Preface

This textbook is designed for the students at Upper Secondary Level (i.e. Grade 10) with the foundation standards falling into the three broad strands mentioned below:

1. Mechanics
2. Energy
3. Modern Physics

The first two strands cover the elementary level of physics whilst the final chapter deals with Modern Physics, which is to be further dealt with in Grade 11. Despite a greater emphasis placed on introductory physics, it is gratifying to note that this updated edition is also in a position to serve as a launch platform for the beginners who have the future potential to become outstanding scholars of physics.

Each chapter includes relevant graphical representations and photographs, not to mention the learner-friendly applications. What's more, the contents cover not only the learning objectives and outcomes but also relate to the conceptual questions, concept maps and links to laboratory work, enabling the learners to acquire considerable knowledge of traditional physics application problems and creative thinking skills. Better still, it may also help the students switch from the typical rote learning to the soft skills practiced commonly in the modern classrooms today. Accordingly, this textbook meets the requirements for a fundamental physics course both in terms of scope and sequence.

In addition, this textbook is intended to foster the **5C's**, the key to success in developing **21st century skills for learning** in the classrooms:

- **Collaboration**
  - in lessons students will be working in groups, to share ideas with their classmates and to find the solution together
- **Communication**
  - students will develop verbal and non-verbal communication skills in group works
- **Critical Thinking and Problem Solving**
  - students will be given interesting problems to solve
  - finding and explaining solutions, looking for correcting errors
- **Creativity and Innovation**
  - thinking 'outside the box' is an important 21st century skill.
  - students will be encouraged to explore new ideas and solve problems in new ways.
- **Citizenship**
  - students will join the school community and develop fairness and conflict resolution skills.

Furthermore, it is organized in such a way that the topics are introduced conceptually with the degree of intensity increased gradually. Besides, the developmental progression is established with the help of the precise definitions and principles in addition to the problems and their practical applications. Remarkably, the textbook also makes sure that the students' problem-solving skills in one topic are consolidated with the key concepts before moving on to another topic. Thoroughly reviewed and revised, this edition bears comparison with most of the contemporary textbooks aimed at the same target audience.

It goes without saying that physics is the study of the world around us. With this textbook as the standard source of information on physics, the students are expected to have greater awareness of what is happening around them every day in the context of physics. Simultaneously, they are also expected to develop superior skills when it comes to their concept formation, comprehension, analysis, synthesis, and evolution, thereby making themselves able to participate in all the lessons actively through the **5C's**, which constitute the integral part of **21st century skills for learning.**

CONTENTS

MECHANICS

ENERGY

CHAPTER 1

UNITS AND MEASUREMENTS

Physics, like any other branch of science, is based on systematic observations and precise measurements. Experiments are an essential feature of science. Most experiments in Physics require the observations made to be quantitative rather than qualitative.

Learning Outcomes

It is expected that students will

- work accurately with basic and derived units of measurement.
- work accurately with standard measurements and conversions between different system of units.
- correctly use the symbols for physical quantities.
- develop skills in accurate measurement of length, mass and time.
- solve problems demonstrating proper use of units, quantities and scientific notation.

1.1 BASIC AND DERIVED UNITS

Measurement essentially is a comparison process. Quantitative measurements must be expressed in numerical comparison to certain agreed upon set of standards. A standard quantity of some kind, referred to as a unit, is first established. Standard is something or a reference used as a measure for length, mass and time. Unit is a quantity or an amount used as a standard of measurement.

There are many things in the world that can be measured accurately. These things are known as 'physical quantities'. A physical quantity is the quantity that can be measured, and consists of a numerical magnitude and a unit. It can be expressed as

$$Q = \mathrm{N\,u}$$

where Q is the physical quantity, N is a dimensionless number and u is the unit. For example, the length of an object is $l = 10\ m$, where 'l' is physical quantity,'10' is the numerical number and 'm' is the unit .

Physical quantities can be classified as the basic type (length, mass, time, temperature, electric current, amount of substance, luminous intensity) and the derived type (area, volume, velocity, work, energy, etc.). Their units are also called the basic units and the derived units. A derived unit is a unit of measurement formed by combining the basic (or base) units of a system.

For example, speed = $\dfrac{\text{distance}}{\text{time}}$, the base unit of distance is 'm' and that of time is 's'.
Therefore the unit of speed is 'm s^{-1}'. This is a derived unit.

Reviewed Exercise

- Explain each of the following terms in your own words:
  physical quantity, basic unit, derived unit.

Key Words : physical quantity, standard, unit, basic unit, derived unit

1.2 SYSTEM OF UNITS

In this text book, we shall be using the following system of units.

(i) the British system
(ii) the metric system
(iii) the SI units

The British system is based on foot (ft), pound (lb) and second (s) and is therefore also called the FPS system.
The metric system consists of (i) the CGS system and (ii) the MKS system.
The CGS system is based on centimetre (cm), gram (g) and second (s).
The MKS system is based on metre (m), kilogram (kg) and second (s).
These two systems are alike in the sense that units of length and mass of one system may be converted to those of the other by using powers of 10. (e.g. 1 m = 10^2 cm, 1 kg = 10^3 g)
The SI unit is just the modified form of the MKS system of units.

> Scientists all over the world like to work with a consistent and coherent system of units. In 1960, the Eleventh General Conference of Weights and Measures in France recommended an International System of Units based on the metric system of units. This recommendation was accepted as SI units (full name, 'Systeme International d' Units').

The SI unit has seven base units and all other units are derived from these base units by multiplying or dividing one unit by another without introducing numerical factors. Table 1.1 shows the seven base units of SI system.

Table 1.1 Seven base units of SI system

Physical quantity	Symbol	SI unit
Length	ℓ, d, s, etc.	metre (m)
Mass	m	kilogram (kg)
Time	t	second (s)
Electric current	I	ampere (A)
Temperature	T	kelvin (K)
Amount of substance	n	mole (mol)
Luminous intensity	L	candela (cd)

Reviewed Exercise

1. Write down the value of (a) 1 564 mm in m, and (b) 1 750 g in kg.
2. In each of the following pairs, which quantity is larger?
   (a) 2 km (or) 2 500 m, (b) 2 m (or) 1 500 mm, (c) 2 000 g (or) 3 kg

Key Words : SI units, metric system, British system

1.3 PREFIXES

Sometimes a physical quantity is too big (or) too small to be conveniently expressed in basic SI units. Prefixes are needed to be used. Prefixes are multiples or sub-multiples of 10. Table 1.2 shows some prefixes used in SI units.

Table 1.2 Some prefixes for SI units

Prefix	Symbol	Factor
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}

Prefix	Symbol	Factor
deca	da	10^{1}
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

Scientific notation (or) standard form may be written as follows:

Place the decimal point after the first nonzero digit. Then determine the power of 10 by counting the number of places we have moved the original decimal point to the marked decimal point. If we moved the point to the left, then power is positive and if we moved it to the right, it is negative.

Reviewed Exercise

- Write the following numbers in scientific notation.
  (a) 320 000 (b) 0.000 075

Key Words : scientific notation

1.4 STANDARDS AND UNITS

(a) The Unit of Length

The standard of length is metre. The metre was originally defined as the length between two marks on a platinum-iridium rod at $0\,^{\circ}\mathrm{C}$, kept at the International Bureau of Weights and Measures at Sevres, near Paris. Copies of the standard were sent all over the world.

Nowadays the standard of length used is based on the wavelength of orange-red light emitted by a krypton 86 isotope. A metre is now defined as the length equivalent to 1 650 763.73 times the wavelength of this orange-red light.

By the 1970s, the speed of light has become one of the most precisely determined quantities. As a result, in 1983 the metre was given a new operational definition. The metre is the length of the path travelled by light in vacuum during a time interval of $\frac{1}{299\,792\,458}$ of a second.

In the CGS system the unit of length is the centimetre (cm) and

$$1\,\text{cm} = \frac{1}{100}\ \text{m} = 10^{-2}\ \text{m}$$

In the FPS system the unit of length is the foot (ft) and

$$1\ \text{ft} = 0.3048\ \text{m}$$

The unit of length used by particle physicists is the 'Fermi' or 'femtometre' (fm) given by

$$1\ \text{fm} = 10^{-15}\ \text{m}$$

In the field of optics, physicists use the unit angstrom (Å), where

$$1\ \text{Å} = 10^{-10}\ \text{m}$$

In astronomy, the most suitable units are the astronomical unit (AU) and the light year unit (*l*y). The light year is the distance which light travels in one year.

$$1\ \text{AU} = 1.496 \times 10^{11}\ \text{m}$$

$$1\ ly = 9.461 \times 10^{15}\ \text{m}$$

The largest unit of length is the 'parsec'(pc).

$$1\ \text{pc} = 3.084 \times 10^{16}\ \text{m}$$

(b) The Unit of Mass

The standard of mass is a cylinder of 1 kg mass made of platinum-iridium alloy. It serves as a standard of mass for international use. Figure 1.1 shows the standard metre and standard kilogram which are kept at the International Bureau of Weights and Measures at Sevres, near Paris. Prototypes of standard kilogram are distributed to research academies and laboratories situated in all parts of the world.

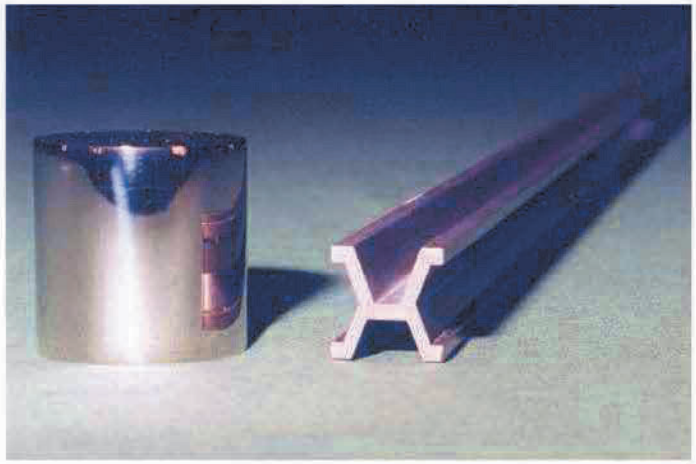


Figure 1.1 The standard kilogram and the standard metre kept at International Bureau of Weights and Measures

[https://www.bipm.org/en/measurement-units/history-si/metre-kilo.html]

(c) The Unit of Time

The SI base unit of time is the second. The second was originally defined as $\frac{1}{60 \times 60 \times 24}$ of a day, one day being the time it takes the Earth to rotate once. But the Earth's rotation is not quite constant. So, for accuracy, the second is now defined in terms of something that never changes: the frequency of oscillation which can occur from a cesium atom. A particular frequency 9 192 631 770 s^{-1} emitted or absorbed by a cesium atom is used to define 1 s.

Reviewed Exercise

- If the density of ice is 920 $kg\ m^{-3}$, convert this value to $g\ cm^{-3}$.

Key Words: light-year, oscillation, frequency

Symbols for Physical Quantities

It is said that 'mathematics is the language of physics'. Physical laws and principles can be fully and effectively represented in mathematical forms. Since we have to express the relation between physical quantities in mathematical equations it is necessary that the symbols for the physical quantities be short and precise.

Some commonly used symbols for physical quantities are:
' s ' for displacement, ' v ' for velocity, ' a ' for acceleration and ' F ' for force .

1.5 MEASUREMENT OF LENGTH

To measure the length of objects some standard objects have to be used. For everyday use, the standard may be a yard stick, ruler, metre stick and so on. Lengths are usually measured in metre, centimetre or millimetre. Greater lengths are measured in kilometre.

In length measurement, we must choose an instrument that is suitable for the length to be measured. Figure 1.2, 1.3 and 1.4 show some various instruments for measurement of length. Table 1.3 summarizes the commonly used instruments, their ranges and accuracies.

Figure 1.2 Measuring tape, metre rule and half-meter rule

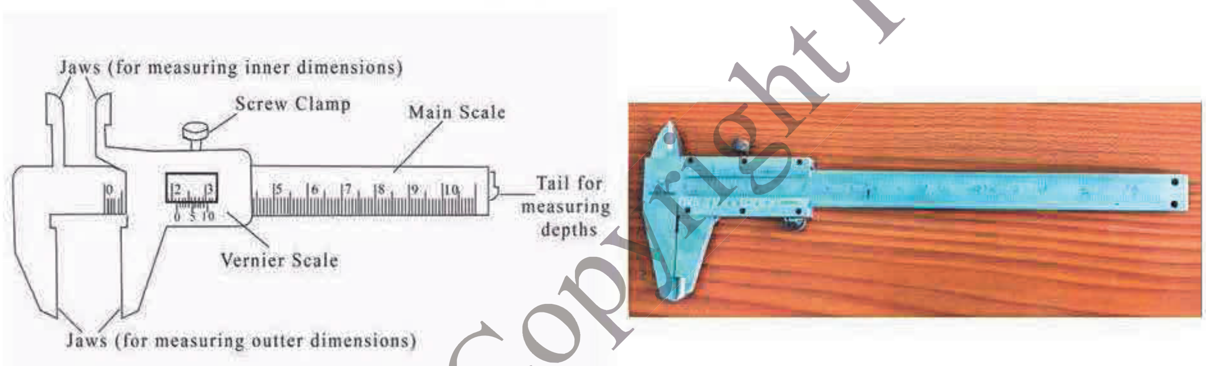


Figure 1.3 Vernier calipers

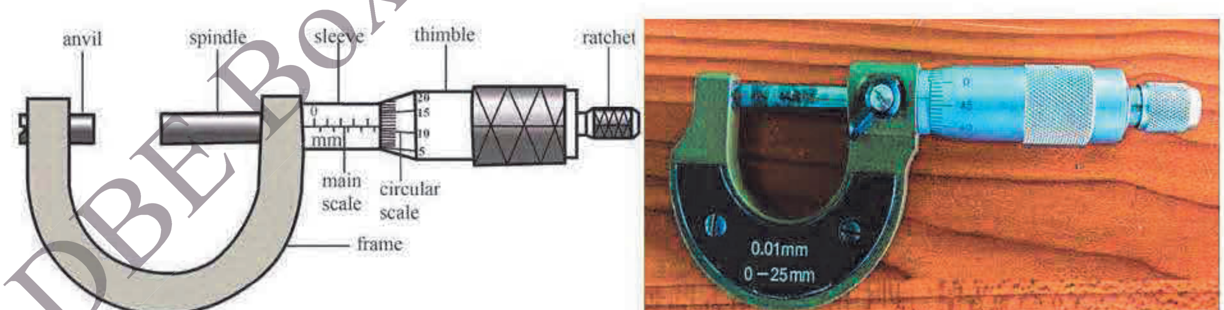


Figure 1.4 Screw gauge (Micrometer)

Table 1.3 Instruments used for length measurement and their accuracy

Length to be measured	Suitable instrument	Accuracy of instrument
several metres (m)	Measuring tape	1 mm (= 0.1 cm)
several centimetres (cm) to 1 m	Metre rule or half-metre rule	1 mm (= 0.1 cm)
between 1 cm and 10 cm	Vernier calipers	0.1 mm (= 0.01 cm)
less than 2 cm	Screw gauge (Micrometer)	0.01 mm (= 0.001 cm)

Key Words: accuracy, range

1.6 MEASUREMENT OF MASS

The mass of an object is a measure of the amount of matter in it.

Mass is measured in laboratories using a sliding mass balance or the electronic balance, as shown in Figure 1.5 and 1.6, respectively. The mass of an object can be found using balance like this.

The electronic balance is easier to use and also more accurate than sliding mass balance. The unknown mass is placed on the top of the pan and its mass is read directly from a display screen.

Figure 1.5 A sliding balance

Figure 1.6 An electronic balance

The balance really detects the gravitational pull on the object (weight), but the scale is marked to show the mass.
The mass of purified drinking water of 1 litre bottle is 1 kg.

1.7 MEASUREMENT OF TIME

Time is measured in years, months, days, hours, minutes and seconds, but the SI unit for time is the second (s). Most common modern clocks and watches depend on the vibration of quartz crystals to keep time accurately. The energy to keep these crystals vibrating comes from a small battery. A stopwatch (or) a stop clock shown in Figure 1.7(a) and (b) can be chosen to measure the time to an accuracy of a few tenths of a second. Digital stopwatches can measure up to 0.01 s as shown in Figure 1.7(c).

(a) Stopwatch (b) Stop Clock (c) Digital Stopwatch

[https://runnerclick.com/best-stopwatches-reviewed]

Figure 1.7 Time measuring instruments

SUMMARY

A **physical quantity** is the quantity that can be measured, and consists of a numerical magnitude and a unit.

Physical quantities can be classified as the **basic type** (length, mass, time, temperature,electric current, amount of substance, luminous intensity) and the **derived type** (area, volume, velocity, work, energy, etc.). Their units are also called the **basic units** and the **derived units.**

A derived unit is a unit of measurement formed by combining the basic (or base) units of a system.

Standard is something (or) a reference used as a measure for length, mass and time.

Unit is a quantity (or) an amount used as a standard of measurement.

