Model Textbook of

Physics 9

Based on National Curriculum of Pakistan 2022-23

National Book Foundation
as
Federal Textbook Board
Islamabad

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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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First Edition - First Impression: March 2024 | **Pages:** 220 | **Quantity:** 00000

Price: PKR 000/-
Code: STE-...., **ISBN:** 978-969-37-0000-00
Printer: 0000000000000000000000

Note: All the pictures, paintings and sketches used in this book are only
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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).

Dr. Raja Mazhar Hameed
Managing Director

بِسۡمِ اللّٰہِ الرَّحۡمٰنِ الرَّحِیۡمِ

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

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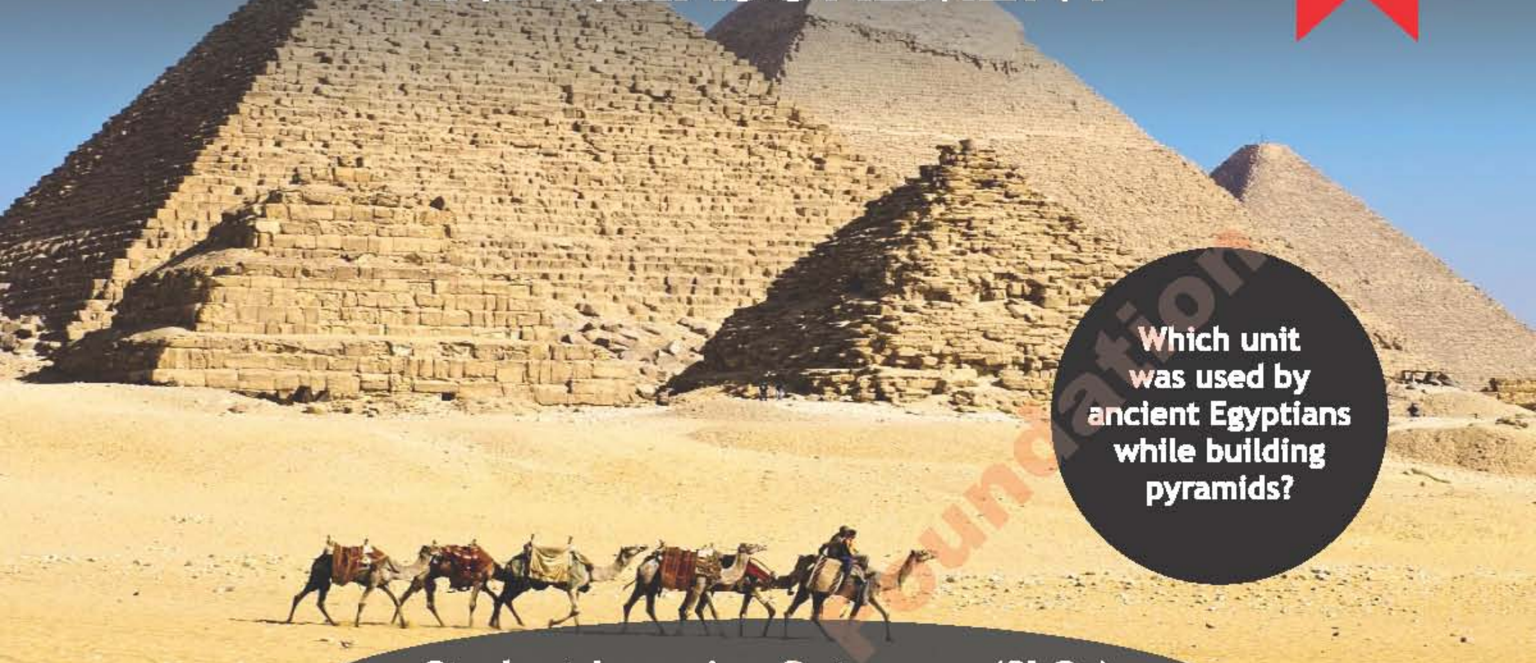
PHYSICAL QUANTITIES AND MEASUREMENT



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.

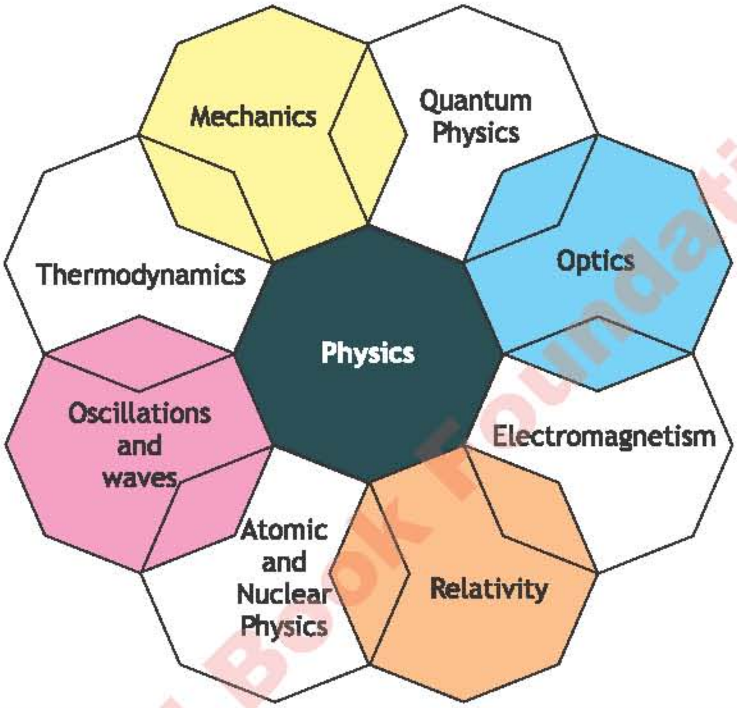
(b) Space shuttle being launched in to the space with rocket.

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.

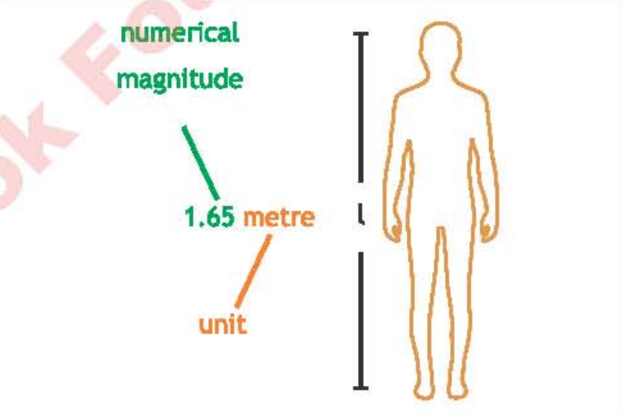
Unit is standard with which physical quantities are compared.

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 '$m \times m = m^2$', in this example base unit of length is used. Similarly the unit for velocity is 'm/s' and acceleration is 'm/s^2'. Some derived units are given special names and symbols. For example force has derived units of '$kg\ m/s^2$' 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/

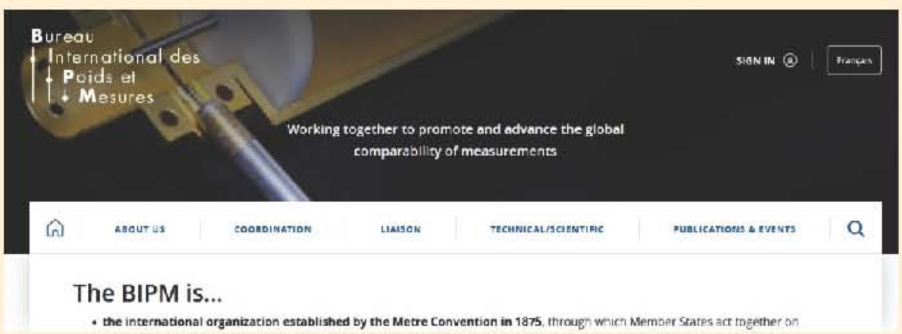


TABLE 1.2 DERIVED UNITS FOR 'INTERNATIONAL SYSTEM OF UNITS

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

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

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

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

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

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

Diameter of proton = 0.0000000000000017 × 10^0 m.

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

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

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

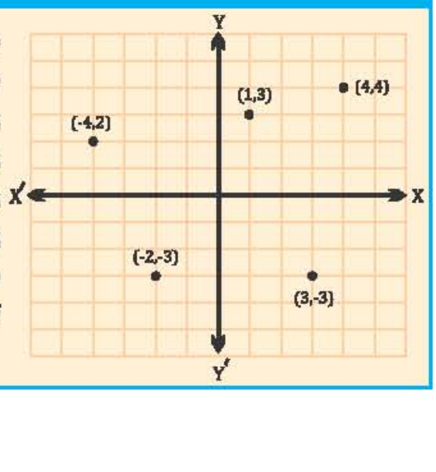


FIGURE 1.3 VECTOR REPRESENTATION

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.

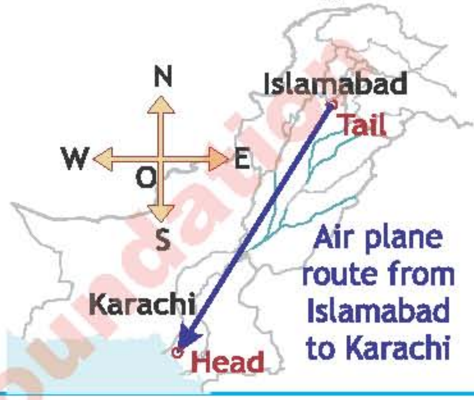
$\vec{F}$

or

$\vec{f}$, $\vec{A}$, $\vec{B}$, $\mathbf{B}$, B, $\underset{\rightarrow}{B}$

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.



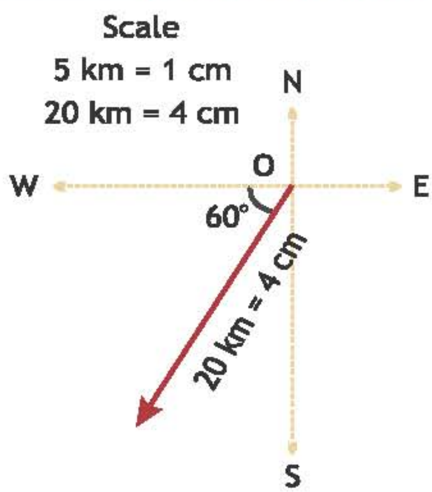
Steps to Represent a Vector in Coordinate System

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

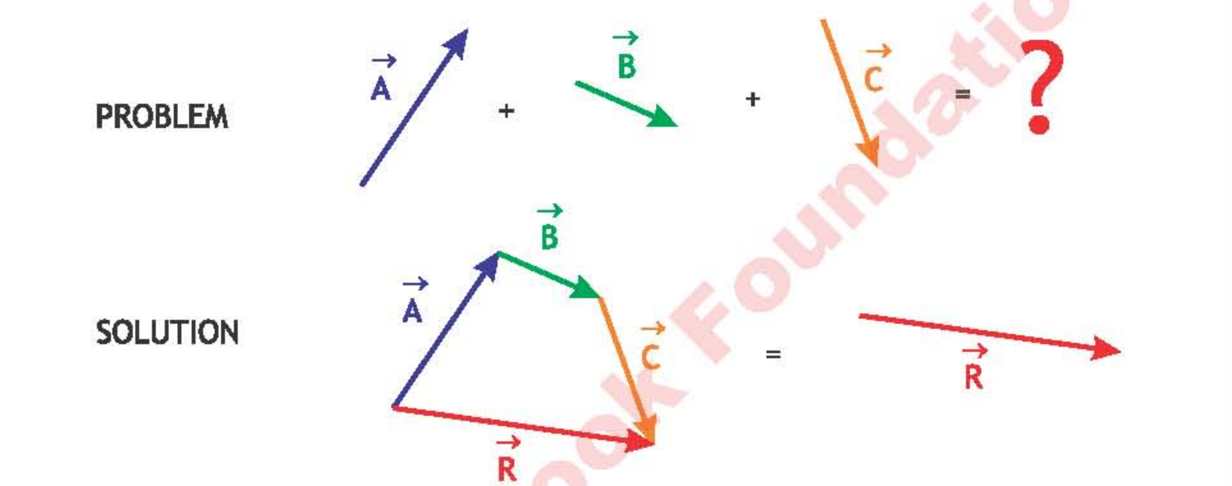


Since displacement, force, weight, velocity, acceleration, momentum, electric field strength, and gravitational field strength are vector quantities or vectors. They will require to follow the rules of vector addition. This means that when we combine two vectors, the resulting value must also result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

1.6.3. ADDING VECTOR QUANTITIES

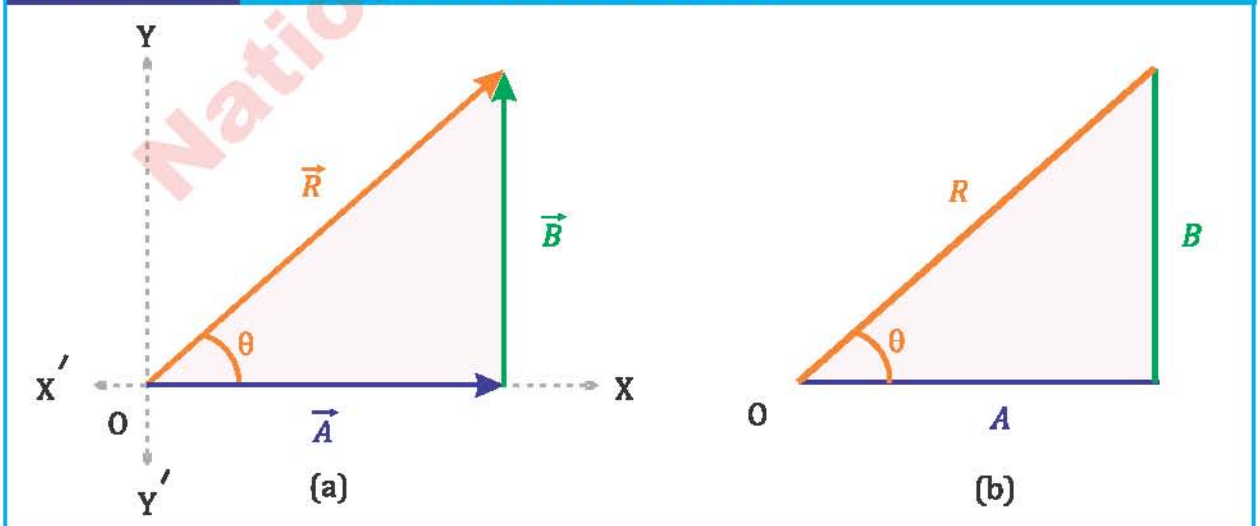
The process of combining two or more vectors to into a single vector (called as resultant vector) to determine their cumulated effect is termed as vector addition. In vector algebra, the resultant vector cannot be simply obtained by adding vector values. Vectors and may be added geometrically by drawing 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.

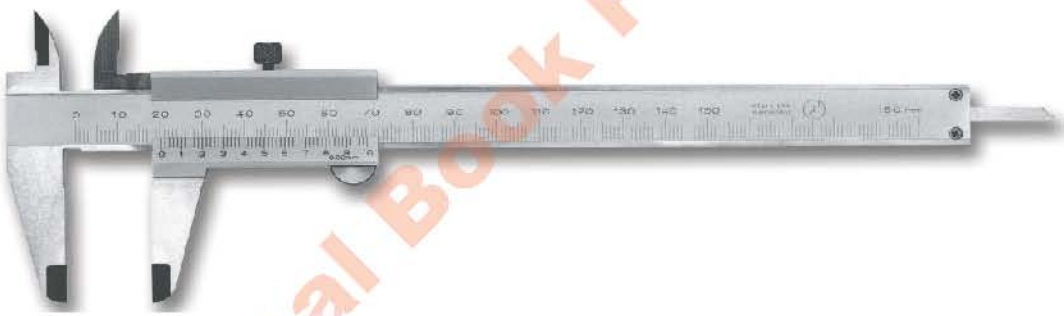
1.7.2 VERNIER CALIPER

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.

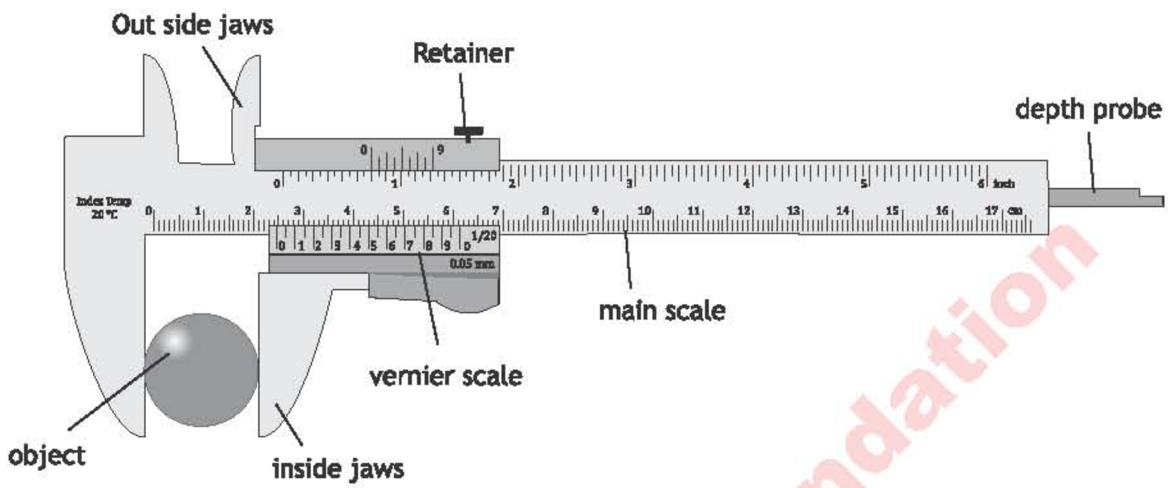
A main scale which has markings of usually of 1 mm each and it contains jaw on its left end.

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.

FIGURE 1.9 VERNIER CALLIPER DIAGRAM



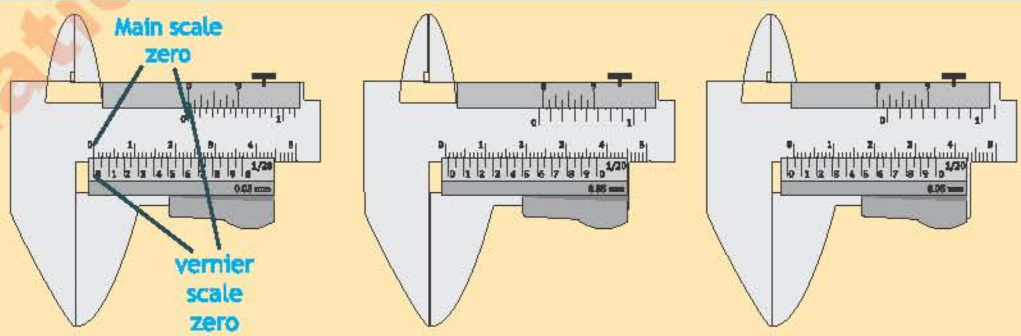
If the smallest main scale division is 1 mm and vernier scale division has 10 division on it then the least count of vernier caliper is:

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.

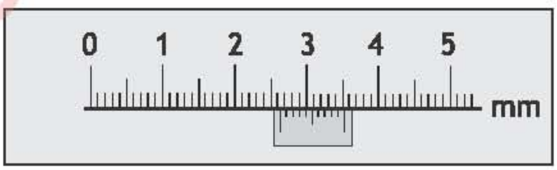
iv. Multiply the vernier scale reading with least count which is the fraction to be added with main scale reading. This fraction will be smaller than the main scale least count, thus vernier calliper measure the reading to the part of millimetre.

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'.

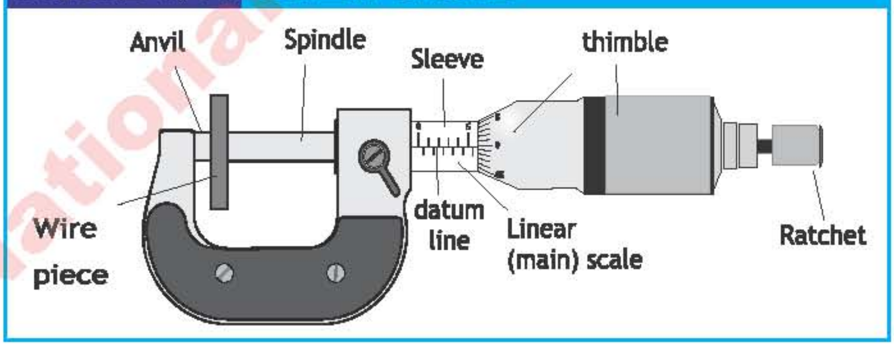
The distance traveled by the circular scale on linear (or main) scale in one rotation is called the pitch of the screw gauge.

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

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

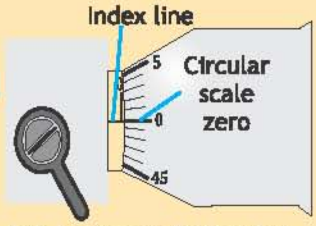
FIGURE 1.11 SCREW GAUGE



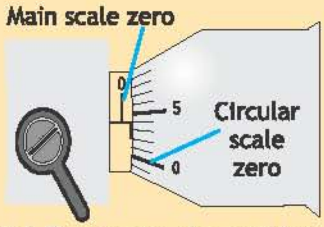
ZERO ERROR IN SCREW GAUGE

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.

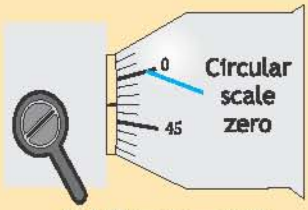
DO YOU KNOW?



(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.

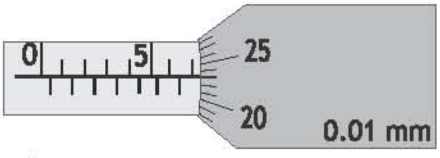
iv. Read the main scale reading, which is the reading shown (or unblocked) by circular scale as shown in figure 1.8.

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.

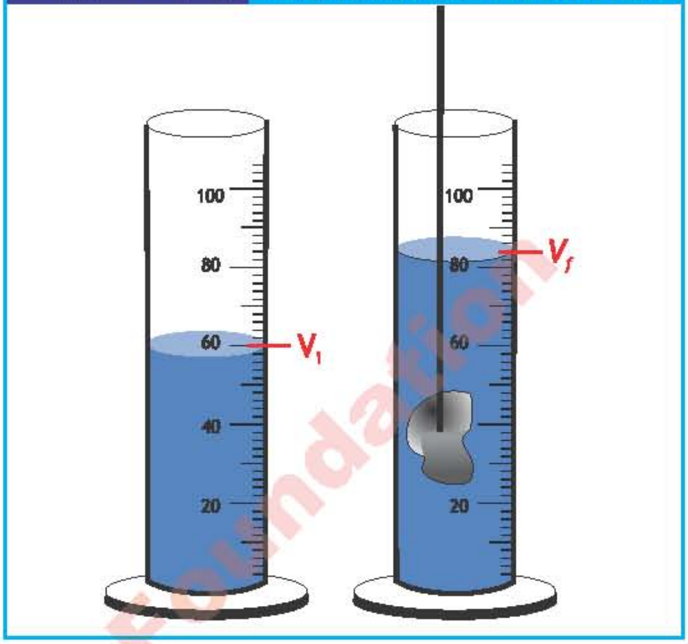
Leveling screws are used to level the physical balance, while the pointer is set at the center of the scale by adjusting screws. It is placed in a protective glass case so that even dust and wind can not affect the accuracy of the instrument. A weight box containing standard weights comes with the balance. 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 carefully taken, 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.

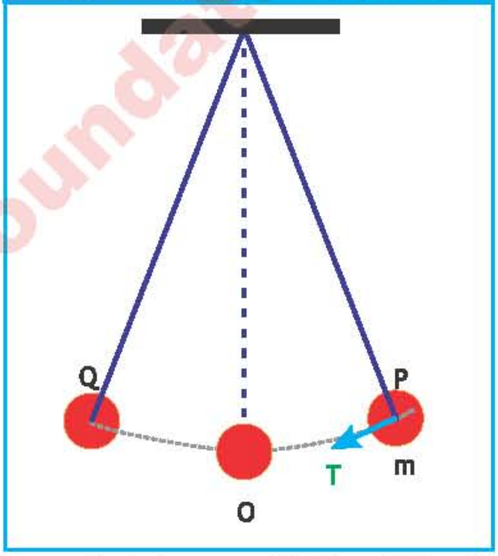
Systematic errors can be reduced by improving experimental techniques, choosing better instruments, and minimizing personal bias as much as possible. These errors can be estimated to some extent for a given setup, and the necessary adjustments can be made to the measurements.

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.

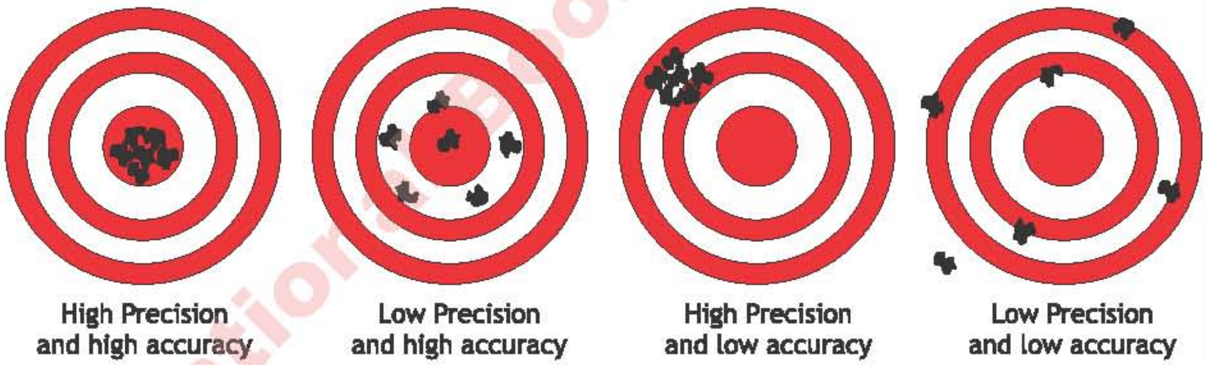
Imagine throwing darts at a target as shown in figure 1.16. If your darts land close to the center of the target (hitting the bullseye is ideal) your aim will be referred as accurate. Your darts are grouped tightly together, even if they're not in the center (a tight cluster off-center) your aim will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



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?

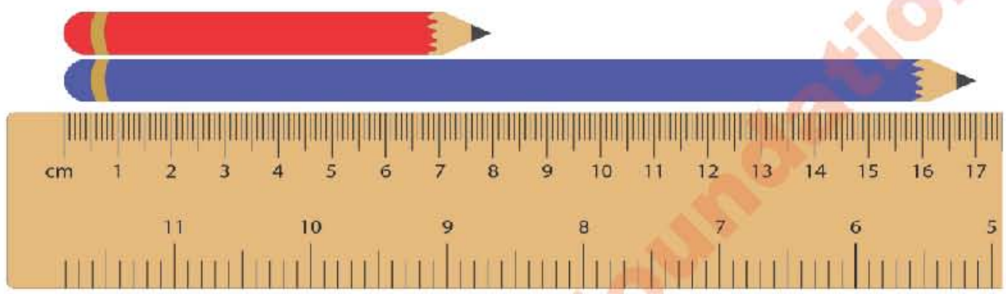
In practice, both precision and accuracy are desirable qualities in measurements. A measurement can be precise but not accurate, or accurate but not precise. Ideally, measurements should be both precise and accurate, meaning that they are both consistent and close to the true value. Achieving both precision 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

$$100.8\ s = 1.008 \times 10^2\ s$$

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

$$5.80 \times 10^{-3}\ km.$$

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

$$210.0\ g = 2.100 \times 10^2 g$$

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.

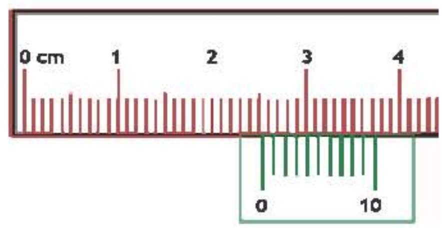
   b. Screw gauge if smallest division on its main scale is 0.5 mm and its movable scale has 50 divisions.

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?

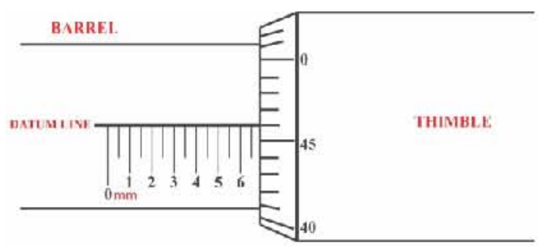


7. Look at the figure of screw gauge, let a small steel ball is place between its thimble and anvil then:

   a. What is its main scale reading?

   b. What is coinciding division of circular scale?

   c. Calculate the total diameter of the ball?



UNIT 2

KINEMATICS

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.

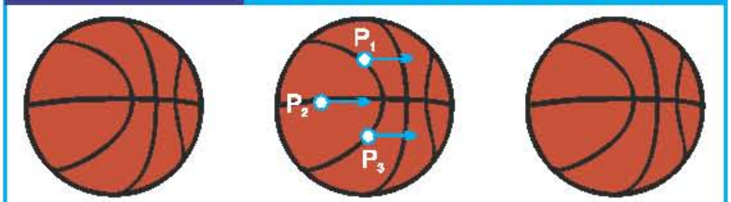
However, we know that Earth is spinning on its axis, so the car along with its road is also in motion. Not only this but Earth is also moving around the sun and the sun along with the rest of the solar system are also moving through our milky way galaxy. Apart from this our galaxy is also traveling through 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).

