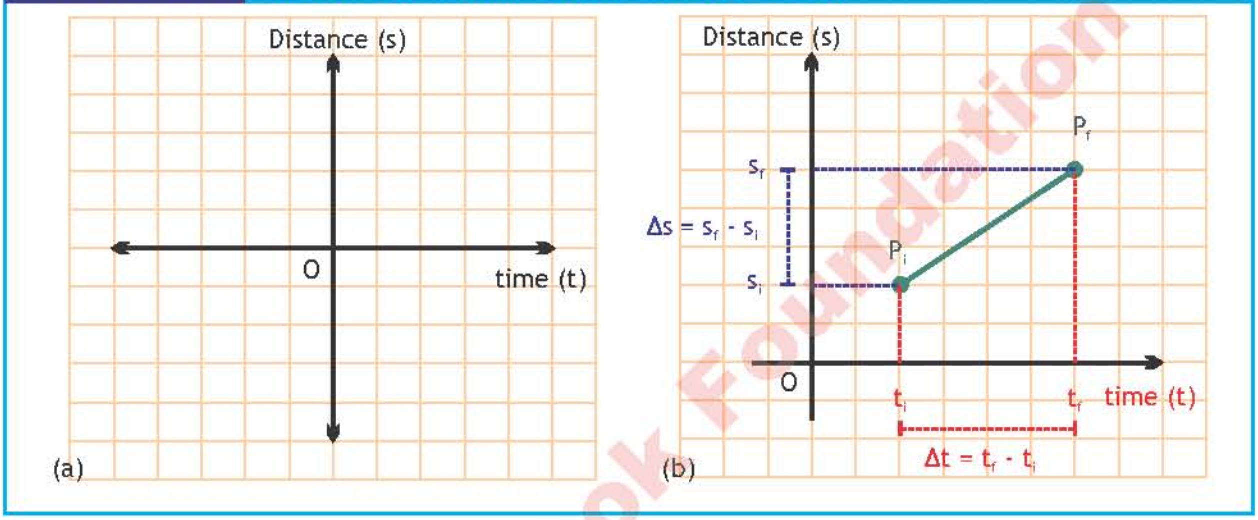
2.6 GRAPHICAL ANALYSIS OF MOTION

Graph (horizontal and vertical lines at equal distances) is an efficient method to show relationship between physical quantities. Graph use coordinate systems to show relationship in various quantities.

2.6.1 DISTANCE-TIME GRAPH

The distance-time graph is plotted between distance (s) and time (t). The time is plotted along horizontal axis (x-axis) and distance is plotted along vertical axis (y-axis) as shown in figure 2.12 (a). Distance time graph is always in the positive XY plane, as with passage of time, distance never goes to negative axis, irrespective of the direction of motion.

FIGURE 2.12 GRAPHICAL ANALYSIS OF MOTION



The gradient (or slope) of distance time curve gives speed. The gradient of the graph means vertical coordinate difference divided by horizontal coordinate difference. The gradient in distance-time graph can be calculated as

1. Choose two points P_i and P_f for which the gradient is to be determined.

2. Determine the coordinates P_i (t_i, s_i) and P_f (t_f, s_f), by drawing perpendicular on each axis from both points as shown in figure 2.11 (b).

3. Determine the difference between horizontal-cordinates ($\Delta t = t_f - t_i$) and vertical-coordinates ($\Delta s = s_f - s_i$).