EXERCISES

1. Is physics useful in the study of chemistry, biology and engineering subjects?
2. Determine the derived units of :
   (a) speed (= distance / time)
   (b) volume (= length × width × height)
   (c) density (= mass / volume)
3. The density of water is 1.0 g cm^{-3}. Convert this value to SI units.
4. Find the area of one page of a book whose dimensions are 20 cm × 25 cm in cm^2 and then convert this value to m^2.
5. Write down in powers of ten the values of the following quantities:
   (a) 60 nF (b) 500 MW (c) 20 000 mm (d) 400 μC

CHAPTER 2

MOTION

This chapter introduces scalar and vector quantities and the manipulations of vectors; that is finding the sum and difference of two vectors and also resolving a vector into two perpendicular components. As motion is a fundamental part of physics, basic quantities associated with motion are also clearly defined and explained. The linear motion, the simplest type of motion, is studied together with the equations of motion under constant velocity and constant acceleration. Motion graphs, their interpretation and analysis are also included.

Learning Outcomes

It is expected that students will

- distinguish between a scalar quantity and a vector quantity.
- demonstrate correct use of vector symbols.
- find the sum and difference of two vectors and resolve a vector into two or more components.
- explain distance, displacement, speed, velocity and acceleration.
- study the equations of motion to analyze the motion under constant velocity and constant acceleration.
- illustrate and interpret motion graphs, namely, distance-time, speed-time graphs.
- solve problems demonstrating proper use of units, quantities and scientific notation for describing motion.

2.1 VECTORS

Scalar and Vector

Some physical quantities of physics are completely described by a single number (or magnitude) with an appropriate unit. Such quantities, that have only magnitude, are called scalar quantities. For example, it is sufficient to say that the length of the ship is 30 m, the mass of the block is 500 g and the area of the blackboard is 48 ft^2.

However, some quantities have a directional quality. Not only the magnitude but also the direction is required for the complete description of such quantities. For example, we have to say that the plane is flying with a velocity of 20 mi h^{-1} towards east, the force acting on the body is 20 N upwards and the displacement of the ship is 150 km northeast from the port. These quantities, that have both magnitude and direction, are called vectors. Since we have to come across vector quantities in most areas of physics, we need to study the addition, subtraction and resolution of vectors.

Vector Symbols

In printing, vectors are represented by boldface type, such as ***A, F, v, s.*** In handwriting, vectors are indicated by placing arrows on the top of their symbols. e.g. $\vec{A}$, $\vec{F}$, $\vec{v}$, $\vec{s}$. The magnitude of $\vec{F}$ is written as $|\vec{F}| = F$. We would use handwriting format to express vectors later in this chapter; that is, by placing arrows on top of their symbols.

Vector relations and their meanings

(i) $\vec{A} = \vec{B}$: $\vec{A}$ and $\vec{B}$ are equal in magnitude and have the same direction.

(ii) $\vec{A} = -\vec{B}$: $\vec{A}$ and $\vec{B}$ are equal in magnitude but have opposite directions.

(iii) $\vec{A} = 2\vec{B}$: The magnitude of $\vec{A}$ is two times the magnitude of $\vec{B}$ and the direction of $\vec{A}$ is the same as that of $\vec{B}$.

(iv) $\vec{A} = -3\vec{B}$: The magnitude of $\vec{A}$ is three times the magnitude of $\vec{B}$ and the direction of $\vec{A}$ is opposite to that of $\vec{B}$.

Graphical Representation of Vectors

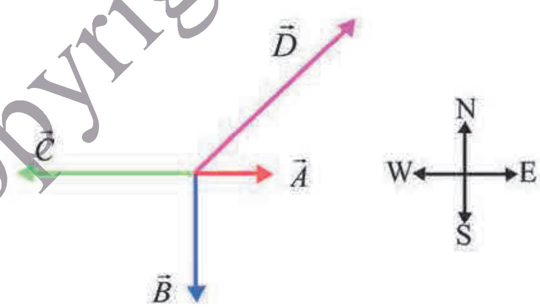
Using graphical method a vector may be represented by an arrow. The length of the arrow is proportional to the magnitude of the vector and the direction of the arrow gives the direction of the vector.

$\vec{A}$ = 5 units (east)

$\vec{B}$ = 10 units (south)

$\vec{C}$ = 15 units (west)

$\vec{D}$ = 20 units (north-east)



Addition of Two Vectors

To add $\vec{A}$ and $\vec{B}$, first draw $\vec{A}$.Then draw $\vec{B}$ in such a way that the tail of $\vec{B}$ is at the tip of $\vec{A}$. Then draw a third vector $\vec{R}$ from the tail of $\vec{A}$ to the tip of $\vec{B}$. $\vec{R}$ is the vector sum $\vec{A} + \vec{B}$ and it is called the resultant vector. It is to be noted that we can also draw $\vec{B}$ first, and then $\vec{A}$.

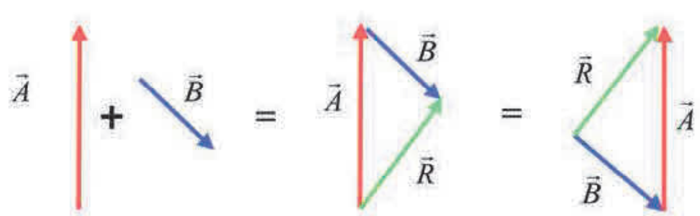


Figure 2.1 Diagram to illustrate vector addition

Subtraction of Two Vectors

In algebraic notation, $\vec{A} - \vec{B} = \vec{A} + (-\vec{B})$. Hence, vector subtraction is, in effect, vector addition. To subtract $\vec{B}$ from $\vec{A}$ (i.e. to find $\vec{A} - \vec{B}$), we add $\vec{A}$ and $(-\vec{B})$. Note that $(-\vec{B})$ has the same magnitude as $\vec{B}$ but its direction is opposite to that of $\vec{B}$.

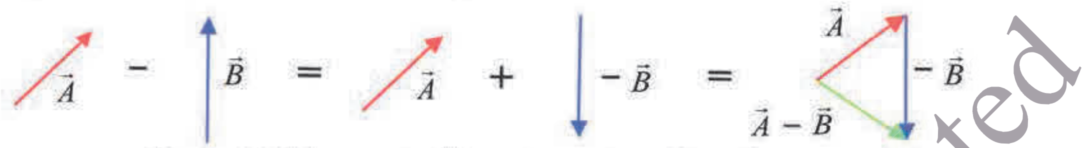


Figure 2.2 Diagram to illustrate vector subtraction

> $\vec{A} + \vec{B} = \vec{B} + \vec{A}$. Vector addition is commutative.
>
> $\vec{A} - \vec{B} = -(\vec{B} - \vec{A})$. Hence, vector subtraction is not commutative.

Example (1)

A boat travels east at 10 mi h^{-1} in a river that flows south at 3 mi h^{-1}. Find the boat's velocity relative to the river bank (the earth).

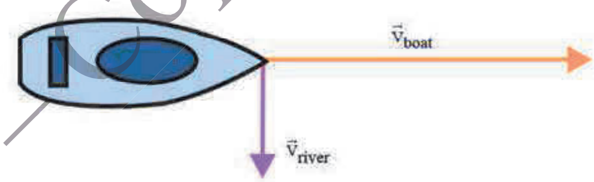
To find the boat's velocity relative to the river bank (the earth) we have to add the boat's velocity to the velocity of the river current.

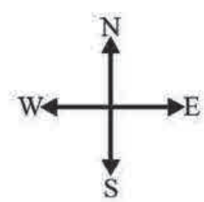
To find the magnitude of $\vec{v}$,

$$v^2 = (v_{boat})^2 + (v_{river})^2$$

$$= (10)^2 + (3)^2 = 109$$

$$v = 10.4 \text{ mi h}^{-1}$$

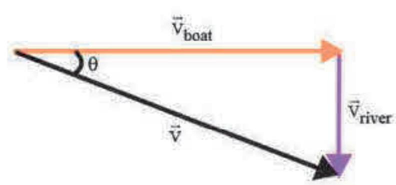




To find the direction,

$$\tan\theta = \frac{v_{river}}{v_{boat}} = \frac{3}{10} = 0.3$$

$$\theta = \tan^{-1}(0.3) = 17^{\circ}$$



The magnitude of the boat's velocity relative to the river bank = 10.4 mi h^{-1}

The direction = east 17° south (or 17° south of east).

Draw a scaled vector diagram and check your answer.

Resolution of a Vector into Two Perpendicular Components

Just as a number of vectors can be added to obtain a resultant vector, it is also possible to sub-divide a given vector into a number of different vectors. The process of sub-dividing a vector into two (or) more vectors is called resolution of a vector, and the new vectors obtained are called vector components of the original vector.

A useful application of vector resolution is sub-dividing a vector into two perpendicular components, namely, horizontal component and vertical component.

$\vec{A}$ = original vector

$\vec{A}_x$ = component of $\vec{A}$ along x-axis, x-component (or) horizontal component

$\vec{A}_y$ = component of $\vec{A}$ along y-axis, y-component (or) vertical component

$A_x = A\cos\theta$, $A_y = A\sin\theta$

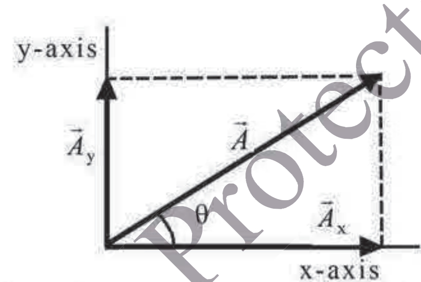


Figure 2.3 Components of a vector

Example (2)

A force of magnitude 5 N is inclined at an angle 37° to the horizontal. Find its horizontal and vertical components. (sin 37° = 0.6, cos 37° = 0.8)

$F = 5\text{ N}, \quad \theta = 37^\circ$

horizontal component $F_x = F\cos\theta = 5\cos 37^\circ = 5 \times 0.8 = 4\text{ N}$

vertical component $F_y = F\sin\theta = 5\sin 37^\circ = 5 \times 0.6 = 3\text{ N}$

Reviewed Exercise

1. Given that $\vec{A}$ = 2 units (west) and $\vec{B}$ = 4 units (south), draw vector diagrams to carry out the following vector operations. (i) $\vec{A}+\vec{B}$ (ii) $2\vec{A}+\vec{B}$ (iii) $\vec{B}-\vec{A}$
2. A force 4 N, directed east, and a force 6 N, directed west, act on a particle. Find the magnitude and direction of the resultant force.

Key Words: scalar, vector, addition of vectors, resolution of a vector

2.2 DESCRIBING MOTION

Distance and Displacement

Consider that a particle moves from a starting point A to an end point B along a curved path as shown in Figure 2.4.

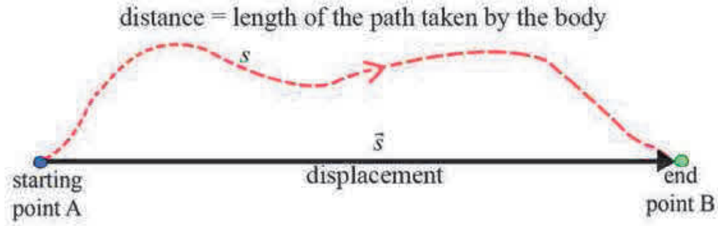


Figure 2.4 Distance and displacement of a body

Distance (or) distance travelled by the body is the length of the path along which the body moves. However, the displacement of the body is a vector directed from the starting point to the end point, as described in the diagram. Displacement is the distance travelled along a particular direction. Distance has no specific direction. It has only magnitude; and therefore, it is a scalar. On the other hand, displacement has a specific direction. It is always directed from the starting point to the end point. It has both magnitude and direction; and therefore, it is a vector.

Speed and Velocity

We can define speed and velocity from distance and displacement, respectively, as follows. Let us assume that, in Figure 2.4, the body moves from starting point A to end point B in a time interval *t*.

The average speed, v_{av} (or) $\overline{v}$, is the ratio of total distance *s* to time taken *t*.

$$v_{av} = \frac{s}{t} \quad \text{(or)} \quad \overline{v} = \frac{s}{t} \qquad (2.1)$$

The average velocity, $\vec{v}_{av}$ (or) $\overline{\vec{v}}$, is the ratio of total displacement $\vec{s}$ to time taken *t*.

$$\vec{v}_{av} = \frac{\vec{s}}{t} \quad \text{(or)} \quad \overline{\vec{v}} = \frac{\vec{s}}{t} \qquad (2.2)$$

If the starting point and the end point are the same, the total displacement is zero. Therefore, average velocity is zero.

Now we would like to introduce the concept of instantaneous speed and instantaneous velocity.

The speed and velocity which represent a motion for a certain period of time interval are called average speed and average velocity, whereas, the speed (or) velocity at a particular instant of time are referred to as instantaneous speed and instantaneous velocity. Note that the speedometer of a car indicates the instantaneous speed of the car.

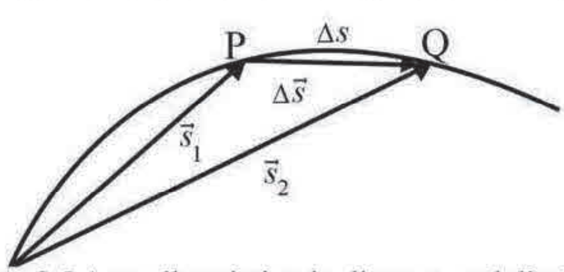


Figure 2.5 A small variation in distance and displacement

In Figure 2.5, a body moves from P to Q in a small interval of time Δt. The corresponding distance travelled is Δs (arc PQ) and the displacement is $\Delta \vec{s}$. Then, the instantaneous speed and instantaneous velocity are defined as the limiting values of $\frac{\Delta s}{\Delta t}$ and $\frac{\Delta \vec{s}}{\Delta t}$ as time Δt approaches zero. It is the limiting case when P and Q coincides.

Instantaneous speed $$v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt} \qquad (2.3)$$

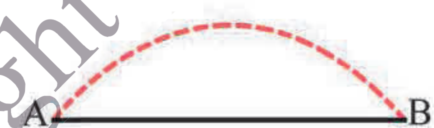
Instantaneous velocity $$\vec{v} = \lim_{\Delta t \to 0} \frac{\Delta \vec{s}}{\Delta t} = \frac{d\vec{s}}{dt} \qquad (2.4)$$

These limiting values are known as the time rate of change of corresponding quantities (s and $\vec{s}$).

The instantaneous speed is defined as the time rate of change of distance and the instantaneous velocity is defined as the time rate of change of displacement.

Example (3)

(a) A body travels from A to B along a straight line and another body travels from A to B along a curve (shown by the dotted line). If the straight-line distance between A and B is 3 km, find the displacement of each body.



(b) The first body moves along the straight line from B back to A. The second body moves along the curved-path back to the same starting point A. What are the displacements of two bodies now? If the first body takes 2 h to travel from A to B, what will be its velocity?

(a) Since the starting point is A and the end point is B for both bodies, the displacement of each body is 3 km, directed from A to B. However, the distance travelled by each body is different.

(b) When both bodies get back to A, the displacement of each body is zero as the starting point as well as the end point is A for both bodies.

$$s = 3\,\text{km}, t = 2\,\text{h}$$

The velocity (i.e. average velocity) of first body is

$$v_{av} = \frac{s}{t} = \frac{3}{2} = 1.5\ \text{km h}^{-1}$$

$$= \frac{3 \times 1\,000}{2 \times 3\,600} = 0.42\ \text{m s}^{-1} \text{ directed from A to B.}$$

Acceleration

When a body is moving along a straight line with a constant speed, the velocity of the body is also constant because its magnitude and direction remain constant. For a motion with constant velocity equal displacements take place in equal intervals of time. Motion with constant velocity is known as uniform motion.

If either magnitude (or) direction (or) both magnitude and direction of the velocity changes, the body is said to have an acceleration $\vec{a}$. Motion with changing velocity is called non-uniform motion (or) accelerated motion.

If the velocity of a body changes from initial velocity $\vec{v}_0$, to final velocity $\vec{v}$, in a time interval t, the average acceleration $\vec{a}_{av}$ is defined by the equation, $\vec{a}_{av} = \dfrac{\vec{v} - \vec{v}_0}{t}$.

It is the ratio of the change in velocity to the time taken. As in the cases of instantaneous speed and instantaneous velocity, instantaneous acceleration can also be defined as

$$\vec{a} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t} = \frac{d\vec{v}}{dt}.$$

Instantaneous acceleration $\quad \vec{a} = \lim_{\Delta t \to 0} \dfrac{\Delta \vec{v}}{\Delta t} = \dfrac{d\vec{v}}{dt} \qquad (2.5)$

Instantaneous acceleration is the time rate of change of velocity.

> Acceleration is said to be positive if the magnitude of velocity is increasing and negative if the magnitude of velocity is decreasing. Negative acceleration is usually called deceleration or retardation.

Reviewed Exercise

1. Define average velocity and instantaneous velocity.
2. Define speed and velocity such that the two may be distinguished.

Key Words : average speed, instantaneous velocity, average velocity, constant velocity

2.3 EQUATIONS OF MOTION

(i) Linear Motion with Constant Velocity

Motion along a straight line is called linear motion. It is the simplest type of motion which can be encountered in many cases. In a linear motion, the magnitude of the displacement is equal to the distance moved. The magnitude of the velocity is also equal to the speed. The most simplest type of motion is the linear motion with constant velocity (uniform motion). Since the velocity is constant, the acceleration is zero. As the body is moving with a non-varying velocity, the instantaneous velocity and average velocity are the same.

We can use equations of motion in calculating the problems of motion. These equations relate the previously mentioned physical quantities associated with motion. In describing the equations of motion we shall not use the vector notation, i.e., we will omit the arrows on the symbols as the direction of motion is already fixed. However, we will use positive (+) and negative (–) signs to describe the two opposite directions along a straight line.

The equation of motion for a linear motion with constant velocity is $v = \dfrac{s}{t}$, where v = constant velocity, s = displacement and t = time taken.