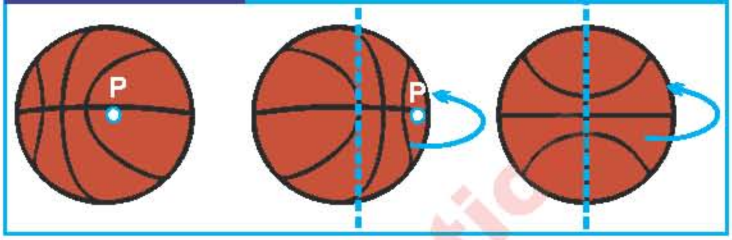
FIGURE 2.1 TRANSLATORY MOTION



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

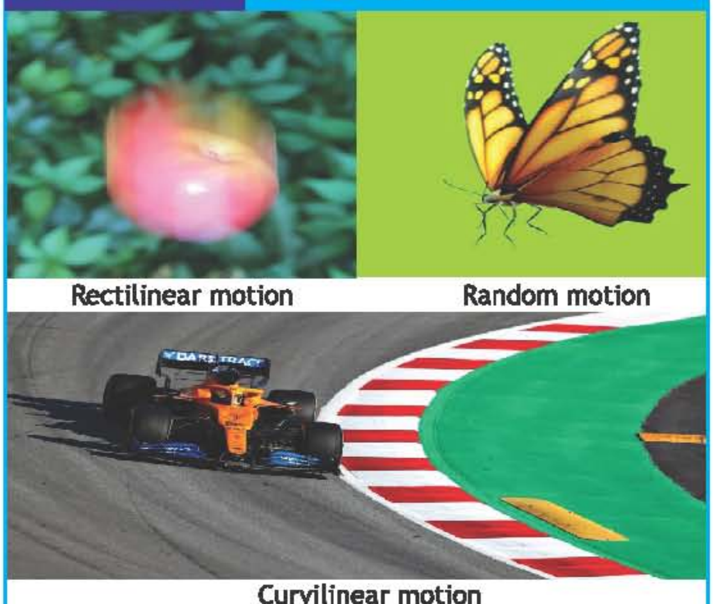
Example is motion of butterfly

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



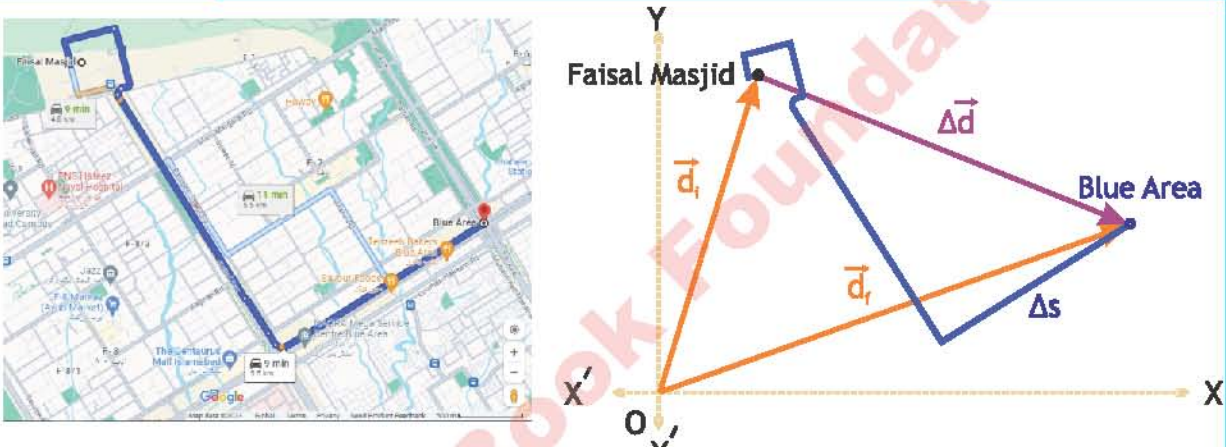
2.2 DISTANCE AND DISPLACEMENT

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).

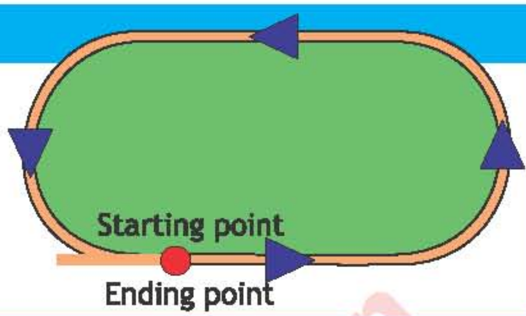
If an object moves then the object's position changes. This change in position vector '$\Delta\vec{d}$' of an object, from initial position '$\vec{d_i}$' to final position '$\vec{d_f}$' is known as displacement as shown in figure 2.6 (b). Mathematically:

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.

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:

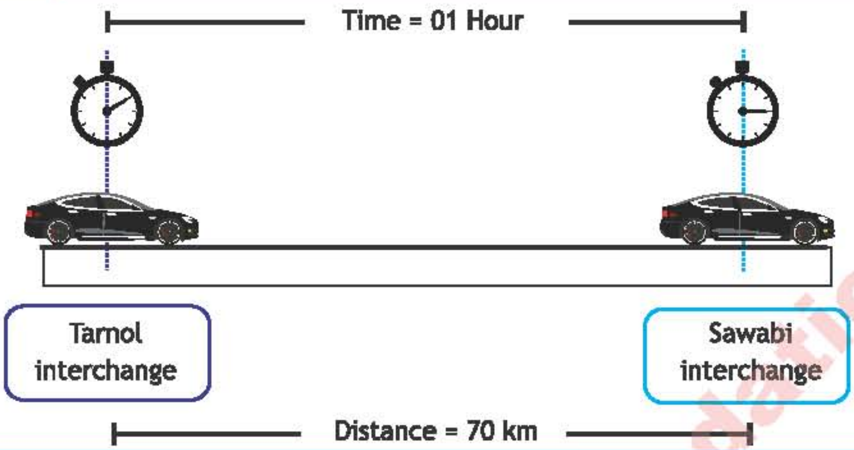
or or (2.1)

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:

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,

2.2

Interchangeably this equation can also be written as 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.

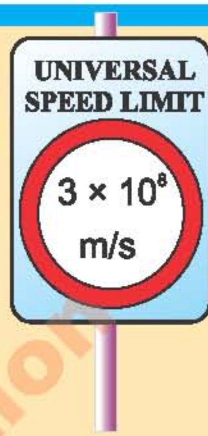
FIGURE 2.8 SPEEDOMETER OF A CAR

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

Putting values

Hence $t = 0.39\ s$ — **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:

Putting values

Hence — Answer

Conversion in km/h

Converting m to km and s to 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**

or or — 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,

2.5

B. INSTANTANEOUS VELOCITY

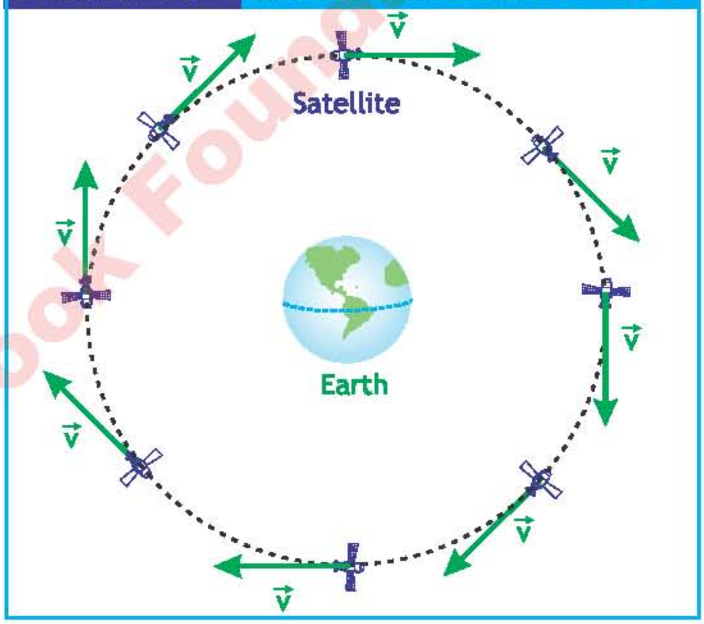
If velocity is measured by keeping the time interval small, such velocity is termed as instantaneous velocity. To calculate velocity both the speed and direction for that moment of time need to be specified.

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 vave = ?

(b). Average Velocity $\vec{vave}$ = ?

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

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

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

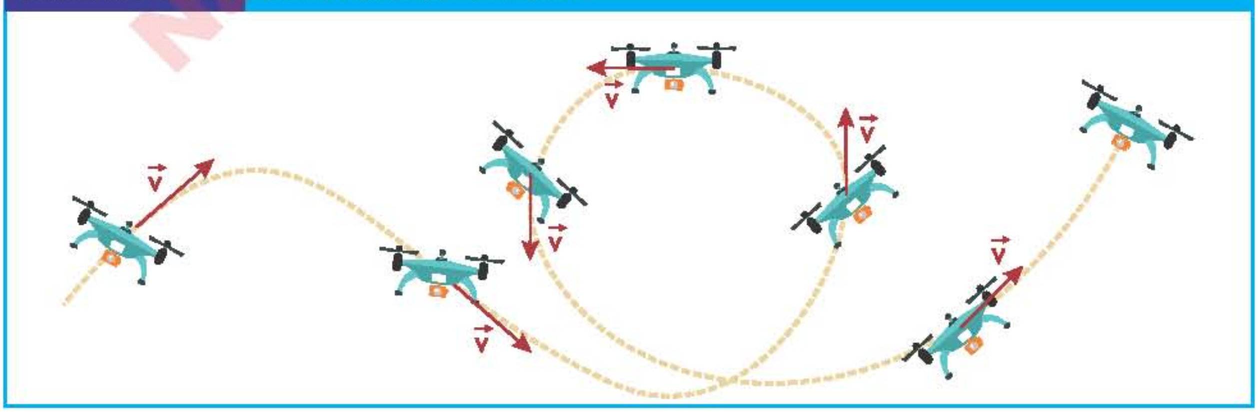
or or — 2.6

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

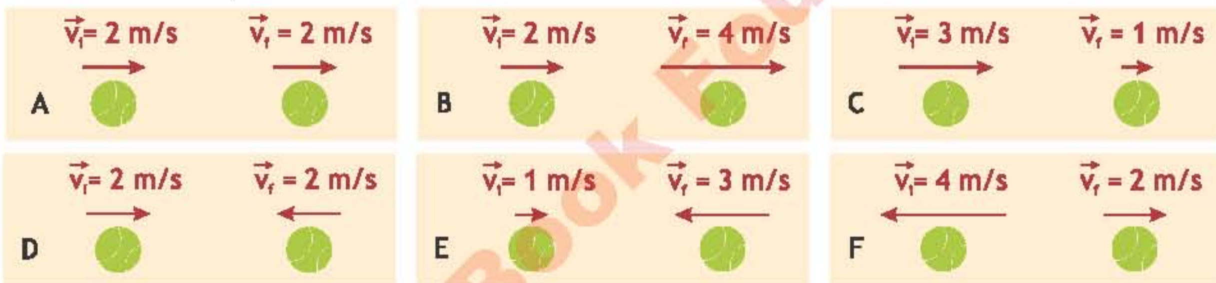


Uniform and Non-uniform Acceleration: **When an object is changing its velocity at the same rate each second we call it uniform acceleration.** A body has uniform acceleration if it has equal changes in velocity in equal intervals of time.

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 $\vec{a}$ = ?

SOLUTION

From the definition of acceleration, equation 2.6 we have

Putting values

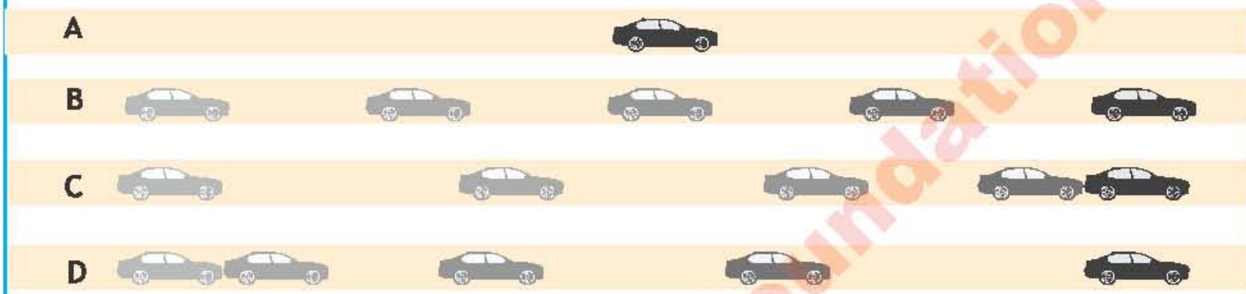
Answer

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

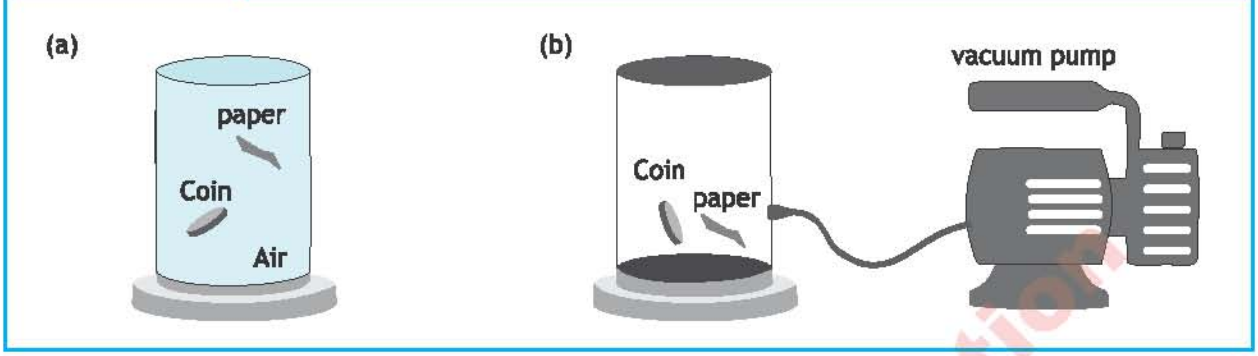
If you drop a ball and large stone from the roof of your school building, which of them will reach the bottom first? All the freely falling objects have the same acceleration called the acceleration due to gravity (g) and is independent of their masses.

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

rearranging for time

Putting values

Therefore, Answer

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

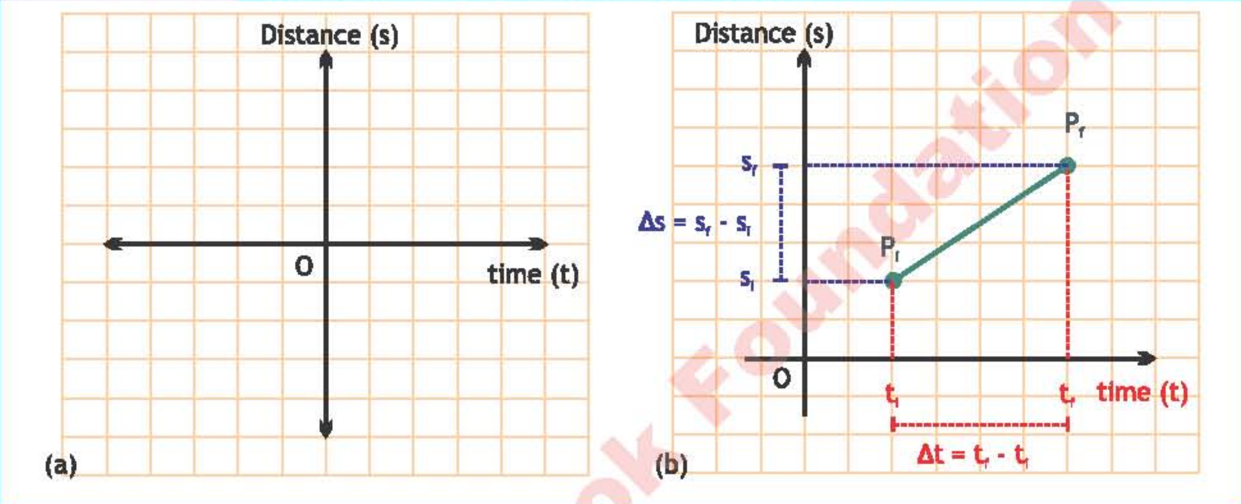
2.6 GRAPHICAL ANALYSIS OF MOTION

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 ($\Delta s = s_f - s_i$).

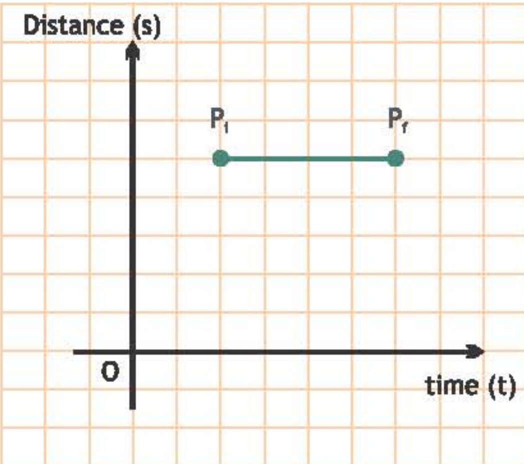
4. Dividing the difference in vertical-coordinates ($\Delta s = s_f - s_i$) by difference in horizontal-cordinates ($\Delta t = t_f - t_i$) gives gradient. Mathematically

2.7

from equation 2.1 it is definition of speed, therefore

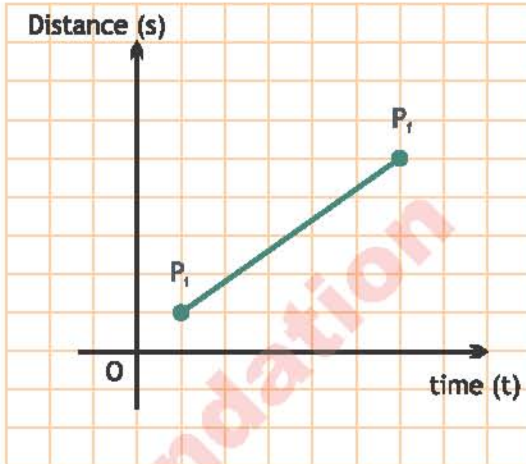
Thus by looking at the graph we get the idea about the speed of a body, shown in figure 2.13.

FIGURE 2.13 DISTANCE - TIME GRAPH



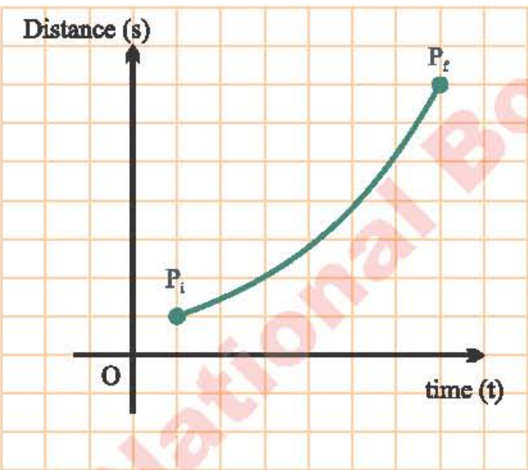
(a) BODY AT REST (ZERO SPEED)

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.



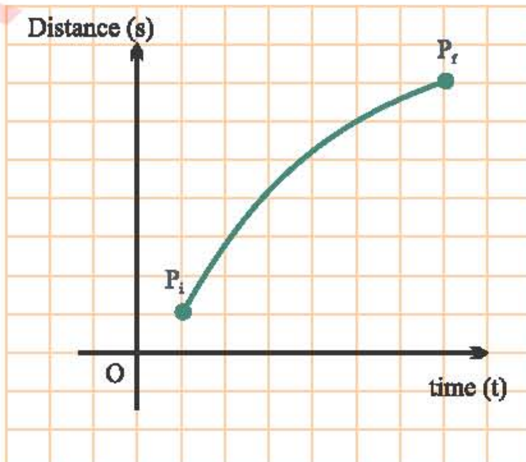
(b) BODY MOVING WITH CONSTANT SPEED

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.

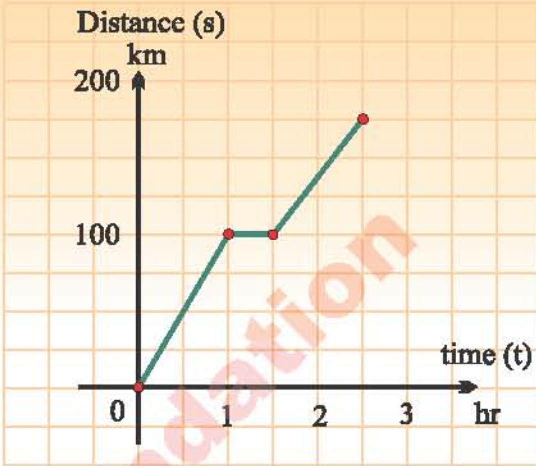
EXAMPLE 2.5: PESHAWAR TO ISLAMABAD THROUGH M1

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 $\Delta s = 100 \text{ km} - 0 \text{ km} = 100 \text{ km}$

time taken from Peshawar to rest area is

$\Delta t = t_f - t_i$ is $\Delta t = 1 \text{ hr} - 0 \text{ hr} = 1 \text{ hr}$

Answer

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

Answer

(b) Distance between rest area and Islamabad is

$\Delta s = s_f - s_i$ is $\Delta s = 175 \text{ km} - 100 \text{ km} = 75 \text{ km}$

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

Answer

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

Answer

(c) Distance from Peshawar to Islamabad is:

$\Delta s = s_f - s_i$ is $\Delta s = 175 \text{ km} - 0 \text{ km} = 175 \text{ km}$

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

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

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).

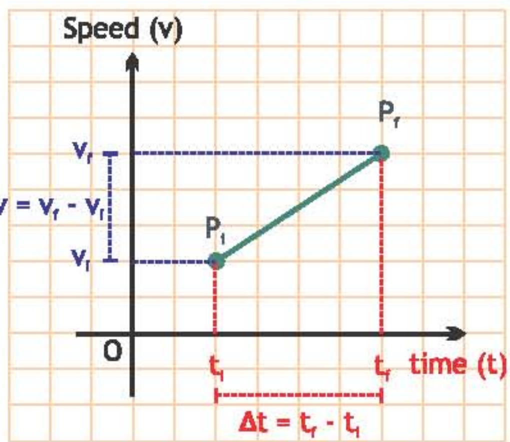
3. Determine the difference between horizontal-cordinates ($\Delta t = t_f - t_i$) and vertical-coordinates ($\Delta v = v_f - v_i$).

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

2.8

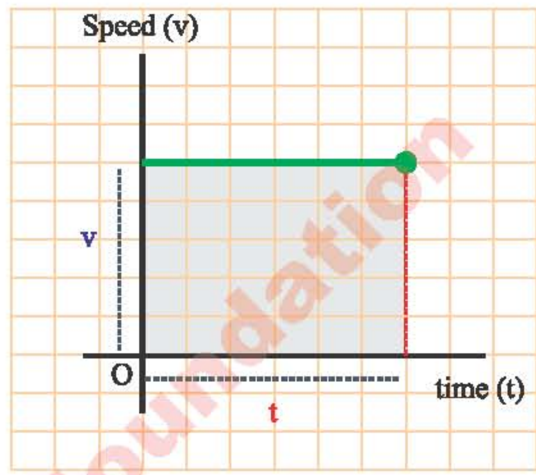
From equation 2.8 we can conclude that the gradient of velocity - time graph gives the magnitude of acceleration.

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.

FIGURE 2.14 RECTANGULAR AREA

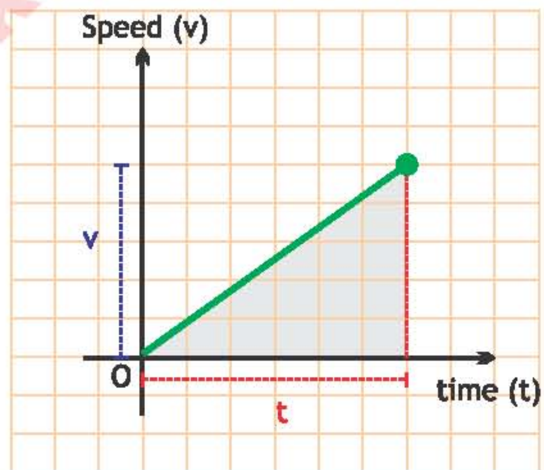


For example consider the figure 2.14 in which the speed time graph of the object in motion is represented by a rectangle. The area of rectangle is

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

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

FIGURE 2.15 TRIANGULAR AREA



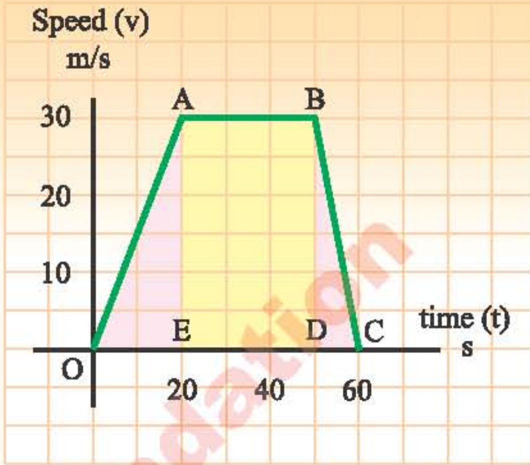
Similarly consider the figure 2.15 in which the speed time graph of the object in motion is represented by a triangle. The area of triangle is

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

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

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

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

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

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

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

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

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

$$|\vec{a}| = -3\ \text{m/s}^2$$ — 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

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

$$s = 300\ m + 900\ m + 150\ m = 1350\ m$$ **Answer**

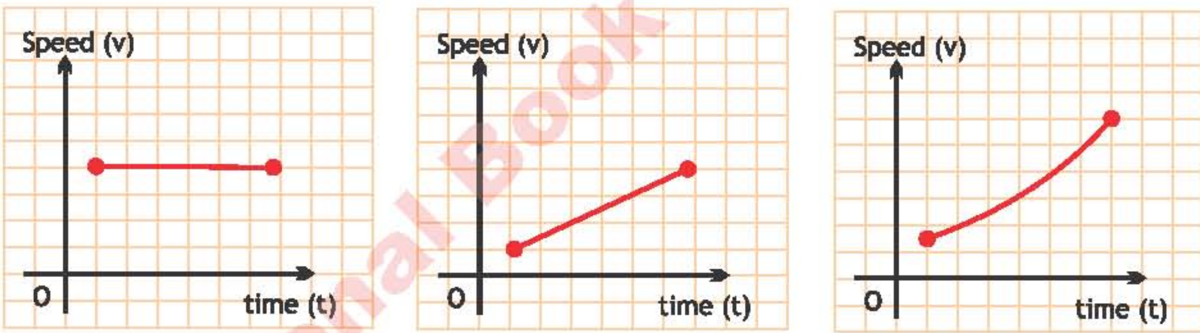
(c). Now the average speed can be calculated when distance s is divided by total time t

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

$$v_{ave} = \frac{1350m}{60s} = 22.5\,m/s$$ **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

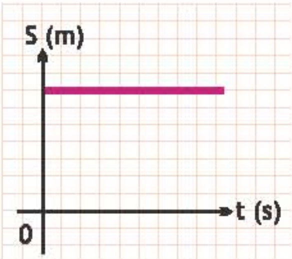
12. In 5 s a car accelerates so that its velocity increases by 20m/s. The acceleration is

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

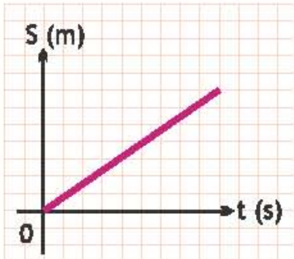
13. Ball dropped freely from a tower reaches ground in 4s, the speed of impact of ball is:

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

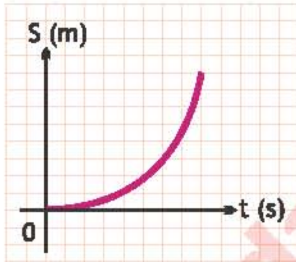
14. Which of following distance time graphs represents increasing speed of a car?



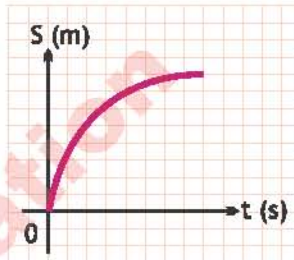
A.



B.



C.



D.

SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

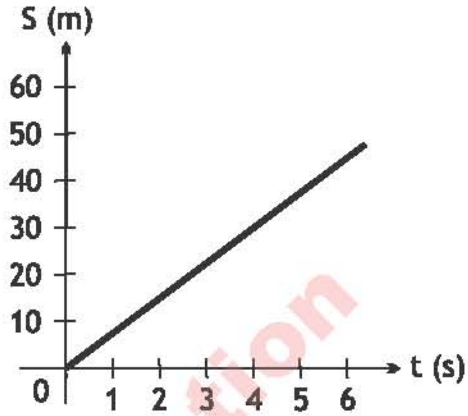
1. In a park, children are enjoying a ride on Ferris wheel as shown. What kind of motion the big wheel has and what kind of motion the riders have?
2. A boy moves for some time, give two situations in which his displacement is zero but covered distance is not zero?
3. A stone tied to string is whirling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

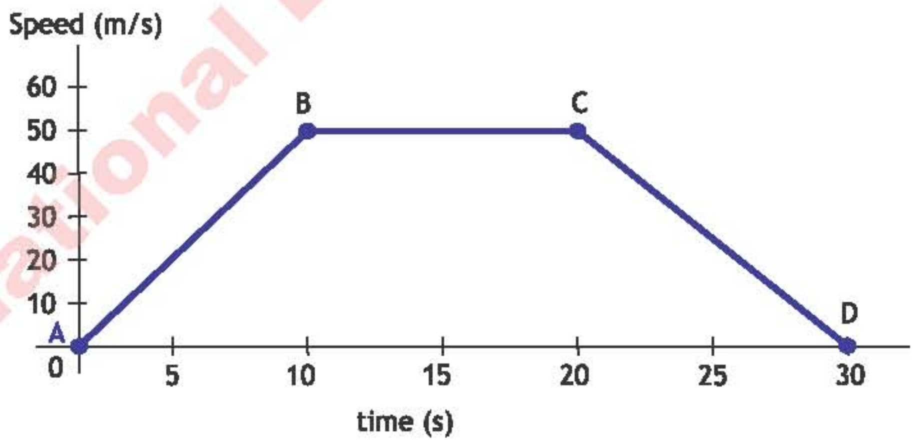
QIII. Give a detailed response to questions below.

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

DYNAMICS - 1

UNIT 3

What force enable us to hold rope tightly?

Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-B-17] Illustrate that mass is a measure of the quantity of matter in an object.
- [SLO: P-09-B-18] Explain that the mass of an object resists change from its state of rest or motion (inertia).
- [SLO: P-09-B-19] Define and calculate weight.
- [SLO: P-09-B-20] Define and calculate gravitational field strength.
- [SLO: P-09-B-21] Justify and illustrate the use electronic balances to measure mass.
- [SLO: P-09-B-22] Justify and illustrate the use of a force meter to measure weight.
- [SLO: P-09-B-23] Differentiate between contact and non-contact forces.
- [SLO: P-09-B-24] Differentiate between different types of forces.
- [SLO: P-09-B-25] State that there are three fundamental forces and describe them in terms of their relative strengths.
- [SLO: P-09-B-26] Represent the forces acting on a body using free body diagrams.
- [SLO: P-09-B-27] State and apply Newton's first law.
- [SLO: P-09-B-28] Identify the effect of force on velocity.
- [SLO: P-09-B-29] Determine the resultant of two or more forces acting along the same straight line.
- [SLO: P-09-B-30] State and apply Newton's second law in terms of acceleration.
- [SLO: P-09-B-31] State and apply Newton's third law.
- [SLO: P-09-B-32] Explain with examples how Newton's third law describes pairs of forces of the same type acting on different objects.
- [SLO: P-09-B-33] State the limitations of Newton's laws of motion.
- [SLO: P-09-B-39] Define and calculate momentum.
- [SLO: P-09-B-40] Define and calculate impulse.
- [SLO: P-09-B-41] Apply the principle of the conservation of momentum to solve simple problems in one dimension.
- [SLO: P-09-B-42] Define resultant force in terms of momentum.

In kinematics we have discussed how motion is described in terms of velocity and acceleration. Now we deal with the questions like: How an object at rest begin to move? What causes an object to accelerate or decelerate? What makes an object to moves in a curved path? The simple answer to all these questions is force. In this Chapter, we will study the connection between force and motion, which is the subject called dynamics.

FIGURE 3.1 FORCE

Every motion you observe or experience is related to a force as shown in figure 3.1. We can start moving a trolley by simply applying force on it, we can use this force to speed it up or slow it down and we can even change its direction.