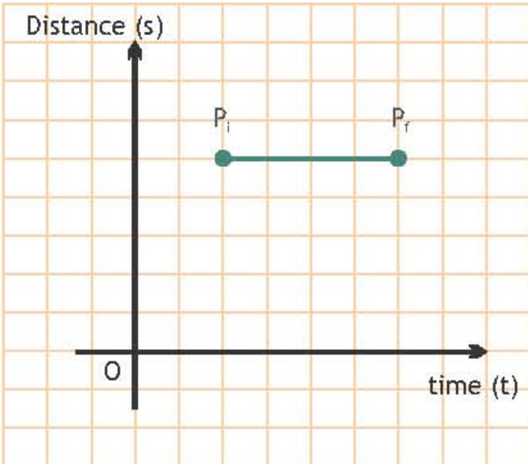
4. Dividing the difference in vertical-coordinates ($\Delta s = s_f - s_i$) by difference in horizontal-cordinates ($\Delta t = t_f - t_i$) gives gradient. Mathematically

$$gradient = \frac{\Delta s}{\Delta t} = \frac{s_f - s_i}{t_f - t_i} = v \qquad (2.7)$$

from equation 2.1 it is definition of speed, therefore $gradient = v$

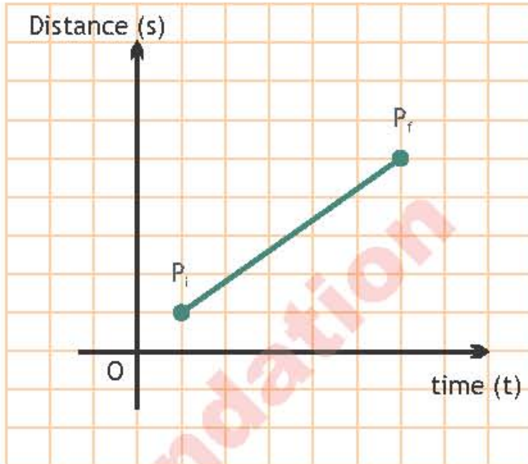
Thus by looking at the graph we get the idea about the speed of a body, shown in figure 2.13.

FIGURE 2.13 DISTANCE - TIME GRAPH



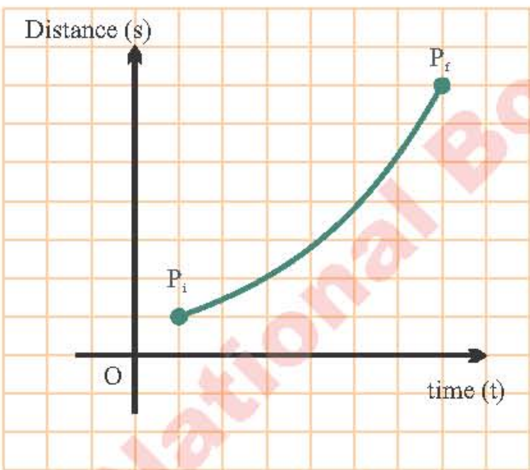
(a) BODY AT REST (ZERO SPEED)

Time is passing and no change in distance is seen. It means the body is at rest. Since there is no slope so the speed is zero.



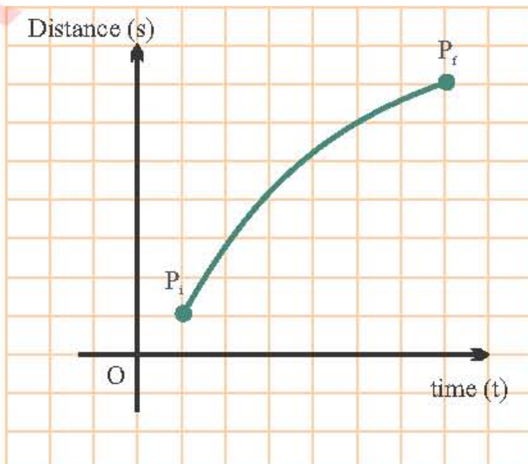
(b) BODY MOVING WITH CONSTANT SPEED

The distance is increasing linearly with time. The slope is constant therefore object is moving with uniform speed.



(c) BODY MOVING WITH VARIABLE SPEED

Increasing speed (accelerating): The distance is changing non-linearly with time (curving up). The slope is increasing therefore object is increasing its speed.



(d) BODY MOVING WITH VARIABLE SPEED

Decreasing Speed (decelerating): The distance is changing non-linearly with time (curving down). The slope is changing therefore object is decreasing its speed.