(ii) Linear Motion with Constant Acceleration

If the rate of change of velocity is constant, i.e., the velocity of a body changes at a constant rate, then the acceleration is said to be constant. For example, if a body is moving with a constant acceleration of 5 m s^{-2}, the velocity of the body changes by 5 m s^{-1} in every second. Since the acceleration is constant, the instantaneous acceleration and average acceleration are the same.

Suppose that a body moving along a straight line with a constant acceleration $\vec{a}$ changes its velocity from $\vec{v}_0$ to $\vec{v}$ in a time interval t and traverses a displacement $\vec{s}$.

We are now going to express the equations of motion for this case. As described previously, we are not going to use the vector notation. These equations are:

$$v = v_0 + a t \qquad (2.6)$$
$$v^2 = v_0^2 + 2 a s \qquad (2.7)$$
$$s = v_0 t + ½ a t^2 \qquad (2.8)$$
$$s = \bar{v}\, t \qquad (2.9)$$
$$\bar{v} = \frac{v_0 + v}{2} \qquad (2.10)$$

where v_0 = initial velocity, v = final velocity
$\bar{v}$ = average velocity
a = acceleration
s = displacement
t = time taken

Note that except Eq.(2.7), the rest equations can be expressed in vector form.
In the above equations, Eq.(2.6), Eq.(2.9) and Eq.(2.10) have their own physical significance, where as Eq.(2.7) and Eq.(2.8) are derived from Eqs. (2.6), (2.9) and (2.10) as shown below.

$$s = \bar{v}\, t = \left(\frac{v_0 + v}{2}\right) t$$
$$= \left(\frac{v_0 + v_0 + a t}{2}\right) t$$
$$= v_0 t + ½ a t^2$$

$$s = \bar{v}\, t = \left(\frac{v_0 + v}{2}\right)\left(\frac{v - v_0}{a}\right)$$
$$= \frac{v^2 - v_0^2}{2 a}$$
$$v^2 = v_0^2 + 2 a s$$

Table 2.1 Units of displacement, velocity and acceleration

Quantity	MKS / SI	CGS	FPS
displacement /distance	m	cm	ft
velocity/speed	m s^{-1}	cm s^{-1}	ft s^{-1}
acceleration	m s^{-2}	cm s^{-2}	ft s^{-2}

m = metre, m s^{-1} = metre per second, m s^{-2} = metre per second square

Example (4)

A car is travelling with a constant velocity of 6 m s^{-1}. The driver applies the brakes as he sees a cow which is at a distance of 24 m from the car. Find the acceleration of the car if it stops just in front of the cow.

initial velocity $v_0 = 6$ m s^{-1}, final velocity $v = 0$, displacement (or distance moved) $s = 24$ m, acceleration $a = ?$

$$v^2 = v_0^2 + 2as$$

$$0 = (6)^2 + 2 \times a \times 24$$

$$a = -0.75 \text{ m s}^{-2}$$

Acceleration is negative because the velocity decreases with time.

Example (5)

A car starting from rest travels with a uniform acceleration of 2 m s^{-2} in the first 6 s. It then travels with a constant velocity for half an hour. Find the distance travelled in the first 6 s as well as the distance travelled in the following half an hour.

For the first part of motion,
initial velocity $v_0 = 0$, acceleration $a = 2$ m s^{-2}, time taken $t = 6$ s,
distance travelled $s = ?$

$$s = v_0 t + \tfrac{1}{2} a t^2$$

$$= 0 + \tfrac{1}{2} \times 2 \times (6)^2 = 36 \text{ m}$$

velocity after 6 s is

$$v = v_0 + at$$

$$= 0 + 2 \times 6 = 12 \text{ m s}^{-1}$$

For the second part of motion,
constant velocity $v = 12$ m s^{-1}, time taken $t = 30$ min = 1 800 s, distance travelled $s = ?$

$$s = vt$$

$$= 12 \times 1\,800 = 21\,600 \text{ m} = 21.6 \text{ km}$$

Reviewed Exercise

- Is the formula for average velocity $\overline{v} = \dfrac{v_0 + v}{2}$ always true?

Key Words : uniform motion, constant accelerated motion

2. 4 MOTION GRAPHS

Motion can also be described (or) analyzed conveniently with the help of graphs. The motion graphs are of three types:

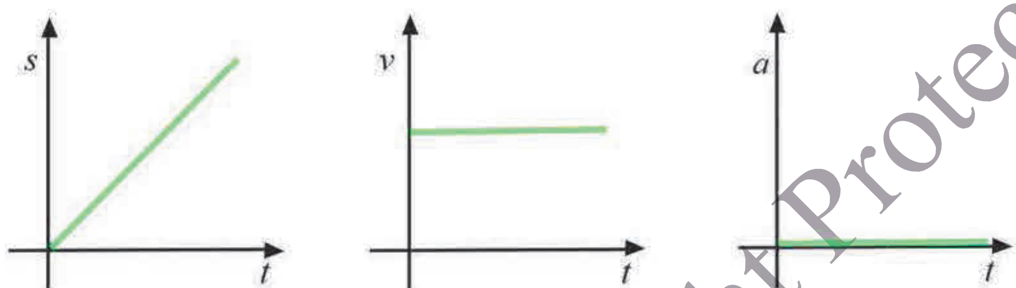
(i) displacement-time graph (*s-t* graph),

(ii) velocity-time graph (*v-t* graph) and

(iii) acceleration-time graph (*a-t* graph).

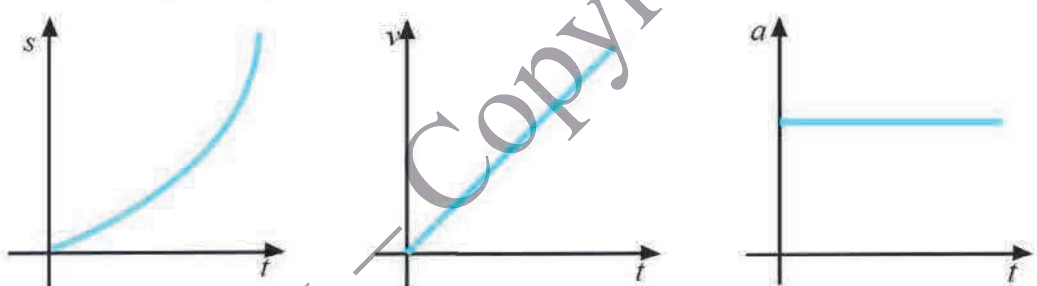
(i) Motion Graphs for a Linear Motion with Constant Velocity (a = 0)

s-t graph *v-t* graph *a-t* graph

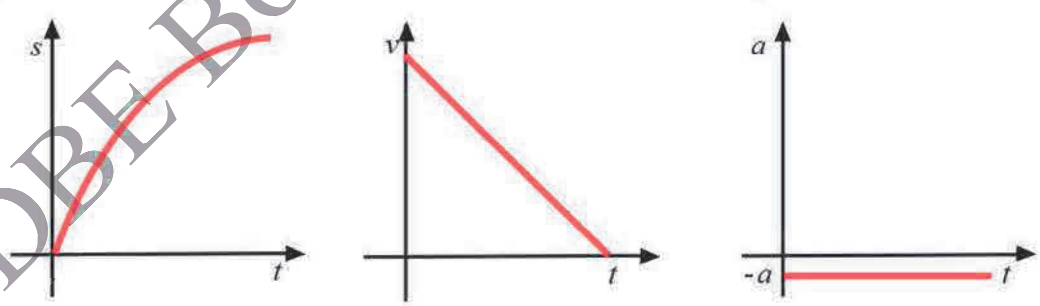


The slope of the *s-t* graph gives the constant velocity.

(ii) Motion Graphs for a Linear Motion with Constant Positive Acceleration



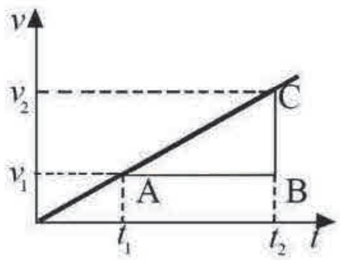
(iii) Motion Graphs for a Linear Motion with Constant Negative Acceleration

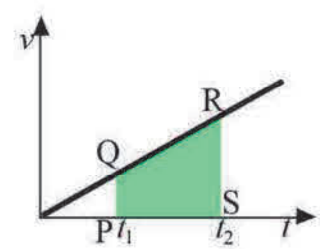


Of three types of motion graphs, *v-t* graph is very useful to analyze a motion.

(i) The slope of a *v-t* graph gives the acceleration of a body.

(ii) The area under a *v-t* graph gives the displacement (or) distance moved by the body.





acceleration a = slope of AC

$$= \frac{CB}{BA} = \frac{v_2 - v_1}{t_2 - t_1}$$

displacement s = distance travelled between t_1 and t_2

= area of PQRS

Example (6)

A train starts from station A, with an acceleration of 0.2 m s^{-2} and attains its maximum speed in 1.5 min. After continuing at this speed for 4 min it is uniformly retarded for 45 s before coming to rest in station B. Find by drawing a suitable graph: (a) the distance between A and B in km, (b) the maximum speed in km h^{-1}, (c) the average speed in m s^{-1}, (d) acceleration during the last stage of motion.

For the first part of motion,
initial velocity $v_0 = 0$, acceleration $a = 0.2$ m s^{-2}, time taken $t = 1.5$ min = 90 s,
velocity after 1.5 min, v = ?

$$v = v_0 + a\,t = 0 + 0.2 \times 90 = 18 \text{ m s}^{-1}$$

(a) the distance between A and B in km

s = area OPQR = area OPN + area PQMN + area MQR

= (½ ON × NP) + (NP × NM) + (½ × MR × MQ)

= (½ × 90 × 18) + (18 × 240) + (½ × 45 × 18) = 810 + 4 320 + 405 = 5 535 m

= 5.535 km

(b) the maximum speed in km h^{-1}

$$v = 18 \text{ m s}^{-1} = \frac{18/1\,000}{1/3\,600} \text{ km h}^{-1} = \frac{18 \times 3\,600}{1\,000} \text{ km h}^{-1} = 64.8 \text{ km h}^{-1}$$

(c) the average speed in m s^{-1}

$$\overline{v} = \frac{s}{t} = \frac{5\,535}{375} = 14.76 \text{ m s}^{-1}$$

(d) acceleration during the last stage of motion

$$a = \text{slope of QR} = \left(\frac{QM}{MR}\right) = \frac{0-18}{375-330} = \left(\frac{-18}{45}\right) = -0.4\ \text{m s}^{-2}$$

The negative sign indicates that the slope is negative. That is, it is a negative acceleration (or) retardation.

Reviewed Exercise

- How can the magnitude of displacement be determined from v-t graph?

SUMMARY

Distance (or) distance travelled by the body is the length of the path along which the body moves.
Displacement is the distance travelled along a particular direction.
The average speed is the ratio of total distance to time taken.
The average velocity is the ratio of total displacement to time taken.
The instantaneous speed is defined as the time rate of change of distance.
The instantaneous velocity is defined as the time rate of change of displacement.
The average acceleration is the ratio of the change in velocity to the time taken.
The instantaneous acceleration is defined as the time rate of change of velocity.

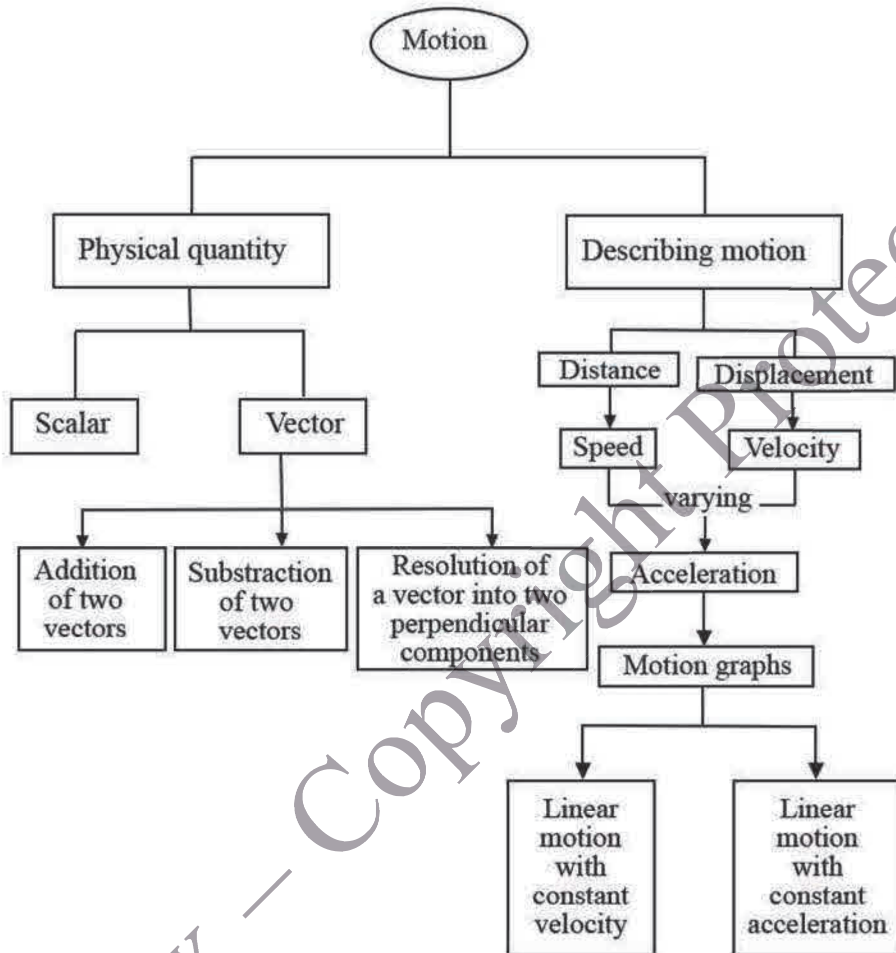
EXERCISES

1. Which of the following quantities are scalars and which are vectors?
   (a) speed (b) velocity (c) average velocity (d) acceleration (e) displacement.
2. Given that $\vec{A} = 3$ units (east) and $\vec{B} = 4$ units (north), draw vector diagrams to carry out the following vector operations. (i) $\vec{A}+\vec{B}$ (ii) $2\vec{A}+\vec{B}$ (iii) $\vec{A}-\vec{B}$ (iv) $\vec{B}-\vec{A}$.
3. A force 3 N pointing east and a force 6 N pointing north acts on a particle. Find the magnitude of the resultant force. Check your answer by drawing a vector diagram.
4. A vector of magnitude 5 units is inclined at an angle 37° to the x-axis and another vector of magnitude 10 units is inclined at 53° to the x-axis. What is the magnitude of the sum of the vector components (i) along the x-axis, (ii) along the y-axis? ($\sin 37^\circ = \cos 53^\circ = 0.6$, $\sin 53^\circ = \cos 37^\circ = 0.8$)
5. A person goes from his house to a nearby shop at the corner of the street and returns home. Can you say that the distance travelled by him is equal to the magnitude of his displacement? Explain.
6. In a one-round-about-town walking race the starting point is the same as the finishing point. Whose magnitude of displacement is greater: the one who completes the race (or) the one who gives up half-way?
7. Check whether the following statements are true or not.
   (a) If the speed changes, the velocity also changes.
   (b) Although speed changes, there is no acceleration.
   (c) If the speed does not change, but the direction changes, there will be acceleration.

8. In a 400 m race, the person running in the innermost lane clocked 50 s and won the gold medal. Find his average velocity. Is the magnitude of the average velocity the same as the value of the average speed? (Hint: For the innermost lane, the starting point is the same as the finishing point.)
9. A man walks 3 miles east and then 3 miles north. Draw a vector diagram to show his resultant displacement from his starting point. If he takes 2 hours to completes his journey, find his average speed and average velocity.
10. A car moving on a straight road with constant acceleration arrives at a certain point after travelling 5 s from the starting point. If the initial velocity is 44 ft s^{-1} and the final velocity is 66 ft s^{-1}, find the acceleration and average velocity of the car. How far has it travelled during this 5 s?
11. A plane starts from rest , speeds over a distance of 450 m with constant acceleration for 15 s and takes off. What is the acceleration of the plane? Find its take-off velocity in km h^{-1}.
12. A car moving with a speed of 108 km h^{-1} stops in 15 s due to a uniform acceleration. Find the value of the acceleration.
13. An object moves with an initial velocity of 5 m s^{-1}. After 10 s its velocity is 10 m s^{-1}. If the object moves with constant acceleration in a straight line, find (a) its average velocity, (b) the distance travelled in 10 s and (c) its acceleration.
14. A particle with an initial velocity of 10 m s^{-1} travel in a straight line and stops completely after 12 s. Find the uniform acceleration of the particle. How far has the particle travelled before coming to rest?
15. A body starts from rest and accelerates at 3 m s^{-2} for 4 s. Its velocity remains constant at the maximum value so reached for 7 s and finally comes to rest with uniform negative acceleration after another 5 s. Use a graphical method to find each of the following : (a) the distance moved during each stage of motion, (b) the average velocity over the whole period.
16. Draw a graph of velocity against time for a body which starts with an initial velocity of 4 m s^{-1} and continues to move with an acceleration of 1.5 m s^{-2} for 6 s. Show how you would find each of the following from the graph: (a) the average velocity, (b) the distance moved in those 6 s.
17. A car is travelling with a constant velocity of 36 km h^{-1}. The driver sees a cow on the road at a distance 28 m from the current position. If the car decelerates at 2 m s^{-2}, will the car hit the cow?
18. Motion of an object is recorded as shown in the table below. (i) Draw the distance-time graph plotting time along the x-axis, (ii) Find the speed of the object.

time / s	0	1	2	3	4	5
distance / m	0	4	8	12	16	20

CONCEPT MAP


Motion
Physical quantity
Describing motion
Scalar
Vector
Distance
Displacement
Speed
Velocity
varying
Addition of two vectors
Substraction of two vectors
Resolution of a vector into two perpendicular components
Acceleration
Motion graphs
Linear motion with constant velocity
Linear motion with constant acceleration

CHAPTER 3

FORCES

The physics describing motion, called kinematics, was discussed in the previous chapter. This chapter is dealt with dynamics which explains motion in relation to the physical factors that affect motion such as force, momentum, mass etc. A fundamental concept in dynamics is force. Force can change the state of motion of an object. Note that forces do not always cause motion.