3.1 FORCE

Force is vector quantity which changes or tends to change state of body; start or stop its motion, speed it up or slow it down and can change the direction of its motion.

3.1.1 TYPES OF FORCES

Forces are broadly classified as contact and non contact forces.

A. CONTACT FORCES

The force acting between two objects that are in physical contact are termed as contact forces. For example, in game of cricket a batter hitting a cricket ball (Figure 3.2) is a contact force since there is physical contact is between the bat and the ball.

FIGURE 3.2 CONTACT FORCE

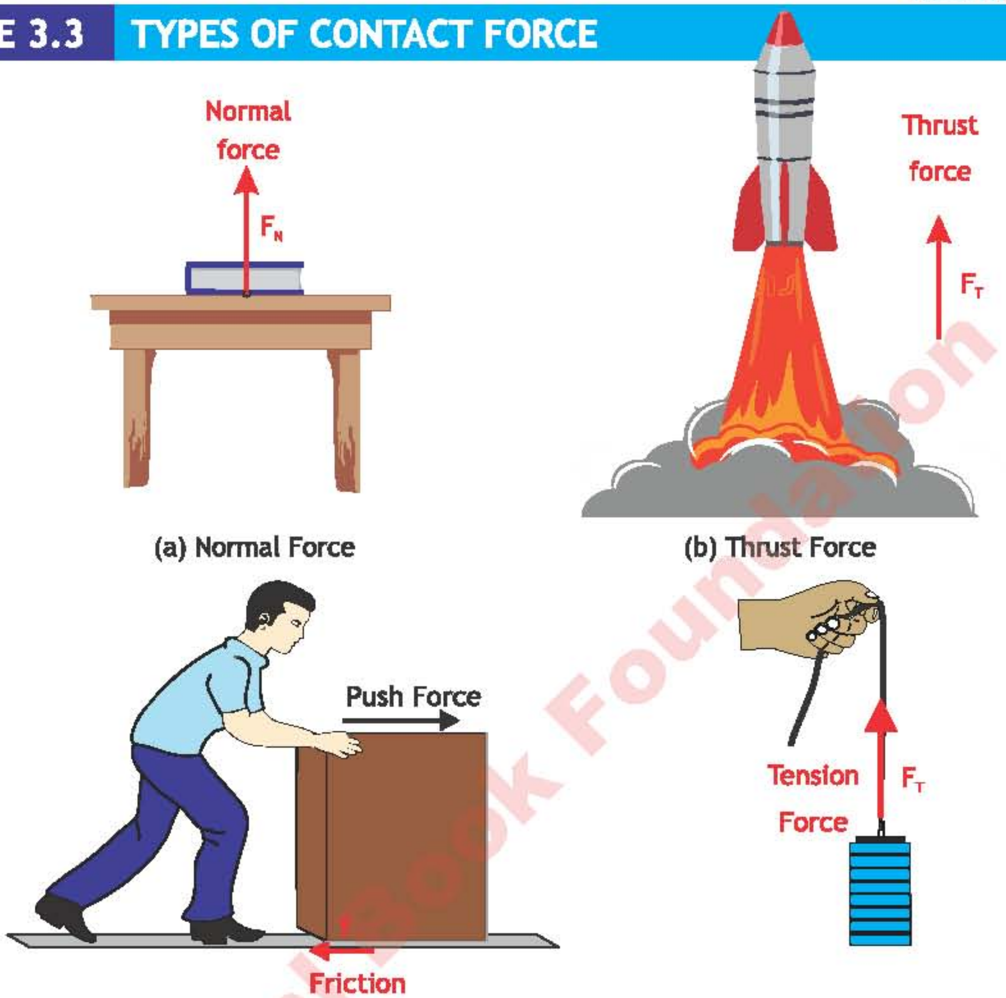
A force perpendicular to the contact surface that keeps objects from passing through each other is called the **normal force** and is represented as F_N. (In geometry, normal means perpendicular). For example the book lying on table, the force perpendicular to the table is normal force figure 3.3 (a).

The force that propels a flying machine in the direction of motion is termed as **thrust**. For example engines produce thrust, the thrust of engine of car cause it to accelerate as shown in figure 3.3 (b).

Force that resist the relative motion of solid surfaces, fluid layers, and material elements in contact and sliding against each other is called **friction**. Friction on an object acts in a direction opposite to the direction of the object's motion or attempted motion figure 3.3 (c).

For example air resistance is also a frictional force which occurs between air and an object. It is the force that the object experiences as it passes through the air. It is a kind of the drag force which resists the motion of a body with fluid.

FIGURE 3.3 TYPES OF CONTACT FORCE



(a) Normal Force (b) Thrust Force

(c) Friction Force (d) Tension Force

The forces exerted by two or more physical objects that are in contact, through string, rope, cable or spring, we call such force as **tension**. For example tension keeps spider web together consists of numerous fine strands that pull on one another. The tension in cord attached to a string is shown in the figure 3.3 (d). The forces that an object exerts to resist a change in its shape are called **elastic forces**; they arise from forces between the particles in the material. For example when force is applied to a spring or rubber band it will stretch and at same time resists being stretched. It must be noted that the tension is the elastic only during extension not compression.

B. NON-CONTACT FORCES

Have you seen magnets exerting push or pull on other magnets at some distance? The force which acts at a distance, without any physical contact between bodies is termed as non-contact force. This force acts even if the objects involved are not touching, also termed as action at a distance force. The attractive force between two objects with mass is called **gravitational force**. For example, the force experienced by moon because of earth. An attractive or repulsive force experienced by charged objects is called **electrostatic force**. For example the attractive force between a positively charged nucleus and negatively charged electron.

An attractive or repulsive force experienced between magnetic poles is called **magnetic force**. For example the repulsive force between the two North poles of magnets.

3.1.2 FUNDAMENTAL FORCES IN NATURE

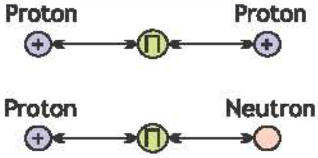
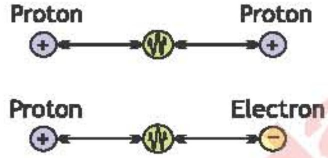
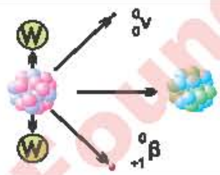
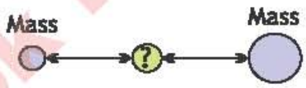
There are many different types of forces around us, but physicists have classified forces into only four categories based on how objects interact with one another. The four fundamental forces of nature are the gravitational force, the electromagnetic force, the strong nuclear force, and the weak nuclear force. Physicists have classified all forces that exist as one of these four fundamental forces. Physicists explain these fundamental forces through exchange particles. Elementary particles, much less massive than a proton, travel from one object to another "carrying" the force. In this way, each force is 'carried' or mediated by the exchange of a particle.

A. Strong Nuclear Force: The strong nuclear force is the strongest of all the fundamental forces. It keeps the positively charged protons tightly packed in the nucleus of an atom, by overcoming the repulsion between them . The exchange particles of strong force are called pions, with other heavy particles. The strong nuclear force has a very short range, nearly equal to the diameter of a proton.

B. Electromagnetic Force: The electromagnetic force act between electric charges. It includes both electric forces and magnetic forces. The electromagnetic force can exert either an attraction or a repulsion, so on average, the forces tend to cancel each other out and its effect is not observed. The electromagnetic force is mediated by a massless particle known as a photon. The massless nature of the photon makes the effective range infinite, even though the strength of the force decreases rapidly as the distance between the objects increases. The normal force, friction, and tension are caused by the interaction of particles on the contact surfaces and are thus a result of the electromagnetic force.

C. Gravitational Force: The gravitational force, or the force of gravity, is the force of attraction between all objects in the universe. Gravity is by far the weakest of the four fundamental forces (with least relative strength), the force of gravity between two objects is noticed only if at least one of the objects has a large mass such as stars, planets, and moons. It holds them together and controls their motions in the same way that it controls the motion of falling objects here on Earth. Gravitational force is theorized to be an exchange force with a massless mediating particle 'graviton'. The massless nature of the graviton allows gravity to have infinite range similar to the electromagnetic force. However, the graviton is the only exchange particle not detected yet.

D. Weak Nuclear force: The weak nuclear force is very weak, 10 000 times weaker than the strong nuclear force and has the shortest range of any of the fundamental forces. Despite this, the weak nuclear force plays a major role in the structure of the universe. It is an exchange force mediated by the exchange of three different particles called vector bosons. The weak nuclear force is responsible for radioactive decay. Specifically, the weak force changes the flavour (type) of an elementary particle called a quark. When this process occurs, a neutron in the nucleus transforms into a proton.

TABLE 3.1: FUNDAMENTAL FORCES IN NATURE				
Fundamental Force	**Range (metre)**	**Relative strength**	**Function**	**Exchange Particles**
Strong Force	10^{-15} (diamete r of proton)	1		Pions (Π) or others)
Electromagnetic Force	infinite	7.3×10^{-3}		Photons (massles)
Weak Force	10^{-17}	10^{-6}		W^+, W^-, Z_0 (vector bosons)
Gravitational Force	infinite	6×10^{-39}		graviton (not yet detected)

For years physicists have sought to show that the four basic forces are simply different manifestations of the same fundamental force. The most successful attempt at such a unification is the electroweak theory, proposed during the late 1960s by Abdus Salam (Pakistani physicist), Steven Weinberg, and Sheldon Lee Glashow. This theory, which incorporates quantum electrodynamics (the quantum field theory of electromagnetism), treats the electromagnetic and weak forces as two aspects of a more-basic electroweak force that is transmitted by four carrier particles, the so-called gauge bosons.

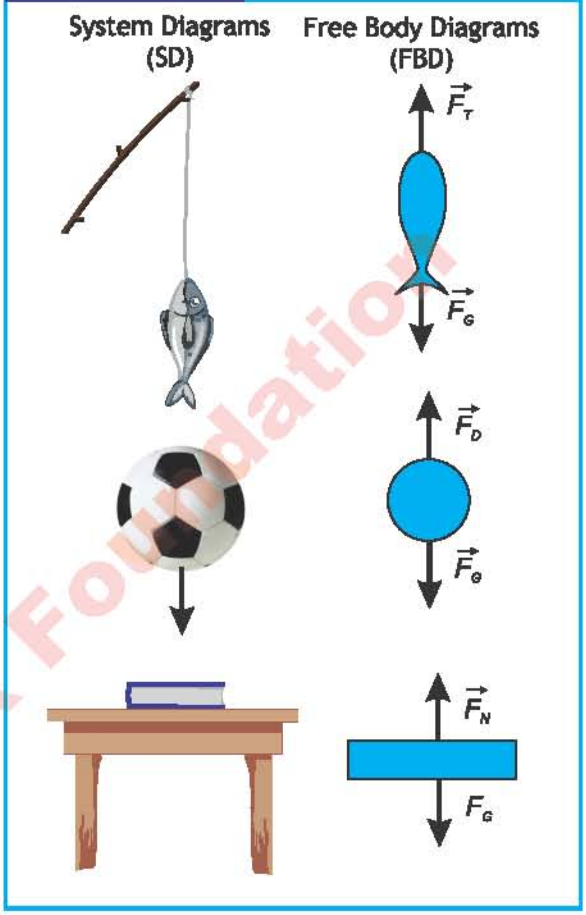
FIGURE 3.4 ABDUS SALAM

One of these carrier particles is the photon of electromagnetism, while the other three—the electrically charged W^+ and W^- particles and the neutral Z_0 particle—are associated with the weak force. Unlike the photon, these weak gauge bosons are massive, and it is the mass of these carrier particles that severely limits the effective range of the weak force.

3.1.3 FORCE DIAGRAMS

In order to study forces and their effects on the objects, we should familiarize ourselves with the skill of drawing force diagrams. Commonly two types of force diagrams, 'system diagrams' and 'free-body diagrams', are used. A system diagram (SD) is a visual expression of all the objects required. A free-body diagram (FBD) is a schematic representation in which only the object being analyzed is drawn, with arrows showing all the forces acting on the object. Figure 3.5 shows three examples SDs and FBDs: the force vectors are drawn with their lengths proportional to the magnitudes of the forces; each force vector is labelled with the symbol '$\vec{F}$', with a subscript (for example, '$\vec{F}_g$' is the force of gravity, '$\vec{F}_N$' is the normal force, '$\vec{F}_f$' is friction, '$\vec{F}_T$' is tension, and '$\vec{F}_A$' is the applied force).

FIGURE 3.5 FORCE DIAGRAMS



3.1.4 CONCEPT OF NET FORCE

Different forces can affect an object, and the net force is the total effect of all these forces. It is calculated by adding up all the forces acting on the object.

The net force helps us determine if the forces on the object are balanced or unbalanced. If the net force is 0 N, it means the forces are balanced, and there will be no change in the object's motion.

FIGURE 3.6 NET FORCE

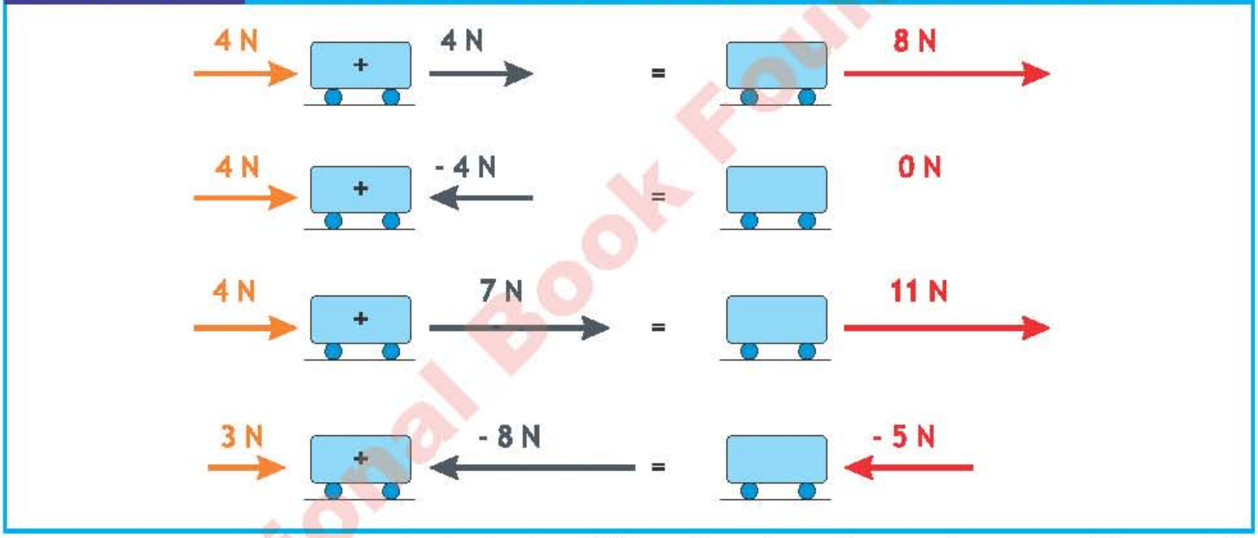
For example, in a tug of war shown in figure 3.6 (a) the forces 'F_1' and 'F_2' are equal in magnitude and opposite in direction, the forces cancel the effect of each other and there is no net force. However, when the net force on an object is not 0 N, the forces are unbalanced and produce a change in motion of an object. For example, for tug of war in figure 3.6 (b) one force 'F_2' exceeds the other force 'F_1', and there is a net force 'F_{net}' to the right.

FREE-BODY DIAGRAMS AND RESULTANT (NET) FORCES

To study the effects of forces acting on any object, we can apply the skill of drawing force diagrams. Since force is a vector quantity, the vector sum of all the forces acting on an object is the resultant force. The resultant force can also be called the net force. These two terms can be used interchangeably. They will be represented by the same symbol, '$\vec{F}_{net}$', in this text.

The net force or resultant force can be obtained by simply adding forces. A resultant force is a single force that has the same effect as the combined effect of all the forces to be added. Forces are vector quantities which require both magnitude with proper unit as well as direction for its complete description. Therefore it is required that we should draw the forces to a common scale as vectors (arrow diagrams). Simply add the magnitudes of vectors in case of like parallel forces and subtract the magnitudes of vectors in case of unlike parallel forces. Few examples are shown in the figure 3.7.

FIGURE 3.7 NET FORCE FOR LIKE AND UNLIKE PARALLEL FORCES

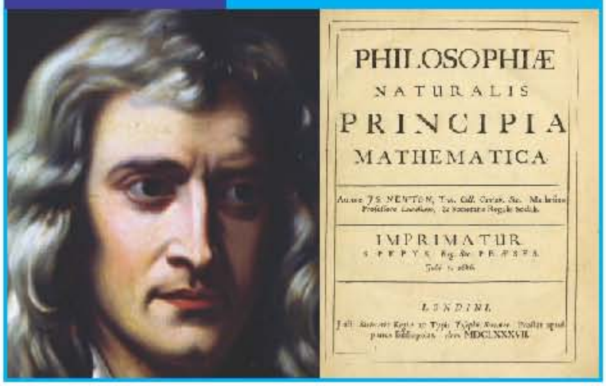


However, we cannot make such algebraic addition of vectors when vectors are making certain angle. In such cases we draw vectors on a coordinate axis and then according to the same scale we can add them by head to tail rule of vector addition.

3.2 NEWTON'S LAWS OF MOTION

In 1686 English Scientist Sir. Isaac Newton (1642-1727) presented his three laws of motion in a book *Philosophiae Naturalis Principia Mathematica* (English: Principles of Natural Mathematics) as shown in the figure 3.8. This book is considered as the greatest scientific work ever written.

FIGURE 3.8 SIR. ISAAC NEWTON



3.2.1 NEWTON'S FIRST LAW OF MOTION

In a soccer game, players kick the ball to each other. When a player kicks the ball, the kick is an unbalanced force. It sends the ball in a new direction with a new speed. What keeps the ball rolling? To answer we have to look into statement of newton's first law of motion.

If the net external force acting on an object is zero, the object will maintain its state of rest or uniform motion (constant velocity).

It means that in absence of external net force, an object at rest, it will remain at rest; While an object in motion will continue to move with constant velocity (no change in velocity or no acceleration). Mathematically,

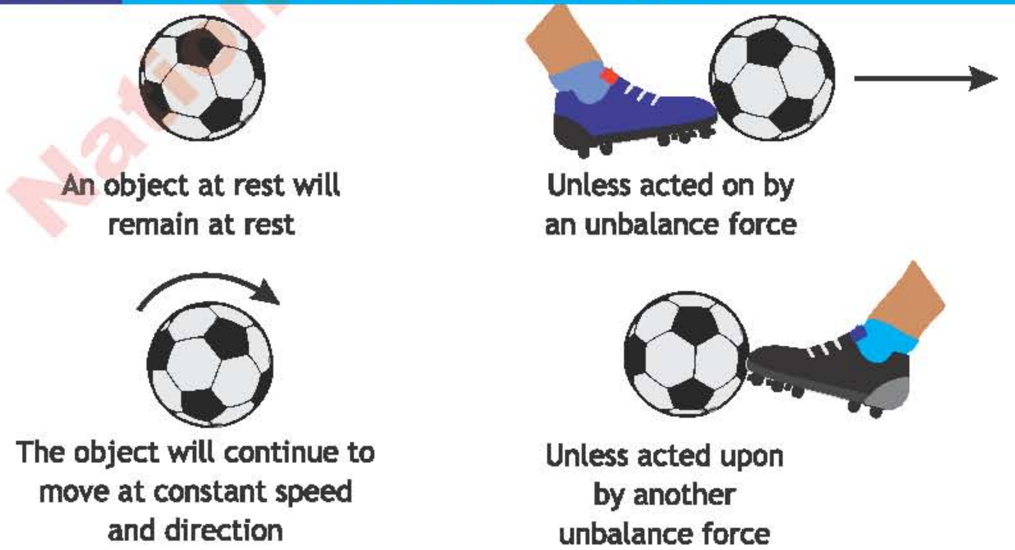
$$\vec{F}_{net} = 0 \quad \text{then} \quad \Delta\vec{v} = 0 \quad \text{or} \quad \vec{a} = 0$$

SCIENCE TIDBITS

An external force is an applied force, applied on to the object or system. There are also internal forces. For example, suppose the object is a train and you are a passenger traveling inside it. You can push (apply a force) on the floor or the walls of cabin, but this has no effect on the train's velocity because your push is an internal force.

This means that object in motion would continue to move in a straight line for ever. However on the Earth, it is difficult to observe an object in a state of uniform motion, because of presence of forces (like gravity and friction), which continually retard motion of the objects. But in free space, where there is no friction and negligible gravitational attraction, an object initially in motion maintains a constant velocity.

FIGURE 3.9 NEWTON'S FIRST LAW OF MOTION



An object can continue to move when the unbalanced forces are removed. For example, when a soccer ball is kicked, it experiences an unbalanced force. The ball keeps rolling on the ground until another unbalanced force alters its movement as shown in figure 3.9.

POINT TO PONDER

Why is it more difficult to push large man on swing compared to a small child?

There is a difference in the resistance to a change in motion between the man and the child. Also, when you try to stop their motions, you would again notice a difference in the resistance to a change in motion. Because large man has more inertia due to more mass.

First law of motion specifies that there is a natural tendency of an object to remain in a state of rest or in uniform motion in a straight line termed as **inertia**. Does all objects have equal tendency to resist its state of rest or uniform motion? Absolutely not, the object with more mass (the measure of the amount of matter in a body) has greater resistance to change (inertia), is the reason why it is difficult to move massive objects. Mass is a quantity that is dependent on inertia (the greater the mass of an object, the greater its inertia, and vice versa).

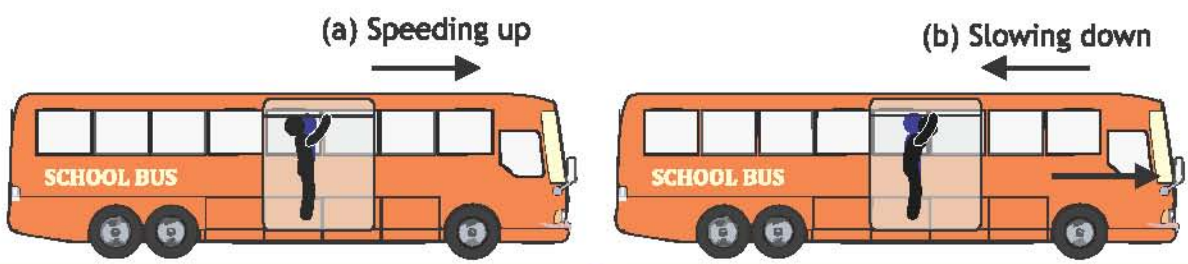
ACTIVITY

Place a stack of coins over a small sheet of paper. Quickly remove the sheet without

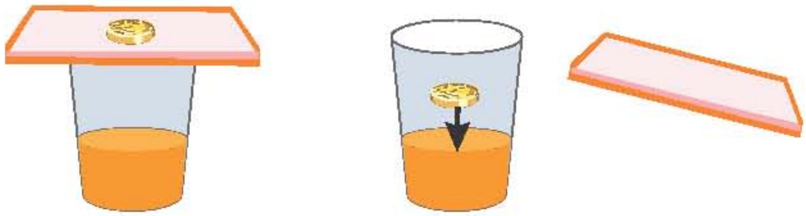
toppling the stack of coins. Increase the number of coins and see who wins the game.

Newton's first law of motion is applied when we ride standing in the aisle of a bus holding a pole as shown in figure 3.10 (a). As the bus begins to move, we tend to remain at rest, therefore we feel a push to back (as our lower body start moving with the bus, but the upper part of body maintains the state of inertia). The same principle is again at work when the bus start to slow down or stops, we feel to move forward due to inertia as shown in the figure 3.10 (b).

FIGURE 3.10 INERTIA AND SUDDEN MOTION OF BUS

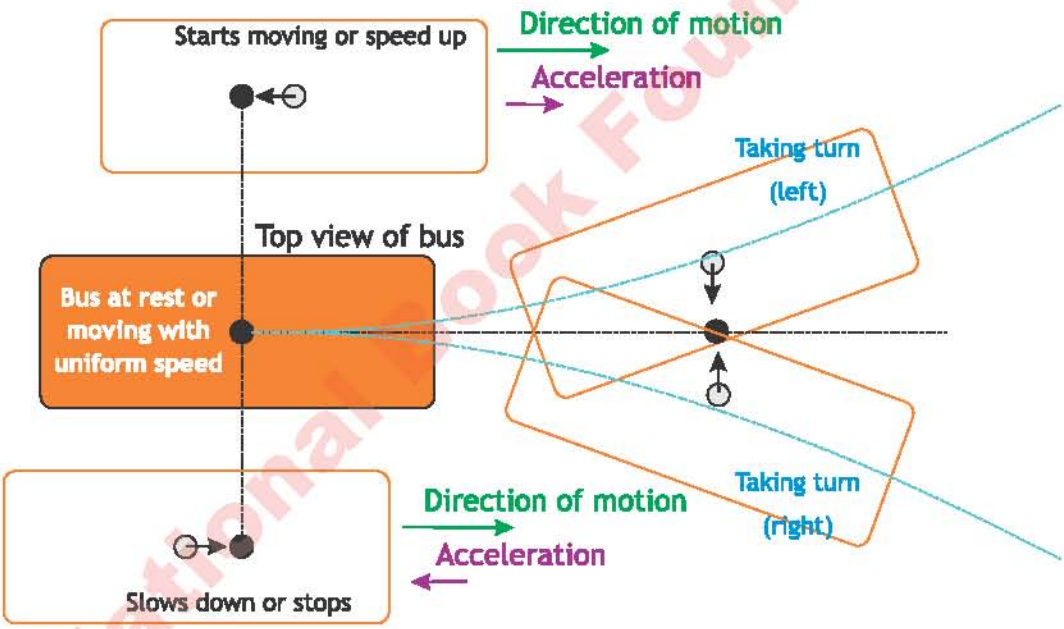


ACTIVITY



Place a card on top of a glass, and put a coin above this arrangement. If you quickly flick the card horizontally, the inertia of the coin will keep it at rest horizontally. The vertical force of gravity will pull it straight down into the glass.

FIGURE 3.11 INERTIA ON AN OBJECT IN BUS



As the bus start moving with uniform speed if we hold on to the pole, it supplies the forces needed to give us the same motion as the bus, we no longer feel pushed. But when the bus goes around a curve, again we feel a tendency to move to the side of the bus. The bus has changed its straight line motion, but we tend to move straight ahead. The same principle is again at work when the bus start to slow down or stops, we feel to move forward as shown in the figure 3.11. Thus the forces we feel when the bus starts moving, speeds up, slows down or turn around a corner are a result of our tendency to remain at rest or follow a straight path.

3.2.2 NEWTON'S SECOND LAW OF MOTION

What causes acceleration (change in velocity)? We can get this answer from Newton's first law of motion as 'external, unbalanced net force is required to produce a change in velocity'. Newton went further and related acceleration to inertia (or mass), that it tend to reduce this acceleration

The acceleration produced by a net force acting on an object (or mass) is directly proportional to the magnitude of the force ($a \propto F_{net}$) and in the direction of the force (the $\propto$ symbol is a proportionality sign). In other words, the greater the unbalanced net force, the greater the acceleration.

The acceleration of an object being acted on by a net force is inversely proportional to the mass of the object ($a = 1/m$). That is, for a given unbalanced net force, the greater the mass of an object, the smaller the acceleration.

Combining these effects of net force and mass on acceleration gives

$$acceleration = \frac{net\ force}{mass}$$

Using appropriate units we can write

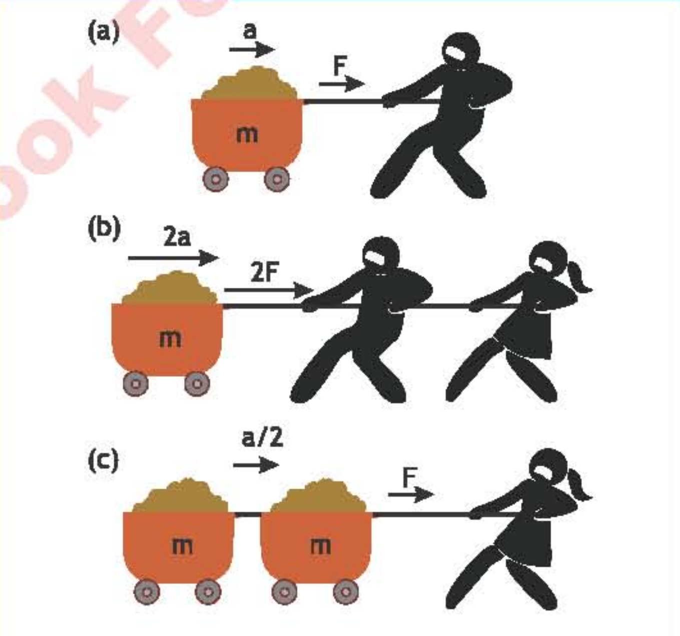
$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

This is Newton's second law of motion which can be formally stated as, **The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.**

Commonly written in terms of force in magnitude form, we have Newton's second law of motion:

$$\vec{F}_{net} = m\vec{a} \quad (3.1)$$

FIGURE 3.12 NEWTON'S SECOND LAW



As an example consider the figure 3.12 (a), mass m is the mass of the system, when net force acts it produces an acceleration 'a'. In figure 3.12 (b) the force is doubled by keeping the mass same, the acceleration also doubles where as in figure 3.12 (c) the mass is doubled while force is kept the same the acceleration is halved.

Newton's second law of motion also enable us to define System International (SI) unit of force **newton** represented by symbol **N**.

One newton is defined as the force that produces acceleration of one meter per second squared (a = 1 m/s²) in a body of mass one kilogram (1 kg).

$$1N = 1kg \times 1m/s^2 \quad \text{or} \quad N = kgm/s^2$$

EXAMPLE 3.1: BUS AND CAR ACCELERATIONS

If the same engine is installed in a bus and car that applies a force of 3000 N. What acceleration will this engine produce in a bus of mass 12,000 kg and a car of mass 1200 kg?

GIVEN

Mass of bus m_b = 12000 kg

Mass of Car m_c = 1200 kg

Force F = 3000 N

REQUIRED

Acceleration in bus a_b = ?

Acceleration in car a_c = ?

SOLUTION:

From Newton 2nd law of motion $a = \frac{F}{m}$

For bus $a_b = \frac{F}{m_b}$ Putting values $a_b = \frac{3000\,N}{12000\,kg} = \frac{3000\,kg\,m/s^2}{12000\,kg}$

Therefore $a_b = 0.25\ m/s^2$ — Answer

For car $a_c = \frac{F}{m_c}$ Putting values $a_c = \frac{3000\,N}{1200\,kg} = \frac{3000\,kg\,m/s^2}{1200\,kg}$

Therefore $a_c = 2.5\ m/s^2$ — Answer

3.2.3 NEWTON'S THIRD LAW OF MOTION

When we press a stone with our finger, the finger is also pressed upon by the stone. The reason is given by Newton's third law of motion, which can be stated as

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object.