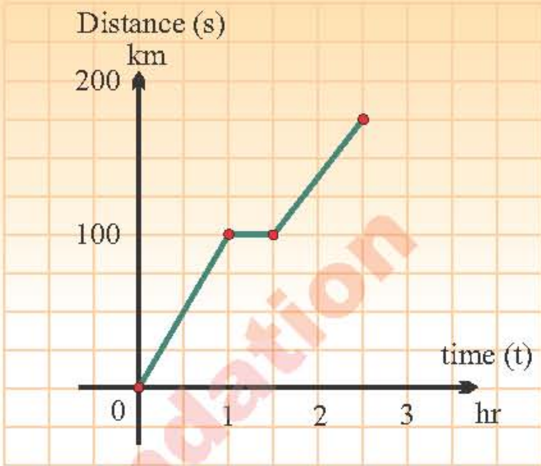
EXAMPLE 2.5: PESHAWAR TO ISLAMABAD THROUGH M1

A car travels from Peshawar to Islamabad on Motorway (M1), stops for 30 minutes at 'rest area'. Calculate the speed of the car in km/hr and m/s for

(a) Journey from Peshawar to rest area.

(b) Journey from rest area to Islamabad.

(c) Journey from Peshawar to Islamabad.



From the graph

(a) Distance between Peshawar to rest area is

$\Delta s = s_f - s_i$ is Δs = 100 km - 0 km = 100 km

time taken from Peshawar to rest area is

$\Delta t = t_f - t_i$ is Δt = 1 hr - 0 hr = 1 hr

$$\boxed{gradient = v = \frac{\Delta s}{\Delta t} = \frac{100\,km}{1hr} = 100\,{}^{km}/_{hr}}$$ Answer

In metre per second 100 km = 100, 000 m and 1 hr = 60 ´ 60 s = 3,600 s, therefore

$$\boxed{gradient = v = \frac{\Delta s}{\Delta t} = \frac{100{,}000\,m}{3600\,s} = 27.78\,{}^{m}/_{s}}$$ Answer

(b) Distance between rest area and Islamabad is

$\Delta s = s_f - s_i$ is Δs = 175 km - 100 km = 75 km

time taken from Peshawar to rest area is

$\Delta t = t_f - t_i$ is Δt = 2 hr 30 mins - 1 hr 30 mins = 1 hr = 60 ´ 60 s = 3,600 s

$$\boxed{gradient = v = \frac{\Delta s}{\Delta t} = \frac{100\,km}{1hr} = 100\,{}^{km}/_{hr}}$$ Answer

In metre per second 75 km = 75, 000 m and 1 hr = 60 ´ 60 s = 3,600 s, Therefore

$$\boxed{gradient = v = \frac{\Delta s}{\Delta t} = \frac{75{,}000\,m}{3600\,s} = 20.83\,{}^{m}/_{s}}$$ Answer

(c) Distance from Peshawar to Islamabad is:

$\Delta s = s_f - s_i$ is Δs = 175 km - 0 km = 175 km

time taken from Peshawar to Islamabad is

$\Delta t = t_f - t_i$ is Δt = 2 hr and 30 mins - 0 hr = 2.5 hr

$$gradient = v = \frac{\Delta s}{\Delta t} = \frac{175\,km}{2.5\,hr} = 70\,{}^{km}/_{hr}$$ Answer

In metre per second

175 km = 175, 000 m

and 2 hr and 30 mins = 2 (60 ´ 60) s + (60 ´ 30) s = 7,200 s + 1,800 s = 9,000 s

$$gradient = v = \frac{\Delta s}{\Delta t} = \frac{175{,}000\,m}{9{,}000\,s} = 19.44\,{}^{m}/_{s}$$ Answer

2.6.2 SPEED - TIME GRAPH

Speed-time graph is the graph plotted between speed (v) and time (t). In this graphical analysis the speed is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis). Speed time graph serve two purposes

- Slope of the graph gives magnitude of acceleration
- Area under the graph gives distance traveled.