Learning Outcomes

It is expected that students will

- describe concept of inertia.
- explain force as a cause for change of state of motion.
- recognize gravitational force between two masses which obeys inverse square law.
- distinguish between mass and weight.
- classify different kinds of forces.
- examine momentum and the application of the law of conservation of momentum.
- determine the characteristics of the freely falling bodies.
- demonstrate basic knowledge and skill related to gravitational force and frictional force.
- use mathematical relationships to solve problems and predict events.

Although a force is commonly understood as a push (or) a pull, it cannot be said that this definition is sufficient and complete. In order that the meaning of force be more complete and exact, the definition must be modified. Force is defined precisely by Newton's laws of motion. In this chapter, force concept and the relation between force and acceleration will be presented and discussed.

3.1 NEWTON'S LAWS OF MOTION

Firstly, Newton's three laws of motion will be stated in words and then expressed in mathematical forms.

First Law

Newton's first law states that:

When no net external force acts upon it, a particle at rest will remain at rest and a particle in motion at a constant velocity will continue to move with the same constant velocity.

In mathematical form, If $\vec{F}_{net} = 0$ then $\vec{a} = 0$, $\vec{v}$ = constant (or) zero (3.1)

This law means that if no net external force acts on a particle, the initial state of the motion of the particle will not be changed.

For example, if two equal and opposite forces act simultaneously on a particle at rest, it will remain at rest. In this case, the net force acting on the particle is zero since the two forces cancel out. Therefore, the initial state of the particle is totally unchanged. Another statement of the first law, if there is no net external force of any kind, a particle initially in motion at a constant velocity will continue to remain in the same state of motion. Again, although external forces are simultaneously acting on a particle, if the resultant of the applied forces is zero, the initial state of the particle will not be changed. It is more correct to say 'force changes the states of motion' rather than to say 'force causes motion'. This is one property of force.

Newton's first law expresses the idea of inertia. Inertia is the natural property of a body which resists the change of its state of motion. The inertia of a body is its reluctance to start moving, and its reluctance to stop once it has begun moving. In fact, the first law is often referred as the law of inertia.

Second Law

Newton's second law predicts what will happen when a net force acts on a particle. Its velocity will change. It will accelerate. More precisely the second law states that:
The net external force acting upon a particle is equal to the product of the mass and the acceleration of particle.

In mathematical form, $\vec{F}_{\text{net}} = m\vec{a}$ (3.2)

In the above equations $\vec{F}_{\text{net}}$ is the net external force. The direction of the acceleration is the same as that of the net force.

The second law may also be viewed as follows:

If a net external force acts upon a particle, the force produces acceleration, and the ratio of the force to the acceleration is the mass of the particle.

Let us consider a particle. Assume that a force $\vec{F}_1$ produces an acceleration $\vec{a}_1$ when applied to the particle, and a force $\vec{F}_2$ applied to the same particle produces an acceleration $\vec{a}_2$ as shown in Figure 3.1.

Hence, according to Newton's second law we have

$$\frac{\vec{F}_1}{\vec{a}_1} = \frac{\vec{F}_2}{\vec{a}_2} = m = \text{constant} \quad (3.3)$$

where the constant m is the mass of the particle. If $F_2 > F_1$ then $a_2 > a_1$, it means that as the magnitude of the force acting on a particle increases, the acceleration of the particle will increase accordingly. It is equivalent to say that acceleration is directly proportional to force.
In symbols, $\vec{a} \propto \vec{F}$

Therefore, second law is also called law of force and acceleration.

Figure 3.1 Illustration for net force and accleration

Third Law

Newton's third law of motion states that:
Whenever two particles interact, the force exerted by the second on the first is equal in magnitude and opposite in direction to the force exerted by the first on the second.

In other words, for every action, there is an equal and opposite reaction.

$$\vec{F}_{\text{second on first}} = -\vec{F}_{\text{first on second}} \qquad (3.4)$$

In order to discuss and explain Newton's third law the following cases will be considered. Consider a man sitting on a chair. The man exerts a force which is equal to his body weight on the chair. At the same time the chair exerts a reaction force, which is equal in magnitude and opposite in direction, on the man. If the force exerted by the man is called 'action', the force exerted by the chair should be called 'reaction' shown in Figure 3.2.

As another case consider a man firing a gun at a target. The gun exerts a force on the bullet, and the bullet exerts an equal and opposite reaction force on the gun. This gives rise to a recoil force to the shoulder. The two forces are equal in magnitude but opposite in direction as shown in Figure 3.3.

Figure 3.2 Action and reaction force for sitting on chair

Figure 3.3 Action and reaction force for firing a gun

In each of the above cases action and reaction act as a pair at the same time but the pair of forces acts on two separate objects.

Important facts relating to force which arise from Newton's third law are as follows:

- It is not a single force acting by itself but a pair of forces acting simultaneously.
- This pair of forces is action - reaction pair. Action - reaction pair does not act on a single object but acts on two separate objects.
- Action force and reaction force cannot cancel out each other.

According to these observations the third law is also known as law of action and reaction.

Units of Force

Units of force can now be defined explicitly from $F = ma$. The newton and the dyne are particularly useful units of force. In SI units, force that is acting on 1 kg mass to give it an acceleration of 1 m s^{-2} is called 1 newton (1 N). 1 N = 1 kg m s^{-2}

Similarly, in CGS system a force that is acting on 1 g mass to give it an acceleration of 1 cm s^{-2} is called 1 dyne. 1 dyne = 1 g cm s^{-2} (1 N = 10^5 dynes)

In FPS system the unit of force is pound (lb).The slug is the unit of mass in British engineering system. It is defined as follows: when 1 pound force acts on a body and the acceleration of the body is 1 ft s^{-2}, the mass of the body is called 1 slug. 1 lb = 1 sl ft s^{-2}

Example (1) If 10 N force acts upon a 2 kg mass, find the acceleration produced.
Since F = 10 N and m = 2 kg, using Newton's second law,

$$F = ma$$
$$10 = 2 \times a$$
$$a = 5 \text{ m s}^{-2}$$

Example (2) A 12 lb force gives a body an acceleration of 4 ft s^{-2}. Find the mass of the body.
Since F = 12 lb and a = 4 ft s^{-2}, using Newton's second law,

$$F = ma$$
$$12 = m \times 4$$
$$m = 3 \text{ sl}$$

Example (3) A 2 kg ball is moving with an initial speed of 15 m s^{-1} on a rough plane which is in a horizontal position, and gradually slows down and stops after travelling 20 m. Find the magnitude of the force which resists the motion of the ball.

The speed of the ball changes from 15 m s^{-1} to 0 m s^{-1} after travelling 20 m. Thus, acceleration of the ball is;

$$v^2 = v_0^2 + 2as$$
$$0 = (15)^2 + 2a \times 20$$
$$0 = 225 + 40a$$
$$a = \frac{-225}{40} = -5.6 \text{ m s}^{-2}$$

Using Newton's second law, the force resisting the motion of the ball is,

$$F = m\,a$$
$$= 2 \times (-5.6) = -11.2 \text{ N}$$

The minus sign indicates that the direction of the force is opposite to that of the motion of the ball. The magnitude of the force is 11.2 N.

Reviewed Exercise

1. Is it correct to describe Newton's second law in symbols as $\vec{F} \propto \vec{a}$?
2. Although two forces act simultaneously on a body, it continues to move with a constant velocity. What can be said about the two forces?
3. Can action and reaction cancel each other? Why?

Key Words : inertia, net external force, action and reaction

3.2 GRAVITATIONAL FORCE AND NEWTON'S LAW OF GRAVITATION

Newton was able to point out and express precisely that all bodies in the universe are attracting one another. Gravitational force causes bodies which are above the earth's surface to fall onto the earth's surface. The gravitational force enables the moon to go round the earth and the earth to go round the sun. These are examples of the effects of gravitational force.

Newton stated the gravitational law as follows:

Everybody attracts every other body in the universe. The gravitational force between the two bodies is directly proportional to the product of the masses and inversely proportional to the square of the distance between them.

In symbols, $$F \propto \frac{m_1 m_2}{r^2}$$

where F is the gravitational force between the masses m_1 and m_2 whose distance apart is r as shown in Figure 3.4.

$$F = G\frac{m_1 m_2}{r^2} \qquad (3.5)$$

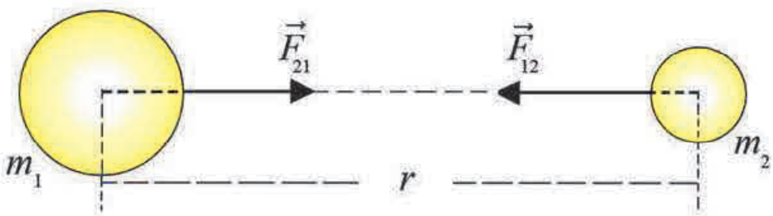


Figure 3.4 The gravitaional force between two bodies

$\vec{F}_{12}$= gravitational force exerted by the first body on the second

$\vec{F}_{21}$= gravitational force exerted by the second body on the first

$\hat{r}_{21}$ = unit vector directed from the second body to the first

Unit vector is a vector that has the magnitude 1.

$$\hat{r}_{21} = \frac{\vec{r}_{21}}{r_{21}}$$

If the Newton's law of gravitation is expressed as an equation in vector notation;

$$\vec{F}_{21} = -\frac{Gm_1m_2}{r_{21}^2}\,\hat{r}_{21} \qquad (3.6)$$

where G is a constant which is the same for all bodies in the universe.

According to experimental measurements the value of G in MKS system is found to be 6.67×10^{-11} $m^3\,kg^{-1}\,s^{-2}$ (or) $N\,m^2\,kg^{-2}$.

Applications of Newton's law of gravitation

(a) The attractions of the moon and the sun upon water of the earth cause tides.

(b) Satellites are kept in their circular orbit by the gravitational attraction of the earth.

Reviewed Exercise

- Express the value of G in the CGS units.

Key Words : gravitational force, gravitational constant

3.3 DIFFERENT KINDS OF FORCES

Four fundamental forces in nature are all field forces. They are the gravitational force, weak force, electromagnetic force and nuclear force. Nuclear force is the strongest and the gravitational force is the weakest of these forces. The electromagnetic force is the second strongest force. Among the four forces the gravitational and the electromagnetic forces are long-range forces and the remaining two forces are short-range forces.

The gravitational force acts between objects. The electromagnetic force acts between electric charges. Weak force acts between subatomic particles. Strong nuclear force acts between elementary particles such as proton, neutron, pion and strange particles.

In the study of mechanics, apart from gravitational force, frictional force and elastic force will also be encountered. However, unlike gravitational force, these two mechanical forces are not fundamental forces. When a spring is stretched (or) a plastic ruler is bent, the force that causes the spring and the ruler to retain their original form is called elastic force. When a body is placed on a floor, the bottom part of the body and the surface of the floor are in contact, and there is a force, between the two surfaces which resists the motion of the body. The force that acts to resist the motion of the body is frictional force. The frictional force depends on the smoothness and cleanliness of the surfaces, the force pressing the two surfaces together and the speed of the body.

Key Words : fundamental forces, long-range forces, short-range forces, frictional force, elastic force

3.4 MASS AND WEIGHT

If a body is dropped from a height above the surface of the earth, it will fall onto the ground. This is due to the force of gravity. The weight of body is the force of gravity acting on it which gives its acceleration when it is falling. The acceleration due to the gravitational force is called acceleration due to gravity and it is represented by the symbol g (9.8 m s^{-2} or 9.8 N kg^{-1}). In FPS system, $g = 32$ ft s^{-2} .

The attracting force of the earth acting on a body is defined as the weight of the body. Let the mass of the body be m; and if $a = g$ is substituted in Newton's second law: $F = m\ a$, the gravitational force acting on the body (or) the weight of the body is found to be

$$w = m\,g \qquad (3.7)$$

This relation is true not only for freely falling bodies but also for bodies on the ground. Weight is a vector and is directed toward the center of the Earth.

> Since weight is force, units of weight are newton, dyne and pound while the units of mass are kilogram, gram and slug.

Mass is the quantity of matter in a body. Mass is also a measure of inertia. The mass of a body measures its inertia. The mass of a body defined from this point of view is called inertial mass while the mass defined by $m = \frac{w}{g}$ is called gravitational mass. Mass should not be confused with weight. Mass and weight are two different quantities. Mass is a scalar and always a constant. Wherever a body may be, there is no change in the value of the mass of the body. But the weight of the body can change.

Example (4) If $G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}, mass of the earth, $M = 5.97 \times 10^{24}$ kg and radius of the earth, $R = 6.37 \times 10^6$ m, find the value of the acceleration due to gravity g.

Consider the mass of a body at the earth's surface as m. The distance, r from the body to the centre of the earth is just the radius of the earth R. The gravitational force acting on the body is $F = G\frac{mM}{r^2} = G\frac{mM}{R^2}$.

According to the definition of the weight of the body, this gravitational force is the weight of the body mg.

$$G\frac{mM}{R^2} = m\,g$$

$$g = G\frac{M}{R^2}$$

Note that the value of g is independent of the properties of the body. The value of g near the earth's surface is $g = 6.67 \times 10^{-11} \times \frac{5.97 \times 10^{24}}{(6.37 \times 10^6)^2} = 9.8$ m s^{-2} (or) 9.8 N kg^{-1}.

Reviewed Exercise

- The weight of a body may change when its location is changed, but mass does not. Why?

Key Words : acceleration due to gravity, weight, inertial mass, gravitational mass

3.5 FREELY FALLING BODIES

If a body is dropped from a height near the earth's surface, the body will fall onto the ground with a constant acceleration *g*. If the air resistance is neglected, the fall of the body is defined as free fall. Equation of motion under constant acceleration described in chapter 2 can be used in the free fall. In these equations we will use the symbol *h* for displacement *s* and *g* for acceleration *a*. Hence, the equations become

$$v = v_0 + g\,t \qquad (3.8)$$

$$v^2 = v_0^2 + 2g\,h \qquad (3.9)$$

$$h = v_0 t + \frac{1}{2} g t^2 \qquad (3.10)$$

Note that the acceleration due to gravity *g* is directed downwards (towards the centre of the earth) and it varies only slightly from one place to another, and therefore, its value is assumed to be constant in the calculations.

In solving the free fall problems we are going to use one dimensional coordinate system with its origin taken as the initial position of the body under consideration. We have to introduce + and – signs for the quantities involved in Eq (3.8) to Eq (3.10). That is, displacement *h* will be positive if it is above the origin and negative below the origin. Velocities v_0 and v will be positive if they are directed upward and negative if directed downward. Since acceleration *g* is always directed downwards its value will be negative (i.e. $g = -9.8\ \text{m s}^{-2}$).

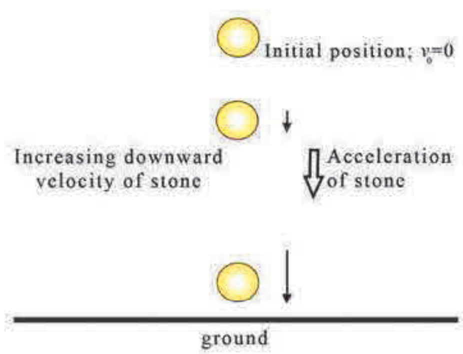
These sign conventions (positive and negative) are easily understandable as described in the following examples.

Example (5) What is the velocity of a stone freely falling from a height of 20 m when it strikes the ground? How long does the stone take to reach the ground? (Assume that $g = 10\ \text{m s}^{-2}$)

$v_0 = 0$, $g = -10\ \text{m s}^{-2}$, $h = -20$ m

'*g*' must be given a negative sign which means that acceleration due to gravity is always be downward.

Since the direction of displacement is downward, height is negative.



$$v^2 = v_0^2 + 2\,g\,h$$
$$= 0 + 2 \times (-10) \times (-20)$$
$$= 400$$
$$v = \pm\ 20\ \text{m s}^{-1}$$

Since the stone is falling, the direction of velocity of ball is downward. $v = -20\ \text{m s}^{-1}$

The time taken for the stone to reach the ground = t

$$h = v_0 t + \frac{1}{2} g t^2$$

$$(-20) = 0 + \frac{1}{2} \times (-10)\, t^2$$

$$t = 2 \text{ s}$$

Example (6) A ball is thrown upwards with a velocity of 40 m s^{-1}. How long does the ball stay in the air? What height does the ball reach?

The initial velocity is positive because the stone is thrown vertically upward from starting point (ground).