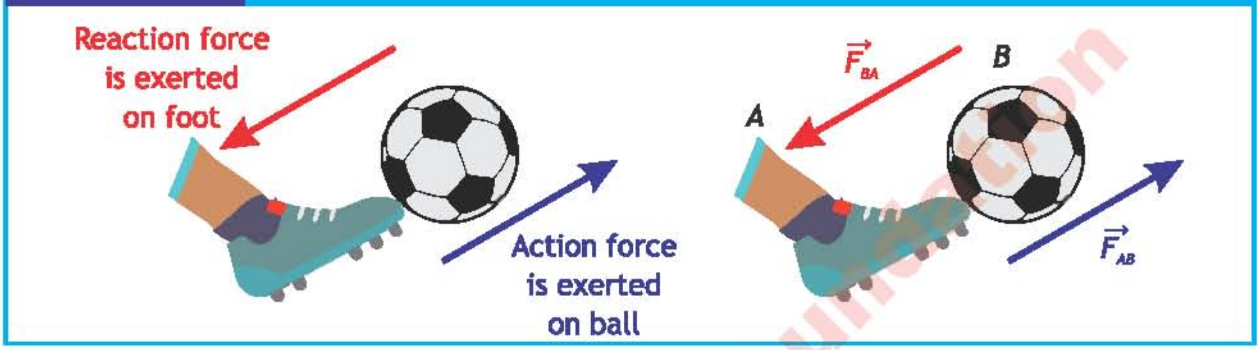
When an object *'A'* exert force on object *'B'* written as '$\vec{F}_{AB}$', object *'B'* also exert equal force on object *'A'* written as '$\vec{F}_{BA}$' but in opposite direction:

$$\vec{F}_{AB} = -\vec{F}_{BA} \qquad (3.3)$$

Here the negative sign shows that force '$\vec{F}_{BA}$' is opposite to force '$\vec{F}_{AB}$'.

These two forces are termed as action - reaction pair. Action and reaction cannot cancel each other because they act on different bodies (action on one body and reaction on another body). When we kick a football as shown in figure 3.13, the foot exerts the action force F_{AB} on the football and as a reaction the foot ball exerts an equal and opposite force F_{BA} on our foot. Both these forces are equal in magnitude and opposite in direction.

FIGURE 3.13 NEWTON'S THIRD LAW OF MOTION



Examples of Newton's third law of motion are present every where, because when we talk of force we also consider its reaction.

For example, when we jump, our legs apply a force to the ground, and the ground applies an equal and opposite reaction force that pushes us into the air. When we punch an object or kick something as an action, we also get a force onto our hands and legs as a reaction force. That is why we feel pain when punching a wall, or falling on the ground. The exhaust from the rocket creates a downward force which creates an equal and opposite thrust in the upward direction as shown in figure 3.14. Applying Newton's third law of motion allow us to explore two important forces normal force and tension force.

FIGURE 3.14 NEWTON'S THIRD LAW

3.2.4 LIMITATIONS OF NEWTON'S LAWS OF MOTION

Although Newton's laws of motion are a fundamental set of principles and are applied in variety of situations. While they are very useful for describing the behavior of everyday objects, there are some limitations to their applicability.

- Newton's laws are not readily applied on the very small scale: As one goes to extremely low energies on the atomic scale, position and acceleration are not well defined, where the concepts of quantum mechanics takes over.

- Newton's laws are not applied for objects moving at high speed (speeds close to the speed of light) relativistic effects complicate the dynamics at high speeds and high energies. In such situations we would require to use relativistic mechanics.

However, Newton's laws are not exact but provide a good approximation on the large (macroscopic) scale and over the vast range of practical energies and forces. Newton's laws are still work spectacularly well in physics and engineering.

3.3 MASS AND WEIGHT

In our daily life we use the term mass and weight in almost the same meaning. However, mass is the amount of matter an object contains (and a measure of inertia). Weight is the gravitational force acting on a mass or object. Newton's second law can be used to relate the two quantities.

On the surface of the Earth, where the acceleration due to gravity is relatively constant ($g = 9.80$ m/s^2), the weight W is

$$\text{weight} = \text{mass} \times \text{acceleration due to gravity}$$

$$\vec{w} = m\vec{g} \qquad (3.2)$$

Note that this equation is a special case of $\vec{F} = m\vec{a}$ where different symbols, W and g, have been used for force and acceleration.

3.3.1 MEASURING FORCE AND MASS:

Two devices used to measure force in the laboratory are the spring scale and the force sensor, as shown in figure 3.15.

Spring scale is a device used for measuring the force acting on an object. It consists of a spring which gets stretched when a force is applied to it. Stretching of the spring is measured by a pointer moving on a graduated scale. The reading on the scale gives the magnitude of the force.

The force sensor uses an electronic gauge to measure force measure force with a high degree of accuracy. It gives a digital readout or a graph of the forces when interfaced with a computer.

Weight is the effect that gravitational force has on an object. Mass is the amount of matter in an object irrespective of the gravitational force. If we to move to the Moon, our weight would be reduced roughly by 5/6, but our mass would stay the same.

However by using Newton's we laws convert our weight into mass easily.

FIGURE 3.15 FORCE AND MASS MEASUREMENT

(a) Spring balance (b) Force sensor

Equation 3.2 can be written as:

→

→

Thus if we somehow measure the force of gravity as weight *'W'* and divide the value by acceleration due to gravity *'g'* we could easily find our mass *'m'*. Weighing-scales (actually force-measurers) as shown in figure 3.16 are therefore graduated in kg to show mass. Thus every time you stand on weight machine it gives your mass in *'kilograms'*, not your weight in *'newtons'*.

FIGURE 3.16 WEIGHT MACHINE

Weight machine can be calibrated to measure mass

EXAMPLE 3.2: WEIGHT OF SCHOOL BAG ON EARTH AND MOON

Mass of your school bag is 8 kg. How much will it weigh (a) here on Earth and on (b) the surface of moon? [Take acceleration due to gravity for Earth as $g_E = 9.8\ m/s^2$ and for Moon as $g_M = 1.625\ m/s^2$]

GIVEN

Mass of school bag 'm' = 8 kg

acceleration due to gravity for Earth $g_E = 9.8\ m/s^2$ and acceleration due to gravity for Moon as $g_M = 24.8\ m/s^2$

REQUIRED

(a). Weight on surface of Earth w_E = ?

(b). Weight on surface of Moon w_M = ?

SOLUTION: Weight of a body is given by: $W = mg$

(a) The weight on surface of earth is $W_E = m\ g_E$

Putting values $W_E = 8\ kg \times 9.8\ m/s^2$

$$W_E = 78.4\ kg\ m/s^2 = 78.4\ N$$ — Answer

(b) The weight on surface of Moon is $W_M = m\ g_M$

Putting values $w_M = 8\ kg \times 1.625\ m/s^2$

$$w_M = 13\ kg\ m/s^2 = 13\ N$$ — Answer

Due to low value of "g" on Moon's surface, it will be much easy for you to carry your bag to school. Similarly, it will be easy for you to do the routine works and will not get tired easily on Moon's surface.

3.4 GRAVITATIONAL FIELD

The region around a non contact forces where a magnetic force is operative is termed as force field. Whereas the region around a massive object (such as earth, sun etc.) where gravitational force is operative is termed as gravitational field.

The gravitational field strength is the amount of force per unit mass acting on objects in the gravitational field. The value of 'g' is equal to the magnitude of the gravitational force exerted on a unit mass at that point, mathematically

$$g = F_g/m.$$

The gravitational field strength (g) is a vector with a magnitude of 'g' that points in the direction of the gravitational force.

The gravitational field strength 'g' for earth is shown in the figure 3.17. Since, from newton's second law of motion:

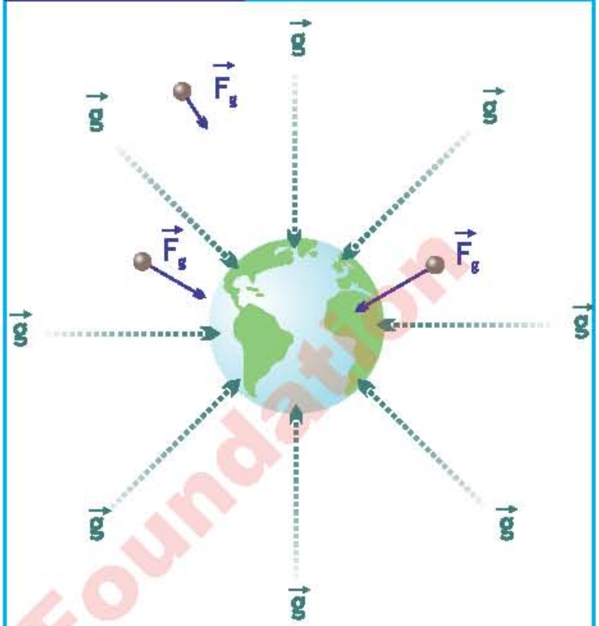
$$\vec{a} = \frac{\vec{F}}{m}$$

similarly $$\vec{a}_g = \frac{\vec{F}_g}{m} = \vec{g} \qquad (3.3)$$

In SI units, gravitational field strength is measured in newton per kilogram (N/kg). It is a vector quantity that has the direction downward or toward the centre of Earth.

Since the gravitational field strength and the acceleration due to gravity are equal in magnitude, the same symbol, $\vec{g}$, is used for both. Therefore, on Earth's surface, $\vec{g}$ = 9.8 N/kg [↓], or $\vec{g}$ = 9.8 m/s² [↓].

FIGURE 3.17 FIELD STRENGTH



Gravitational field strength 'g'

TABLE 3.2: GRAVITATIONAL FIELD STRENGTH IN THE SOLAR SYSTEM

Planet	g (N/kg)
Mercury	3.7
Venus	8.9
Earth	9.8
Mars	3.7
Jupiter	24.7
Saturn	9.0
Uranus	8.7
Neptune	11.0
Sun	274

The gravitational field strength is not the same everywhere. Gravitational force decrease as we move away from the surface of earth, therefore gravitational field strength also decreases. Also on different planets we have different gravitational field strengths as shown in table 3.2.

EXAMPLE 3.2: WEIGHT OF SCHOOL BAG ON EARTH AND MOON

A box weighs 400 N on earth while 150 N on an unknown planet. Find the gravitational field strength on that planet.

GIVEN

Weight on Earth 'W_E' = 400 N
Weight on unknown planet 'W_N' = 150 N
Gravitational field strength on Earth 'g_E' = 9.8 N/kg

REQUIRED

Gravitational field strength on the unknown planet 'g_N' = ?

SOLUTION

Since, weight of a body is the product of its mass and acceleration due to gravity, given by:

or

Since, mass of a body remains constant, therefore,

or

Putting values

Hence — Answer

The value 3.675 agrees with the numerical value of gravitational field strength on the surface of Mars. So, the unknown planet is Mars (red planet), the nearest planet to earth.

3.5 MOMENTUM

The product of the object's mass 'm' and velocity '$\vec{v}$' is called momentum, denoted by '$\vec{P}$'. Mathematically

$$\vec{p} = m\vec{v} \qquad (3.4)$$

Momentum is a vector quantity that points in the same direction as the velocity. SI Unit of momentum is kilogram-meter per second (kgm/s), or newton-second (Ns). Newton's second law is used to relate force and momentum.

EXAMPLE 3.4: GOLF BALL MOMENTUM

A golfer hits a ball having mass 45 g. If after the shot, the ball travels with a speed of 80 m/s, what magnitude of momentum does the golfer imparted to ball?

GIVEN

Mass of ball 'm' = 45 g = 0.045 kg
Velocity of ball 'v' = 80 m/s

REQUIRED

Momentum of ball 'P' =?

SOLUTION

From the mathematical form of linear momentum: $\vec{p} = m\vec{v}$

for magnitude ignoring the vector signs: $p = mv$

putting values $p = 0.045\ kg \times 80\,{}^{m}\!/_{s}$

Therefore $p = 3.6\ kg\,{}^{m}\!/_{s}$ — **Answer**

In order to increase the speed of ball, the golfer needs to impart a greater momentum to the ball.

3.5.1 FORCE AND CHANGE IN MOMENTUM

A force '$\vec{F}$' produces acceleration '$\vec{a}$' in a body of mass 'm'. By Newton's second law of motion it is written as

$$\vec{F}_{net} = m\vec{a} \quad (1)$$

The acceleration produced changes the velocity of the body from initial velocity '$\vec{v}_i$' to final velocity '$\vec{v}_f$' during time interval 'Δt'. Then by definition of acceleration

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \quad (2)$$

Putting equation 2 in equation 1

$$\vec{F}_{net} = m\frac{\vec{v}_f - \vec{v}_i}{\Delta t} \quad \text{or} \quad \vec{F}_{net} = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t}$$

FIGURE 3.18 CATCHING

Hence $\vec{F}_{net} = \frac{\vec{p}_f - \vec{p}_i}{\Delta t} = \frac{\Delta \vec{p}}{\Delta t}$ —— 3.5

The time rate of change of linear momentum of a body is equal to the net force acting on the body. This means that for sudden change in momentum force is large and vice versa.

For example, catching a ball with your bare hands will hurt depending on the force of the ball. However, if you allow your hands to move with the ball as you catch it, duration of time 'Δt' will increase, and force will be smaller, and your hands will hurt less.

EXAMPLE 3.5: FORCE REQUIRED TO STOP A TRUCK AND CAR

What is difficult to stop if their brakes fail and are travelling from an inclined road:

(a) A car of mass 1200 kg moving with a velocity of 8 m/s in 5 seconds,

(b) A truck of mass 10,000 kg moving with the same velocity in the same time?

GIVEN

Mass of car m_c = 1200 kg

Mass of truck m_T = 10,000 kg

Initial Velocity v_i = 8 m/s

Change in time Δt = 5 s

Final Velocity v_f = 0 m/s (As both car and truck have to stop finally)

REQUIRED

(a) Average force required to stop car F_c = ?

(b) Average Force required to stop truck F_T = ?

SOLUTION

From the relation between force and momentum: p —— 1

Putting Values in equation 1 for car:

Therefore, $F_c = -1920$ N —— Answer

(b) Putting Values in equation 1 for truck:

Therefore, $F_T = -16{,}000$ N —— Answer

The negative sign shows that force is applied opposite to the direction of motion i.e., velocity.

3.5.2 IMPULSE AND CHANGE IN MOMENTUM

Newton's second law enable us to write force and change in momentum relation as:

$$\vec{F}_{net} = \frac{\vec{p}_f - \vec{p}_i}{\Delta t} = \frac{\Delta \vec{p}}{\Delta t}$$

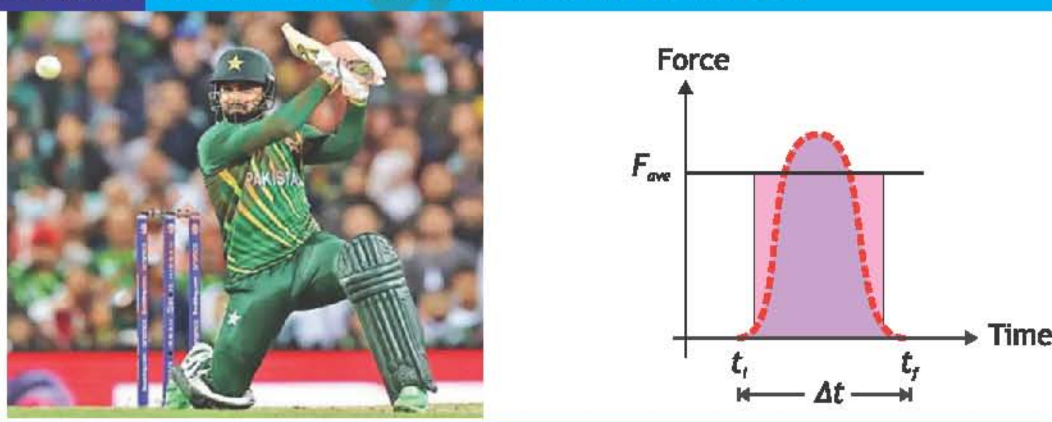
$$\vec{F}_{net} \times \Delta t = \Delta \vec{p} \qquad (3.6)$$

Equation 3.6 enable us to define a new quantity termed as 'impulse'. Impulse is the product of the force exerted on an object and the time interval over which the force acts, and is often given the symbol 'J'. Impulse is a vector quantity, and the direction of the impulse is the same as the direction of the force that causes it, and have the same SI units as momentum.

In many situations, the net force on the object is not constant and the force applied to an object changes non-linearly during its time of application. The equation 3.8 still applies, provided the net force 'F_{net}' is equal to the average force acting on the object over the time interval Δt.

For example, when a batter hits a cricket ball, initially the force is very small. Within milliseconds, the force is large enough to deform the ball. The ball then begins to move by return to its original shape and the force soon drops back to zero. Graph in figure 3.19 shows how the force changes with time. We can find the impulse by calculating the area under the curve in force versus time graph.

FIGURE 3.19 IMPULSE AND CHANGE IN MOMENTUM

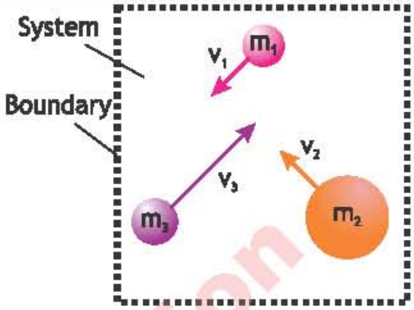


In many collisions, it is difficult to make the precise measurements of force and time that you need in order to calculate the impulse. The relationship between impulse and momentum provides an alternative approach to analyzing such collisions, as well as other interactions. By analyzing the momentum before and after an interaction between two objects, we can determine the impulse.

SCIENCE TIDBITS

Group of bodies or particles, under study separated by a boundary is called as a system. If the net external force on the system is zero, it is termed as isolated system.

An isolated system is a collection of bodies that can interact with each other but whose interactions with the environment have a no effect on their properties is termed as an isolated system.



3.5.3 NEWTON'S LAWS AND CONSERVATION OF MOMENTUM

For an isolated system there is no net force acting '$\vec{F} = 0$', therefore Newton's second law in terms of momentum (equation 3.) can be written as

$$0 = \frac{\Delta \vec{P}}{\Delta t} \quad \text{or} \quad 0 = \frac{\vec{p}_f - \vec{p}_i}{\Delta t}$$

$$\text{therefore} \quad \vec{p}_f = \vec{p}_i \quad \text{or} \quad m_f \vec{v}_f = m_i \vec{v}_i \qquad (3.8)$$

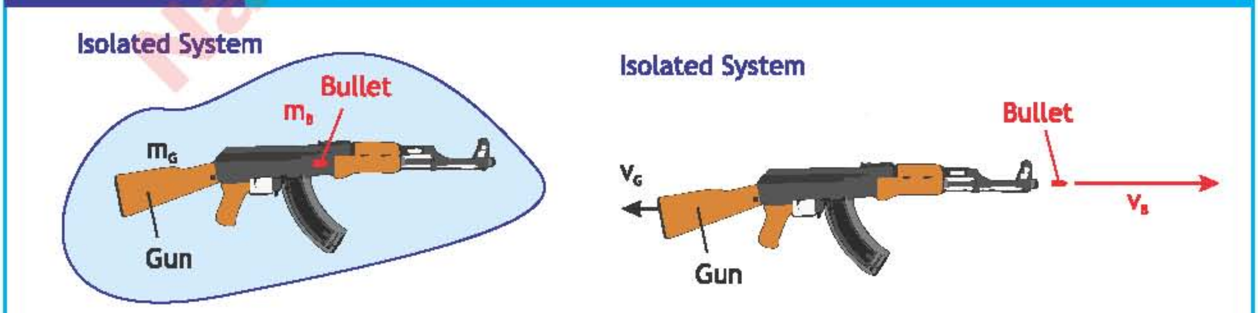
In the absence of external force (isolated system) the final momentum '$\vec{P}_f$' of the system must be equal to initial momentum '$\vec{P}_i$'. If no net external force acts on a system of particles, the total momentum of the system cannot change.

This enable us to write the law of conservation of momentum which states:

'The momentum of an isolated system remains constant'.

Consider an isolated system of bullet of mass m_B and gun of mass m_G. Such that before firing the total initial momentum ($p_i = 0$) of the system is zero as shown in figure 3.20.

FIGURE 3.20 RECOIL OF GUN



After firing the bullet moves with velocity 'v_B' in one direction and the rifle recoils with velocity 'v_G' in the other direction such that the total final momentum ($P_f = 0$) is again zero.

By conservation of momentum $\vec{p}_f = \vec{p}_i = 0$ or $m_B\vec{v}_B + m_G\vec{v}_G = 0$

or $m_G\vec{v}_G = -m_B\vec{v}_B$

Hence $$\vec{v}_G = -\frac{m_B\vec{v}_B}{m_G} \quad (3.9)$$

Negative sign indicates that velocity of the gun is opposite to the velocity of the bullet, i.e., the gun recoils. Since mass of the gun is much larger than the bullet, therefore, the recoil is much smaller than the velocity of the bullet.

POINT TO PONDER

How rockets accelerate in space as there is no air in space to push against such that as a reaction rocket pushed forward?

In rockets, hot gases produced by burning of fuel rush out with large momentum. The rockets gain an equal and opposite momentum, thereby causing them to accelerate.

EXAMPLE 3.6: RIFLE RECOIL

Ahmad fired a bullet of mass 17 g from his hunting gun, of mass 3 kg. If the velocity of the bullet were 350 m/s, what would be the recoil velocity of the air gun?

GIVEN

Mass of Rifle m_G = 3 kg

Mass of bullet m_B = 17 g = 0.017 kg

Velocity of bullet after firing v_B = 350 m/s

REQUIRED

Velocity of Rifle after firing (Recoil speed) v_G = ?

SOLUTION

By law of conservation of momentum the final momentum must be zero, therefore

$m_Bv_B + m_Gv_G = 0$ or $m_Gv_G = -m_Bv_B$ Hence $v_G = -\frac{m_Bv_B}{m_G}$

Putting values $$v_G = -\frac{0.017\ kg \times 350\ m/s}{3\ kg}$$

Therefore $\boxed{v_G = -1.98\ m/s}$ **Answer**

Negative sign is for direction opposite to that of bullet's velocity.

The gun will move in the opposite direction but with a smaller velocity as compared to the bullet because of its greater mass than the bullet..

SUMMARY

- **Dynamics** is the branch of mechanics in which we discuss the motion of bodies along with causes of motion of bodies.
- **Force** is a physical quantity which moves or tends to move a body, stops or tends to stop a moving body or which tends to change the speed and direction of a moving body.
- **Newton's First Law of Motion** states that every body continues in its state of rest or uniform motion in a straight line unless an external net force acts upon it.
- **Newton's Second Law of Motion** states that whenever a net force acts on a body, it produces acceleration in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the mass of the body.
- **Newton's Third Law of Motion** states that to every action there is an equal and opposite reaction.
- **Mass** is the quantity of matter in a body.
- **Weight** is the downward force with which the earth pulls a body towards its center.
- **Gravitational Field Strength** is defined as the force per unit mass that earth exerts on a body.
- **Momentum** is the product of mass and velocity. It is a vector quantity.
- **Law of Conservation of Momentum** states that if there is no external force applied to a system, the momentum of that system remain constant.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option.

1. Inertia of a body is related to which of the following quantities

A. mass B. force C. weight D. friction

2. A force of 5N is applied to a body weighing 10 N. Its acceleration in m/s^2 is:

A. 0.5 B. 2 C. 5 D. 50

3. SI unit of linear momentum is:

A. $kg\ m^{-1}s^{-1}$ B. $kg\ m^2s^{-1}$ C. N m D. $kg\ m\ s^{-1}$

4. The rate of change of momentum of free falling body is equal to its:

A. momentum B. velocity C. weight D. size

5. Change in momentum of a body is equal to:

A. (force) (velocity) B. (force) (time) C. (mass) (time) D. force

6. A book of mass 5 kg is placed on the table, the magnitude of net force acting on the book is:

A. 50 N B. 5N C. 25 N D. 10 N

7. Thrust force is a consequence of which law of motion:

A. First B. second C. third D. fourth

8. A force acts on a body for 2 seconds and it produces 50 kgm/s change in its momentum. The force acting on the body is:

A. 100 N B. 50 N C. 25 N D. 2 N

9. At the fairground, the force that balances your weight is:

A. gravitational force B. centripetal force

C. electrostatic force D. frictional force

10. When a hanging carpet is beaten by stick. Dust flies off the carpet. It is mainly due to:

A. Action force on carpet B. Reaction force by carpet

C. Inertia of dust D. Rate of change of momentum of carpet

12. A bucket having some water is revolved in vertical circle. Water does not spill out, even the bucket is upside down, due to:

A. Weight of water

B. Centrifugal force on water

C. Inertia of water

D. Action and Reaction balance each other

13. The force which moves the car is:

A. Force developed by engine B. Force of friction between road and tyre

C. Weight of car D. Water spilt on the road

14. $N\ kg^{-1}$ is equivalent to:

A. $m\ s^{-1}$ B. $m\ s^{-2}$ C. $kg\ m\ s^{-1}$ D. $kg\ s^{-2}$

15. An object of mass 1 kg placed at earth's surface experiences a force of:

A. 1 N B. 9.8 N C. 100 N D. any value

16. Net force on the body falling in air with uniform velocity is equal to __________.

A. Weight of the body B. air resistance on the body

C. difference of weight of body and air resistance on it D. zero

SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

1. When a motor cyclist hit a stationary car, he may fly off the motor cycle and driver in the car may get neck injury. Explain
2. In autumn, when you shake a branch, the leaves are detached. Why?
3. Why it is not safe to apply brakes only on the front wheel of a bicycle?
4. Deduce Newton's first law of motion form Newton's second law of motion.
5. Action and reaction are equal but opposite in direction. These forces always act in pair. Do they balance each other? Can bodies move under action - reaction pair?
6. A man slips on the oily floor; he wants to move out of this area. He is alone. He throws his bag to move out of this slippery area. Why is it so?
7. How would you use Newton's 3rd law of motion and law of conservation of momentum to explain motion of rocket?
8. Why are cricket batter gloves padded with foam?
9. Where will your weight be greater, near earth or near moon? What about mass?
10. When Ronaldo kicks the ball, at the highest point of ball both Earth and ball attract each other with the same magnitude of force. Why then the ball moves towards Earth and not the Earth?

LONG RESPONSE QUESTIONS

QIII. Give a an extended response to the following questions

1. State first law of motion. Explain with the help of examples. Why is it called law of inertia?
2. Define inertia. Why is it important to have knowledge of inertia in our daily life? Elaborate your answer with examples.
3. State and prove Newton's second law of motion. Deduce Newton's second law of motion from its first law?
4. State Newton's 3rd law of motion. Explain with examples from daily life.
5. State the limitations of Newton's laws of motion.
6. Differentiate with examples between contact and non-contact forces. Also, explain fundamental forces and the role of Dr. Abdus Salam from Pakistan in unifying two fundamental forces.
7. Represent the forces acting on a body using free body diagrams.
8. Define momentum. What is its formula and unit? Is it a scalar or vector quantity? Show that units of momentum, Ns and kgm/s are equal.
9. Differentiate between mass and weight of body.

10. What are gravitational field and gravitational field strength? Explain.
11. Justify and illustrate the use of electronic balances to measure mass.
12. State and prove Newton's second law of motion in term of momentum.
13. Define isolated system. State law of conservation of linear momentum. Explain with example.

NUMERICAL RESPONSE QUESTIONS

QIV. Solve the following numerical questions.

1. A boy is holding a book of mass 2 kg. How much force is he applying on the book? If he moves it up with acceleration of 3 m/s^2, how much should he apply total force on the book?

   (Ans. 19.6 N, 25.6 N)

2. A girl of mass 30 kg is running with velocity of 4 m/s. Find her momentum.

   (Ans. 120 N)

3. A 2 kg steel ball is moving with speed of 15 m/s. It hits with bulk of sand and comes to rest in 0.2 second. Find force applied by sand bulk on the ball.

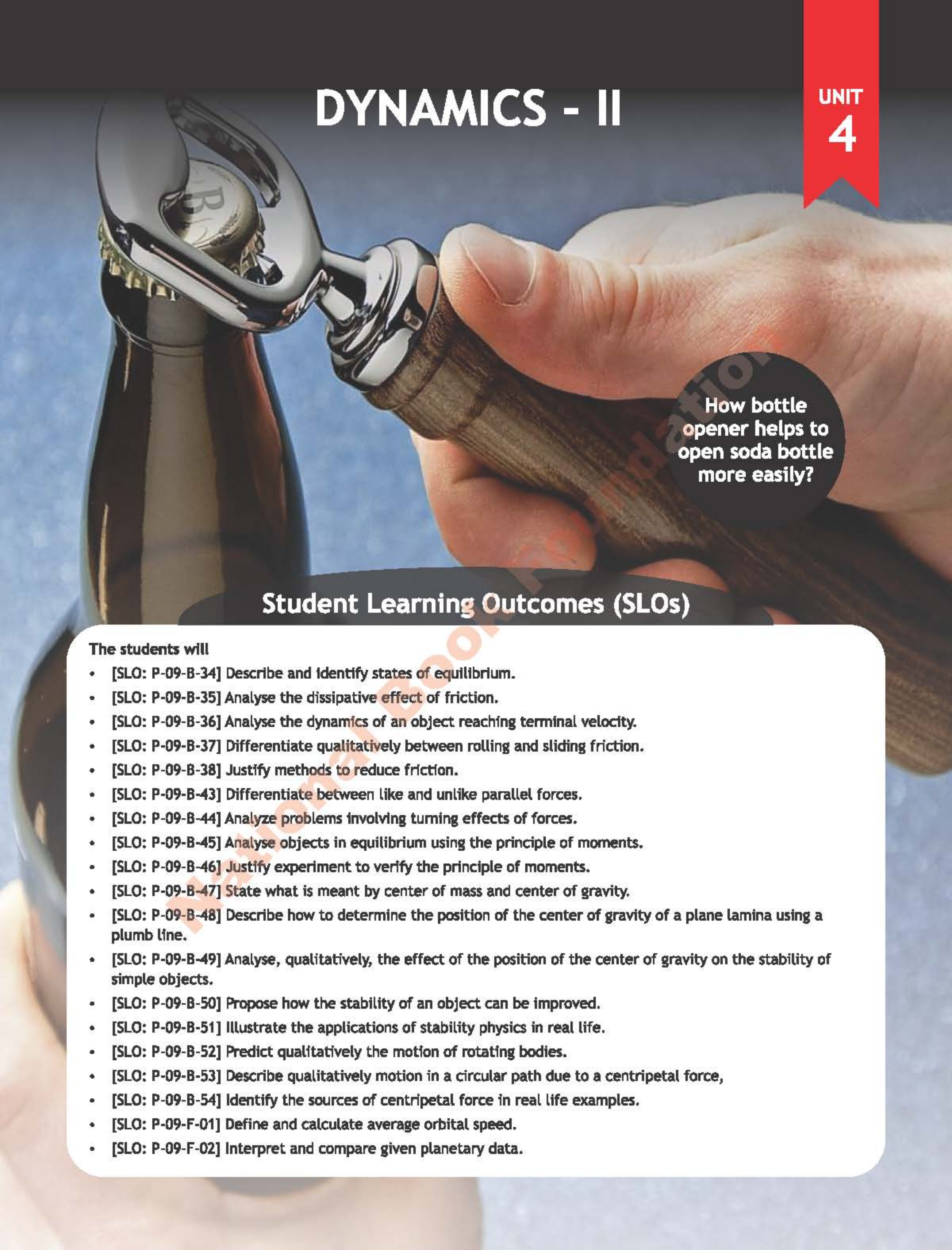
   (Ans. - 150 N)

4. A 100 grams bullet is fired from 5 kg gun. Muzzle velocity of bullet is 20 m/s. Find recoil velocity of the gun.

   (Ans. 0.4 m/s)

5. A robotic car of 15 kg is moving with 25 m/s. Brakes are applied to stop it. Brakes apply constant force of 50 N. How long does the car take to stop?