The slope of speed time curve gives magnitude of acceleration. As discussed in the graph for the distance graph, the slope of velocity time graph gives by definition the magnitude (value) of acceleration

The gradient (or slope) of speed time curve gives magnitude of acceleration. The gradient of the graph means vertical coordinate difference divided by horizontal coordinate difference. The gradient in distance-time graph can be calculated as:

1. Choose two points 'P_i' and 'P_f' for which the gradient is to be determined.

2. Determine the coordinates '$P_i\,(t_i, v_i)$' and '$P_f\,(t_f, v_f)$', by drawing perpendicular on each axis from both points as shown in figure 2.9 (b).

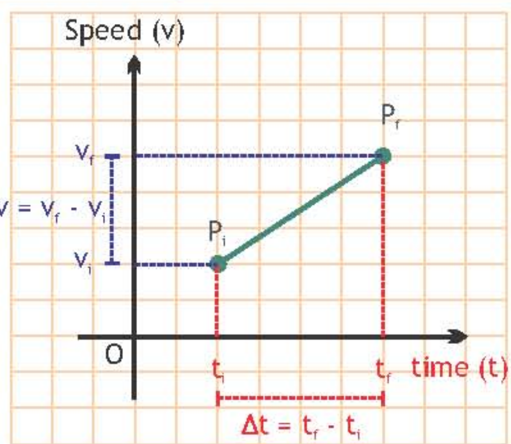
3. Determine the difference between horizontal-cordinates ($\Delta t = t_f - t_i$) and vertical-coordinates ($\Delta v = v_f - v_i$).

4. Dividing the difference in vertical-coordinates ($\Delta v = v_f - v_i$) by difference in horizontal-cordinates ($\Delta t = t_f - t_i$) gives gradient. Mathematically

$$gradient = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} = |a| \qquad (2.8)$$

From equation 2.8 we can conclude that the gradient of velocity - time graph gives the magnitude of acceleration.

FIGURE 2.13 SPEED TIME GRAPH



B. Area under speed time graphs represent the distance traveled: If the motion of a body represented by the speed time graph is symmetric shape then the area can be calculated using appropriate formula for geometrical shapes.

For example consider the figure 2.14 in which the speed time graph of the object in motion is represented by a rectangle. The area of rectangle is

$$Area = width \times length$$

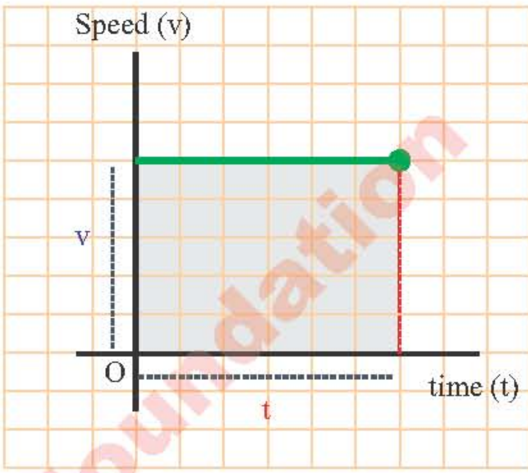
$$Area = v \times t$$

The distance by average speed is given by equation 2.3, is also

$$s = v\ t$$

Thus the area under speed time graphs represent the distance traveled.

FIGURE 2.14 RECTANGULAR AREA



Similarly consider the figure 2.15 in which the speed time graph of the object in motion is represented by a triangle. The area of triangle is