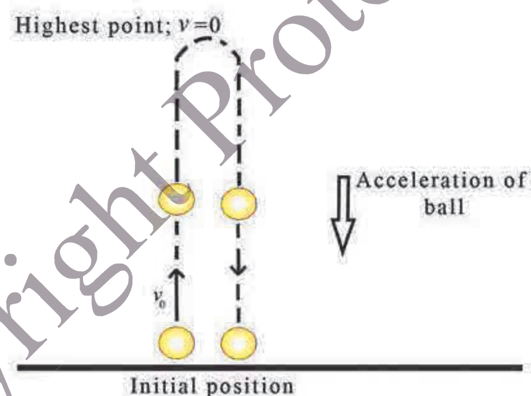
$v_0 = +\,40$ m s^{-1} (upward),

$g = -\,10$ m s^{-2}, $v = 0$ (at the highest point)

$$v = v_0 + g\,t$$

$$0 = 40 + (-10)\,t$$

$$t = 4 \text{ s}$$



Since the time of ascending is the same as the time of descending, the total time the ball stays in the air $T = 2 \times 4 = 8$s

$$v^2 = v_0^2 + 2\,g\,h$$

$$0 = (40)^2 + 2 \times (-10) \times h$$

$$20\,h = 1600$$

$$h = 80 \text{ m}$$

Example (7) A ball is thrown vertically upward and it is caught again after 6 s.

(a) Find the total displacement for the whole distance travelled.

(b) Find the velocity with which it is thrown.

(c) Find the maximum height reached.

(d) Find the average velocity for the whole distance travelled.

(a) Total displacement for the whole distance travelled is zero because the starting point and end point are the same.

(b) $v_0 = ?$, $t = 6$ s, $g = -\,10$ m s^{-2}, total displacement = 0

$$h = v_0 t + \frac{1}{2} g t^2$$

$$0 = v_0 \times 6 + \frac{1}{2}(-10)\, 6^2$$

$$v_0 = +\ 30 \text{ m s}^{-1} \text{ (upward direction)}$$

(c) Maximum height = ? , $v = 0$

$$v^2 = v_0^2 + 2\,g\,h$$

$$0 = (30)^2 + 2\,(-10)\,h$$

$$h = +\,45 \text{ m}$$

(d) average velocity = ?

$$\text{average velocity} = \frac{\text{total displacement}}{\text{time taken}} = \frac{0}{6} = 0$$

Reviewed Exercise

- A stone is thrown vertically straight up with 40 m s^{-1}. What will be its respective velocities at 3 s , 4 s and 5 s after it have been thrown? Find the height of stone at 3 s, 4 s and 5 s.

Key Words : air resistance, freely falling

3.6 MOMENTUM AND LAW OF CONSERVATION OF MOMENTUM

According to the Newton's second law;

$$\vec{F} = m\vec{a} = m\,(\frac{\vec{v} - \vec{v}_0}{t})\ \text{(or)}\ \frac{m\vec{v} - m\vec{v}_0}{t}$$

where another important physical quantity in the above equation is the product of mass and velocity. Hence, momentum (p) of a body is defined as the product of the mass of the body and its velocity, which is written as

$$\vec{p} = m\vec{v} \qquad (3.11)$$

Momentum of a body is directly proportional to its velocity. Momentum is a vector quantity. Direction of momentum is the same as that of velocity. Unit of momentum is expressed as the product of mass unit and velocity unit. In MKS system it is kg m s^{-1}.

One fundamental law of physics is the law of conservation of momentum.
This law states that:

If there is no net external force acting on an isolated system, the total momentum of the system is constant.

The law of conservation of momentum is a general law and is true for both macroscopic and microscopic objects.

Let us consider a collision between two bodies of masses m_A and m_B. These two bodies constitute an isolated system shown in Figure 3.5 (a) and 3.5 (b).

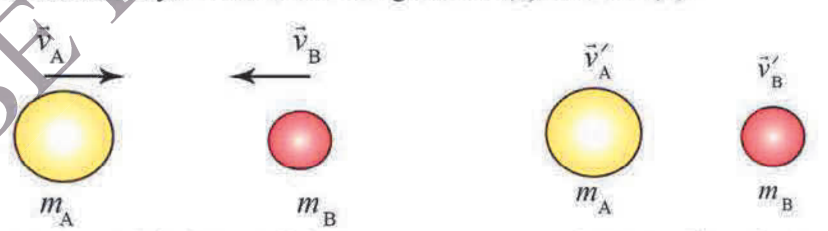


Figure 3.5 (a) before collision Figure 3.5(b) after collision

According to law of conservation of momentum,

Total momentum before collision = total momentum after collision

$$\vec{p}_A + \vec{p}_B = \vec{p}'_A + \vec{p}'_B$$

$$m_A\,\vec{v}_A + m_B\,\vec{v}_B = m_A\,\vec{v}'_A + m_B\,\vec{v}'_B$$

CHAPTER 4

PRESSURE

Pressure, density and specific gravity are important quantities in physics and pressure is the basic of hydrostatic and hydrodynamic. The study of fluids at rest is called hydrostatics and the study of fluids at motion is hydrodynamic.

Learning Outcomes

It is expected that students will

- explain pressure and its units of daily usage.
- skillfully construct and use hydrometer to measure the density of liquids.
- distinguish between the density and the specific gravity.
- apply basic knowledge of pressure and density to daily-life phenomena.

4.1 PRESSURE

Pressure is defined as the force exerted normally on unit area.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \qquad (4.1)$$

$$p = \frac{F}{A}$$

In SI units, pressure is measured in 'pascal' (Pa).

$$1 \text{ Pa} = 1 \text{ N m}^{-2}$$

The force in the pressure formula must be normal (90º) to the surface. Pressure is a scalar quantity.

From the definition of pressure, it is obtained that pointed nails penetrate the surfaces because for a definite force, the exerted area is too small.

Similarly sharp knives can cut easily than blunt knives because of smaller cutting area. Elephants have four large flat feet so they reduce the pressure and less likely sink into the ground.

Most obvious is tractors used for ploughing has large tire areas so that they do not sink in the muddy fields.

Pressure is applied in many scientific fields and many units are used although they have the same meaning.

In FPS system, the unit of pressure is pound per square inch (psi).

In Meteorology, the unit of pressure is hectopascal (hPa).

Standard Atmospheric Pressure is 1 atmosphere (1atm).
The relation between different units of pressure are ;

$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa} = 760$ millimetre mercury (760 mm Hg)

$1 \text{ atm} = 1\,013 \text{ h Pa} = 1\,013$ millibar (1 013 mb)

$1 \text{ hPa} = 100 \text{ Pa} = 1 \text{ mb}$

$1\text{Pa} = 1.45\times10^{-4} \text{ lb in}^{-2}$ (psi)

$1\text{psi} = 6.90 \times 10^3 \text{ Pa}$

Example (1) Bicycle tire has 6 cm × 4 cm area touching the ground. The mass of the bicycle is 22 kg and mass of the cyclist is 60 kg. Find the minimum pressure needed in the tire.

Total area, $A = 2 \times (6\times4) = 48 \text{ cm}^2 = 48 \times 10^{-4} \text{m}^2$
Total mass, $m = 60 + 22 = 82$ kg

$$F = w = mg = 82 \times 10 = 820 \text{ N}$$

$$p = \frac{F}{A} = \frac{820}{48\times10^{-4}} = 1.708 \times 10^5 \text{ Pa}$$

Example(2) Low pressure area in the bay of Bengal is 998 hPa. Fishing boat nearby has sail area 4 m² at the normal atmospheric pressure. (a) Find the pressure difference (b) Find the force exerted on the sail. (Hints : Force exerts due to the atmospheric pressure difference.)

$$\Delta p = p_{atm} - p_{low\ pressure} = 1\,013 \text{ hPa} - 998 \text{ hPa} = 15 \text{ hPa} = 1\,500 \text{ Pa}$$

F (Force exerted on the sail) = $\Delta p \times$ sail area

$= 1\,500 \times 4 = 6\,000$ N

Example (3) The pressure in the motor car tire is 40 psi .What is the equivalent MKS unit and atm unit?

$1 \text{ psi} = 6.9 \times 10^3 \text{ Pa}$

$1 \text{ atm} = 1.013\times10^5 \text{ Pa}$

$40 \text{ psi} = 6.9 \times 10^3 \times 40 = 276\,000 \text{ Pa} = 276\,000 \text{ Nm}^{-2}$

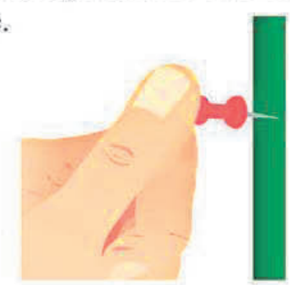
$$40 \text{ psi} = 276\,000 \text{ Pa} = \frac{276\,000}{1.013 \times 10^5} = 2.724 \text{ atm}$$

Example (4) A drawing pin is pressed into the notice board. The pointed pin area is 0.25 mm² and the force exerted on the pin is 10 newton. Compute the pressure.

$A = 0.25 \text{ mm}^2 = 0.25 \times 10^{-6} \text{m}^2$

$F = 10 \text{ N}, p = ?$

$$p = \frac{F}{A} = \frac{10}{0.25\times10^{-6}} = 4\times10^7 \text{Pa}$$



Reviewed Exercise

- A person exerts pressure on the floor when standing, sitting and lying. Explain why the pressure is different when the person is in each of these positions.

Key Words: pressure, normal force

4.2 DENSITY

There is Myanmar riddle 'Which is heavier, a viss of cotton (or) a viss of iron ?' (leading to the puzzle how small (or) large is the volume of them.)
Density is the ratio of mass to volume of a substance. Density is the scalar quantity.

$$\text{density} = \frac{\text{mass of substance}}{\text{volume of the substance}} \tag{4.2}$$

$$\rho = \frac{m}{V} \qquad [\rho = \text{rho} = \text{Greek alphabet}]$$

In SI unit, density is expressed in kilogram per cubic metre ($kg\ m^{-3}$).
In CGS unit, it is expressed in gram per cubic centimetre ($g\ cm^{-3}$) or gram per mililitre ($g\ mL^{-1}$).
Mass of an object can be measured using a balance and volume can be measured using a measuring cylinder. When studying three states of matter (solid, liquid and gas), density is an important factor. Mass of the object does not change, but the volume depends on the temperature. If the volume changes, the density will change. Densities of some substances are shown in Table 4.1.

Table 4.1 Densities of some substances

Substances	CGS ($g\ cm^{-3}$)	MKS ($kg\ m^{-3}$)
helium	1.64×10^{-4}	0.164
air	1.3×10^{-3}	1.3
water, $4^\circ C$	1	1 000
ice, $0^\circ C$	1.029	1 029
aluminium	2.7	2 700
copper	8.9	8 900
lead	11.4	11 400
mercury	13.6	13 600
gold	19.3	19 300
uranium	19.05	19 050

(**Note** Average density of a human body is a little less than water density)

Example (5)

The helium flying balloon has the size of 6 m radius.
(a) Find the volume and mass of helium.
(b) Find the mass of air displaced by the balloon.
(Assume, $\rho_{helium} = 0.164\,kg\,m^{-3}$, $\rho_{air} = 1.3\,kg\,m^{-3}$)

(Hint: volume $= \frac{4}{3}\pi r^3$, mass = density × volume)

$r = 6$ m

(a) $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times 6^3 = 904.8\ m^3$

mass of helium = ρ_{Helium} × volume
$= 0.164 \times 904.8 = 148.4$ kg

(b) $m_{air} = \rho_{air}$ × volume $= 1.3 \times 904.8 = 1\ 176$ kg

Example (6) A concrete slab 1.0 m by a 0.5 m by 0.1 m has a mass of 120 kg. What is the density of the concrete?

$m = 120$ kg , $\rho = ?$

Volume = length × width × height
= 1.0 × 0.5 × 0.1
= 0.05 m^3

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

$= \frac{120}{0.05} = 2\ 400\ kg\ m^{-3}$

Reviewed Exercise

- We say that the density of iron is 7.9 g cm^{-3}. Write this in kg m^{-3}.

Key Words : mass, volume, density

4.3 RELATIVE DENSITY (OR) SPECIFIC GRAVITY

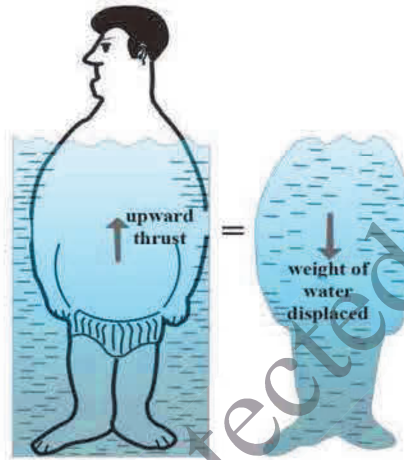
Relative density is how much a substance is denser than water. Relative density is also known as specific gravity.

$$\text{relative density} = \frac{\text{density of substance}}{\text{density of water at } 4\ ^{\circ}C} \quad (4.3)$$

As the density of water is 1 $g\,cm^{-3}$ in CGS units, then density of substance can be taken as the relative density.

For example, the density of aluminium is 2.7 $g\,cm^{-3}$ and so relative density of aluminium is 2.7. As the relative density is the ratio of two densities, it is just a number without unit.

"Archimedes' Principle" (250 B.C)



Part I - When an object is partially (or) totally immersed in a liquid, the object displaces liquid volume that is equal to the volume of the immersed portion.

Part II - The loss in weight of the object is equal to the weight of the liquid displaced. (or) The upward thrust acting on a body which is immersed partially or totally in a liquid is equal to the weight of the liquid displaced by the body.

This is the introduction of Archimedes' principle.

upward thrust = uplift force = buoyancy = weight of liquid displaced

By Archimedes' principle, weight of a body is more than buoyancy (or) upward thrust, it will sink in the liquid. Substances having relative density greater than one will sink in water.

Archimedes and the Crown

King of Syracuse was suspicious with his crown; King let Archimedes to test whether the crown was made of pure gold. The crown had mass 3.75 kg or 3 750 g. As the density of gold is 19.3 g cm^{-3}, the crown must have volume 194 cm^3. Archimedes found that the volume(by his principle Part I) was 315 cm^3. Then, he answered to the King that the crown was not pure gold. (Hint-The added metal is copper because it has similar color.)

The mass of gold in the crown is M_g and mass of copper be M_{Cu},
M_g can be calculated by solving these simultaneous equations.

$$\frac{M_g}{19.3} + \frac{M_{Cu}}{8.9} = 315 \quad \text{and} \quad M_g + M_{Cu} = 3\,750$$

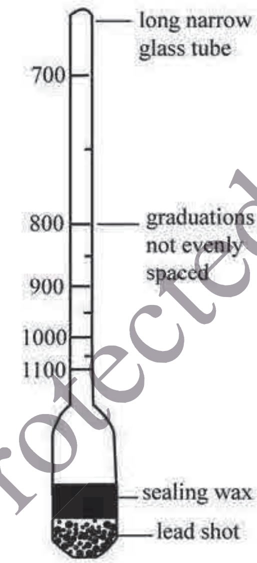
(The student can extended the problem why the gold smith did not use lead metal instead of copper.)

Reviewed Exercise

- The relative density of sulphur is 2. Find the volume of 1 kg of sulphur. (density of water = 1 000 kg m^{-3})

Key Words: relative density

4.4 HYDROMETER



When an object is placed in a liquid of a lower density, the object sinks. If it is placed in a liquid of a greater density, it floats.

Since the amount of submerged portion for a floating body is inversely propotional to the specific gravity of the liquid the more submerged, the less the specific gravity.

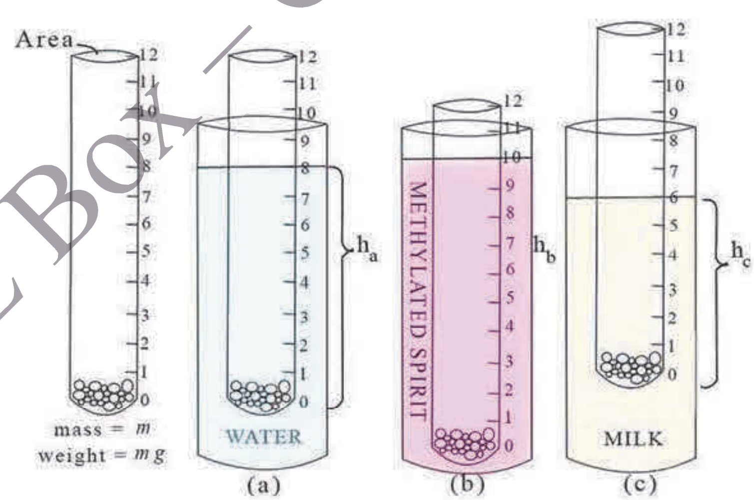
The hydrometer is an instrument for measuring the density (or) relative density of liquids. It usually consists of a glass tube with a long bulb at one end. The bulb is weighted with lead shot so that the device floats vertically in the liquid, as shown in figure, the relative density being read off its calibrated stem by the depth of immersion. If the hydrometer floats higher, it indicates that the liquid has a higher density.

The hydrometer sinks in the liquid until the weight of the liquid displaced is equal to the weight of the hydrometer. The hydrometer is calibrated to measure the density of the liquid in kg m^{-3}.

Special hydrometers are used to test the specific gravity of solutions in storage batteries in order to determine the condition of the battery. The relative density of the acid in a fully charged car battery is 1.25. Milk and wine can be tested to make sure they have not been diluted with water.