   (Ans. 7.5 s)



DYNAMICS - II

UNIT 4

How bottle opener helps to open soda bottle more easily?

Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-B-34] Describe and identify states of equilibrium.
- [SLO: P-09-B-35] Analyse the dissipative effect of friction.
- [SLO: P-09-B-36] Analyse the dynamics of an object reaching terminal velocity.
- [SLO: P-09-B-37] Differentiate qualitatively between rolling and sliding friction.
- [SLO: P-09-B-38] Justify methods to reduce friction.
- [SLO: P-09-B-43] Differentiate between like and unlike parallel forces.
- [SLO: P-09-B-44] Analyze problems involving turning effects of forces.
- [SLO: P-09-B-45] Analyse objects in equilibrium using the principle of moments.
- [SLO: P-09-B-46] Justify experiment to verify the principle of moments.
- [SLO: P-09-B-47] State what is meant by center of mass and center of gravity.
- [SLO: P-09-B-48] Describe how to determine the position of the center of gravity of a plane lamina using a plumb line.
- [SLO: P-09-B-49] Analyse, qualitatively, the effect of the position of the center of gravity on the stability of simple objects.
- [SLO: P-09-B-50] Propose how the stability of an object can be improved.
- [SLO: P-09-B-51] Illustrate the applications of stability physics in real life.
- [SLO: P-09-B-52] Predict qualitatively the motion of rotating bodies.
- [SLO: P-09-B-53] Describe qualitatively motion in a circular path due to a centripetal force,
- [SLO: P-09-B-54] Identify the sources of centripetal force in real life examples.
- [SLO: P-09-F-01] Define and calculate average orbital speed.
- [SLO: P-09-F-02] Interpret and compare given planetary data.

UNIT 4 DYNAMICS - II

In Dynamics I, we learnt about the force and Newton's laws of motion. Here in Dynamics II, we will study different effects of force on a body including its resistive nature, turning effect and its ability to rotate a body in a circle. We will also know about the stability of different bodies and the role of centre of mass and centre of gravity.

4.1 FORCES ON BODIES

Some times we need to extend the direction in which the force acts. The line along which a force acts is called the line of action of the force as shown in figure 4.1.

Multiple forces may act on bodies at same time, under such condition we have to determine the net force 'F_{net}'. However in such situations the line of action of these forces become important. Suppose you are trying to move a heavy piece of furniture, if a friend helps and you both push together, now the ease at which the furniture will depend on the line of action of both forces on the object.

FIGURE 4.1 LINE OF ACTION OF FORCE

If the directions of forces are parallel to each other, even if they are in opposite direction, those forces are called parallel forces. If they are in the same direction they are called 'Like parallel forces'. If they are in the opposite direction they will be known as 'Unlike parallel forces'. For example, when we push a cart with both hands, we are applying like parallel forces from each support as shown in the figure 4.2 (a) and when we apply force with our both hands on handle of a bike to turn it the force from one hand may be greater or equal, we are applying unlike parallel forces as shown in the figure 4.2 (b).

FIGURE 4.2 PARALLEL FORCES

4.2 MOMENT OF A FORCE

Force can be used to produce rotation in an object, for example in opening a door or tightening a nut with spanner or wrench.

Turning effect produced in a body about a fixed point due to applied force is called moment of force (or torque).

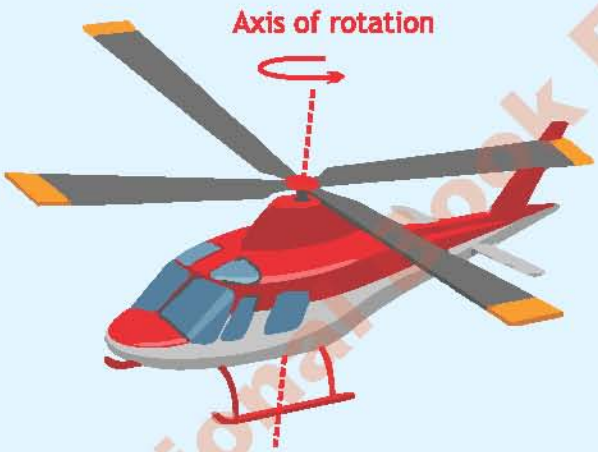
Moment of force or torque is a vector quantity and have the SI unit as N m.

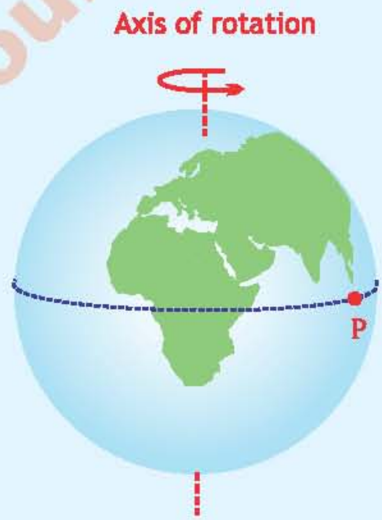
Just like force causes change in motion, moment of force causes change in rotation. This means that moment of force play the same role in rotational motion as force in translational motion. It implies that an object at rest tends to remain at rest, and an object that is rotating (or spinning) tends to spin with a constant angular velocity, unless it is acted on by a nonzero net external moment of force. Similarly, the moment of force tend to produce acceleration in rotational (or spinning) motion.

FOR YOUR INFORMATION

AXIS OF ROTATION

Rotational motion is the turning or spinning motion of an object about an axis that passes through it. Axis of rotation is a line about which rotation takes place. This line remain fixed during rotational motion, while the other points of the body move in circles about it. it may be a pivot, hinges or any other support. The axis of rotation for earth and helicopter rotor spinning is shown in figure.





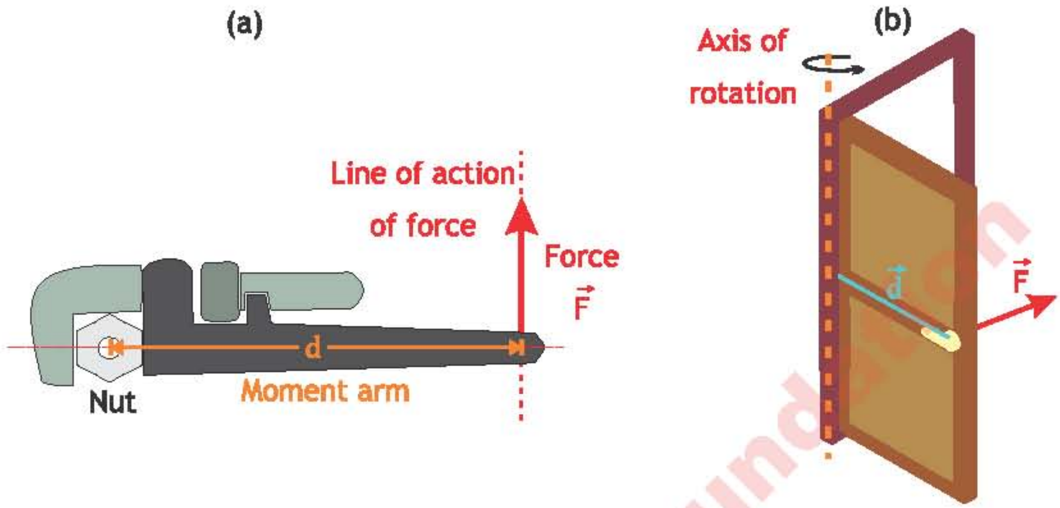
The moment of force or torque '$\vec{\tau}$' is equal to the magnitude of the force *'F'* multiplied by the perpendicular distance from the axis of rotation to the line of action of force *'d'*. mathematically

$$\vec{\tau} = F \times d \qquad (4.1)$$

Here the perpendicular distance from the axis of rotation *'d'* is termed as moment arm. So we can redefine moment of force as the **product of force and moment arm.**

Moment of force can cause rotation in a wrench to tighten a nut, for a wrench the axis of rotation is at the center of the nut as shown in the figure 4.3 (a). Similarly moment of force can cause the rotation in a door, for door the axis of rotation is at its hinges as shown in the figure 4.3 (b).

FIGURE 4.3 MOMENT OF FORCE OR TORQUE 'T'



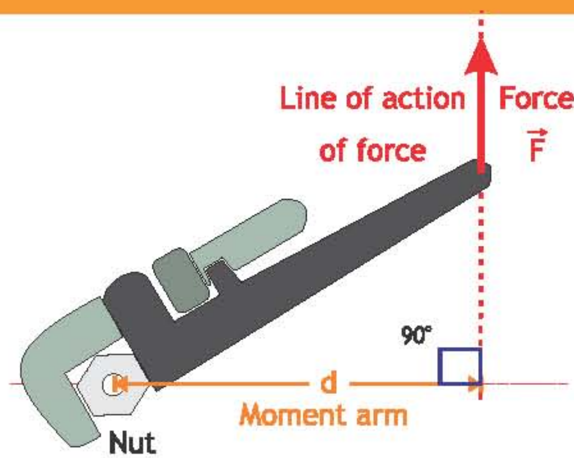
Increasing the magnitude of applied force *'F'* or the moment arm *'d'* increases the moment of force and vice versa. Thus for same force we can use a long handle wrench to produce more moment of force or torque.

CAN YOU TELL?

Why applying force along the hinges does not produce rotation in a door?

SCIENCE TIDBITS

However moment arm 'd' and force 'F' is not always perpendicular, in this situation we have to extend the line of action of force applied 'F' and take the moment arm 'd' as perpendicular distance from the axis of rotation to the line of action of force as shown in figure.



Moment arm is key to the operation of the lever, pulley, gear, and many other simple machines.

There are two senses of rotation. If the force is capable of rotating the body in clockwise direction, the moment is known as **clockwise moment.** Similarly, the force is capable of producing rotation in the anti-clockwise direction, the torque is known as **anti-clockwise moment.**

Conventionally, **clockwise moment is taken as negative, whereas anticlockwise moment is taken as positive.**

Newton's laws when applied to rotating bodies we see that moment of force is rotational analogue for force. It implies that an object at rest tends to remain at rest, and an object that is rotating (or spinning) tends to spin with a constant angular velocity, unless it is acted on by a nonzero net external moment of force. Similarly the torque tend to produce acceleration in rotation (or spinning).

EXAMPLE 4.1: TORQUE

A Physics teacher was explaining the role of moment arm in torque by performing an experiment. The teacher applied a force of 60 N to open a door. The force is applied at three different points perpendicularly and their distances from the axis of rotation are: (a) $d_A = 0.40$ m, (b) $d_B = 0.20$ m and (c) $d_C = 0.0$ m. Find the torque produced in each case.

GIVEN

Force 'F' = 60 N

Moment arm 'd_A' = 0.40 m

Moment arm 'd_B' = 0.20 m

Moment arm 'd_C' = 0.0 m

REQUIRED

(a) Torque 'τ_A' =?

(b) Torque 'τ_B' =?

(c) Torque 'τ_C' =?

SOLUTION

In each case the moment arm is the perpendicular distance between the axis of rotation and the line of action of force.

(a). Using the definition of torque $\tau_A = d_A \times F$

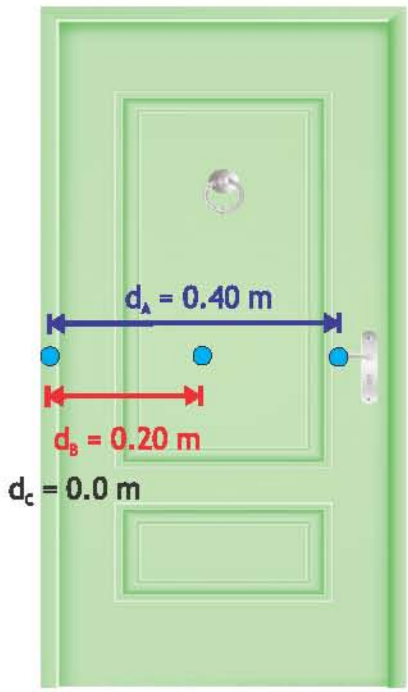
Putting values $\tau_A = 0.40\ m \times 60\ N$

Therefore $\tau_A = 24.0\ N\ m$ — **Answer**

(b). Using the definition of torque $\tau_B = d_B \times F$

Putting values $\tau_B = 0.20\ m \times 60\ N$

Therefore $\tau_B = 12.0\ N\ m$ — **Answer**



(c). Using the definition of torque $\tau_c = d_c \times F$ Putting values $\tau_c = 0\ m \times 60\ N$

Therefore $\tau_c = 0\ N\ m$ — Answer

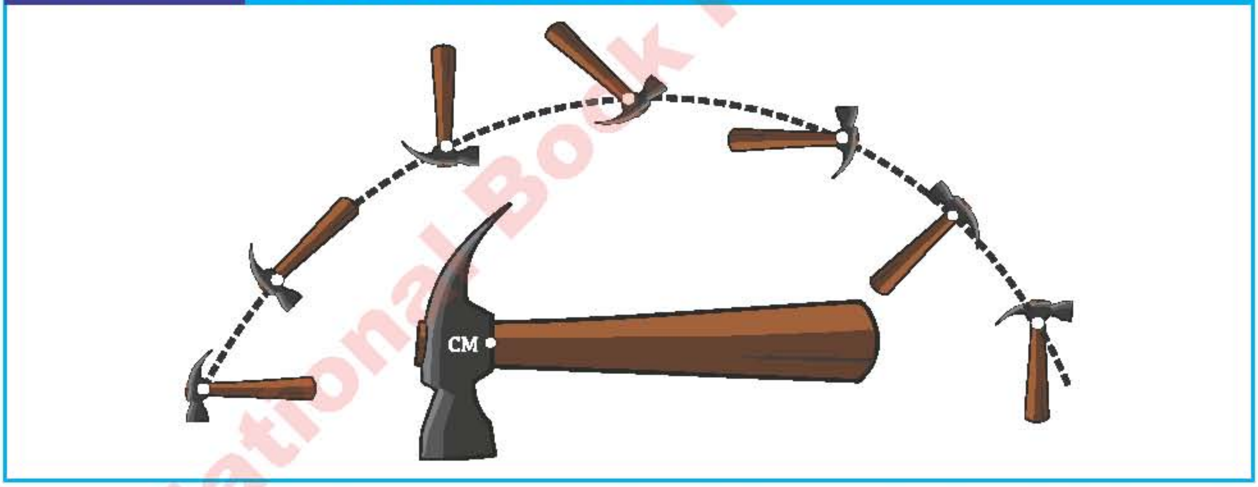
In parts a and b, the torques are positive since the forces tend to produce an anti-clockwise rotation of the door. In part c the line of action of force passes through the axis of rotation (the hinge). Hence the moment arm is zero, and the torque is zero.

4.3 CENTER OF MASS

A rigid body (a body that does not deform or change shape) is made of large number of small interconnected particles. The center of mass (abbreviated CM) of a rigid body is **the point about which mass is equally distributed**.

If the line of action of force pass through the center of mass of a body it will not produce any rotation in it. As an example, consider the motion of the center of mass of the hammer as shown in Figure 4.4. When the hammer is thrown from handle the center of mass follows a smooth parabolic path while other points in the rotating hammer travel along more complicated paths.

FIGURE 4.4 MOTION OF CENTER OF MASS

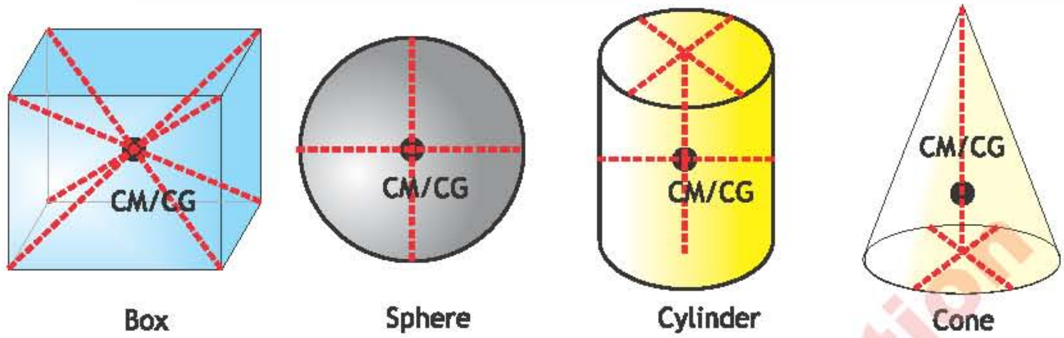


The center of mass can be considered as a point at which all the mass of an object is concentrated. In physics we often deal with weight (the force of gravity). Therefore we can assume that the entire force of gravity (weight) is concentrated at one point. **The center of gravity (abbreviated 'CG') is the point where whole weight of the body appear to act.**

The center of mass and center of gravity (CM/CG) are same for small objects. But since the value of acceleration due to gravity decrease with altitude, therefore for tall objects (like mountains and building) there is a slight difference.

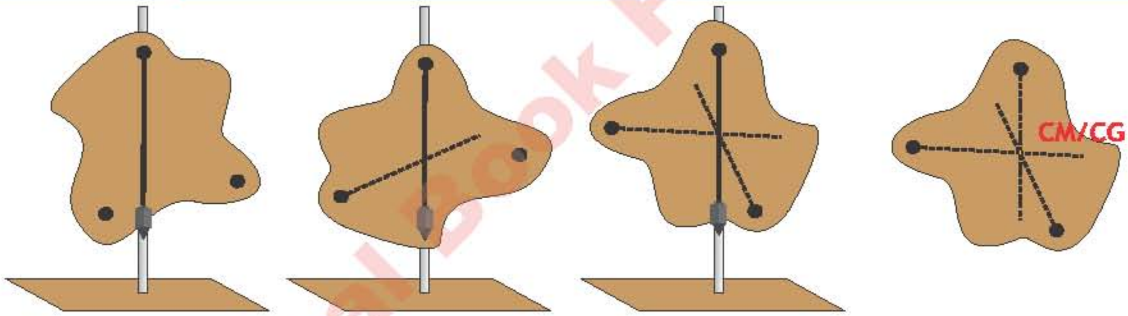
The CM/CG of a homogeneous cube or sphere is at its geometric center, whereas the CM/CG of a right circular cylinder or cone is on the axis of symmetry, and so on as shown in the figure 4.5. Similarly the CM/CG of a uniform wooden rod is at its mid-point, and therefore it can balanced from its center.

FIGURE 4.5 CENTER OF MASS OF SYMMETRICAL OBJECTS



For irregular objects one way to determine the center of gravity is to hang it randomly from at least three different points, and then connecting vertical lines drawn with the help of plumb line. These line will meet each other at a common point which will be the center of gravity CG of the irregular object (sheet) as shown in figure 4.6.

FIGURE 4.6 CENTER OF GRAVITY OF IRREGULAR OBJECT

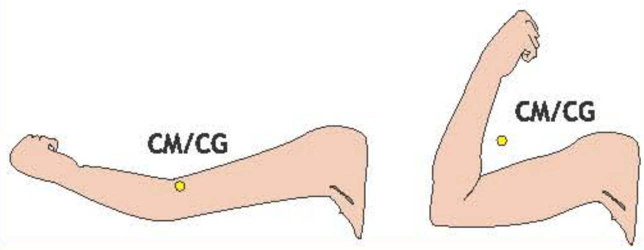


The CM/CG doesn't always lie inside the mass and may change its location depending upon the orientation of the object. For example the arm is stretched out the CM/CG lies inside the mass distribution, but when the arm is bent, the CM/CG shifts to the new location outside the mass distribution as shown in figure 4.7.

CAN YOU TELL?

Is there any difference between center of mass and center of gravity? When would the center of mass of object be different than its center of gravity?

FIGURE 4.7 CENTER OF GRAVITY MAY CHANGE POSITION



4.4 EQUILIBRIUM

Forces produce change in translational motion, therefore, when the net force on the object is zero the object will either be at rest or move with uniform velocity in a straight line. The same is also true for the moment of force which produces change in rotational motion, therefore, when the net torque on the object is zero the object will not rotate or will rotate with uniform velocity.

The effect of force is to produce change in translational motion and effect of moment of force or torque is to produce change in rotational motion.

Equilibrium is the state in which all the individual forces and moment of forces or torques exerted upon an object are balanced. This means that net force and torque on the object are zero the object is said to be in equilibrium.

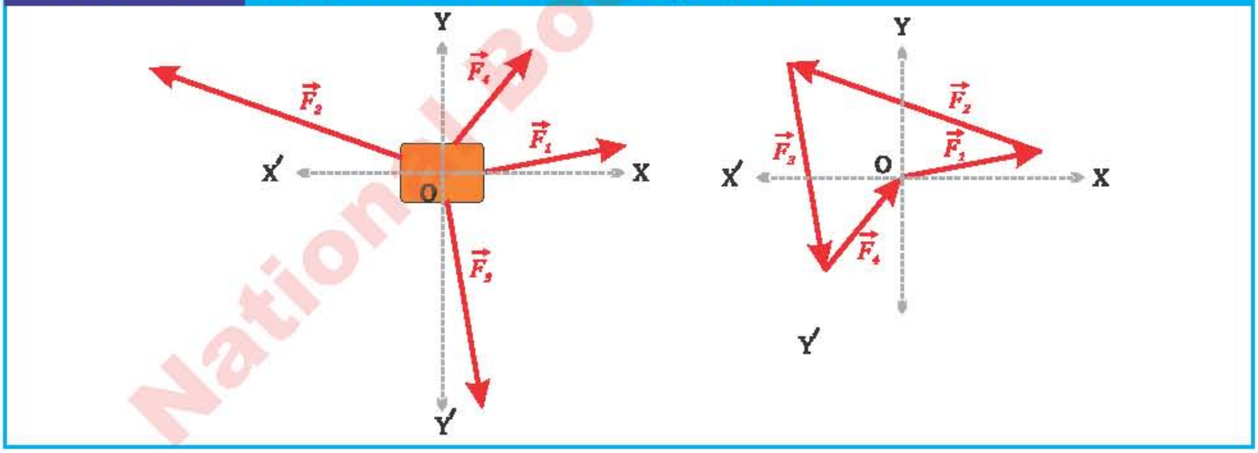
4.4.1 CONDITION OF EQUILIBRIUM

Therefore for complete equilibrium two conditions must be met.

A. First Condition of Equilibrium: *When the vector sum of all the forces acting on the body is ZERO then the first condition of equilibrium is satisfied.* Mathematically if $\vec{F}_{net}$ is the sum of forces $\vec{F}_1, \vec{F}_2, \vec{F}_3, \ldots, \vec{F}_n$ then

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots\ldots + \vec{F}_n = 0 \qquad (4.2)$$

FIGURE 4.8 FIRST CONDITION OF EQUILIBRIUM



For an object to satisfy the first condition of equilibrium the force polygon must close.

For example if there are four forces on the object and their vector sum is zero as shown in the figure 4.8, the first condition of equilibrium will be satisfied and the object will either be at rest or will move with uniform velocity. Mathematically if $\vec{F}_{net}$ is the sum of forces $\vec{F}_1$, $\vec{F}_2$, $\vec{F}_3$, *and* $\vec{F}_4$ by head to tail rule it must be ZERO.

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \vec{F}_4 = 0$$

B. Second Condition of equilibrium: *When the vector sum of all the torques acting on the body is ZERO then the second condition of equilibrium is satisfied.* If $\vec{\tau}_{net}$ is the sum of torques $\vec{\tau}_1, \vec{\tau}_2, \vec{\tau}_3, ...$, $\vec{\tau}_n$ then mathematically

$$\vec{\tau}_{net} = \vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 + ... + \vec{\tau}_n = 0 \qquad (4.3)$$

For complete equilibrium both the first and second conditions of equilibrium must be satisfied.

4.4.2 PRINCIPLE OF MOMENTS

Second condition of equilibrium is also called the principle of moments, which states that

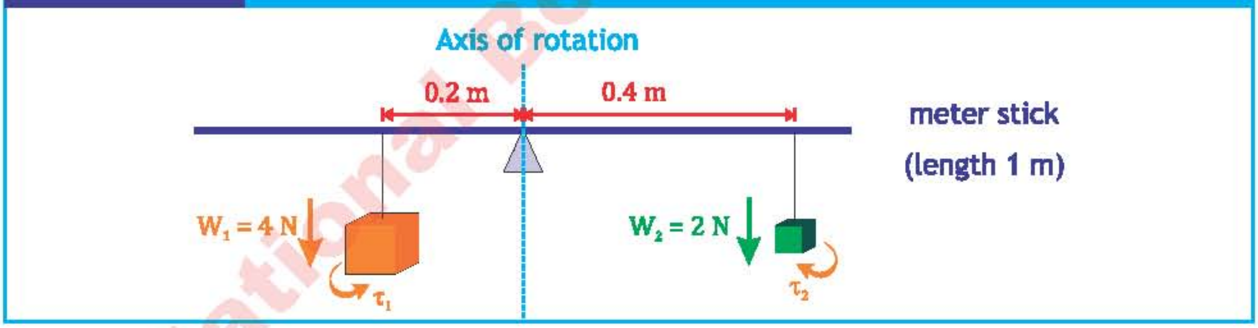
'For an object in equilibrium, the sum of the clockwise moments taken about the pivot must be equal to the sum of anti-clockwise moments taken about the same pivot'.

To balance torques or moment of force, the perpendicular distance from the axis of rotation play an important role.

By convention the anticlockwise torques are taken as positive while clockwise torques are taken as negative, which leads to second condition of equilibrium that the sum of both these torques must be zero.

For example, Let a uniform meter stick is balanced from center. Now if we suspend weight of 4 N at 0.1 m from the pivot, it exerts the same torque as 2 N weight at 0.4 m from the fulcrum. A uniform meter stick will balance on pivot under these conditions as shown in the figure 4.9.

FIGURE 4.9 VERIFICATION OF PRINCIPLE OF MOMENTS



Anticlockwise torque (positive)	Clockwise torque (negative)
$\tau_1 = W_1 \times d_1$	$\tau_2 = -(W_2 \times d_2)$
$\tau_1 = 4\,N \times 0.2\,m$	$\tau_2 = -(2\,N \times 0.4\,m)$
$\tau_1 = 0.8\,N\,m$	$\tau_2 = -\,0.8\,N\,m$

$$\tau_{net} = \tau_1 + \tau_2 = 0.8\,N\,m - 0.8\,N\,m$$

$$\tau_{net} = 0\,N\,m$$

Similarly three or more torques around a pivot (as axis of rotation) can also balance each other.

EXAMPLE 4.2: SEESAW BALANCE

Kamil and Bilal are sitting on a seesaw at F9 Park Islamabad. Kamil, weighing 250 N, is sitting at a distance of 0.6 m from the pivot. At what distance from the pivot should Bilal, weighing 200 N sit in order to balance the seesaw?

GIVEN

Weight of Kamil 'W_k' = 250 N

Moment arm of Kamil 'd_k' = 0.6 m

Weight of Bilal 'W_B' = 200 N

REQUIRED

Moment arm of Bilal 'd_B' = ?

SOLUTION

Kamil's weight is producing anticlockwise moment, while Bilal's weight is producing clockwise moment, Therefore, by principle of moments:

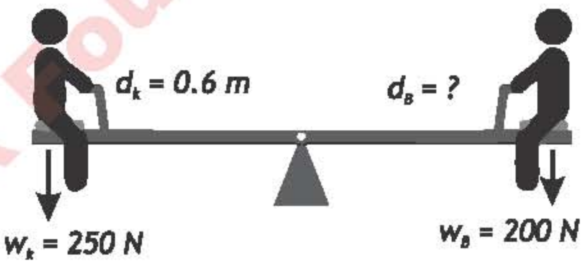
$$\tau_{anticlockwise} = \tau_{clockwise} \quad \text{or} \quad \tau_k = \tau_B$$

Hence $d_k \times W_k = d_B \times W_B$

or $d_B = \dfrac{d_k \times w_k}{w_B}$

Putting values $d_B = \dfrac{0.6\ m \times 250\ N}{200\ N}$

Therefore $d_B = 0.75\ m$ **Answer**



This means that having less weight (or force), the moment arm should be greater in order to produce same torque as produced by a greater weight and small moment arm.

4.4.3 TYPES OF EQUILIBRIUM

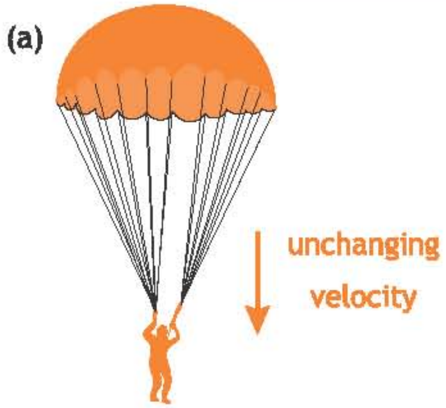
The equilibrium is divided into two types

A. Static equilibrium: *When a body is at rest under the action of several forces acting together and several torques acting the body is said to be in static equilibrium.* For example a book resting on the table is in static equilibrium, the weight mg of the book is balanced by a normal reaction force from the table surface.

B. Dynamic equilibrium: *When a body is moving at uniform velocity under the action of several forces acting together the body is said to be in dynamic equilibrium.* It is further divided in to two types.

I. Dynamic Translational Equilibrium: When a body is moving with uniform linear velocity the body is said to be in dynamic translational equilibrium. For example a paratrooper falling down with constant velocity is in dynamic translational equilibrium as shown in figure 4.10 (a).

FIGURE 4.10 DYNAMIC EQUILIBRIUM



II. Dynamic Rotational Equilibrium: When a body is moving with uniform rotation the body is said to be in dynamic rotational equilibrium. For example when the ceiling fan is rotating with unchanging speed as shown in figure 4.10 (b).

4.5 STABILITY

'A measure of the ability of an object to return to its original position when the force that changed its position is removed is called stability'. Stable objects are very difficult to topple over, while unstable objects topple over very easily.

The position of the Center of gravity or center of mass (CG/CM) of a body affects whether or not it topples over easily. This is important in the design of such things as tall vehicles (which tend to overturn when rounding a corner), racing cars, reading lamps and even drinking glasses.

FIGURE 4.11 STABILITY OF VEHICALS

4.5.1 STABLE EQUILIBRIUM

A body is in stable equilibrium if when slightly tilt and after releasing it returns to its original position. Its centre of mass rises when it is displaced. It regain its position back because its weight has a moment of force about the point of contact that acts to reduce the displacement. For example consider a book lying on the table. Tilt the book slightly about its one edge by lifting it from the opposite side. It returns to its previous position when sets free. Such a state of the body is called a stable equilibrium.

4.5.2 UNSTABLE EQUILIBRIUM

A body is in unstable equilibrium if it moves further away from its previous position when slightly displaced and released. Its centre of mass falls when it is displaced, because there is a moment which increases the displacement. for example Take a pencil and try to keep it in the vertical position on its tip. Whenever you leave it, the pencil topples over about its tip and falls down. This is called an unstable equilibrium.

