2
Motion

SYLLABUS

1. Motion — change in position with respect to a set of stationary landmarks.

   Types of motion and examples of the same – translatory (rectilinear and curvilinear), rotatory, oscillatory, vibratory, periodic, multiple motion and random motion.

2. The motion of a simple pendulum — definitions of one oscillation, amplitude, time period, rest or mean position, frequency, factors affecting time period of simple pendulum.

   Finding the time period of simple pendulum, seconds pendulum.
   - Finding the time period of a simple pendulum (E). Acceleration due to gravity, uniform acceleration
   - Making a seconds pendulum (E).
   - Exploring the relationship between time period and the length of the pendulum/the mass of the bob (E). (Optional – may be taken as additional project work).

3. Uniform and non-uniform motion.

4. Speed, velocity — the difference between them. Calculating speed from the formula :

   S = D ÷ T and using the correct units.

   Acceleration.

   v = u + at and simple problems based on this equation. Students need to identify clearly initial and final velocity, and acceleration.
   - Observing examples of different kinds of motion and classifying them (E).

REST AND MOTION

If we look around, we observe that many objects do not appear to move, rather they are considered to be at rest. **A body is said to be at rest if it does not change its position with respect to a fixed point in its surroundings.**

Examples : A book lying on the table will not change its position if it is not disturbed and will be considered to be in a state of rest.

A bench fixed under a tree is at rest as there is no change in the position of the bench with respect to the tree and other stationary objects. **Therefore, when the position of a body with respect to its surroundings does not change with time, the body is said to be at rest.**

Many things around us move from one place to another. A flying bird, a moving bus, a boy playing football, motion of the pendulum of a wall clock, a moving train, a sailing ship, a walking man, *etc*. are some of the examples of motion. A moving object keeps on changing its position continuously with time.

A moving car changes its position with respect to a tree or a lamp post by the side of the road. So, the car is said to be in motion.

Similarly, a flying bird is also said to be in motion as it changes its position with respect to the stationary objects. Hence, **when the position of a body with respect to its surroundings changes with time, the body is said to be in motion.**

Rest and Motion are Relative Terms

Imagine yourself sitting inside a moving bus. When you look outside, you will observe that you are moving. Now look up at the roof of the bus. With respect to the roof, you will find yourself in a position of rest. Hence we conclude that rest and motion are relative terms.

You will further observe that a boy sitting on a bench near the road is at rest while you are moving with the bus.

Fig. 2.1

To conclude, an object is in motion with respect to a set of objects but at the same time, it may be in a state of rest with respect to the other objects (moving with the same speed and in the same direction). It is the observer and the surroundings that decide whether a given object is at rest or in motion.

Things to do

It is our common experience that the motion of some objects is slow while that of some others is fast. Make a list of ten objects moving along a straight path. Group the motion of these objects as slow or fast.