Test tube as a hydrometer

Hydrometer is a test tube like cylinder with overall density less than one (or) less than the density of water. So, hydrometer needs to float vertically in liquid.



The mass of hydrometer = m

The weight of hydrometer = mg

The hydrometer is floating in water (Fig - a)

Weight of hydrometer = Weight of water displaced

= (volume of water displaced × density of water)×g

$$mg = A\,h_a \rho_{water}\, g$$

The hydrometer is floating in methylated spirit (Fig - b)

$$mg = A\,h_b \rho_{spirit}\, g$$

The hydrometer is floating in milk (Fig - c)

$$mg = A\,h_c \rho_{milk}\, g$$

For specific gravity of methylated spirit,

$$A\,h_a \rho_{water}\, g = A\,h_b \rho_{spirit}\, g$$

$$\frac{\rho_{spirit}}{\rho_{water}} = \frac{h_a}{h_b}$$

$$= \frac{8}{10} = 0.8$$

For specific gravity of milk,

$$A\,h_a \rho_{water}\, g = A\,h_c \rho_{milk}\, g$$

$$\frac{\rho_{milk}}{\rho_{water}} = \frac{h_a}{h_c}$$

$$= \frac{8}{6} = 1.33$$

Reviewed Exercise

- An alloy is made by mixing 360 g of copper, of density 9 g cm^{-3}, with 80 g of iron, of density 8 g cm^{-3}. Find the density of the alloy. Assuming the volume of each metal used does not change during mixing.

Key Words : hydrometer, upward thrust, liquid displaced

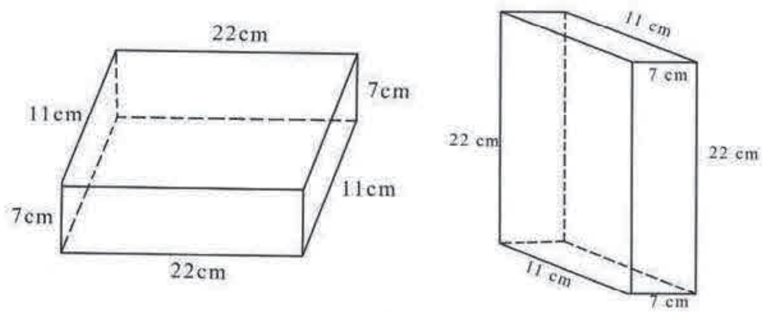
SUMMARY

Pressure is force acting on unit area; pressure is scalar quantity.
Density is the ratio of mass to volume of a substance.
Relative density is the ratio of density of substance to density of water; it has no unit.
Hydrometer is an instrument for measuring the density (or) relative density of liquids.

EXERCISES

1. Normal atmospheric pressure 1 atm is equal to 1.013×10^5 Pa. How much force due to atmosphere acts on a man whose total area is 2 m^2?
2. A man has mass 55 kg. His foot has the dimension of 24 cm × 8 cm. Find the pressure on his feet.
3. A four wheels truck has each tire 20 cm × 12 cm area touching the ground. The mass of the truck and the passengers are altogether 4 400 kg. Find the minimum pressure needed in a tire.

4. A brick of mass 2 kg has length 22 cm, breadth 11 cm and height 7 cm.
   Calculate the weight and 3 kinds of pressure when it lies on a plane for three positions. In the missing (c), draw a sketch with base 22 cm × 7 cm.

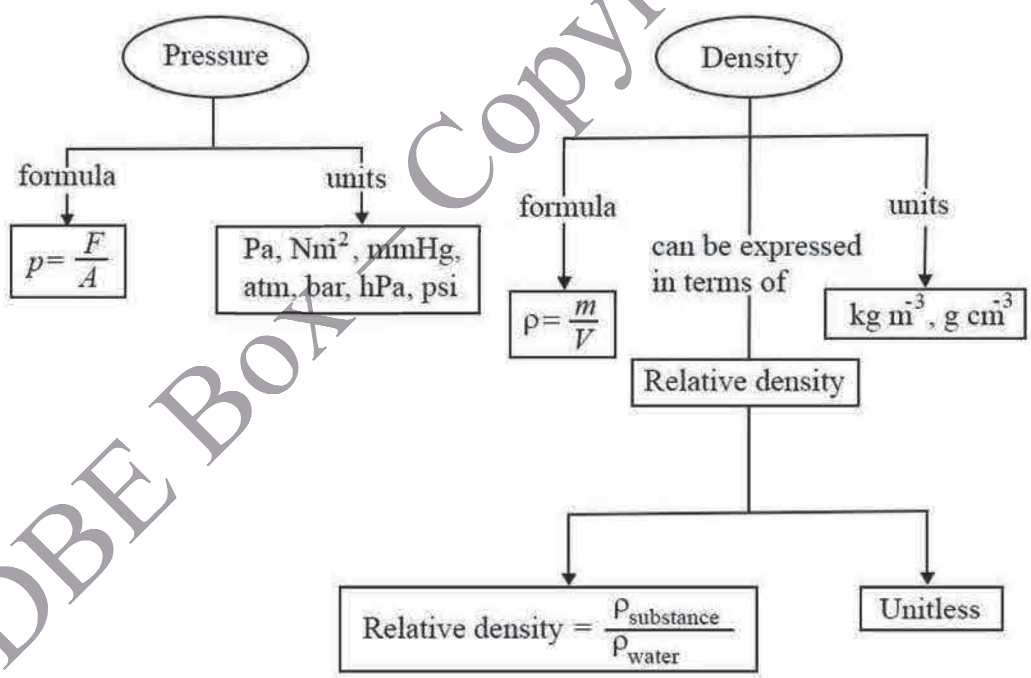


(a) (b) (c)

5. One litre of milk (density 1.2 g cm^{-3}) is mixed with 0.5 litre of water (density 1 gcm^{-3}). What is the density of the mixture? Find the relative density of the mixture.

6. Mini-submarine has the total volume of 24 m^3. Its mass is 2 000 kg. Can it carry a load of another 3 000 kg?

CONCEPT MAP



CHAPTER 5
WORK AND ENERGY

In this chapter work and mechanical energy will be discussed. Before discussing mechanical energy it is necessary to introduce a concept called 'work' which is related to energy.

Learning Outcomes

It is expected that students will

- develop an understanding of work as a physics student compared to an ordinary person.
- evaluate the mathematical expressions of work done.
- investigate gravitational potential energy and the elastic potential energy.
- realize the relationship between work and energy.
- demonstrate that energy can be transformed from one form to another and how it is conserved.
- apply basic knowledge of work and energy to daily-life phenomena.
- use mathematical relationships of work and energy in solving problems.

5.1 WORK

Normally, the work is used to describe the different kinds of activities that people do every day. In physics, work specifies the action (force) and the movement produced by the force.

Work is said to be done when a force produces motion.

Work is defined as the product of force and distance moved in the direction of the force.

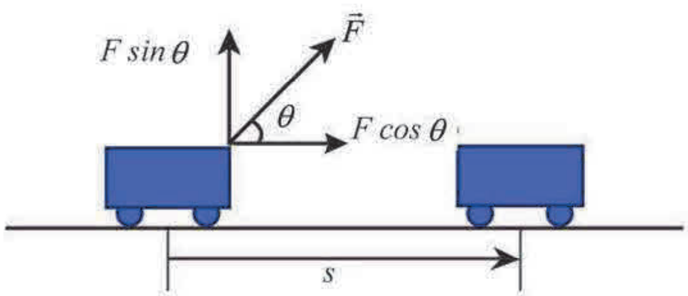
$$W = F\,s \qquad (5.1)$$

where 'W' is work done, 'F' is force acting on the particle and 's' is the distance moved in the direction of the force.

Work is a scalar quantity. The SI unit of work is the joule (J). 1 joule of work is done when a force of 1 newton moves an object through a distance of 1 metre in the direction of the force. When the unit of force is in pound (lb) and the distance is in foot (ft), the unit of work is foot-pound (ft-lb). When the unit of force is in dyne and the distance is in centimetre, the unit of work is erg. (1 J = 10^7 ergs)

When the force is constant, and the direction of the force makes an angle θ with that of motion, work is defined as follows.

$$W = (F\cos\theta)s = Fs\cos\theta \qquad (5.2)$$



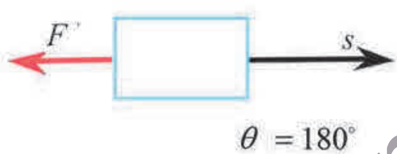
(i) when the directions of the force and the motion are the same

$W = F\,s\cos\theta$

$\cos\theta = \cos 0^\circ = 1$

$W = F\,s$

(ii) when the force and the motion are in opposite directions

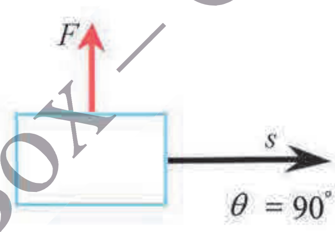


$W = Fs\cos\theta$

$\cos\theta = \cos 180^\circ = -1$

$W = -F\,s$

(iii) when the force and the motion are perpendicular to each other



$W = F\,s\cos\theta$

$\cos\theta = \cos 90^\circ = 0$

$W = 0$

Figure 5.1 Examples of work done by constant forces

Example (1) A child is pulling a toy car with a 10 N force.The direction of the force makes an angle of 20° with horizontal plane. If the car moves 6 m, how much work does the child do?

$$F = 10\text{ N}, \theta = 20^\circ, s = 6\text{m}$$
$$W = F\,s\cos\theta$$
$$= 10 \times 6 \times \cos 20^\circ = 56.38\text{ J}$$

Example (2) How much work is done when a box is pushed with a force of 20 N through horizontal distance of 3 m?

$$F = 20 \text{ N}, s = 3 \text{ m}$$

Since, F and s are in the same direction, $\theta = 0^\circ$

$$W = F\, s \cos\theta$$
$$= 20 \times 3 \times \cos 0^\circ$$
$$= 60 \text{ J}$$

Reviewed Exercise

- A woman pushes a child, who is riding a tricycle, with a 200 N force. The tricycle moves a distance of 2 m and the work done by the woman is 100 J. Find the angle between the force and the displacement.

Key Words: force, work

5.2 ENERGY

Energy is defined as the capacity to do work.

The SI unit for energy is joule (J). Energy is a scalar quantity. Energy possessed by a body is measured by the amount of work done. Whenever work is done on the body, the energy gained by the body is equal to the amount of work done. There are different forms of energy. They are mechanical energy, heat energy, light energy, electrical energy, nuclear energy and so on. In this chapter only mechanical energy will be discussed.

Mechanical Energy

The mechanical energy is divided into two types : kinetic energy and potential energy.

Kinetic Energy (KE)

Energy acquired by a body due to its motion is called kinetic energy.

Let us consider a body of mass m which is at rest. Let an external force F_{external} be applied to the body. Then, according to Newton's second law, the acceleration of the body must be

$$a = \frac{F_{external}}{m}$$

Due to the applied force the body will be in motion and its velocity increases to v after travelling the distance s, we have

$$v^2 = 2as$$

$$v^2 = 2\left(\frac{F_{external}}{m}\right)s$$

$$\frac{1}{2}mv^2 = F_{external}\, s$$

In the above equation, $F_{external}\,s$ is the work done on the body and is the amount of energy given to the body. Therefore, $\frac{1}{2}mv^2$ is the kinetic energy received by the body which is expressed as

$$KE = \frac{1}{2}mv^2 \qquad (5.3)$$

If the body is moving with an initial velocity v_0 and its final velocity is v then the change in kinetic energy is

$$\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = F_{external}\,s \qquad (5.4)$$

The change in kinetic energy is equal to the work done.

Example (3) A truck with mass 1 500 kg is travelling with speed of 20 m s^{-1}. What is the kinetic energy of the truck?

$$m = 1\,500 \text{ kg},\ v = 20 \text{ m s}^{-1}$$

$$KE = \frac{1}{2}mv^2$$

$$KE = \frac{1}{2}\times 1\,500 \times 20^2$$

$$KE = 300\,000 = 3\times10^5 \text{ J}$$

Potential Energy (*PE*)

The energy stored in a body due to its position or configuration is called the potential energy.

Gravitational Potential Energy

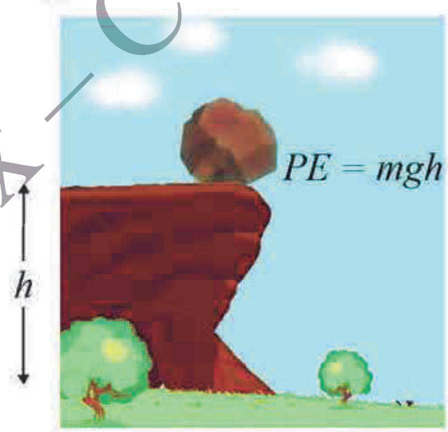


Figure 5.2 A rock on the top of a cliff has the gravitational potential energy

Let us consider a body of mass m which is on the ground. When the body is raised to a height h above the ground, the amount of work done against the gravitational force mg is

$$W = Fs = mgh.$$

This amount of work done (mgh) is stored by the body as gravitational potential energy. Thus the energy stored in a body due to its position is called the gravitational potential energy (PE).

$$PE = mgh \qquad (5.5)$$

Gravitational potential energy is the energy which a body possesses because of its position relative to the ground.

When an object with mass m near the Earth's surface is raised from a height h_0 to a height h, the change in potential energy is given by

$$\Delta PE = mgh - mgh_0 \quad (5.6)$$

where, g = acceleration due to gravity

The change in potential energy is equal to the work done.

Elastic Potential Energy

The potential energy due to configuration is called elastic potential energy. For examples, the energy stored in the compressed or stretched springs, the stretched rubber band of a catapult (or) the stretched bow.

The elastic potential energy in compressed (or) stretched springs $= \frac{1}{2} k x^2$

where k = spring constant, x = extension (or) compression of spring.

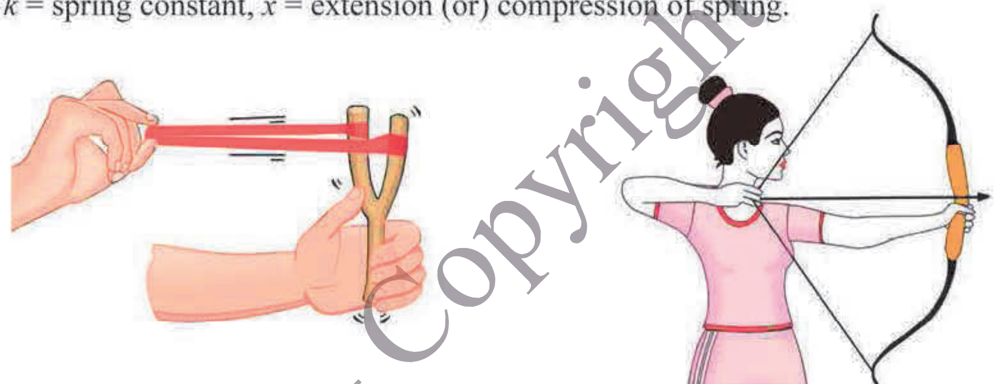


Figure 5.3 Elastic potential energy due to a stretched elastic rubber band and a stretched bow

Example (4) A girl lifts her school bag of mass 3 kg from the floor onto her lap through a height of 0.5 m. What is the gravitational potential energy gained by the bag?

$$m = 3\text{ kg}, \; h = 0.5\text{ m}$$

Gravitational potential energy gained

$$PE = mgh = 3 \times 10 \times 0.5 = 15\text{ J}$$

Example (5) How much more gravitational potential energy does a 20 kg box have when it is moved from a shelf 0.3 m height to a shelf 1.8 m height?

$$m = 20\text{ kg}, \; h = 1.8\text{ m}, \; h_0 = 0.3\text{ m}$$

Gravitational potential energy gained (ΔPE) $= mgh - mgh_0 = mg(h - h_0)$

$$= 20 \times 10 \times (1.8 - 0.3)$$
$$= 20 \times 10 \times 1.5 = 300\text{ J}$$

Conservation of Energy

The law of conservation of energy is a very important rule. It states that:
The total energy of an isolated system is constant.

This law is also expressed as:
Energy cannot be created (or) destroyed in any process. The total energy of the universe is constant. These two statements are equivalent. In the second statement the whole universe is taken as an isolated system.

Energy cannot be created (or) destroyed but energy can be changed from one form to another. Therefore, for an isolated system the sum of the different forms of energy must be constant.

Physicists believe that the amount of energy in the universe is constant. Energy can be changed from one form to another but there is never any more (or) any less of it.

Let us verify the conservation of energy with a particular example.

Let us consider a two-particle system which consists of only a stone and the earth. Let the mass of the stone be m. The stone is dropped from a height h_0 above the ground. The freely falling stone and the earth are attracting each other with equal forces. But only the motion of the stone is noticeable and the motion of the earth can be neglected since the mass of the earth when compared with the stone is many times larger.