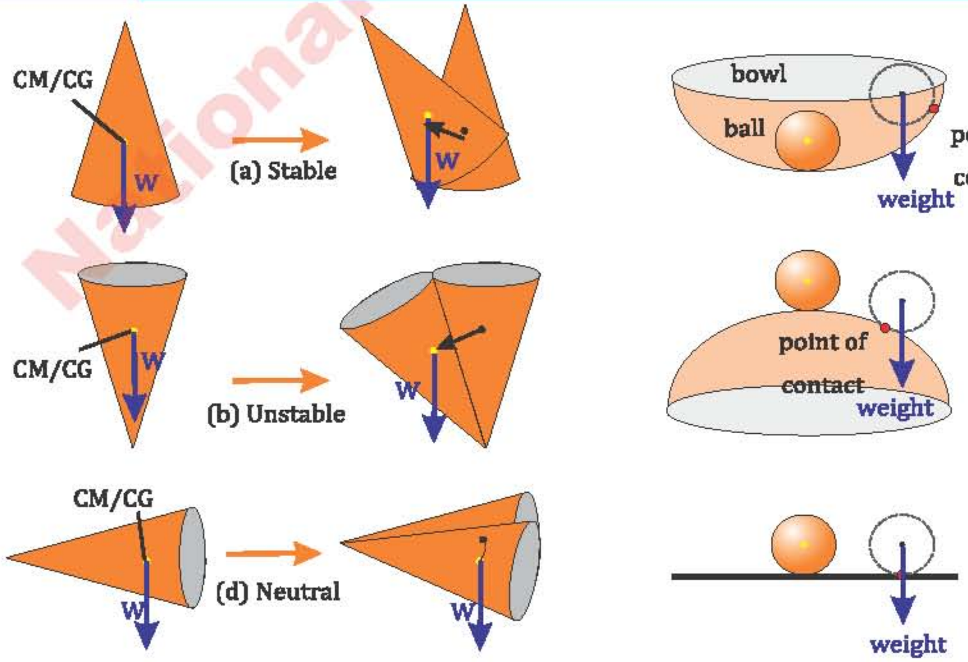
4.5.3 NEUTRAL EQUILIBRIUM

A body is in neutral equilibrium if it stays in its new position when displaced. Its center of mass does not rise or fall because there is no moment to increase or decrease the displacement.

For example take a ball and place it on a horizontal surface. Roll the ball over the surface and leave it after displacing from its previous position. It remains in its new position and does not return to its previous position. This is called a neutral equilibrium.

The illustrations in figure 4.12 shows the three states of equilibrium for the cone and ball and bowl.

FIGURE 4.12 STABLE, UNSTABLE AND NEUTRAL EQUILIBRIM



An object's stability can be improved by:

(a) lowering the center of mass; or

(b) increasing the area of support; or

(c) by both.

When the object's center of mass is directly beneath the point of support, it is in a stable equilibrium state. The center of mass represents the average position of the mass distribution within the object. In simple terms, "vertically below" means that the center of mass is aligned vertically beneath the point of support.

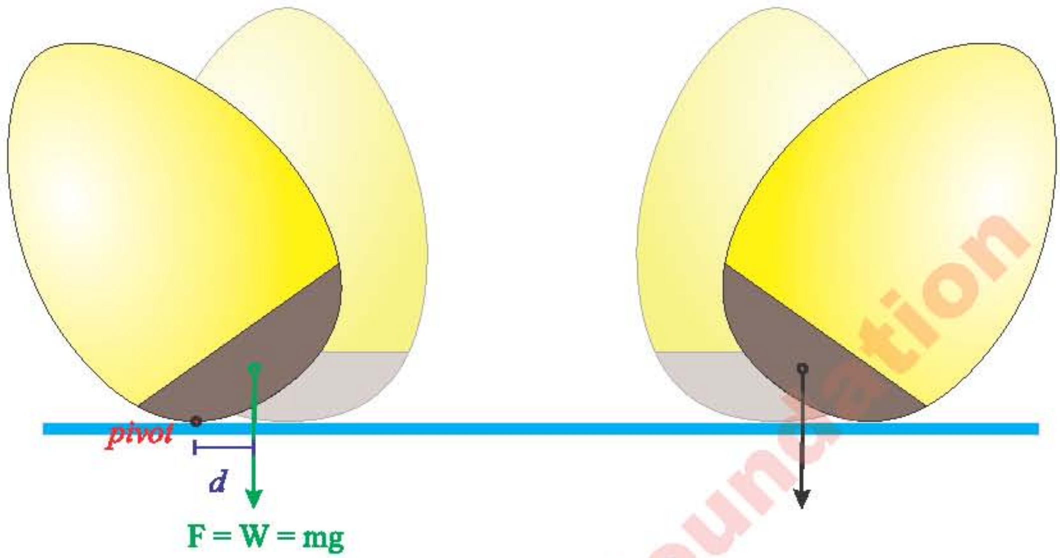
When an object is in stable equilibrium, it means that if it is slightly disturbed or tilted, it has a tendency to return to its original position. This is because the gravitational force acting on the object causes it to rotate around the point of support, and the object's weight acts through its center of mass. As a result, the object naturally realigns itself to maintain its stable equilibrium state.

Various toys and equipment use the principle of stable equilibrium to regain their balance after being disturbed. These objects are often called "self-righting" or "self-balancing" toys. They are designed with their center of mass below the support point and have a specific weight distribution that helps them restore their original position. These objects might include balancing birds, wobbling dolls, or weighted-bottom drinking cups, all of which exhibit the stable equilibrium principle as shown in figure 4.13.

FIGURE 4.13 SELF BALANCING TOYS

Once such toy is of shape of an egg, when it is tilted, the position of the pivot changes because of its round bottom. In figure 14.14 (a), when tilted to the left, the weight *'W'* from the center of gravity (CG) is to the right of the pivot with moment arm (perpendicular distance) 'd'. This creates a clockwise moment that makes the toy turn clockwise. Due to inertia, the toy will go past the vertical position and tilt to the right, as shown in the figure 14.14 (b). Similarly, since the weight is to the left of the pivot, it creates an anti-clockwise moment.

FIGURE 4.14 EGG SHAPED SELF BALANCING TOY



Therefore, this toy always has a restoring mechanism that brings it back to its vertical position, where the weight is directly above the pivot. In this position, the weight passing through the pivot does not create any moment (no perpendicular distance). Hence, the toy will be at rest.

4.6 FRICTION

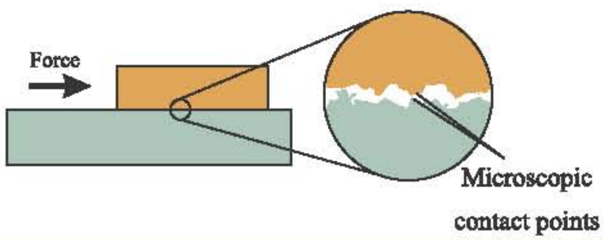
Friction (denoted by letter '*f*') is the resistance to relative motion that occurs whenever two materials are in contact with each other, whether they are solids, liquids, or gases. Since it is a force therefore it is a vector quantity and has unit as newton (N).

Friction always acts in a direction to oppose motion. If you push a solid block along a floor to the right, the force of friction on the block will be to the left. When an object falls downward through the air, the force of friction, air resistance, acts upward.

4.6.1 Microscopic description of friction

Every surface is rough, even surfaces that appear to be highly polished can actually look quite rough when examined under a microscope as shown in figure 4.15. There is no such thing as a perfectly flat surface. As a result the two surfaces that are touching are not really touching across the entire area that appears to be touching.

FIGURE 4.15



Thus roughness of both surfaces interlock which makes friction.

Sliding friction is the resistance created by any two objects when sliding against each other. It is the sliding friction between the brake pads and our bike rims, that slows the rolling wheels so we can stop our bike in time.

Rim brakes, are the most effective and most popular bicycle brakes, as they provide adequate braking power without too much maintenance. They are controlled by hand levers which are attached to the actual brake by a cable. When the rider pulls on the brake lever the cable attached to it moves the two pads, one on each side of rim. These pads attached to break leather press against the rim, causing the wheel to slow down due to friction as shown in figure 4.16.

FIGURE 4.16 BICYCLE BREAKS

4.6.2 ADVANTAGES AND DISADVANTAGES OF FRICTION

Friction is required in many situations, for example

- Friction between the soles of our shoes (or feet) and the ground help us walk.
- Friction between tyre and road helps to drive cars.
- Friction holds the screw and nails in wood.

Friction can sometime be a hindrance, for example

- It slows down moving objects and causes heating of moving parts in machinery.
- Energy is wasted to overcome friction in machinery.
- Produce wear and tear.

4.6.3 METHODS OF REDUCING FRICTION

There are many ways to reduce unwanted friction, few are discussed below.

- **By polishing:** If we polish the rough surfaces, they become smooth and friction is reduced.
- **By using Ball Bearing:** This method converts the sliding friction is converted into rolling friction by use of ball bearings.
- **By applying Lubricants (oil or Grease) to surfaces:** Friction of certain liquids is less than that of solid surfaces, therefore, oil or grease is applied between the parts of machinery.

ACTIVITY

Take the book and slide it on the table now place book on few pencils and roll it you will see that less effort is required.

FIGURE 4.17 METHODS TO REDUCE FRICTION

(a) Polishing (b) Ball Bearing (c) Lubricant

4.6.4 ROLLING FRICTION

If we set a heavy spherical ball, ring or cylinder rolling, it experiences an opposing force called rolling friction. **When a body rolls over a surface, the force of friction is called rolling friction.** For the same weight, rolling friction is much smaller (even by 2 or 3 orders of magnitude) than static or sliding friction.

FIGURE 4.18 ROLLING FRICTION

This is the reason why discovery of the wheel has been a major milestone in human history. It is rolling friction that helps a heavy deep freezer with wheels to easily move as shown in figure 4.18.

4.6.5 FLUID FRICTION

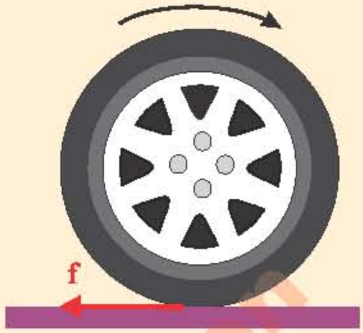
A fluid is a collection of molecules that are held together by weak cohesive forces and the forces exerted by the walls of container. Both liquids and gases are fluids as they can flow and can exert force on the walls of their container.

When an object moves through a fluid, the fluid exerts a retarding force that tends to reduce the speed of the object. The moving body exerts a force on the fluid to push it out of the way. By Newton's third law, the fluid pushes back on the body with an equal and opposite force. This retarding force experienced by an object moving through a fluid is called the drag force, which is the result of fluid friction.

POINT TO PONDER

Does wider tyres increase friction and thus road grip of our car?

It seems intuitive that wider tyres will provide more friction, however, the friction is same for narrow and wide tyres of same weight. It is because friction does not depend on the area of contact. The wider tyre simply spreads the weight of the car over more surface area thereby reducing heat and wear.



Friction resists sliding

Similarly treads (traction) on tyres also does not increase friction. These treads are much larger compared to microscopic roghness which lock the contact surfaces together and produce friction while sliding. The treads are made in the tyre only to displace water from the road to avoid skidding. Many racing cars use tires without treads because they race on dry days.

For example when you extend your hand out of the window in a moving vehicle as shown in figure 4.19. If you set the palm of your hand in the direction of motion you can observe the fluid friction and the drag force it exerts on your palm. You can also see variation in the drag force by changing its orientations.

FIGURE 4.19 FLUID FRICTION

The drag force depends upon the

- Size, shape and orientation of the object
- Type (Properties) of the fluid
- Speed of the object relative to the fluid

Skydivers and swimmers change their effective size and orientation by bending, twisting and starching their body parts. This allow them to manipulate drag and thereby allowing them to control speed and direction of motion.

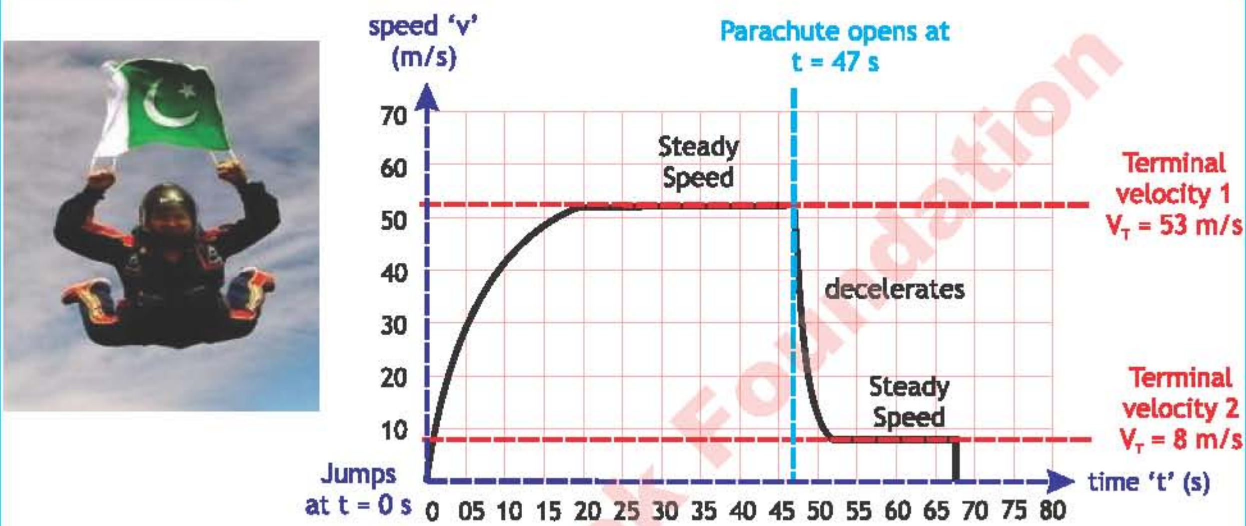
During free fall the objects does not speed up indefinitely. The speed of free falling object initially increases because of weight of the object, but as the speed increases the drag force also increase, slowing the object down.

A point reaches where both the weight and drag force become equal and dynamic translational equilibrium is achieved. The object has now attained its maximum velocity termed as **terminal velocity**. At terminal speed, the diver's acceleration is zero; in other words, the speed remains constant.

The constant maximum velocity that is attained and maintained by an object while falling through air (or any other resistive medium) is called terminal velocity.

For humans, terminal speed in air is about 53 m/s or 190 km/h. After the parachute opens, the terminal speed is reduced to between 5 m/s and 10 m/s, as shown in figure 4.20.

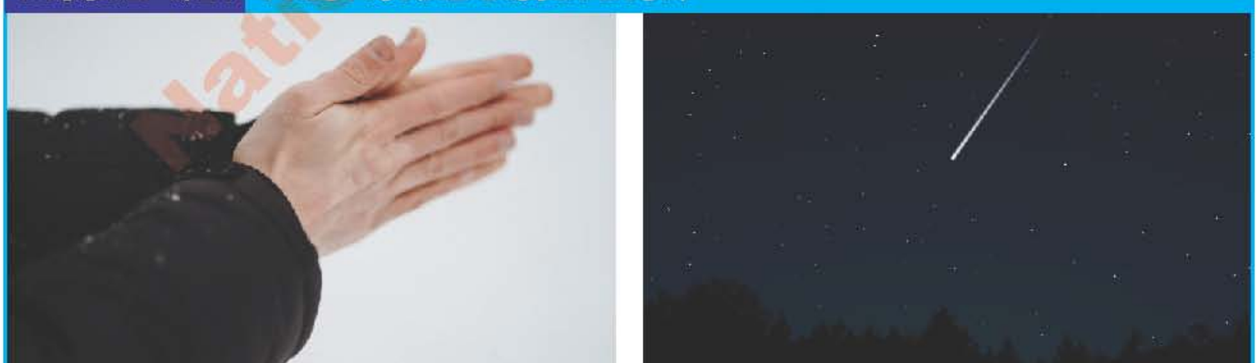
FIGURE 4.20 SPEED TIME GRAPH OF PARACHUTE JUMP



4.6.6 FRICTIONAL DISSIPATION

Dissipative force decreases the mechanical energy in a system. Dissipative forces acting on an object always oppose the motion of the object, For example in case of the sky diver, when the parachute opened some energy is dissipated into the air thereby increasing its temperature. The sky diver safety depends on air resistance as a dissipative force.

FIGURE 4.21 FRICTIONAL DISSIPATION



(a) Rubbing hands

(b) Shooting stars

In winter when we rub our hands together we feel the sensation of warmth as shown in figure 4.21 (a). It is because friction causes the increase in the temperature our hands, which makes our hands warm. Similarly you would have noticed shooting stars (a small piece of rock or dust that hits Earth's atmosphere from space) as shown in figure 4.21 (b). When they plow through the atmosphere, meteors are heated, and they glow. A meteor compresses air in front of it. The air heats up, in turn heating the meteor. The intense heat vaporizes most meteors, creating what we call shooting stars.

4.7 CENTRIPETAL FORCE

When the speed of the moving object does not change as it travels in the circular path is called uniform circular motion.

The speed of the object may remain constant however the direction is continuously changing, giving rise to a change in velocity and an acceleration as shown in figure 3.22. This acceleration is perpendicular (or at a right angle) to the velocity. In uniform circular motion, it is towards the center of the circle called centripetal acceleration.

Now there must be some unbalanced force acting on the object which is pulling it towards the center.

The force that pulls an object out of its straight-line path and into a circular path is called centripetal (center-seeking) force.

Consider a communications satellite that is moving at a uniform speed around Earth in a circular orbit as shown in figure 4.23. According to the first law of motion there must be some unbalanced force acting on the satellite that is pulling it out of a straight-line path. This unbalanced force is termed as centripetal force.

The magnitude of the centripetal force 'F_c' of an object with a mass 'm' that is moving with a velocity 'v' in a circular orbit of a radius 'r' is:

$$F_c = -\frac{mv^2}{r} \quad (4.4)$$

Equation 4.4 gives the magnitude of centripetal force, where negative sign indicates that force is directed towards the center of the circular path.

FIGURE 4.22 CIRCULAR MOTION

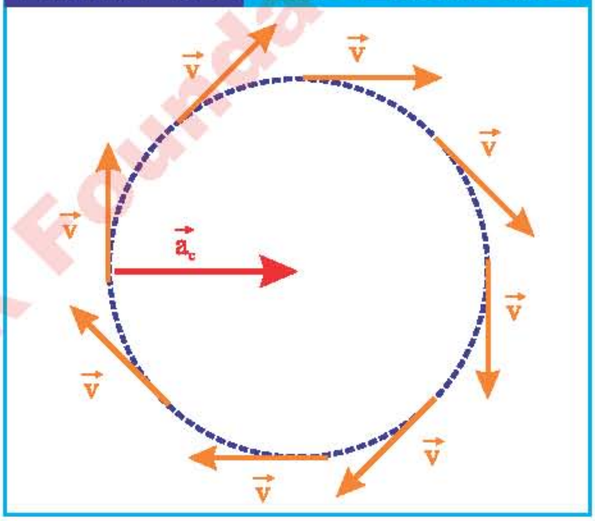
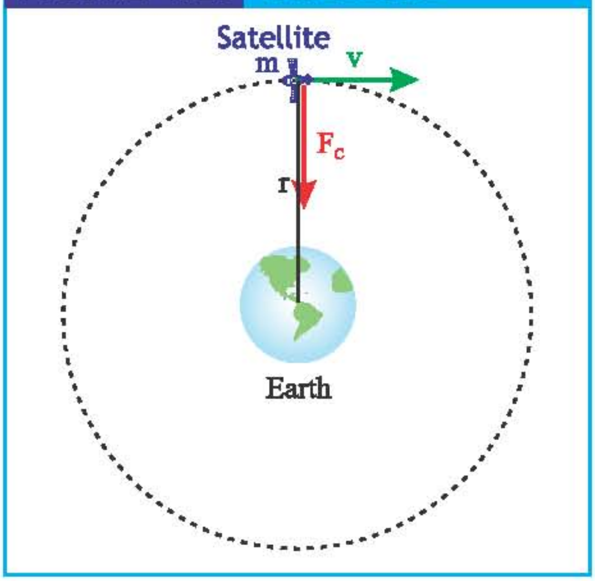
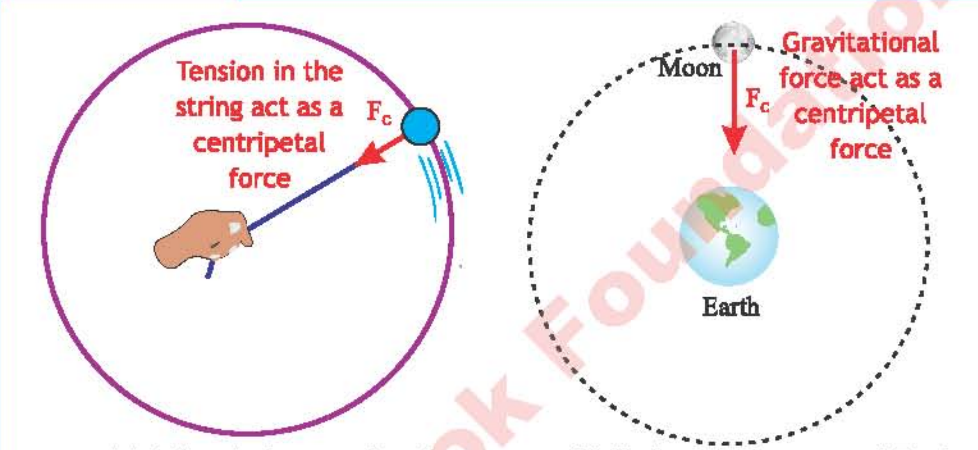


FIGURE 4.23 SATELLITE



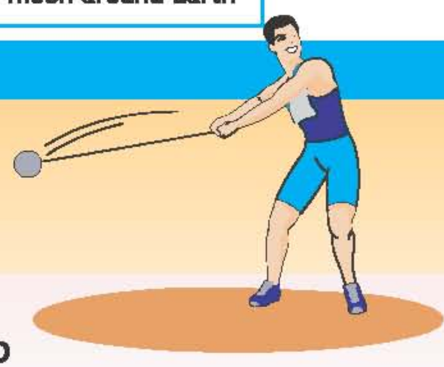
Perhaps you have swung a ball on the end of a string in a circle over your head. Once you have the ball moving, the tension on the string keeps it moving in a circular path as you twirl it. That tension is centripetal force, which pulls the ball from its natural straight-line path into a circular path as shown in figure 4.24 (a). The force that keeps a planets in orbit around sun is centripetal force, which, in this case is the 'gravitational force'. This center is exactly where the Sun is located. In the case of the Moon, the centripetal force acting on it is directed towards the center of the Earth as shown in figure 4.24 (b).

FIGURE 4.24 CENTRIPETAL FORCE EXAMPLES



(a) Ball swinging over head (b) Motion of moon around Earth

EXAMPLE 4.3: HAMMER THROW



Bilal is performing in hammer throw game as shown in the figure. Mass of the metal ball is 5 kg and length of the string is 1.5 m. What centripetal force must Bilal apply to get a speed of 25 m/s?

GIVEN

Mass of metal ball attached by a steel wire 'm' = 5 kg

Radius 'r' = 1.5 m

speed 'v' = 25 m/s

REQUIRED

Centripetal force F_c = ?

SOLUTION

The centripetal force acting on a body of mass "m" is given by:

Putting values

therefore

Answer

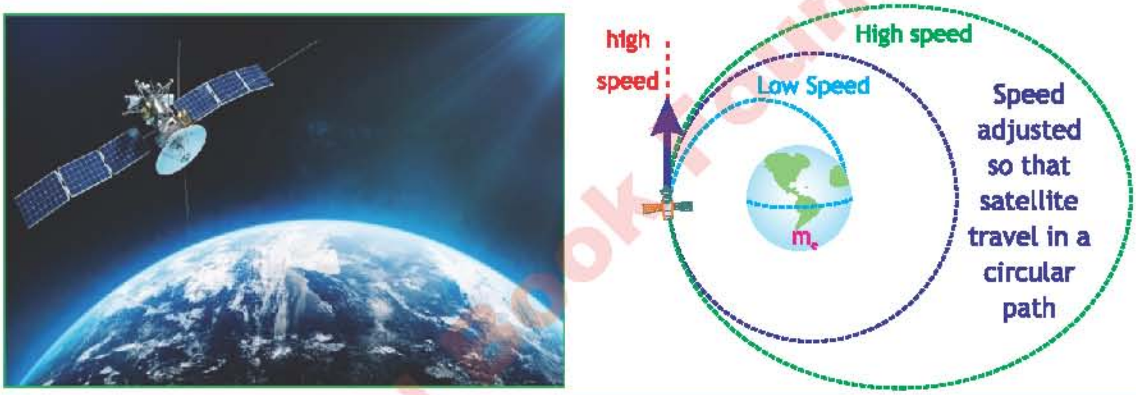
This means that Bilal's hand must apply a centripetal force of 2083.3 N on the metal in order to give a velocity of 25 m/s to the ball.

4.8 ORBITAL MOTION

An orbit is a regular, repeating path that one object in space takes around another one. **An object in an orbit is termed as a satellite.** A satellite can be natural, like Earth or the moon. Objects orbit each other because of gravity. Many planets have moons that orbit them, and many stars have planets, comets, asteroids and other objects that orbit them. A satellite can also be man-made, like the International Space Station. Such man-made satellites are termed as artificial satellites.

To put an artificial satellite into orbit, first we move it to high altitude and then accelerate it to a required tangential speed using rockets, as shown in Figure. 4.25. If the speed is too high, the spacecraft either move in elliptical orbit or will escape, never to return. If the speed is too low, it will fall back to Earth. Satellites are typically put into circular (or nearly circular) orbits.

FIGURE 4.25 MOTION OF ARTIFICIAL SATELLITE



4.8.1 AVERAGE ORBITAL SPEED OF SATELLITE

The orbital speed of the body is the speed at which it orbits around the center of the system. This system is usually around a massive body.

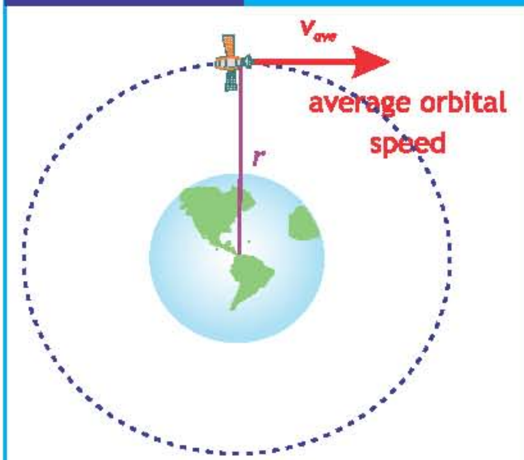
The relationship between speed, distance and time is:

(1)

This means that in one orbit, a satellite travels a distance equal to the circumference of a circle (the shape of the orbit). This is equal to '2πr' where 'r' is the radius a circle, thus:

$$\text{Distance} = 2\pi r \quad (2)$$

FIGURE 4.26 SPEED IN ORBIT



The time it takes for an object to orbit around another object is called its orbital period 'T'. Earth completes its orbital period around the sun every 365 days. The further away a planet is from the sun, the longer its orbital period. The planet Neptune, for example, takes almost 165 years to orbit the sun.

$$\text{time} = \text{Orbital period} = T \quad \text{——— (3)}$$

putting equation 2 and equation 3 in equation 1, the average orbital speed 'v_{ave}' is:

$$\text{——— (4.5)}$$

Which means that for particular distance from the center of earth, all the satellite should have the same orbital speed irrespective of the size of satellite.

QUIZ

Two satellites are following one another in the same circular orbit. If one satellite tries to catch another (leading one) satellite, can it be done by increasing its speed?

No, if the speed of the satellite is somehow increased, its radius will also increase and it will be unable to catch up the leading satellite.

EXAMPLE 4.4: ORBITAL SPEED OF EARTH

Earth completes one revolution around the sun in 365.25 days. Find the orbital speed of Earth around the sun if it is 150 million km away from the sun.

GIVEN

Orbital period 'T' = 365.25 days = $365.25 \times 24 \times 60 \times 60$ s = 3.16×10^7 s

Radius 'r' = 150 million km = $150 \times 10^8 \times 10^3$ m = 1.5×10^{11} m

REQUIRED

Orbital speed of Earth around sun v = ?

SOLUTION

The relation for average orbital speed is given by:

putting values

therefore $\boxed{v = 2.98\ 10^4 \text{ m/s}}$ ——— **Answer**

or $v = 29.8$ km/s or $v = 107{,}280$ km/h

This is a huge speed as compared to the speeds of our daily life objects. The reason we do not feel it is that we are relatively at rest i.e. we also move with the earth.

4.9 PLANETARY DATA

An astronomical body orbiting a star or stellar remnant that is massive enough to be rounded by its gravity, is termed as planet. There are more planets in our galaxy than stars.

Our solar system consists of our star, the Sun, and everything bound to it by gravity - the planets Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune; dwarf planets such as Pluto; dozens of moons; and millions of asteroids, comets, and meteoroids. Table 4.1, summarizes the physical parameters of the planets in solar system.

TABLE 4.1: SELECTED DATA FOR THE SOLAR SYSTEM

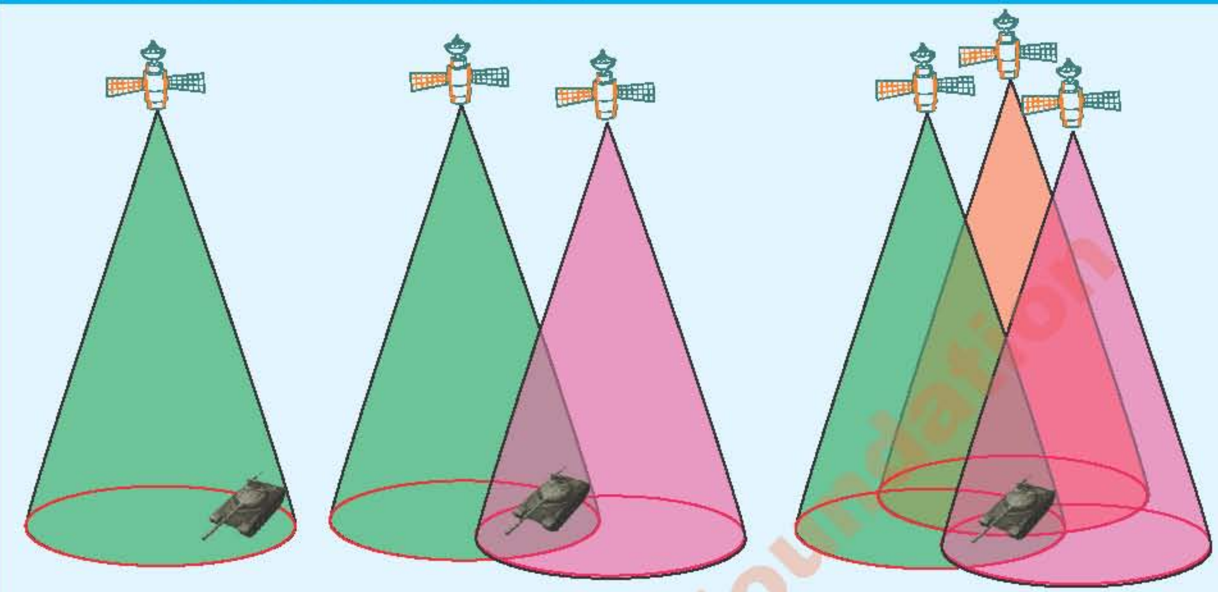
Planet	Distance from Sun (Gm)	Mass (10^{24} kg)	g (N/kg)	Orbital Period (yr)	Density (kg/m^3)	Average Surface temperature (°C)
Mercury	57.9	0.330	3.7	0.241	5429	167
Venus	108.2	4.87	8.9	0.615	5243	464
Earth	149.6	5.97	9.8	1	5514	15
Mars	228.0	0.642	3.7	1.88	3934	- 65
Jupiter	778.5	1898	24.7	11.9	1326	- 110
Saturn	1432.0	568	9.0	29.4	687	- 140
Uranus	2867.0	86.8	8.7	83.8	1270	- 195
Neptune	4515.0	102	11.0	164	1638	- 200
Sun	5906.4	1,990,000	274	-	1408	5,600

FOR YOUR INFORMATION

INFORMATION: GLOBAL POSITIONING SYSTEM (GPS)

Many applications of satellite technology affect our lives. An increasingly important application is the network of 24 satellites called the Global Positioning System (GPS), which can be used to determine the position of an object. Figure illustrates how the system works, by locating position of enemy tank. A measurement using a single satellite locates the tank somewhere on a green circle, as Figure (a) shows, while a measurement using a second satellite locates the tank on another circle. The intersection of the circles reveals two possible positions for the tank, as in Figure (b). With the aid of a third satellite, a third circle can be established, which intersects the other two and identifies the tank's exact position, as in Figure (c).