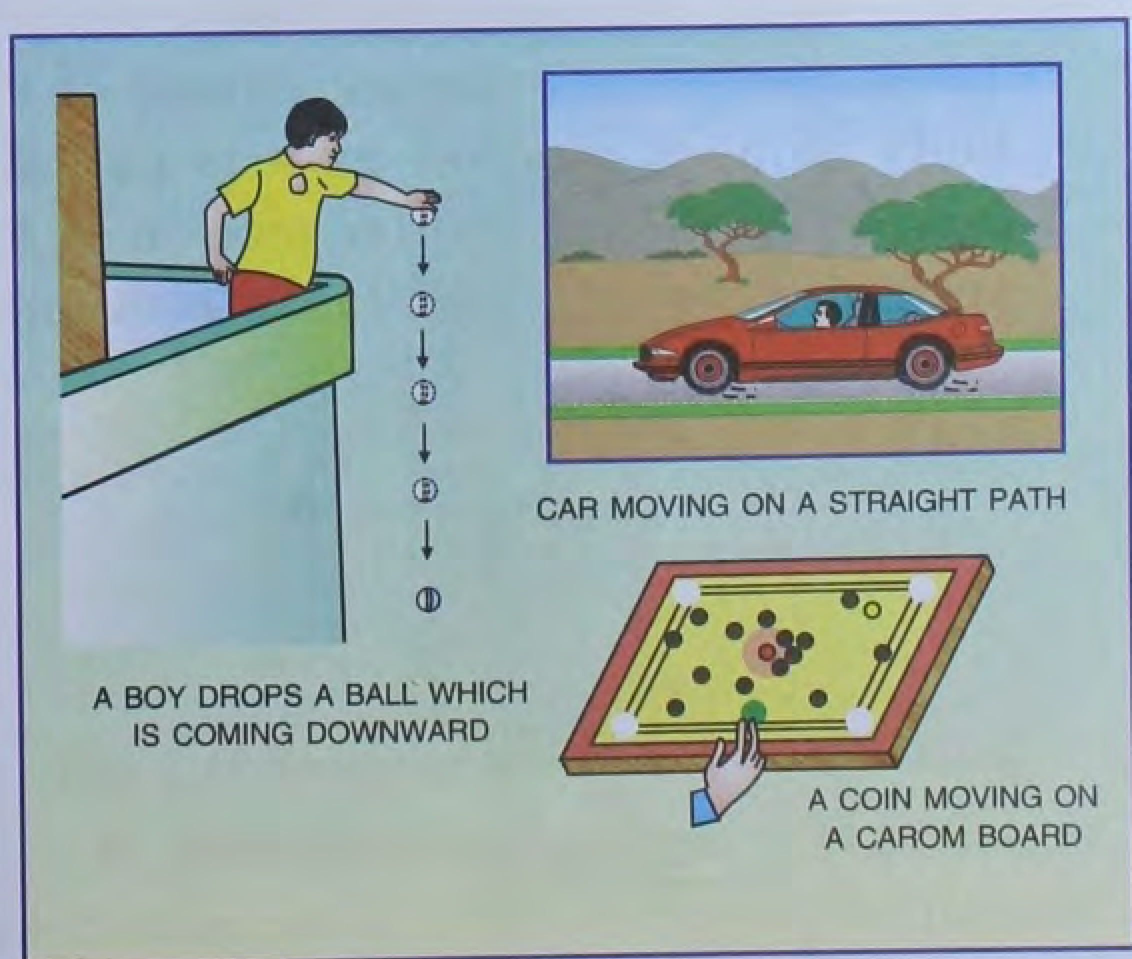
Types of Motion

Various objects have different types of movement. To name a few, a train moves straight along its track, a fan rotates, the earth revolves around the sun. There can be many more such examples. These different kinds of motions can be classified into the following types.

1. Translatory motion : If an object, like a vehicle, moves in a line in such a way that every point of the object moves through the same distance in the same time, then the motion of an object is called **translatory motion.** There are two types of translatory motions :

(a) **Rectilinear motion :** If an object moves along a straight line, its motion is called *rectilinear motion*. For example, a stone falling straight towards the surface of the earth, a car moving on a straight road and a coin moving over a carom board.

Rectilinear motion is also called **linear motion**.



Following are some more examples of linear motion.

(1) The motion of a bullet fired from a gun (upto some distance).

(2) March past of the soldiers in a parade.

(3) A boy running on a straight road.

(b) **Curvilinear motion :** If an object moves along a curved or circular path, its motion is called **curvilinear motion.** For example, a car moving along a curved path or a javelin thrown by an athlete are in curvilinear motion. A ball thrown at an angle also has curvilinear motion.