Due to the gravitational force acting on the stone its acceleration will be g. Let us assume that the stone has fallen from the height h_0 to the height h and its velocity changes from v_0 to v during the period of time t. The kinetic energy will change because the velocity of the stone changes. The relationship between the energy change and work is

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2$$

$$W = F\,s$$

Since the weight of the stone $F = m\,g$ and the distance s = $h_0 - h$, we get

$$mg\,(h_0 - h) = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2$$

$$\frac{1}{2}mv^2 + mgh = \frac{1}{2}mv_0^2 + mgh_0$$

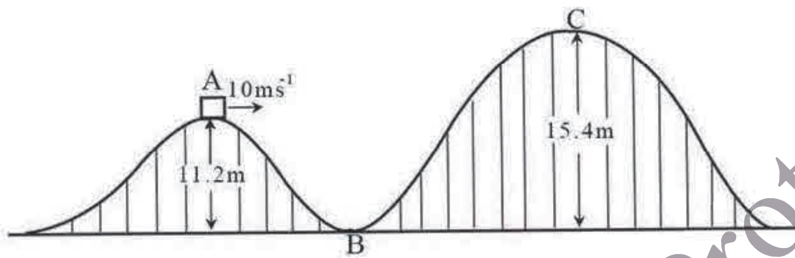
The quantity at the left is the sum of the potential energy and the kinetic energy or the total mechanical energy at the time t after the stone has started to fall; and the quantity at the right is the initial total mechanical energy of the stone. The value of this quantity (the total mechanical energy) is conserved throughout the distance travelled by the falling stone. It can be easily remembered by writing it as

kinetic energy + potential energy = total energy = constant

If the symbol *KE* is used for kinetic energy, *PE* for potential energy and *E* for total energy the above relation can be represented as

$$E = KE + PE = \text{constant}$$

Example (6) The figure shows the heights above the ground of some points on the track of a roller coaster. The speed of the carriage at A is 10 m s^{-1}. What is the speed of the carriage at B and C? The friction and air resistance are assumed to be negligible.



The total energy at B = Total energy at A

$$\frac{1}{2}mv_B^2 = mgh_A + \frac{1}{2}mv_A^2 \quad (PE \text{ at B} = 0)$$

$$\frac{1}{2}mv_B^2 = (m\times 10\times 11.2) + \frac{1}{2}\times m\times (10)^2$$

$$v_B^2 = 2(112+50)$$

$$= 324$$

$$v_B = 18 \text{ m s}^{-1}$$

The total energy at C = Total energy at A

$$mgh_C + \frac{1}{2}mv_C^2 = mgh_A + \frac{1}{2}mv_A^2$$

$$(m\times 10\times 15.4) + \frac{1}{2}\times m\times v_C^2 = (m\times 10\times 11.2) + \frac{1}{2}\times m\times (10)^2$$

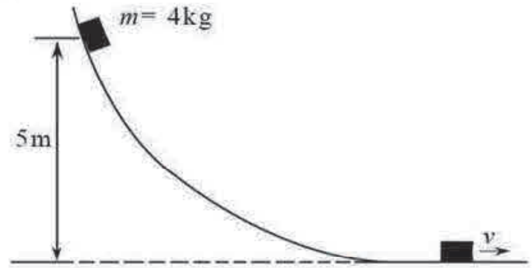
$$154 + \frac{1}{2}v_C^2 = 112 + \frac{1}{2}\times (10)^2$$

$$v_C^2 = 2\times [112 + \frac{1}{2}\times (10)^2 - 154]$$

$$v_C^2 = 16$$

$$v_C = 4 \text{ m s}^{-1}$$

Example (7) A parcel of mass 4 kg slides down a smooth curved ramp as shown in figure. What is the speed of the parcel when it reaches the bottom?



At the top of the ramp, the parcel has only gravitational potential energy. As the parcel slides down the ramp, it gradually loses its potential energy and gains kinetic energy. By the time it reaches the bottom, all the potential energy has been changed to kinetic energy.

Total energy at the bottom of the ramp = Total energy at the top of the ramp

$$\frac{1}{2}mv^2 = mgh$$

$$\frac{1}{2}\times 4\times v^2 = 4\times 10\times 5$$

$$v^2 = 2\times 10\times 5 = 100$$

$$v = 10\ \text{ms}^{-1}$$

Reviewed Exercise

1. Give the examples of electrical energy transforming into light energy.
2. Why are the units of energy and work the same?
3. Write down the law of conservation of energy. Identify this law as being a fundamental law or not and explain your answer.

Key Words: energy, kinetic energy, potential energy, gravational potential energy, elastic potential energy, conservation of energy

SUMMARY

Work is defined as the product of force and distance moved in the direction of the force.

Energy is defined as the capacity to do work.

Energy acquired by a body due to its motion is called **kinetic energy**.

The energy stored in a body due to its position or configuration is called the **potential energy**.

Gravitational potential energy is the energy which a body possesses because of its position relative to the ground.

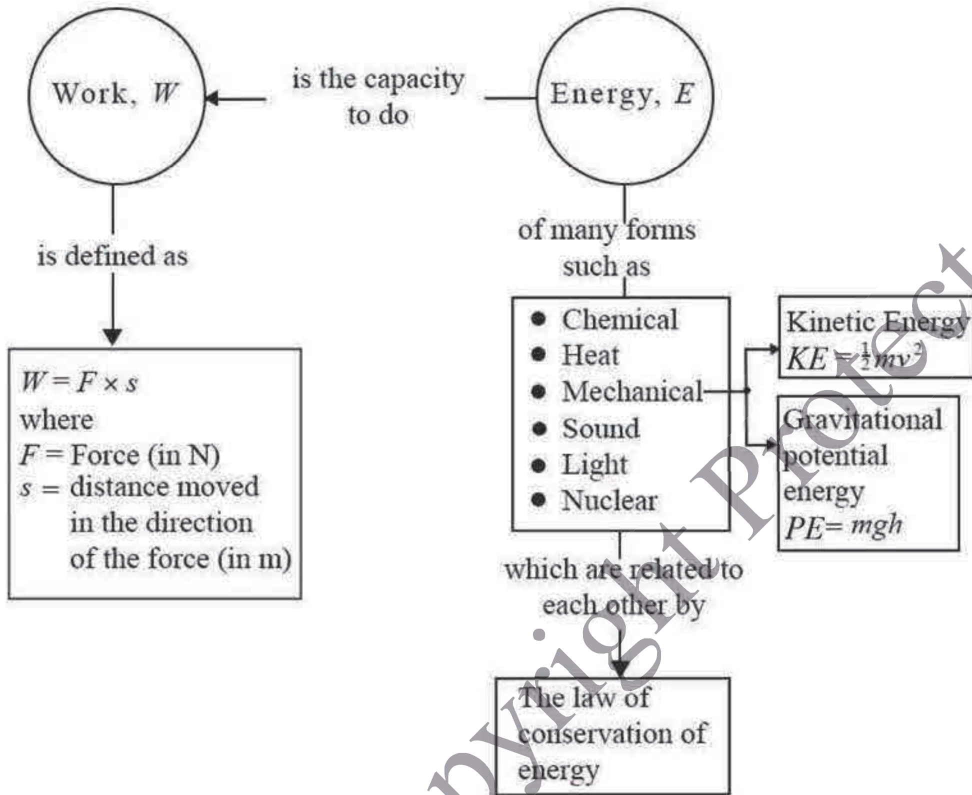
The potential energy due to configuration is called **elastic potential energy**.

The law of conservation of energy states that: the total energy of an isolated system is constant.

EXERCISES

1. A car with a mass of 800 kg travels at a speed of 20 m s^{-1}.What is its kinetic energy?
2. What is the change in potential energy of a flower pot of mass 2 kg that falls from a balcony? The height of the balcony from the ground is 20 m. What happens to this energy?
3. What is the change in potential energy if you move a brick of 1.5 kg mass through a distance of 0.4 m on a horizontal table?
4. A ball is thrown vertically upwards with a velocity of 10 m s^{-1}. What is the maximum height it can reach?
5. Calculate the kinetic energy of
   (a) 1 kg mass of a toy car moving at 2 m s^{-1},
   (b) 2 g (0.002 kg) bullet travelling at 400 m s^{-1},
   (c) 500 kg car travelling at 72 km h^{-1}.
6. (a) What is the velocity of an object of mass 1 kg which has 200 J of kinetic energy?
   (b) Calculate the potential energy of a 5 kg mass when it is (i) 3 m, (ii) 6 m, above the ground. (g = 10 N kg^{-1})
7. A 100 g steel ball falls from a height of 1.8 m onto a metal plate and rebounds to a height of 1.25 m. Find
   (a) potential energy of the ball before the fall (g = 10 m s^{-2}),
   (b) its kinetic energy as it hits the plate,
   (c) its velocity on hitting the plate,
   (d) the kinetic energy as it leaves the plate on the rebound,
   (e) its velocity of rebound.
8. The block of wood is placed on a rough horizontal plane. If the friction between the block and the plane is 6 N, what is the work done to move the block through a distance of 1.5 m?
9. A student lifts a box weighing 50 N through a vertical height 1.1 m and then walks horizontally for 2.0 m at constant speed while holding the box. What is the work done by the student on the box?
10. A weightlifter raising an object that weight is 500 N through a distance of 2 m. How much work is done?
11. A man lifts a brick of mass 5 kg from the floor to a shelf 3 meters high. How much work is done?
12. A tennis ball which is thrown verticaly upward reaches the height of 50 m. Find the initial velocity of the ball. (Neglect air resistance)

CONCEPT MAP


Work, W
is the capacity to do
Energy, E
is defined as
W = F × s
where
F = Force (in N)
s = distance moved in the direction of the force (in m)
of many forms such as
Chemical
Heat
Mechanical
Sound
Light
Nuclear
Kinetic Energy
KE = ½mv²
Gravitational potential energy
PE= mgh
which are related to each other by
The law of conservation of energy

CHAPTER 6

HEAT AND TEMPERATURE

The concept of temperature is very important for the physical and biological sciences. This is because the temperature of an object is directly related to the energies of molecules composing the object. Natural processes often involve energy changes and the temperature is an indicator for these changes.

Learning Outcomes

It is expected that students will

- identify that thermal energy is an internal energy of a matter.
- explain why heat is considered to be a form of energy.
- distinguish between heat and temperature.
- examine thermometric properties of substances and differentiate thermometric properties of mercury and alcohol.
- examine linear, area and volume expansion.
- explain heat as the energy transferred between substances that are at different temperatures.
- apply basic knowledge and skill of thermal physics to daily-life phenomenon such as thermal expansion.

6.1 HEAT AND TEMPERATURE

The sensations of hotness, warmness and coldness can be experienced by touching objects. Temperature is the quantity that determines how cold (or) how hot the object is. The temperature of a hot body is higher than that of a cold body. To measure temperature accurately, we use instruments called thermometers.

There is a relation between heat and temperature. The energy exchanged between an object and its surrounding due to different temperatures is defined as heat. Heat is the energy in transit. The unit of heat is the same as units of energy. Heat and temperature are different quantities. When a body at a higher temperature is in contact with a body at a lower temperature, heat flows from the first to the second body.

The motions and positions of molecules in matter result in the kinetic energy and potential energy. The total energy, that is, the sum of the potential energy and the kinetic energy, of molecules in matter is in fact the internal energy of that matter. Temperature is related to that internal energy. Temperature is a measure of the internal energy of molecules.

Key Words: internal energy, energy exchange

Reviewed Exercise

- Distinguish between heat and temperature.

6.2 TYPES OF THERMOMETER

Every thermometer uses a physical property that varies with temperature. This property is referred to as the thermometric property of the thermometer. For example, the thermometric property of a liquid-in-glass thermometer is the thermal expansion of the liquid.

Liquid-in-Glass Thermometer

The liquid-in-glass thermometer consists of a thin glass bulb joined to a capillary tube with a narrow bore which is sealed at its other end. The liquid fills the bulb and the adjoining section of the capillary tube **(Figure 6.1)**. When the bulb becomes warmer:

- the liquid in it expands more than the bulb so some of the liquid in the bulb is forced into the capillary tube.
- the thread of liquid in the capillary tube increases in length.
- the thinner the bulb wall is, the faster the response of the thermometer will be when the temperature changes.

The liquid used usually contains mercury (or) coloured alcohol. Alcohol has a lower freezing points than mercury so it is more suitable for low-temperature measurements.

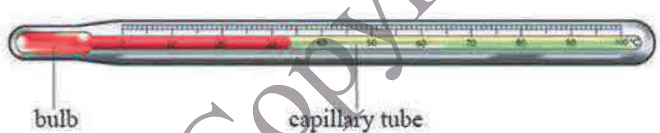


Figure 6.1 A liquid-in-glass thermometer

Thermocouple Thermometer

Thermocouple thermometers are electrical thermometers which make use of the voltage that develops when two different metals are in contact. This voltage varies with temperature. An iron wire and two copper wires may be used to make a thermocouple thermometer, as shown in Figure 6.2. One of the junctions is maintained at 0 ˚C and the other junction is used as the temperature probe. The voltmeter can be calibrated directly in ˚C.

Because of the small size of a thermocouple junction, thermocouple thermometers are used to measure rapidly changing temperatures. In addition, they can be used to measure much higher temperatures than liquid-in-glass thermometers. Also, the voltage of a thermocouple can be measured and recorded automatically.

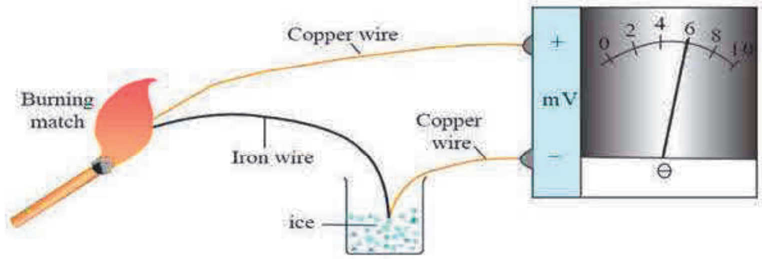


Figure 6.2 A thermocouple thermometer

Resistance Thermometer

Resistance thermometer uses the fact that the electrical resistance of a metal (e.g platinum) wire increases with temperature.

A resistance thermometer can measure temperatures accurately in the range −200 ˚C to 1 200 ˚C and best for steady temperatures, but it is bulky.

Thermometric substances can be solids, liquids (or) gases. They have physical properties that vary continuously and linearly with temperature. These properties are called thermometric properties.

Reviewed Exercise

1. State the physical property that varies with temperature in
   (a) liquid-in-glass thermometer, (b) thermocouple thermometer.
2. Why the temperature range of a clinical thermometer is from 35 ˚C to 42 ˚C?

Key Words: thermometric properties, temperature difference, voltage, electrical resistance

6.3 UNITS OF TEMPERATURE (OR) TEMPERATURE SCALES

Temperature units depend on the scale used. The temperature scales most widely used today are Celsius (Centigrade), Fahrenheit and Kelvin scales. The SI unit of temperature is kelvin (K).

To calibrate a thermometer, two reference points are chosen and the interval between these points is subdivided into a number of equal parts. The freezing point and boiling point of water under normal atmospheric pressure are chosen as reference points which are marked on the thermometer. The interval between these two points is divided into one hundred equal parts for the Celsius scale. If the freezing point of water (or) ice point is marked 0 ˚C and the boiling point of water (or) steam point is marked 100 ˚C, the thermometer scale is the Celsius scale. On the Celsius scale, the ice point is 0 ˚C and the steam point is 100 ˚C. On the Fahrenheit scale the ice point is 32 ˚F and the steam point 212 ˚F. On the Kelvin scale the ice point is 273 K and the steam point is 373 K.

The relationship between the Celsius temperature T_C and the Fahrenheit temperature T_F is given by the equation

$$T_C = \frac{5}{9}\ (T_F - 32)\ \text{(or)}\ T_F = 1.8\ T_C + 32 \qquad (6.1)$$

For example, normal body temperature is 98.6 ˚F. On the Celsius scale, this is

$$T_C = \frac{5}{9}(T_F - 32)$$

$$= \frac{5}{9}(98.6 - 32)$$

$$= 37.0\ ˚\text{C}$$

The relationship between the Celsius temperature T_C and kelvin temperature T_K is given by

$$T_C + 273 = T_K \qquad (6.2)$$

Example (1) The room temperature is found to be 27 ˚C. What is the temperature in kelvin?

$$T_C = 27\ ˚\text{C}$$

$$T_K = T_C + 273$$

$$= 27 + 273$$

$$= 300\ \text{K}$$

Example (2) The lowest air temperature recorded in the world is 184 K. This temperature was measured in Antarctica in 1983. What is the temperature in degree Celsius?

$$T_K = 184\ \text{K}$$

$$T_K = T_C + 273$$

$$T_C = T_K - 273$$

$$= 184 - 273$$

$$= -89\ ˚\text{C}$$

Reviewed Exercise

- What temperature on the celsius scale corresponding to 104 ˚F, the body temperature of the person who is gravely ill?

Key Words: body temperature, room temperature, freezing point, boiling point.

6.4 THERMAL EXPANSION OF SUBSTANCES

When a substance is heated, its volume usually increases. The dimensions of the substance increase correspondingly. This increase in size can be explained in terms of the increased kinetic energy of the molecules. The additional kinetic energy results in each molecule colliding more forcefully with its neighbours. Therefore, the molecules push each other further apart and the substance which is heated increases in size.

Increasing the temperature of a gas at constant pressure cause the volume of the gas to increase. This increase occurs not only for gases, but also for liquids and solids. In general, if the temperature of a substance increases, so does its volume. This phenomenon is known as thermal expansion.

You may have noticed that the concrete roadway segments of a sidewalk are separated by gaps. This is necessary because concrete expands with increasing temperature. Without these gaps, thermal expansion would cause the segments to push against each other, and they would eventually buckle and break apart.

Linear Expansion

Although two different metal bars of the same length are heated such that the increase in temperature is the same, the magnitudes of their expansion may not be the same. For example, the expansion of copper is one and a half times that of steel. Aluminium expands twice as much as steel does.