Cont.... FOR YOUR INFORMATION



(a) (b) (c)

SUMMARY

Moment of a force or Torque is the measure of an object tendency to rotate about some point O.

Moment of a force = force × perpendicular distance of the force to the point.

Principle of moments states that for an object in equilibrium, the sum of the clockwise moments taken about the pivot must be equal to the sum of the anti-clockwise moments taken about the same pivot.

Centre of mass of the body is the point about which mass is equally distributed in all directions.

Centre of gravity is a single point where the whole weight of an object appears to act.

Stability of an object refers to the ability of the object to return to its original position when the force that changed its orientation is removed.

Frictional force is the force that resists motion of objects on a surface.

Terminal velocity is the maximum constant velocity that a body can achieve while passing through a resistive (viscous) medium.

Centripetal force is the force that compels a body to travel a circular path. It may be electric, gravitational, or any other force.

Orbital velocity is the speed of a an object revolving around another heavy object in an orbit.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option.

1. A seesaw balances perfectly with two children of equal weight sitting at equal distances from the fulcrum. If one child moves closer to the fulcrum:

   A. The seesaw remains balanced.

   B. The seesaw tips towards the child who moved closer.

   C. The seesaw tips towards the child who stayed further away.

   D. The seesaw topples.

2. When line of action of the applied force passes through its pivot point then moment of force acting on the body is:

   A. maximum B. minimum C. zero D. infinite

3. If a body is at rest or moving with uniform rotational velocity, then torque acting on the body will be

   A. maximum B. minimum C. zero D. infinite

4. A body in equilibrium must not have:

   A. speed B. quantity of motion C. velocity D. acceleration

5. A uniformly rotating fan is said to be in:

   A. static equilibrium only B. dynamic equilibrium only

   C. both in static and dynamic equilibrium D. not in equilibrium

6. You throw a weighted fishing net into a calm lake. As the net sinks, it opens fully underwater, spreading out its mesh evenly. Compared to the moment it left your hand, where is the net's center of mass now?

   A. Higher in the water column. B. Lower in the water column.

   C. At the same depth but slightly shifted horizontally.

   D. Unchanged from its position when thrown.

7. A tightrope walker is carrying a long pole while walking across a rope. The stability of the walker is affected if the pole is

   A. long and placed vertically B. long and placed horizontally

   C. short and placed vertically D. short and placed horizontally

8. It is more difficult to walk on a slippery surface than on a nonslippery one because of:

   A. reduced friction B. increased friction C. high grip D. lower weight

9. For an object moving with terminal velocity, its acceleration:
   A. increases with time
   B. decreases with time
   C. is zero
   D. first increases then decreases

10. The correct order of comparison for the terminal speeds of a raindrop, snowflake, and hailstone is:
   A. Raindrop > Snowflake > Hailstone
   B. Hailstone > Raindrop > Snowflake
   C. Snowflake > Raindrop > Hailstone
   D. Raindrop = Snowflake = Hailstone

11. You are trying to loosen a nut using a spanner, but it is not working. In order to open the nut, you need to:
   A. insert a pipe to increase length of spanner
   B. use a spanner of small length
   C. use plastic and soft spanner
   D. tie a rope with spanner

12. The force that always changes direction of velocity and not its magnitude is called:
   A. gravitational force
   B. electric force
   C. centripetal force
   D. friction

13. The reason that a car moving on a horizontal road gets thrown out of the road while taking a turn is:
   A. the reaction of the ground
   B. rolling friction between tyre and road
   C. gravitational force
   D. lack of sufficient centripetal force

14. A car drives at steady speed around a perfectly circular track.
   A. The car's acceleration is zero.
   B. The net force on the car is zero.
   C. Both the acceleration and net force on the car point outward.
   D. Both the acceleration and net force on the car point inward.

15. A satellite of mass 'm' is revolving around the earth with an orbital speed 'v'. If mass of the satellite is doubled, its orbital speed will become:
   A. double
   B. half
   C. one fourth
   D. remain the same

SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

1. Why long spanner is used to open or tight nuts of vehicle's tyre? While tightening a small nut, extra-long wrench is not suitable. Why?
2. Why door knobs are fixed at the edge of door? What will happen it the door knob is at the middle of the door?
3. If you drop a feather and a bowling ball from the same height, which one will reach the terminal velocity first? Which one of them will hit the ground first?
4. Why do ice skates effortlessly slide on ice, while your shoes cause skidding?
5. Explain why it's easier to push a car on flat tyres than inflated ones. What happens to the frictional force between the tyres and the road?

6. When standing on a crowded school bus, which stance would provide better stability and prevent you from being pushed over: legs joined or legs spread apart?
7. Why a moving bicycle is easier to balance? Relate this to the principles of rotational motion.
8. Why is a pencil standing on its tip unstable, and what factors affect the stability of an object balanced on a point?
9. While driving what happens if the driver take the curve too fast? How does centripetal force play a role in keeping the car from skidding off the road?
10. Consider a situation where you swing a ball connected to a string in a circle. How does the tension in the string vary as the ball moves across different points in its circular path, and what forces are involved?
11. Why is it important for communication satellites in geostationary orbit to maintain a specific speed?

LONG RESPONSE QUESTIONS

QIII. Give a an extended response to the following questions

1. Differentiate between like and unlike parallel forces.
2. What is moment of force or torque? On what factors it depends? Write its mathematical formula
3. Define center of mass. What is effect of mass distribution in a body on its center of mass?
4. What is center of gravity? Where will be center of gravity of these regular shaped bodies; circular plate, rectangular and square shaped plate, triangular shaped plate, cylinder, sphere (also draw figures to support your answer). Differentiate between center of mass and center of gravity.
5. How can you find center of gravity of an irregular shaped thin sheet of plastic?
6. What is equilibrium? Describe the conditions of equilibrium. State an explain principle of moments.
7. Propose how the stability of an object can be improved. Illustrate the applications of stability physics in real life.
8. Define force of friction. What causes friction? What are advantages and disadvantages of friction? Explain with examples. How can friction be reduced?
9. Compare rolling friction and sliding friction. How are they different in terms of contact surfaces, motion, and forces involved? Explain with examples.
10. Analyse the dynamics of an object reaching terminal velocity.
11. Define centripetal force. Describe the motion of a body in a circular path under the action of centripetal force.
12. Identify different sources of centripetal force in real life examples.
13. Define orbital velocity. How do scientists use the concept of orbital speed to launch satellites into specific orbits? What factors influence the chosen speed?

NUMERICAL RESPONSE QUESTIONS

QIV. Solve the following questions.

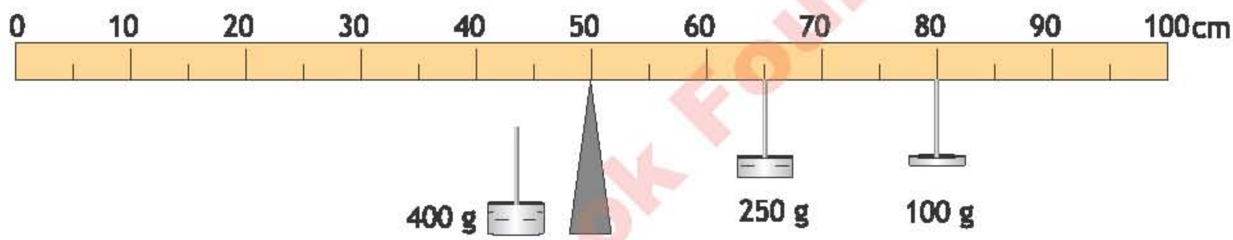
1. Calculate the torque acting on spanner of length 20 cm to loosen a nut by a force of 50 N. if the same nut is to be loosen up by force of 100 N, what should be length of spanner?

(Ans. 10 N m and 10 cm)

2. A long uniform steel bar of length 1.0 m is balanced by a pivot at its middle. Two mass m_1 and m_2 are suspended at a distance of 0.2 m and 0.3 m respectively from the pivot. Ignoring mass of the steel bar, if mass m_1 = 0.6 kg find mass m_2.

(Ans. 0.4 kg)

3. Two masses, 250 g and 100 g, are hanging at positions 65 cm and 80 cm, respectively, on a on a uniform meter rod, pivoted at 50 cm mark as shown. Where should a third mass of 400 g be positioned to balance the rod?



(Ans. 33.1 cm)

4. A car weighing 1200 kg enters a roundabout with a diameter of 60 meters at a speed of 25 km/h. Calculate the centripetal force acting on the car as it navigates the curve.

(Ans. 693.3 N)

5. A geostationary satellite revolves around earth in an orbit of radius 42000 km. Find orbital speed of the satellite at this height.

(Ans. 3.052 km/s)

PRESSURE AND DEFORMATION IN SOLIDS

UNIT 5

Why it is difficult to cook food at high altitudes?

Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-B-55] Illustrate that forces may produce a change in size and shape of an object.
- [SLO: P-09-B-56] Define and calculate the spring constant.
- [SLO: P-09-B-57] Sketch, plot and interpret load-extension graphs for an elastic solid and describe the associated experimental procedures.
- [SLO: P-09-B-58] Define and use the term 'limit of proportionality' for a load-extension graph.
- [SLO: P-09-B-59] Illustrate the applications of Hooke's law.
- [SLO: P-09-B-77] Define and calculate pressure.
- [SLO: P-09-B-78] Describe how pressure varies with force and area in the context of everyday examples.
- [SLO: P-09-B-79] Analyse in situations how pressure at a surface produces a force in a direction at right angles to the surface.
- [SLO: P-09-B-80] Justify that the atmosphere exerts a pressure.
- [SLO: P-09-B-81] Describe that atmospheric pressure decreases with the increase in height above the Earth's surface.
- [SLO: P-09-B-82] Explain that changes in atmospheric pressure in a region may indicate a change in the weather.
- [SLO: P-09-B-83] Analyse the workings and applications of a liquid barometer.
- [SLO: P-09-B-84] Just why and analyse quantitatively how pressure varies with depth in a liquid.
- [SLO: P-09-B-85] Analyse the workings and applications of a manometer.
- [SLO: P-09-B-86] Define and apply Pascal's law.

UNIT 5 PRESSURE AND DEFORMATION IN SOLIDS

Matter is made up of atoms and molecules. Applying external forces like weight, pressure, heat, etc., causes the deformation of the matter, which in turn changes the matter's shape, dimension, and orientation.

Solid matter is made up of atoms and molecules which packed closely. The intermolecular space between the atoms is significantly less than in liquid and gas. Because of this property of solids, they retain their original shapes easily, and the atoms or molecules return to equilibrium after removal force.

In the case of liquid and gaseous matter, the atoms and molecules are loosely packed, and the deformation of this matter takes less force as compared to solids, Liquids and gaseous matter do not retain their equilibrium state unless an external force is applied again. Some examples include a stretched rubber band as shown in figure 5.1, a bent metal rod and a shattered glass as shown in figure 5.2.

FIGURE 5.1 RUBBER BAND

FIGURE 5.2 BENT METAL ROD AND SHATTERED GLASS

5.1 ELASTICITY

'The ability of a deformed body to return to its original shape and size when the deforming forces are removed is called elasticity'.

When a stretched spring is released, it comes back to its original form. When a tennis racket hits a tennis ball, the shape of the ball is distorted or deformed, but it regains its original shape when it bounces off the tennis ball. Similarly, when an archer shoots an arrow, she bends the bow which comes back to its original form after the arrow is released as shown in figure 5.3.

Not all materials return to their original shapes when a deforming force acting on it is removed. Materials that do not return to their original shapes after being distorted are said to be inelastic. Examples of inelastic materials are plasticine, clay and dough.

Most materials are elastic up to a certain limit known as the elastic limit. Beyond the elastic limit a material will not return to its original dimensions when the deforming force is removed.

FIGURE 5.3 ELSATICITY

5.1.1 HOOKE'S LAW

When a spring is stretched or compressed (with in elastic limit), the extension or compression is directly proportional to the applied force (Figure 5.4). This relationship is known as Hooke's law which states that **within elastic limits the extension (or compression) x is directly proportional to the restoring force F_{res}**, i.e.

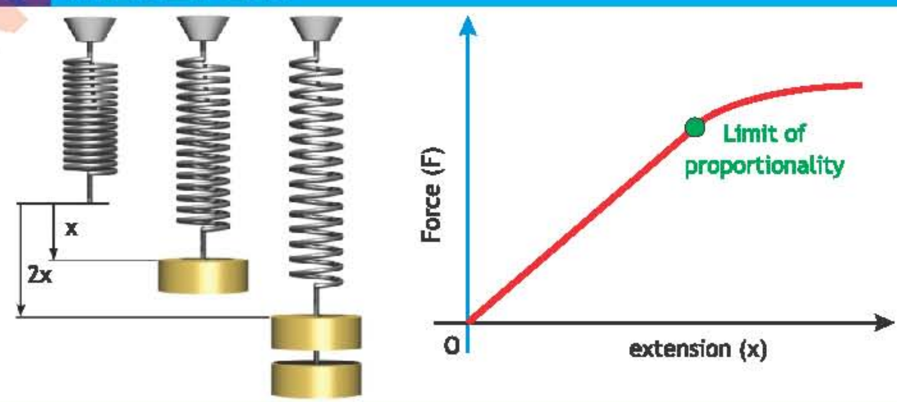
or

therefore (5.1)

where 'k' is the ratio of restoring force to the extension and is known as the force constant or spring constant having units N m^{-1}. The negative sign shows that force is directed against displacement. This relationship is also true for a wire under tension. Provided that the limit of proportionality is not exceeded, a graph of stretching force against extension is a straight line through the origin, as shown in figure 5.4.

The gradient of the line F/x is the spring constant 'k'. Hooke's Law is obeyed up to the limit of proportionality. Beyond this point, stretching force and extension are no longer directly proportional and the graph begins to curve.

FIGURE 5.4 HOOKES LAW



5.1.2 APPLICATIONS OF HOOKE'S LAW

Hooke's law has many important practical applications, with one being the creation of a balance wheel, which made possible the creation of the mechanical clock, the portable timepiece. Hooke's law is also used as a fundamental principle behind spring scale. It is also used as the foundation for diving boards and car suspension systems, seismology, acoustics molecular mechanics and even in medical science.The spring is a marvel of human engineering and creativity, still in use in many modern day instruments.

A. Balance wheel of the mechanical watches: A balance wheel is the timekeeping device used in mechanical watches. It is a weighted wheel that rotates back and forth, being returned toward its center position by a spiral torsion spring or hairspring as shown in figure 5.5 (a). It is driven by the escapement, which transforms the rotating motion of the watch gear train into impulses delivered to the balance wheel. Each swing of the wheel (called a 'tick' or 'beat') allows the gear train to advance a set amount, moving the hands of watch forward. The combination of the mass of the balance wheel and the elasticity of the spring keep the time between each oscillation or 'tick' very constant.

B. Spring Scale: A spring scale (spring balance) is a type of mechanical force measuring instrument that make use of spring. This device is mainly used to weigh items or objects by connecting them to a hook at it bottom as shown in figure 5.5 (b). Since by Hooke's law the force or weight that extends a spring is directly related to the distance that the spring is extended from its initial position. The spring scale converts this extension to measuring weight using an analog or digital gauge attached to the device.

C. Galvanometer: Galvanometer is a device used for detecting current or voltage. It make use of the hair spring which not only electrical connection to coil and restoring the pointer back, but also make the deflection proportional to the force according to Hooke's law as shown in figure 5.5 (c). And since the force is proportional to the current, it permits us to draw an analogue scale under the pointer and measure the current.

FIGURE 5.5 APPLICATIONS OF HOOKE'S LAW

(a) Balance wheel (b) Spring Scale (c) Hair spring in galvanometer

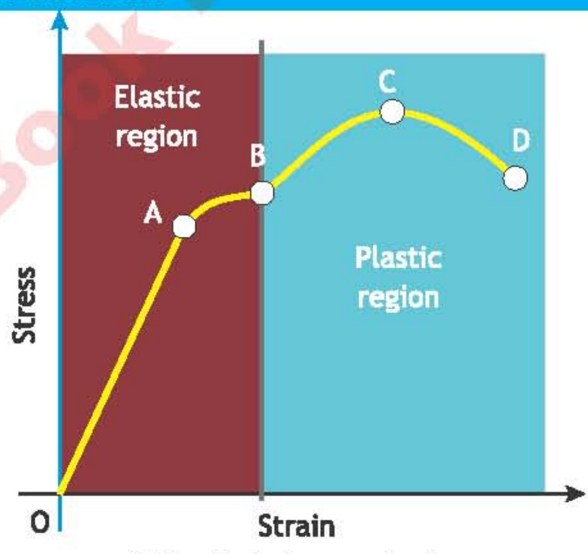
MINI-LAB

What would happen to the reading if two or more spring balances are hung one below the other in series?

Stress and strain curves: Stress and strain curves are measured by stress tester, one such machine Rockwell hardness tester is shown in the figure 5.6 (a). The applied stress is increased and the change in length is noted. The values are then printed on graph. A typical graph for metal is shown in the figure 5.6 (b). Here, Point, A, is the limit of proportionality, the limit up to which Hooke' law is obeyed called **proportional limit.** Point, B, is the elastic limit, the limit up to which material shows elastic behavior also called **yield strength**, point C is the maximum stress a material can bear before fracture (breaking) called **ultimate stress** and point D, is the breaking point, where material breaks.

FIGURE 5.6 STRESS STRAIN ANALYSIS

(a) Hardness testing machine



(b) typical stress - strain curve

EXAMPLE 5.1: SPRING CONSTANT OF A SPRING CHAIR

Kamil sits on a spring chair as shown in the figure. If Kamil's weight is 50 kg and compresses the spring by about 10 cm, when he sits on the chair, find the spring constant of this chair's spring.

GIVEN

Mass of Kamil 'm' = 50 kg

Extension in spring 'x' = 10 cm = 0.1 m

REQUIRED

Spring constant 'k' = ?

SOLUTION:

The force stretching the spring is equal to weight of the body, given by:

$$W = F = mg = 50\ kg \times 9.8\ m/s^2 = 490\ N$$

From Hook's law: or Putting values:

Therefore, Answer

So, the given chair spring has a spring constant of 4,900 N/m.

5.2 PRESSURE

Pressure is defined as force per unit area. Pressure is represented by letter 'P', if force 'F' is applied on area 'A', the pressure is given by

$$P = \frac{F}{A} \qquad (5.2)$$

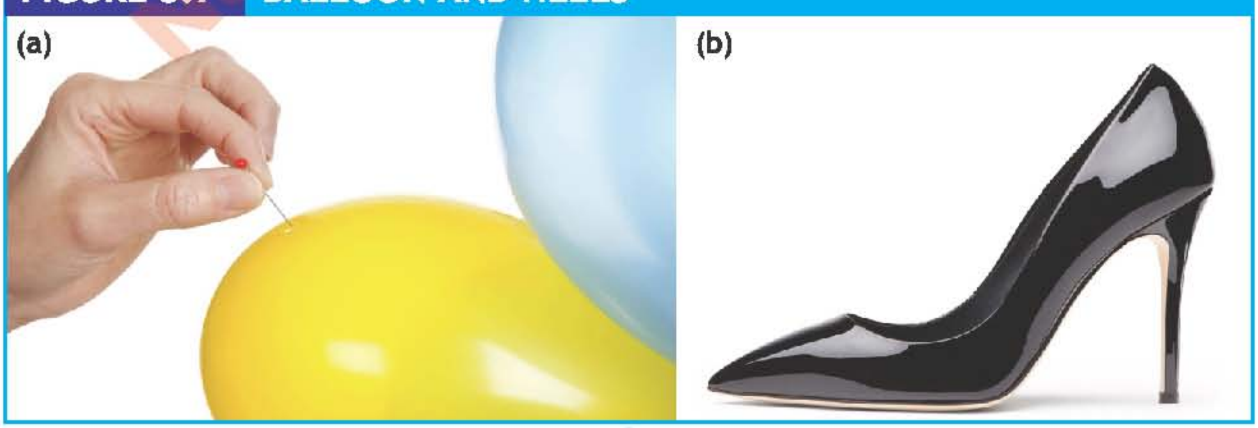
The SI unit of pressure is pascal (Pa) which equals newton per square meter (N/m²).

$$1\,Pa = \frac{1\,N}{1\,m^2}$$

The pressure increases when the force on a specific area is increased or when a smaller area is subjected to a given force. Why does a balloon burst easily when pricked with a pin, but not when squeezed by our hand? The reason is that the force applied to the small area of the needle tip creates enough pressure to burst the balloon as shown in figure 5.7 (a).

FIGURE 5.7 BALLOON AND HEELS

(a) (b)



Getting stepped on by a high-heeled shoe hurts more than getting stepped on by a flat one. This is because the weight of the body is concentrated on a smaller area with a pencil heel shoe, as illustrated in figure 5.7 (b).

Have you ever wondered why a blunt knife cannot cut meat easily? When you apply the same force on sharp and blunt knife, the sharp knife offers little surface area thereby increasing pressure, which help to cut meat easily as shown in figure 5.8.

FIGURE 5.8 SHARP AND BLUNT KNIFE

EXAMPLE 5.2: WEIGHT AS PRESSURE ON GROUND

Abdurrahman was standing at the stage of a hall for a speech. What pressure does he apply on the stage if his two feet cover an area of 400 cm^2? (b). If for a while he stands on one foot, what will be the pressure under that foot? (Take his mass 50 kg).

GIVEN

Mass of Abdullah 'm' = 50 kg

Area of two feet 'A_1' = 400 cm^2 = 400 × 10^4 m^2 = 0.04 m^2

Area of one foot 'A_2' = $A_1/2$ = 0.04 m^2/2 = 0.02 m^2

REQUIRED

(a) Pressure with both feet 'P_1' =?

(b) Pressure with one foot 'P_2' =?

SOLUTION:

Weight of Abdurrahman will be given by: W = mg = 40 kg × 9.8 m/s^2 = 490 N

—— (1)

(a) For both feet the equation 1 can be written as: $P_1 = \frac{W}{A_1}$

Putting values

Therefore [ ] —— Answer

(b) For one foot the above equation can be written as $P_2 = \frac{W}{A_2}$

Putting values

Therefore [ ] — Answer

Thus, for the same force (or weight), if area is halved pressure becomes double.

5.3 ATMOSPHERIC PRESSURE

Pressure is particularly useful for dealing with liquids and gases, as it exerts pressure in every direction. That's why during swimming we feel pressure on all parts of our body. Similarly we live at the bottom of the earth's atmosphere, which pushes inward on our bodies just like the water in a swimming pool.

'The pressure that atmospheric particles exert on the surface of earth and all over the surface of objects on the earth is called atmospheric pressure'. The pressure of the air at a given place varies slightly according to the weather and height from sea level. At sea level, the pressure of the atmosphere on average is $1.013 \times 10^5\ Nm^2$ (or 1.013×10^5 Pa).This value lets us define a commonly used unit of pressure, the atmosphere (abbreviated atm), such that

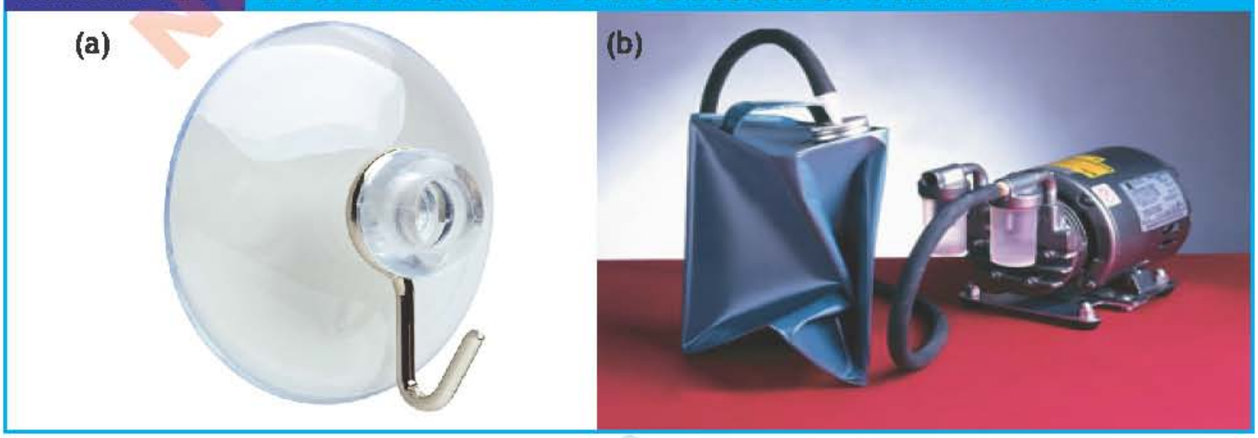
$$1\ \text{atm} = 1.013 \times 10^5\ \text{Pa}$$

Another unit of pressure sometimes used (in meteorology and on weather maps) is the bar, which is defined as

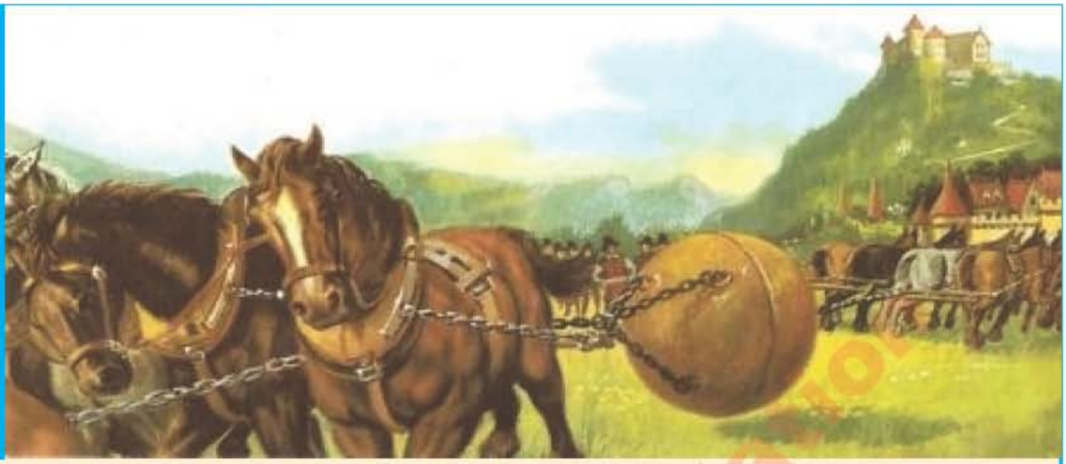
$$1\ \text{bar} = 1.000 \times 10^5\ \text{Pa.}$$

How a suction cup gets its sticking force? It is because of the atmospheric pressure. When we push the cup against a smooth wall, we actually force the air out of the cup, allowing atmospheric pressure to hold it to the wall. Another example of atmospheric pressure can be seen when we pump the air out of sealed can, atmospheric pressure produces an inward force that is unopposed, this results in the collapse of the can (figure 5.9).

FIGURE 5.9 SUCTION CUP AND AIR EVACUATED FROM SEALED CAN



POINT TO PONDER



In 17th century Otto Von Guricke (German physicist) fitted two hollow bronze hemispheres together and removed the air from the resulting sphere with a pump. Two eight horse teams were unable to pull the halves apart, even though the hemispheres fell apart when the air was readmitted.

5.3.1 MEASUREMENT OF ATMOSPHERIC PRESSURE

A liquid barometer is a device that measures atmospheric pressure using the principles of hydrostatics and the behavior of liquids. The most common type of liquid barometer is the mercury barometer.

The liquid barometer works on the principle of hydrostatic equilibrium, which states that the pressure at any point in a fluid at rest is the same at all depths.

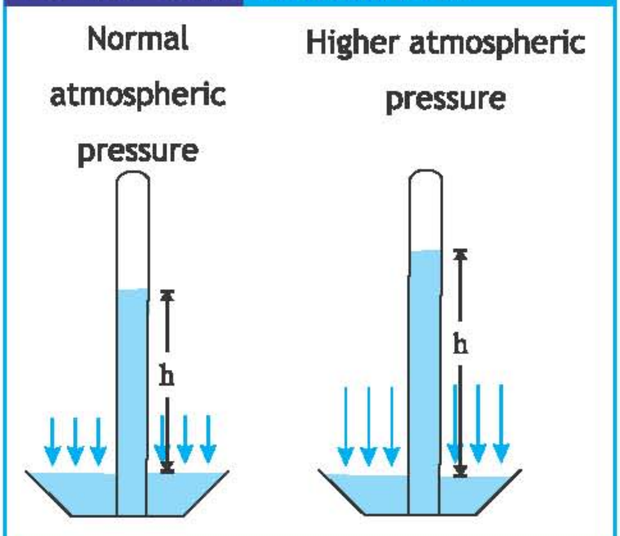
In a mercury barometer, a tube filled with mercury is inverted into a container of mercury. The mercury in the tube seeks a level where the weight of the mercury column is balanced by atmospheric pressure on the surface of the mercury in the container. The height of the mercury column in the tube represents the atmospheric pressure as shown in the figure 5.10. At sea level, the atmosphere will push down mercury in the tub and make it rise up in a tube to a height of approximately 760 millimeters (mmHg) or 29.92 inches.

1 atm = 760 mmHg ≈ 101.325 kPa

The torr is another unit of pressure, equivalent to 1 mmHg.

1 atm = 760 torr

FIGURE 5.10 BAROMETER



Changes in pressure cause the mercury level to rise or fall, indicating pressure variations associated with altitude and local weather conditions.

Mercury barometers are precise, but they can be harmful to health because of the toxic nature of mercury. When safety is a priority, aneroid or digital barometers are commonly chosen as alternatives.

Liquid barometers have various applications:

A. Altitude Measurement: Liquid barometers (including mercury barometers), can estimate altitude. As atmospheric pressure decreases with increasing altitude, the height of the mercury column decreases, allowing for altitude calculations. They are essential instruments in aviation for altitude measurements and setting aircraft altimeters.