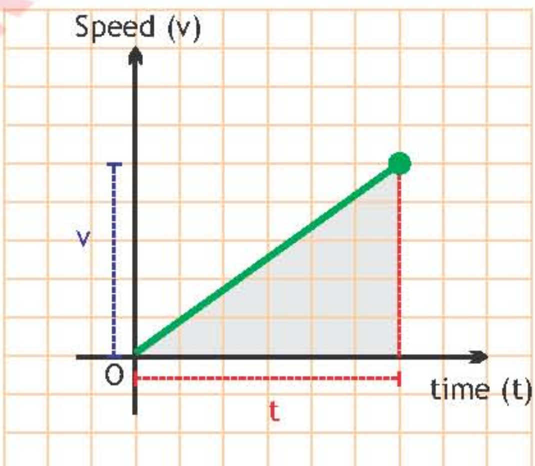
$$Area = \frac{1}{2} width \times length$$

$$Area = \frac{1}{2} v \times t$$

The distance by average speed is given by equation 2.4, is again

$$s = \frac{1}{2} v\ t$$

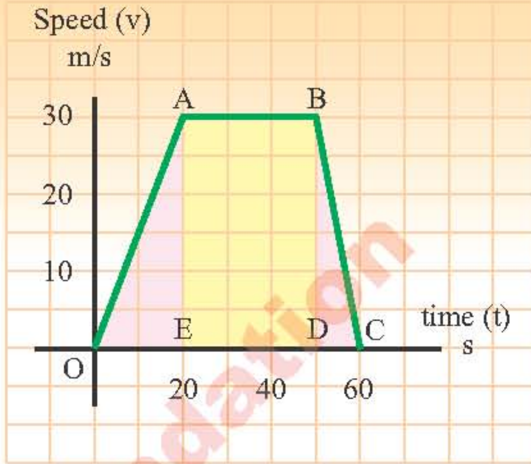
FIGURE 2.15 TRIANGULAR AREA



EXAMPLE 2.6: GRAPHICAL REPRESENTATION OF SPEED OF CAR

A car increases its speed from zero to a 30 m/s in 20 s. Then it moves with uniform speed for the next 30 seconds and then the driver applies brakes and the speed of the car decreases uniformly to zero in 10 s. The graph is plotted for the journey, use this graph to calculate:

(a). magnitude of acceleration (i) in first 20 s (ii) from 20 s to 50 s and (iii) in last 10 s (b). total distance covered (c). average speed



(a) The slope of the graph will give magnitude of` acceleration.

$$\text{Slope} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} = \text{Magnitude of acceleration}$$

(i) For the first 20 seconds, OA line represents the slope

$$\text{Magnitude of acceleration} = |\vec{a}| = \frac{(30-0)\ \text{m/s}}{(20-0)\ \text{s}} = \frac{30\ \text{m/s}}{20\ \text{s}}$$

$$\boxed{|\vec{a}| = 1.5\ \text{m/s}^2}$$ Answer

(ii). From 20 s to 50 s, the slope is represented by line AB

$$\text{Magnitude of acceleration} = |\vec{a}| = \frac{(30-30)\ \text{m/s}}{(50-20)\ \text{s}} = \frac{0\ \text{m/s}}{30\ \text{s}}$$

$$\boxed{|\vec{a}| = 0\ \text{m/s}^2}$$ Answer

(iii). In the last 10 seconds, the slope is represented by BC

$$\text{Magnitude of acceleration} = |\vec{a}| = \frac{(0-30)\ \text{m/s}}{(60-50)\ \text{s}} = \frac{-30\ \text{m/s}}{10\ \text{s}}$$

$$\boxed{|\vec{a}| = -3\ \text{m/s}^2}$$ Answer

The negative sign shows that the car is slowing down.

(b). Now the total distance covered is equal to the area under the speed-time graph.

Total distance covered = Area of triangle OAE + Area of rectangle ABDE + Area of triangle CBD

$$s = \left[\frac{1}{2} \times (30\ \text{m/s} \times 20\ \text{s})\right] + \left[30\text{m/s} \times 30\ \text{s}\right] + \left[\frac{1}{2} \times (30\ \text{m/s} \times 10\ \text{s})\right]$$

$$\boxed{s = 300\ \text{m} + 900\ \text{m} + 150\ \text{m} = 1350\ \text{m}}$$ Answer