The dependence of the change in length of an object on its original length and change in temperature is

$$\Delta l \propto l\,\Delta T$$

$$\Delta l = \alpha\, l\,\Delta T$$

$$\alpha = \frac{\Delta l}{l} \times \frac{1}{\Delta T}$$

$$l' = l(1+\alpha\,\Delta T) \qquad (6.3)$$

where Δl = change in length

ΔT = change in temperature

α = coefficient of linear expansion

l = original length of the object

l' = length of the object at $T + \Delta T$

The coefficient of linear expansion is the change in length per unit length for one degree change in temperature.

The unit of α is per K, which can be written as K^{-1}. The value of α for some materials are given in Table 6.1.

Table 6.1 The value of α for some materials

Material	α (K^{-1})
Celluloid	1.09×10^{-4}
Steel	1.27×10^{-5}
Copper	1.70×10^{-5}
Aluminium	2.30×10^{-5}
Diamond	1.00×10^{-6}
Glass	8.30×10^{-6}
Platinum	8.90×10^{-6}

CHAPTER 7

WAVE AND SOUND

When we think of the word waves, water wave on the water surface of a pond and sea waves usually come to mind. Besides these waves there are other types of wave such as sound wave, radio waves, etc. Wave is a basic concept of physics. Energy and momentum are transferred through the medium from the wave source. All waves are produced by a vibrating source.

Learning Outcomes

It is expected that students will

- examine wave motion as a form of energy transfer.
- compare transverse and longitudinal wave and give suitable examples of each.
- illustrate displacement-time graph and displacement-position graph.
- express the concept of wave equation and use it to solve problems.
- describe the reflection, refraction and diffraction of waves.
- apply the basic knowledge of generation, propagation and hearing of sound in daily life.

7.1 DESCRIBING WAVE MOTION

Wave motion is a method of transferring energy by successive disturbances through the medium. This movement of energy takes place without transferring matter.

For examples, (1) Waves are produced if you drop a stone onto a quiet surface of a pond. The waves spread out from the point of impact, carrying energy to all parts of the pond (Figure 7.1). But the water in the pond does not move from the centre to the edges. This shows that wave transfer energy without transferring matter.

Figure 7.1 Water wave on the surface of a pond [Physics Matter]

(2) Waves can be produced along a rope by fixed end and moving the other end up and down rapidly shown in Figure 7.2. It can be seen that the rope waves move toward the fixed end, while the rope segments only vibrate up and down about their rest (equilibrium) position. The energy from hand is transferred by the rope waves toward the fixed end. The rope is the medium through which the waves move.

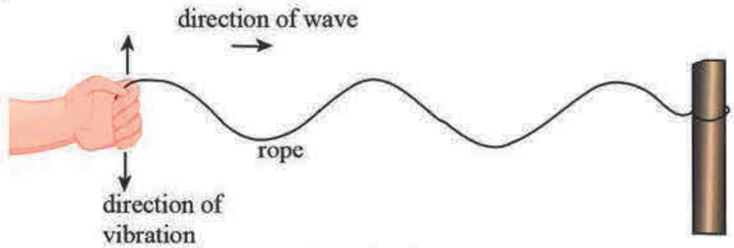


Figure 7.2 Producing wave on a rope

There are two types of waves. They are mechanical waves and electromagnetic waves. The mechanical waves need material medium to propagate and cannot pass through vacuum.

Sound waves and seismic waves, which are produced by an earthquake, are mechanical waves. Electromagnetic waves can pass through vacuum and they do not need medium for propagation. Light wave and X-rays are electromagnetic waves.

Reviewed Exercise

- Give examples of mechanical and electromagnetic waves.

Key Words: disturbance, energy, vibration

7.2 TRANSVERSE AND LONGITUDINAL WAVES

Waves are classified as transverse and longitudinal waves depending on vibration of particles in the medium through which they propagate.

If the displacements of particles of the medium are perpendicular to the direction of the wave, such a wave is called a transverse wave. Waves in a vibrating string are transverse waves. They can be demonstrated by moving up and down the free end of a rope (or) slinky spring which is fitted at one end as shown in Figure 7.3. Light waves and other electromagnetic waves are also transverse waves.

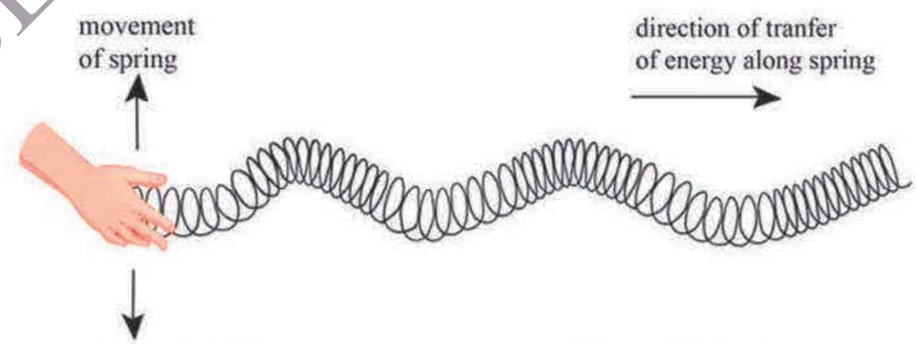


Figure 7.3 The transverse waves on slinky coiled spring

If the displacements of particles of medium are parallel to the direction of the waves, such a wave is called a longitudinal wave. Compressional waves in a slinky coiled spring and sound waves are longitudinal waves.

A longitudinal wave is demonstrated by rapidly pushing forth and pulling back at one end of a slinky coiled spring while another end is fixed. It can be seen that the back and forth movement of the coil is parallel to the wave direction as shown in Figure 7.4.

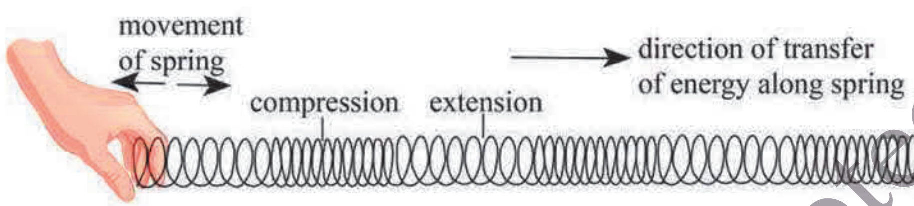


Figure 7.4 Longitudinal waves on slinky coiled spring

Some waves in nature exhibit a combination of transverse and longitudinal waves. Water waves are good example of combinational waves.

The longitudinal slinky spring wave is represented by a graph (Figure 7.5) which shows the compression and extension of spring segments. This graph is similar to the wave produced by the vibrating rope shown in Figure 7.2.

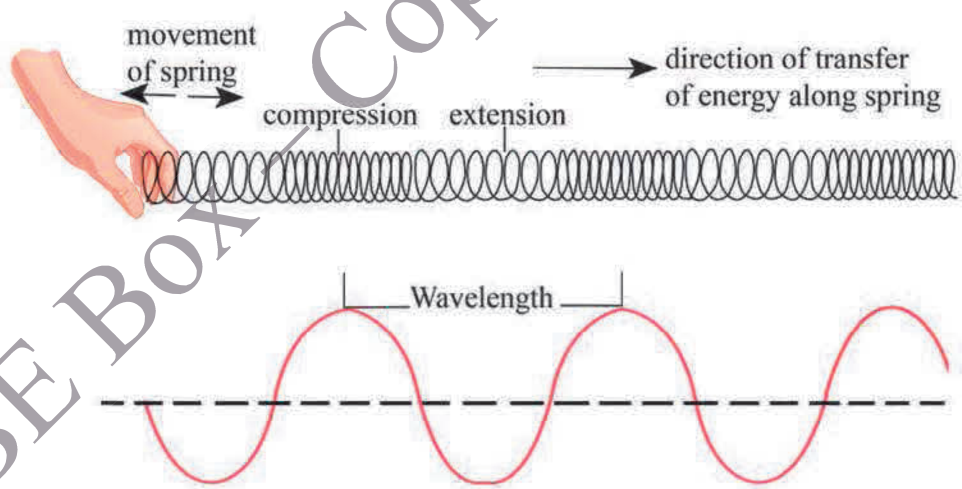


Figure 7.5 Graphical presentation of longitudinal wave

Reviewed Exercise

- Describe the similarities and differences between sound waves and water waves.

Key Words: transverse waves, longitudinal waves, compression, extension

7.3 CHARACTERISTICS OF WAVES

This section will discuss some quantities of periodic waves.

Wave Crest and Trough of Periodic Waves

The highest and the lowest points (Figure 7.6) which show the maximum displacement of vibrating particle from its rest position (or) equilibrium line are called wave crest and wave trough respectively. The arrows indicate the direction of displacement of the vibrating particle.

Wavelength (λ): The distance between any two consecutive wave crests (or) two consecutive wave troughs is called wavelength. The unit of wavelength in SI unit is metre (m).

> Generally the wavelength is the distance between two nearest points of same phase.

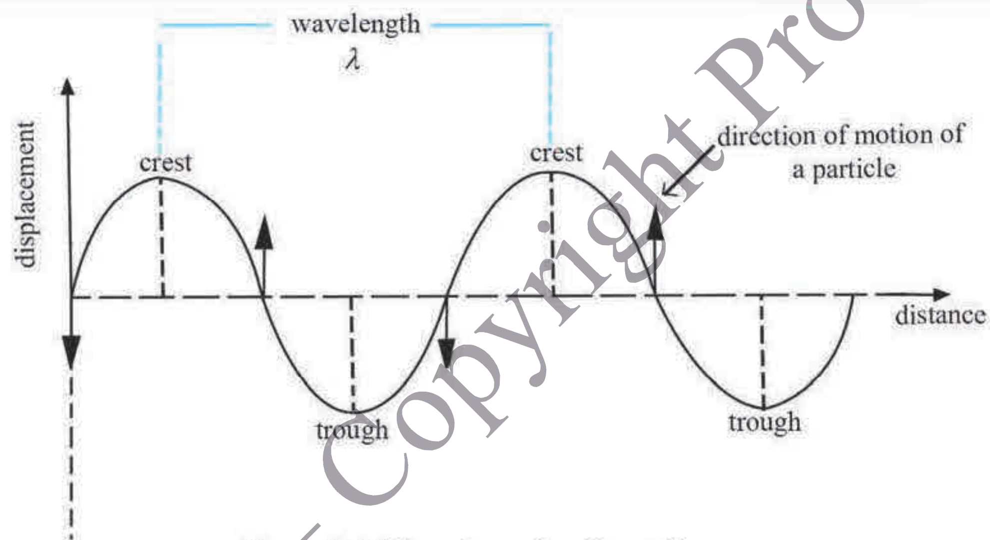


Figure 7.6 Wave in a vibrating string

Frequency (f) : The number of complete waves passing a point per second is called frequency of waves. The frequency of the wave depends on the vibrating source. The number of oscillation of a vibrating source in one second is also called frequency. The SI unit of frequency is hertz (Hz). One hertz is equal to one complete cycle per second.

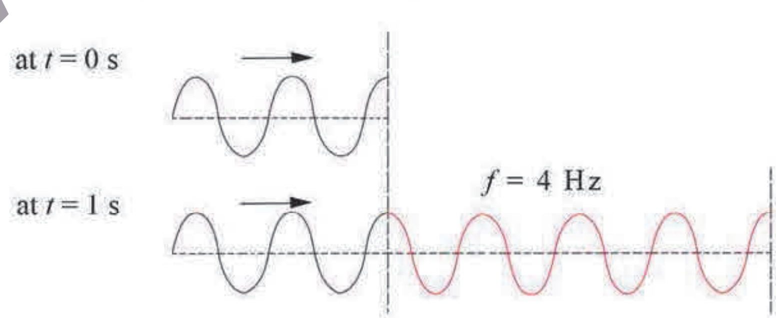


Figure 7.7 Frequency of a periodic wave (four complete waves pass a point in one second)

Period (T) : The time taken by the wave to travel the distance between any two consecutive wave crests (or) the time required for one complete vibration is called period of a wave. The unit of period is the second (s).

The period is the reciprocal or inverse of the frequency. Thus,

$$T = \frac{1}{f}$$

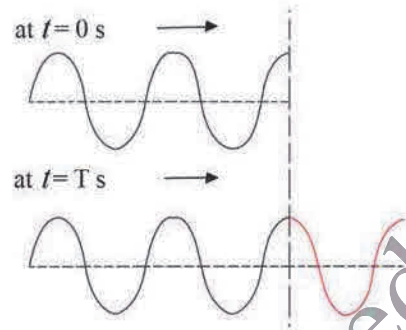


Figure 7.8 Period of the wave

Amplitude : The amplitude of a wave is the maximum value of displacement of vibrating particle. It can be seen on the wave graph shown in Figure 7.6 as the perpendicular distance from the equilibrium line to the wave crest (or) trough.

Velocity of Wave (v) : Velocity of wave is the speed with which a wave crest travels. The unit of wave velocity is metre per second (m s^{-1}).

> Most of the periodic waves are represented by sine (or) cosine graphs. Therefore they can be called sine waves.

The relationship between the frequency, wavelength and velocity of a periodic wave can be obtained by

$$\text{velocity} = \frac{\text{distance moved}}{\text{time taken}}$$

A complete wave travels through the distance equal to its wavelength in time period T.

$$\text{velocity} = \frac{\text{wavelength}}{\text{period}}$$

$$v = \frac{\lambda}{T}$$

Since ,

$$T = \frac{1}{f}$$

$$v = f\lambda$$

Reviewed Exercise

- Write down the relation between period and frequency. Explain it.

Key Words: hertz, oscillation

7.4 GRAPHICAL REPRESENTATION OF WAVE

Displacement-Distance Graph

A displacement-distance graph describes the displacement of all particles at a particular instant of time. Note that displacement of particle is plotted on y- axis and distance moved by the wave is on x - axis.

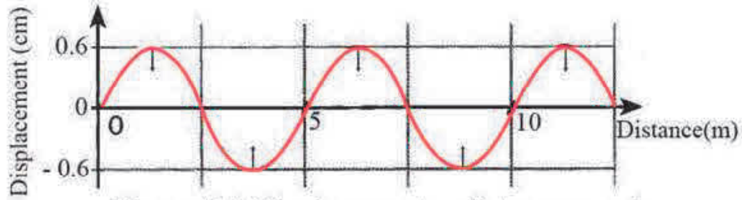


Figure 7.9 Displacement – distance graph

The arrows shown on the graph indicate the direction of the displacement of vibrating particle. According to the graph the amplitude is 0.6 cm and wavelength is 5 m respectively.

Displacement-Time Graph

A displacement-time graph describes the displacement of particle of a certain position as a function of time taken to travel by a wave. Note that displacement of particle is on Y axis and time interval is on X axis.

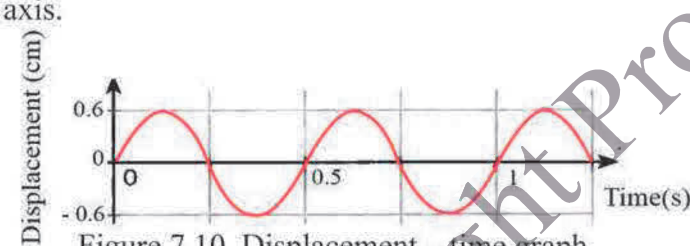


Figure 7.10 Displacement – time graph

According to the graph, the amplitude and the period of the wave are 0.6 cm and 0.5 s respectively. Since $T = \frac{1}{f}$, the frequency of the wave is 2 Hz.

7.5 REFLECTION, REFRACTION AND DIFFRACTION OF WAVE

Wave can undergo reflection, refraction and diffraction. These phenomena are usually studied by means of water wave in a ripple tank.

Ripple Tank : The ripple tank is a convenient piece of apparatus for demonstrating the properties of waves.

Wavefront : The surface that joins all the points of same phase is called wavefront.

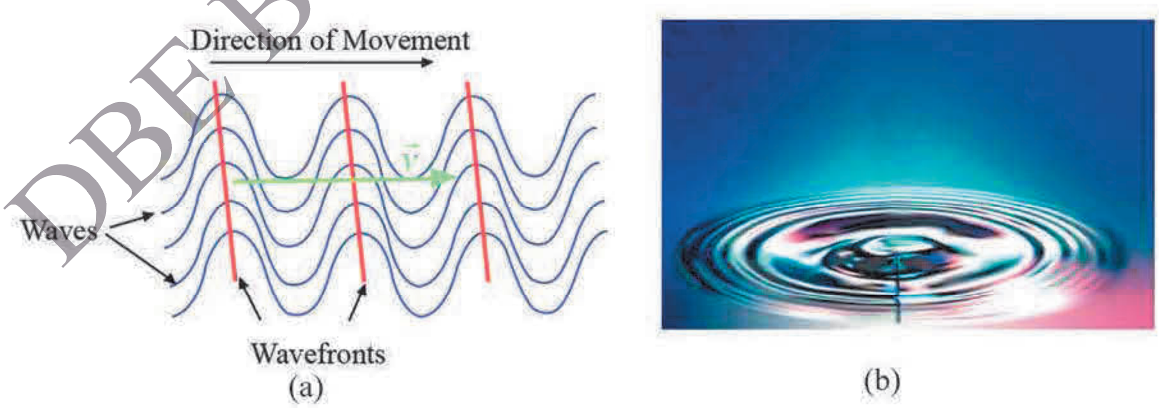


Figure 7.11 The wavefronts of (a) plane wave and (b) circular waves