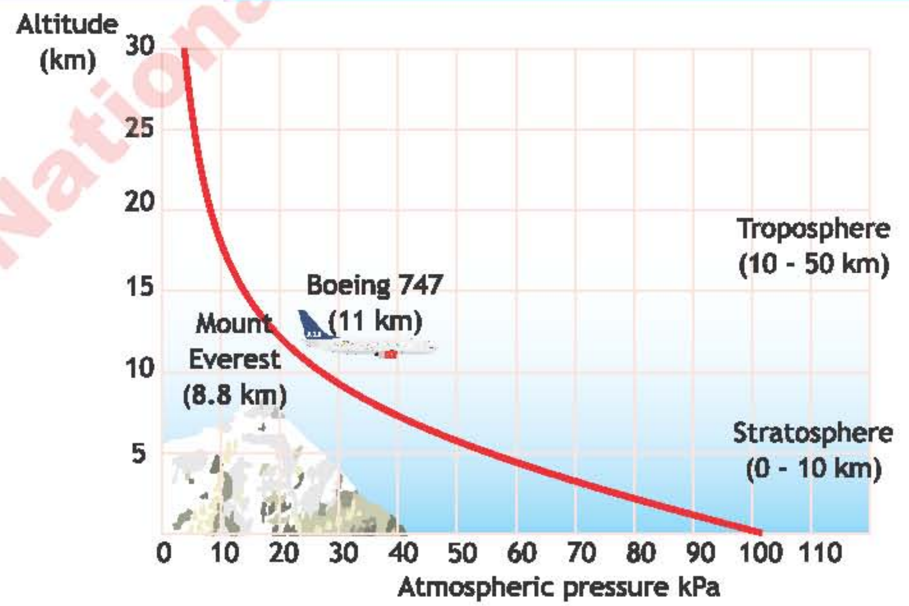
B. Weather Forecasting: They are used in meteorology to measure atmospheric pressure, which is associated with weather changes. A falling barometer may indicate an approaching storm, while a rising barometer suggests improvement in weather conditions.

C. Industrial Applications: Liquid barometers are used in industrial settings where precise pressure measurements are needed for specific processes or equipment.

5.3.2 ATMOSPHERIC PRESSURE AND HEIGHT FROM SURFACE OF EARTH

The atmospheric pressure decreases as we go up from the surface of earth. On mountains the atmospheric pressure is lower than at sea level, decreasing gradually to zero. The climbers at high altitudes encounter lower atmospheric pressure due to the thinner air. The thinner air causes breathing difficulties due to the lower level of oxygen. The graph in figure 5.11 shows that at Mount Everest (height of 8.8 km above sea level) the atmospheric pressure is only 33 kPa, and where Boing 747 flies the atmospheric pressure is around 23 kPa.

FIGURE 5.11 ATMOSPHERIC PRESSURE AND HEIGHT

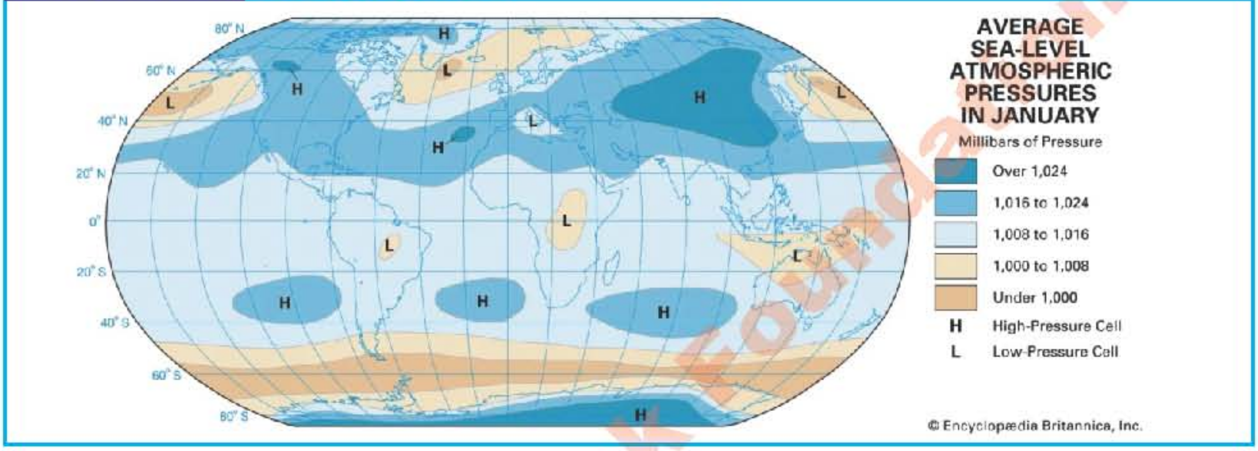


5.3.3 ATMOSPHERIC PRESSURE AND WEATHER

Barometers that are kept in the same place at the same height above sea level show some variation in atmospheric pressure from day to day. These pressure variations are shown on weather maps (fig. 5.12). The lines in the map joining all those places with the same atmospheric pressure are called isobars. The unit for pressure used in weather maps is the millibar (mbar).

1 mbar = 100 Pa

FIGURE 5.12 PRESSURE MAP



Usually the range of atmospheric pressure varies from the very high pressure of 1040 mbar to as low as 950 mbar. Winds move from high pressure regions to low pressure regions. The strength of the wind is determined by the pressure difference. From the weather map, when the isobars are packed closely together, it indicates a high pressure difference.

5.3.4 APPLICATIONS OF ATMOSPHERIC PRESSURE

(A) DRINKING BY STRAW: The drinking through straw is possible by lowering the pressure in the mouth below atmospheric pressure as shown in figure 5.13 (a). The action of sucking increases the volume of lungs, thereby reducing the air pressure in the lungs and the mouth. The atmospheric pressure acting on the surface of the liquid will then be greater than the pressure in the mouth, thus forcing the liquid to rise up the straw into the mouth.

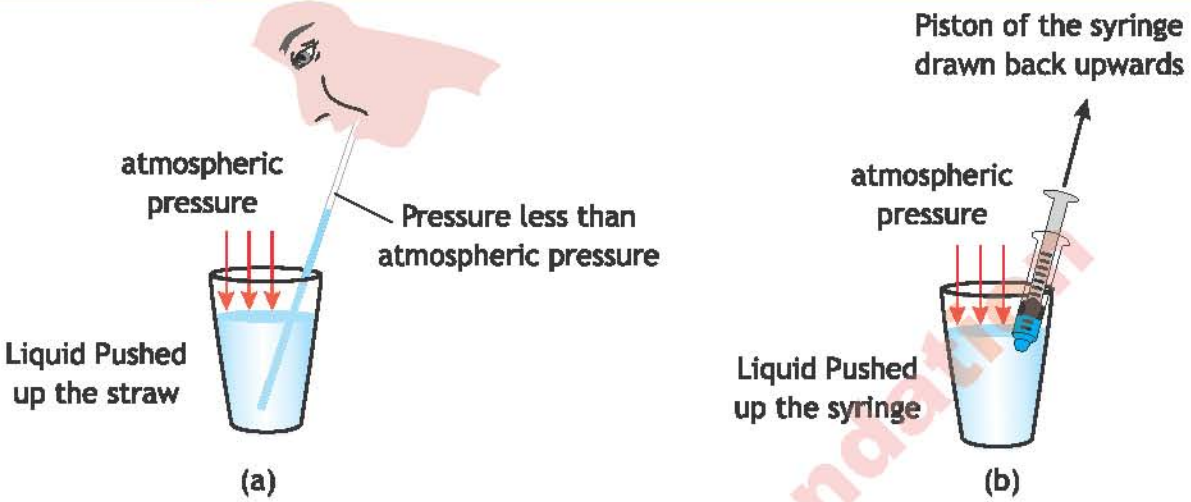
(B) DRAWING LIQUID BY SYRINGE: We can draw liquid up the syringe, as shown in Figure 5.13 (b), the piston of the syringe is drawn back upwards. This decreases the pressure within the cylinder. Atmospheric pressure acting on the surface of the liquid drives the liquid into the cylinder through the nozzle of the syringe.

POINT TO PONDER

Why it is difficult to cook food at high altitudes?

As altitude increases and atmospheric pressure decreases, the boiling point of water decreases. To compensate for the lower boiling point of water, the cooking time must be increased. Turning up the heat will not help cook food.

FIGURE 5.13 APPLICATIONS OF ATMOSPHERIC PRESSURE



5.4 LIQUID PRESSURE

Just like gases liquids also exert pressure. The pressure in liquid is due to its weight. We will determine that how pressure of incompressible liquid increases with depth.

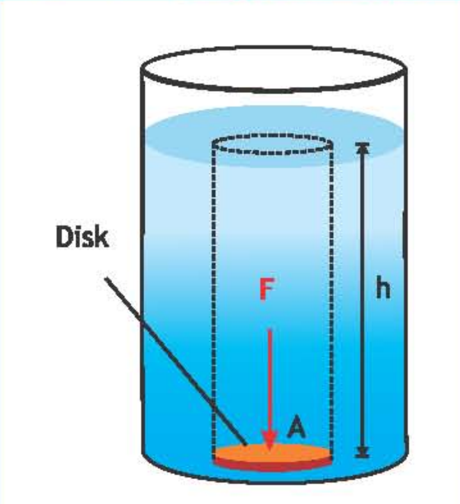
Consider a column of liquid of height 'h' , base area 'A' at the bottom of a tank in liquid and density 'ρ' as shown in figure 5.14. The force acting on a base area is the weight of the cylindrical column of liquid of mass 'm' is,

$$F = W = mg \quad \text{——— (1)}$$

The mass 'm' of the cylindrical liquid, in terms of density 'ρ' is given by,

$$\rho = \frac{m}{V} \quad \text{or} \quad m = \rho V \quad \text{——— (2)}$$

FIGURE 5.14 LIQUID PRESSURE



Since the fluid forms a cylindrical volume V shown by dotted lines in the figure which has height h and area of cross section A. Therefore

$$V = Ah \quad \text{——— (3)}$$

putting equation 3 in equation 2, we get

$$m = \rho Ah \quad \text{——— (4)}$$

putting equation 4 in equation 1, we get

$$F = \rho Ahg \quad \text{——— (5)}$$

Since pressure is defined as $P = \frac{F}{A}$ ——— (6)

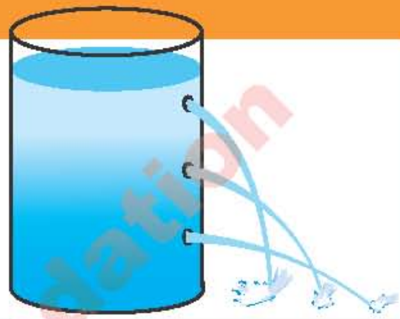
putting equation 5 in equation 6, we get $P = \frac{\rho Ahg}{A}$

therefore $P = \rho h g$ —— 5.3

from equation 7.3 we deduce that the pressure in a liquid depends on the depth and density of the liquid.

ACTIVITY

Drill holes at different heights on a can as shown in the figure and fill it with water. Water will spurt out fastest and furthest from the lowest hole and slowest and nearest from the highest hole. This means that the pressure in a liquid increases with depth because the further down you go, the greater the weight of liquid above it.



EXAMPLE 7.3: LIMITS ON SUBMARINE DEPTH

A submarine was moving in the Pacific Ocean (the largest and deepest ocean) at a depth of 8.5 km. How much pressure is exerted upon the submarine if density of water is 1000 kg/m^3?

GIVEN

Depth = height h = 8.5 km = 8500 m

Density of water ρ = 1000 kg/m^3

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

REQUIRED

Pressure P = ?

SOLUTION:

The pressure exerted on a body inside a liquid, can be given by:

Putting values

Therefore $P = 8.55 \times 10^7$ N/m^2 = 8.55×10^7 Pa —— **Answer**

The water will exert a pressure of 8.33×10^7 Pa or 83.3 MPa on the submarine.

5.5 MANOMETER

A manometer can be defined as a device that is used to measure the pressure in a fluid using fluid dynamics. The fluid can be a gas or a liquid.

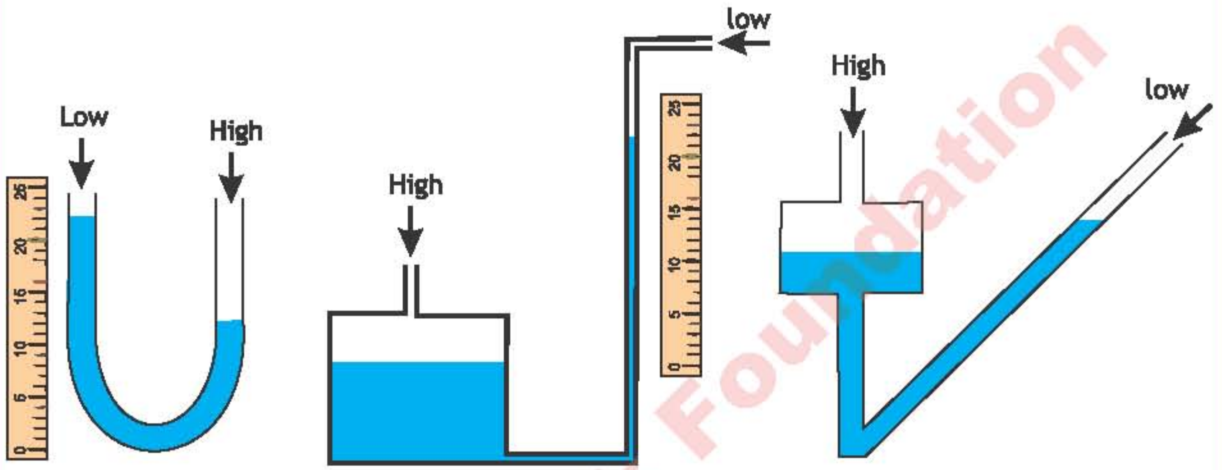
In other words, we can define it as a gauge that is used to measure pressure present in the fluids. Also, it is used in laboratory experiments to demonstrate the pressure of air on a liquid column or vice versa

The formula of a manometer is as follows:

$$P = \rho g h \quad (5.4)$$

Where '*P*' is the pressure of the fluid, '*ρ*' is the density of the fluid, '*g*' is the gravitational acceleration exerted by the earth, and '*h*' is the height till which the fluid rises in a manometer.

FIGURE 5.15 MANOMTRE TYPES



(a) U-tube Manometer (b) Well Reservoir Manometer (c) Inclined Manometer

The working principle of a manometer is that one end is connected to a seal-tight gas to measure the source of pressure. Whereas, its other end is left open to the atmospheric pressure of the earth. If the pressure present in it is greater than 1 atm then the fluid present in the column will be forced down by that pressure. However, it will cause an increase in equal amounts in the present column.

5.5.1 APPLICATION OF MANOMETER

- It is used to measure the pressure of the fluids using mechanical properties of fluids.
- It is also used to measure vacuum.
- It is also used to measure the flow of the fluid.
- It is used to measure the filter pressure drop of the fluids.
- It is also used for meter calibrations.
- It is used to measure leak testing.
- It is also used to measure the liquid level present in a tank.

TABLE 5.2: DIFFERENCE BETWEEN MANOMETER AND BAROMETER	
Manometer	**Barometer**
It is a device that is used to measure the pressure of the fluid but that of a liquid concerning the earth's atmospheric pressure.	It is a device that is used to measure fluid pressure but that of air as it can differ with distance when it's below or above sea level
It comes in different forms	It comes only in one basic design for all its types
These are filled with mercury or any heavy liquid material but in some cases, they can be filled with a lighter liquid material	In all its cases, these are only filled with mercury or any heavy liquid material

5.6 PASCAL'S PRINCIPLE

When we pump a bicycle tire, we apply a force on the pump that in turn exerts a force on the air inside the tyre. The air responds by pushing not only against the pump but also against the walls of the tyre. As a result, the pressure increases by an equal amount throughout the tyre as shown in figure 5.16.

FIGURE 5.16 AIR FILLING IN BICYCLE

In general, if the pressure in a fluid is increased at any point in a container (such as at the valve of the tyre), the pressure increases at all points inside the container by exactly the same amount. Blaise Pascal (1623-1662) noted this fact, what is now called Pascal's principle (or Pascal's law):

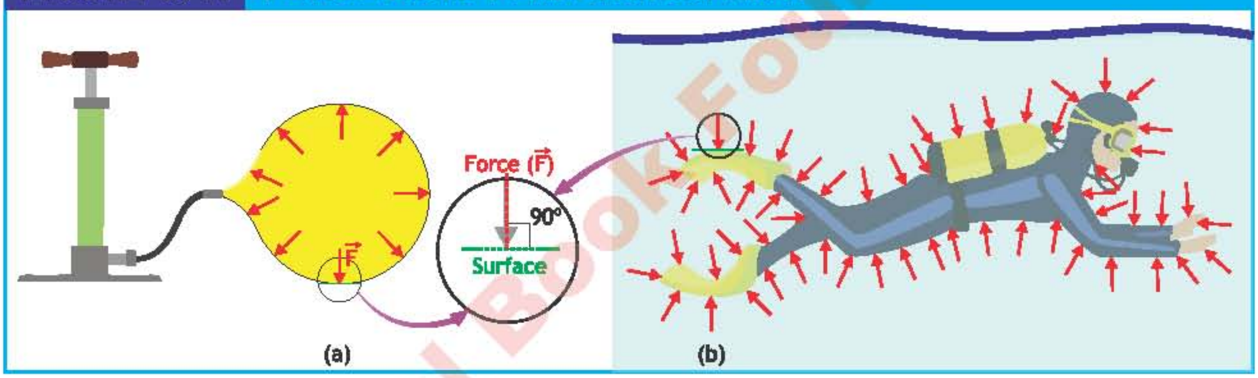
An external pressure applied to an enclosed fluid is transmitted unchanged to every point within the fluid.

The relationship between pressure and force on a surface is described by Pascal's Principle, which explain how pressure at a surface produces a force in a direction perpendicular (at right angles) to the surface.

Since pressure is transmitted equally in all directions, the force generated ($F = P \times A$) is also distributed equally in all directions. The force acts perpendicular to the surface because the pressure is acting uniformly in all directions. If there were a component of force parallel to the surface, the object would exert force on the fluid parallel to it as a consequence of Newton's third law. This would result in an uneven distribution of forces, contradicting the principles of Pascal's Principle.

When you blow up a balloon, the pressure inside the balloon goes up. This pressure spreads out evenly in all directions. The force from the pressure pushes outward and goes straight across the surface of the balloon, making it get bigger as shown in figure 5.17 (a).

FIGURE 5.17 FORCE ACTS PERPENDICULARLY



As you dive deeper underwater, the pressure increases due to the weight of the water above. The force exerted by this pressure is perpendicular to the surface of your body. This is why divers feel pressure on their ears, and it also explains why deep-sea divers need specialized suits to counteract the pressure as shown in figure 5.17 (b).

5.7.1 HYDRAULIC LIFT

Pascal's principle at work in hydraulic lift, which is shown schematically in Figure 5.18. Here we see two cylinders, one of cross-sectional area A_1 and the other of cross-sectional area A_2 (such that $A_2 > A_1$). The cylinders, each of which is fitted with a piston, are connected by a tube and filled with a Hydraulic fluid. Initially the pistons are at the same level and exposed to the atmosphere.

Now, suppose we push down on piston 1 with the force F_1. The pressure P_1 exerted by this piston is:

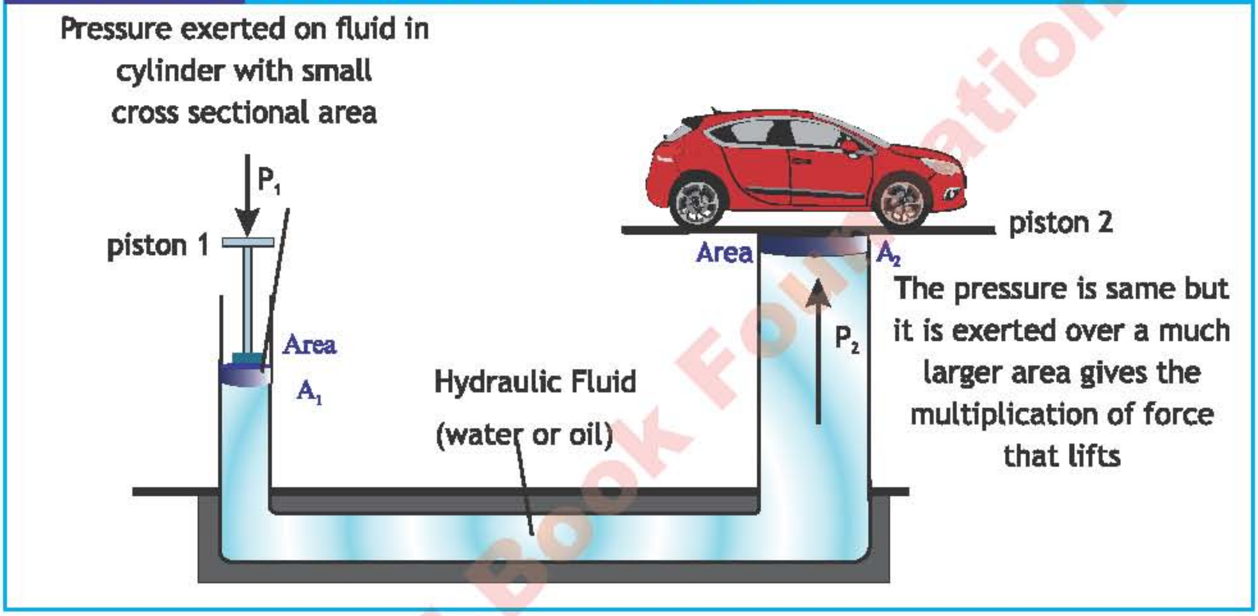
1

Similarly, the pressure on the piston lifting vehicle is P_2, which can be written as

—— 2

By pascal's principle —— 3

FIGURE 5.18 HYDRAULIC ELEVATOR OR LIFT



putting values from equation 1 and equation 2 in equation 3 and rearranging for F_2 , we get

—— 5.5

Equation 5.5 shows that depending on the ratio A_2/A_1 the force F_2 can be as large as possible. To be specific, let's assume that A_1 is 100 times greater than A_2. Then, by pushing down on piston 1 with a force F_1 we push upward on piston 2 with a force of $F_2 = 100\ F_1$. Our force has been magnified 100 times! Hence a relatively small effort can be used to overcome a much larger load.

FIGURE 5.19 HYDRAULIC CAR LIFT

5.7.2 HYDRAULIC CAR BRAKE SYSTEM

The operation of hydraulic car brake system as shown in figure 5.20 is based on Pascal's principle, in the brake system:

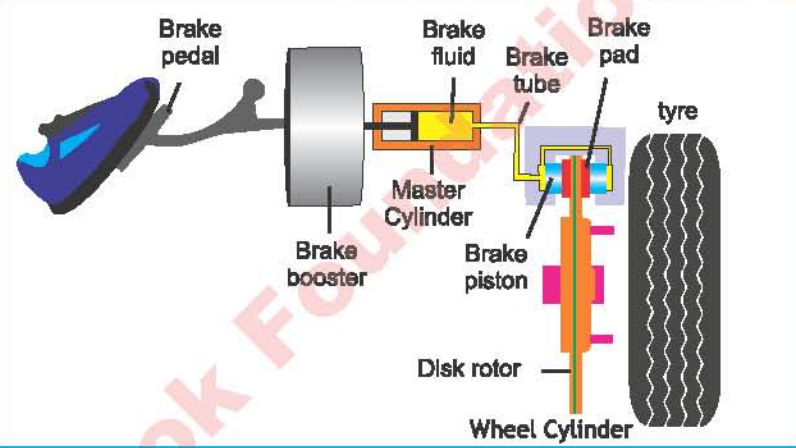
A. Brake Pedal (Force Input): When we press the brake pedal, it exerts force on the master cylinder's piston.

B. Master Cylinder (Pressure Increase): The force on the piston increases the pressure in the brake fluid.

C. **Brake Lines (Pressure Transmission):** The increased pressure is transmitted equally through the brake fluid in the brake lines to all wheels.

D. **Brake Calipers or Wheel Cylinders (Force Application):** At each wheel, the pressure acts on brake calipers or wheel cylinders, applying force to brake pads.

FIGURE 5.20 HYDRAULIC CAR BRAKE SYSTEM



EXAMPLE 7.4: PASCAL'S PRINCIPLE

A hydraulic lift has 0.002 m² narrow cylinder area while 0.9 m² wider cylinder area. How much force must be applied at the narrow cylinder if a car weighing 1800 kg is to be lifted?

GIVEN

Area of narrow cylinder 'A_1' = 0.002 m^2

Area of wider cylinder 'A_2' = 0.9 m^2

Mass of car 'm' = 1800 kg

REQUIRED

Force at narrow cylinder F_1 = ?

SOLUTION: First we will find weight of the car as this will be the force applied on car:

$$w = mg = F_2 = 1800\ \text{kg} \times 9.8\ \text{m/s}^2 = 17{,}640\ \text{N}$$

From Pascal's principle $F_1 = \frac{A_1}{A_2} F_2$ Putting values $F_1 = \frac{0.002\, m^2}{0.9 m^2} \times 17{,}640\, N$

Therefore $F_1 = 39.2\,\text{N}$ Answer

That is why we use hydraulic lifts to lift heavy weights with much smaller force than their weight.

SUMMARY

- **Elasticity** is the property of a body, which enables the body to regain its original dimension when the deforming force acting on it is removed.
- **Hooke's law** states that within elastic limits the extension (or compression) is directly proportional to the force applied.
- **Pressure** is force applied per unit area.
- **Atmospheric Pressure** or barometric pressure is the force exerted by the air (its weight) on unit area.
- **Barometer** is a device used to measure atmospheric pressure.
- **Monometer** is one of the most accurate devices for measuring pressure, including atmospheric pressure in the lower ranges.
- **Pascal's Principle** states that if the pressure at one point of a confined fluid is increased by an amount, the pressure increases by the same amount at all other parts throughout the fluid.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option.

1. The most elastic material of the following is:

   A. Rubber   B. Wood   C. Glass   D. Steel

2. Hooke's law hold good up to:

   A. proportional limit   B. yield limit
   C. elastic limit   D. plastic limit

3. A mass of 2 kg is hung by spring, which displaces it through 5 cm. The spring constant is:

   A. 400 N/m   B. 40 N/m   C. 4 N/m   D. 4000 N/m

4. Materials which does not regain its original shape after removal of the load producing deformation are termed as:

   A. Elastic materials   B. Plastic materials
   C. Rigid materials   D. Hooke's materials

5. SI unit of pressure is:

   A. bar   B. newton   C. psi   D. pascal

6. Which will exert greater pressure?

   A. 3 g needle of tip area 1mm^2 B. 4000 kg elephant of total feet area 0.5 m^2
   C. A girl of mass 40 kg wearing high heel shoes of cross-sectional area 0.5 cm^2
   D. A loaded ship of mass 2.2 x 10^7 kg having area 600 m^2

7. Pressure of 1000 mbars is equivalent to:
   A. 0.1 kPa B. 1 kPa C. 10 kPa D. 100 kPa
8. Pressure of 1 mm Hg is equal to:
   A. 1.316×10^{-3} atm B. 1 atm C. 133.29 atm D. 1.316×10^{5} atm
9. Atmospheric pressure is commonly measured using a:
   A. hygrometer B. barometer C. manometer D. thermometer
10. Pressure of liquid in a container increase with:
   A. base B. volume C. depth D. mass
11. The atmospheric pressure will be smaller at:
   A. Islamabad B. Peshawar C. Lahore D. Murree
12. A girl of mass 50 kg wears heels with an area of 2 cm^2 in contact with the ground. The pressure she exerts on ground is:
   A. 4×10^{-5} Pa B 4×10^{4} Pa C. 4×10^{-4} Pa D. 4×10^{5} Pa
13. Divers wear special suits in order to protect them from:
   A. low pressure B. high pressure
   C. low temperature D. high temperature
14. In a stationary fluid, the local pressure of the fluid vary:
   A. with depth only B. horizontally only
   C. both with depth and along horizontal direction
   D. neither with depth nor along horizontal direction
15. The pressure exerted by a man on the surface of earth will be smaller when he:
   A. stands on both feet B. sits on the ground
   C. stands on one leg D. sleeps on the ground

SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

1. While walking on a trampoline. Do you feel more pressure when you stand still or jump up and down? Why does pressure change with movement?
2. How does the shape of a thumb pin help it penetrate surfaces easily?
3. If you blow up a balloon and then tie it closed, why does it stay inflated even though you stop blowing? How does pressure play a role here?
4. Why an inner airtight layer of a space suit is designed to maintain a constant pressure around the astronaut?
5. If a liquid has density twice the density of mercury, what will be height of liquid column in barometer?
6. Why we wouldn't be able to sip water with a straw on the moon?

7. How are we able to break a metal wire by bending it repeatedly?
8. A spring, having spring constant k when loaded with mass 'm', is cut into two equal parts. One of the pars is loaded with the same mass m again. What will be its spring constant now?
9. Why do static fluids always exert a force perpendicular to the surface?
10. How can a small car lifter lifts load heavier than itself?

LONG RESPONSE QUESTIONS

QIII. Give a an extended response to the following questions

1. Define elasticity and elastic limit. Show that a force may produce change in size and shape of solids.
2. What is Hook's law? Illustrate its applications. Also, define and calculate spring constant.
3. Draw and explain force-extension graph for elastic solids.
4. Define and explain pressure. What is effect of area on pressure acting on surface?
5. Explain the term atmospheric pressure along with its units. How atmospheric pressure is measured with liquid barometer? Explain its construction and applications.
6. Explain with examples how atmospheric pressure varies with altitude. What kind of weather change is indicated by variation in the atmospheric pressure? What are different applications of atmospheric pressure?
7. Show that liquid in a container exerts pressure equal to $P = \rho g h$. What is effect of depth on pressure of liquid?
8. State Pascal's law? Describe working principle of hydraulic lift using Pascal's law? What do you mean by force multiplier?

NUMERICAL RESPONSE QUESTIONS

QIV. Solve the following numerical questions.

1. Consider a spring with a spring constant of 8000 N/m. If a force of 500 N is applied to the spring, what will be the displacement of the spring?

(Ans. 6.25 cm)

2. In a force multiplier, small piston has diameter of 15 cm and large piston has diameter of 30 cm. If 250 N force is applied on the small piston then how much force will produce on large piston?

(Ans. 1000 N)

3. A hydraulic car lift lifts a car of mass 1000 kg when we apply force of 50 N on small piston. Radius of its small piston is 20 cm. Find the radius of its large piston.

(Ans. 78.4 cm)

4. Water column in a beaker is 70 cm. Find the pressure of water in beaker. Take density of water as 1000 kg/m^3.

(Ans. 6.86 kPa)

5. How much force should be applied on an area of 20 cm^2 to get a pressure of 4500 Pa?

(Ans. 9 N)

Approved by National Curriculum Council, Secretariat
Ministry of Federal Education & Professional Training
vide letter No. F.1-1 (2024)-NCC/DEA/Dir/English, Dated: 04th March 2024

قومی ترانہ

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

پاک سر زمین کا نظام قوّتِ اخوّتِ عوام
قوم ، مُلک ، سلطنت پائندہ تابندہ باد!
شاد باد منزلِ مُراد!

پرچم ستارہ و ہلال رہبرِ ترقی و کمال
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