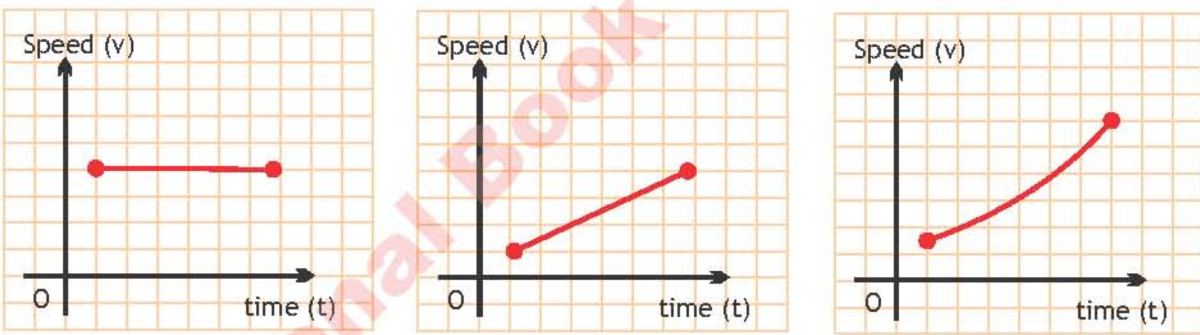
(c). Now the average speed can be calculated when distance s is divided by total time t

$$\text{Average Speed} = \frac{\text{Total distance covered}}{\text{Total time}}$$

$$\boxed{v_{ave} = \frac{1350\text{m}}{60\text{s}} = 22.5\ \text{m/s}}$$ Answer

CAN YOU TELL?

What does the slope of these graphs tells about acceleration?



SUMMARY

- **Position** is the distance and direction of a body from a fixed reference point.
- **Distance** is the length of a path traveled by an object.
- **Displacement** is the shortest distance from the initial and final position of a body.
- **Speed** is time rate of change of distance and is a scalar quantity.
- **Velocity** is the time rate of change of displacement and is a vector quantity.
- **Acceleration** is the time rate of change of velocity and is a vector quantity.
- **Gradient of distance-time graph** gives speed of the body.
- **Gradient of speed-time graph** gives acceleration of the body.
- **Area under the speed-time graph** gives distance travelled by the body.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose best possible option:

1. Change in position of a body from initial to final point is called:
   A. Distance B. Displacement C. Speed D. Velocity
2. Motion of a screw of rotating fan is:
   A. Circular motion B. Vibratory motion C. Random motion D. Rotatory motion
3. A cyclist is travelling in a westward direction and produces a deceleration of 8 m/s^2 to stop. The direction of its acceleration is towards
   A. North B. East C. South D. West
4. A girl walks 3 km towards west and 4 km towards south. What is the magnitude of her total distance and displacement respectively?
   A. 7 km, 7 km B. 1 km, 7 km C. 7 km, 1 km D. 7 km, 5 km
5. A rider is training a horse. Horse moves 60 metres towards right in 3 seconds. Then it turns back and travels 30 metres in 2 seconds. Find its average velocity?
   A. 6 m/s B. 18 m/s C. 35 m/s D. zero
6. If a cyclist has acceleration of 2m/s^2 for 5 seconds, the change in velocity of the cyclist is
   A. 2 m/s B. 10 m/s C. 20 m/s D. 15 m/s
7. A car is moving with velocity of 10 m/s. If it has acceleration of 2 m/s2 for 10 seconds. What is final velocity of the car?
   A. 30 m/s B. 20 m/s C. 10 m/s D. 15 m/s
8. When the slope of a body's displacement-time graph increases, the body is moving with:
   A. increasing velocity B. decreasing velocity
   C. constant velocity D. all of these
9. A ball is thrown straight up, what is the magnitude of acceleration at the top of its path?
   A. zero B. 9.8 m/s^2 C. 4.9 m/s^2 D. 19.6 m/s^2
10. Slope of distance-time graph is:
    A. velocity B. acceleration C. speed D. displacement
11. Area under speed-time graph is equal to ____________ of moving body:
    A. distance B. change in velocity C. uniform velocity D. acceleration

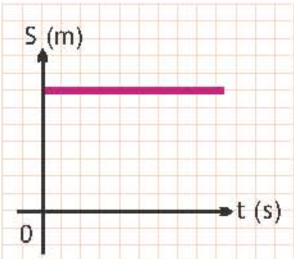
12. In 5 s a car accelerates so that its velocity increases by 20m/s. The acceleration is

A. $0.25\ m/s^2$ B. $4\ m/s^2$ C. $25\ m/s^2$ D. $100\ m/s^2$

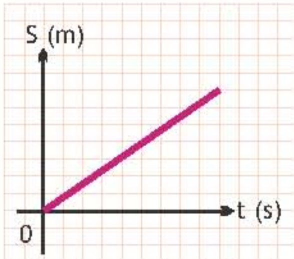
13. Ball dropped freely from a tower reaches ground in 4s, the speed of impact of ball is:

A. 0 m/s B. 2.45 m/s C. 19.6 m/s D. 39.2 m/s

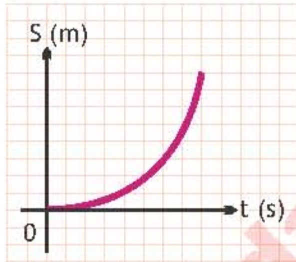
14. Which of following distance time graphs represents increasing speed of a car?



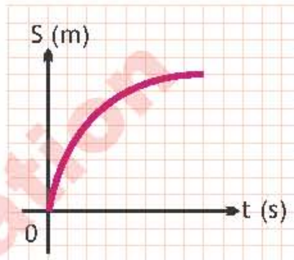
A.



B.



C.



D.

SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

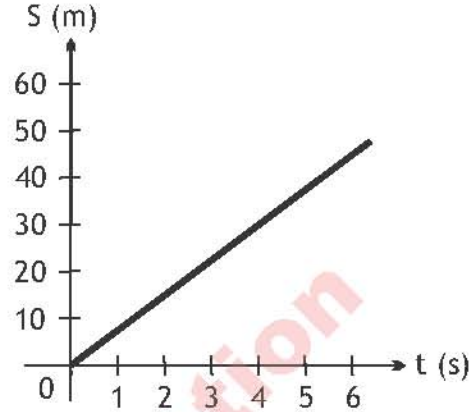
1. In a park, children are enjoying a ride on Ferris wheel as shown. What kind of motion the big wheel has and what kind of motion the riders have?
2. A boy moves for some time, give two situations in which his displacement is zero but covered distance is not zero?
3. A stone tied to string is whirling in circle, what is direction of its velocity at any instant?


Side view


Top view

4. Is it possible to accelerate an object without speeding it up or slowing it down?
5. Can a car moving towards right have direction of acceleration towards left?
6. With the help of daily life examples, describe the situations in which:
   a. acceleration is in the direction of motion.
   b. acceleration is against the direction of motion.
   c. acceleration is zero and body is in motion.

7. Examine distance-time graph of a motorcyclist (as shown), what does this graph tell us about the speed of motorcyclist? Also plot its velocity-time graph.



DISTANCE - TIME GRAPH

8. Which controls in the car can produce acceleration or deceleration in it?
9. If two stones of 10 kg and 1 kg are dropped from a 1 km high tower. Which will hit the ground with greater velocity? Which will hit the ground first? (Neglect the air resistance)
10. A 100 g ball is just released (from rest) and another is thrown downward with velocity of 10 m/s, which will have greater acceleration? (Neglect the air resistance)

LONG RESPONSE QUESTIONS

QIII. Give a detailed response to questions below.

1. Differentiate between rest and motion. With the help of example, show that rest and motion are relative to observer?
2. What are different types of motion? Define each type of motion with examples from daily life.
3. What are scalars and vectors? Give examples. How are vectors represented symbolically and graphically?
4. Define the term position. Differentiate between distance and displacement.
5. Differentiate between speed and velocity. Also define average speed, uniform and variable speeds, average velocity, uniform and variable velocities.
6. What are freely falling bodies? What is gravitational acceleration? Write down sign conventions for gravitational acceleration? Write three equations of motion of a freely falling body?
7. Draw distance-time graphs for rest, uniform speed, increasing speed and decreasing speed.
8. Draw speed-time graphs for zero acceleration, uniform acceleration, uniform deceleration. Also show that area under speed time graph represents distance covered by the body.

NUMERICAL RESPONSE QUESTIONS

QIV. Solve the following

1. Convert the following:

   a. 160 km /h into m/s *(Ans. 44.44 m/s)* b. 36 m/s into km/h *(Ans. 129.6 km/h)*

   c. 15 km/h^2 into m/s^2 *(Ans. 0.001 m/s^2)* d. 1 m/s^2 into km/h^2 *(Ans. 12,960 km/hs^2)*

2. In 10 seconds, a cyclist increases its speed from 5 km/h to 7 km/h, while a car moves from rest to 20 km/h in same time. Calculate and compare acceleration in each case.

   (Ans. 0.055 m/s^2 and 0.55 m/s^2)

3. A ball is thrown straight up such that it took 2 seconds to reach the top after which it started falling back. What was the speed with which the ball was thrown up? *(Ans. 19.6 m/s)*

4. A car is moving with uniform velocity of 20 m/s for 20 seconds. Then brakes are applied and it comes to rest with uniform deceleration in 30 s. Plot the graph to calculate this distance using speed time graph? *(Ans. 1 km)*

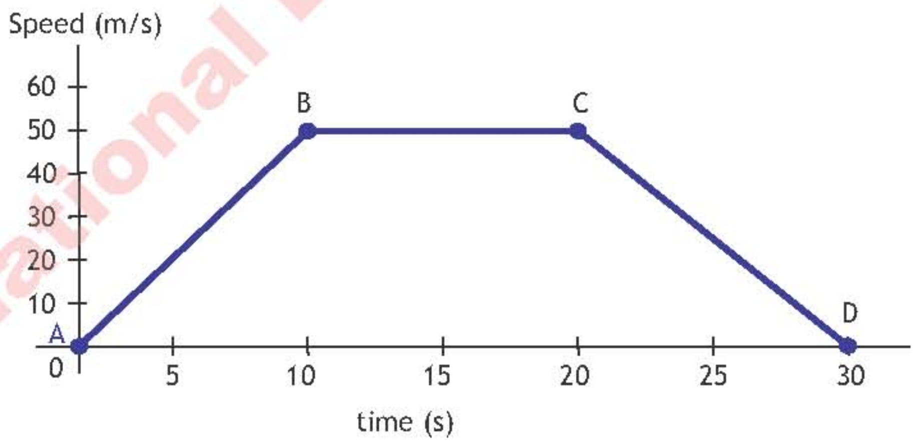
5. A girl starts her motion by a racing bicycle in a straight line at a speed of 50 km/h. Her speed is changing at a constant rate. If she stops after 60 s, what is her acceleration? *(Ans. 0.23 m/s^2)*

6. Consider the following speed time graph. Tell:

   a. Which part of the graph is showing acceleration, deceleration and zero acceleration?

   b. Calculate covered distance from 10 seconds to 20 seconds from the graph.

   (Ans. (a) OA, BC, AB, (b) 500 m)



SPEED - TIME GRAPH

Approved by National Curriculum Council, Secretariat
Ministry of Federal Education & Professional Training
vide letter No. Dated:

قومی ترانہ

پاک سرزمین شاد باد! کشورِ حسین شاد باد!
تو نشانِ عزمِ عالی شان ارضِ پاکستان
مرکزِ یقین شاد باد!

پاک سرزمین کا نظام قوتِ اخوتِ عوام
قوم ، ملک ، سلطنت پائندہ تابندہ باد!
شاد باد منزلِ مراد!

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