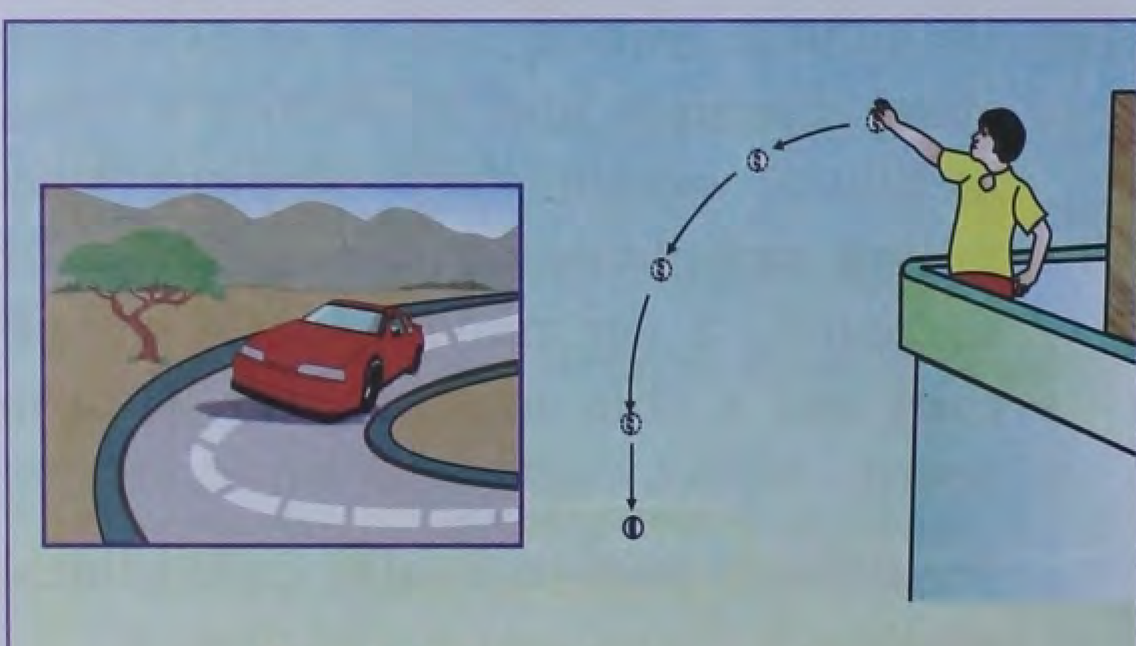


Fig. 2.3 Curvilinear motion

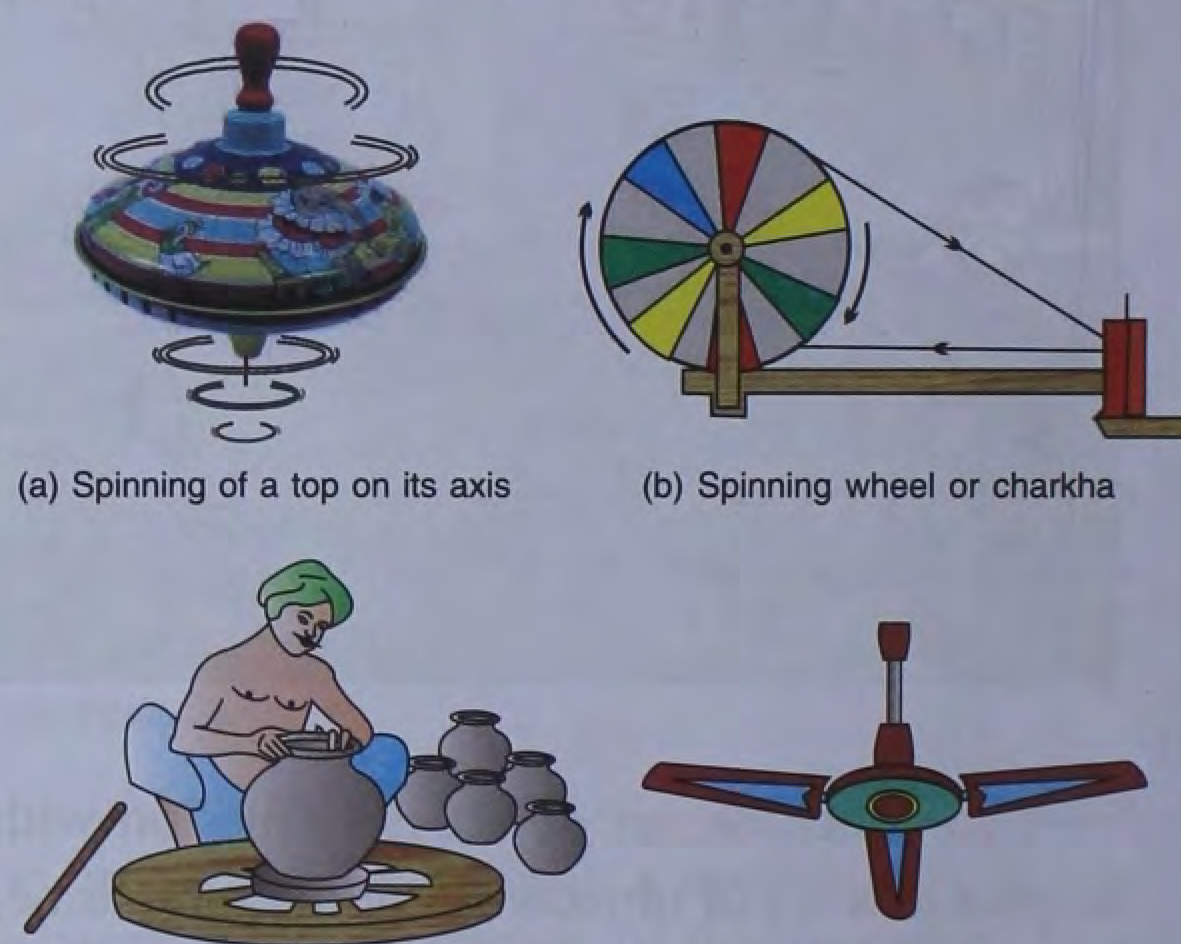
Circular motion : The movement of a body along a circular path is called circular motion. Circular motion is a special type of curvilinear motion.

Fig. 2.4 Circular motion

Whirling of a stone tied to a string is an example of circular motion.

2. Rotatory motion : A body is said to be in a rotatory motion or a circular motion if it moves about a fixed axis without changing the radius of its motion. For example, the blades of a fan, a spinning top, a spinning wheel or *potter's wheel*, a merry-go-round, rotation of the earth about its axis, etc.

A rotatory motion is different from a translatory motion, because in a rotatory motion, different parts of the object move through different distances during the same time.



(a) Spinning of a top on its axis

(b) Spinning wheel or charkha

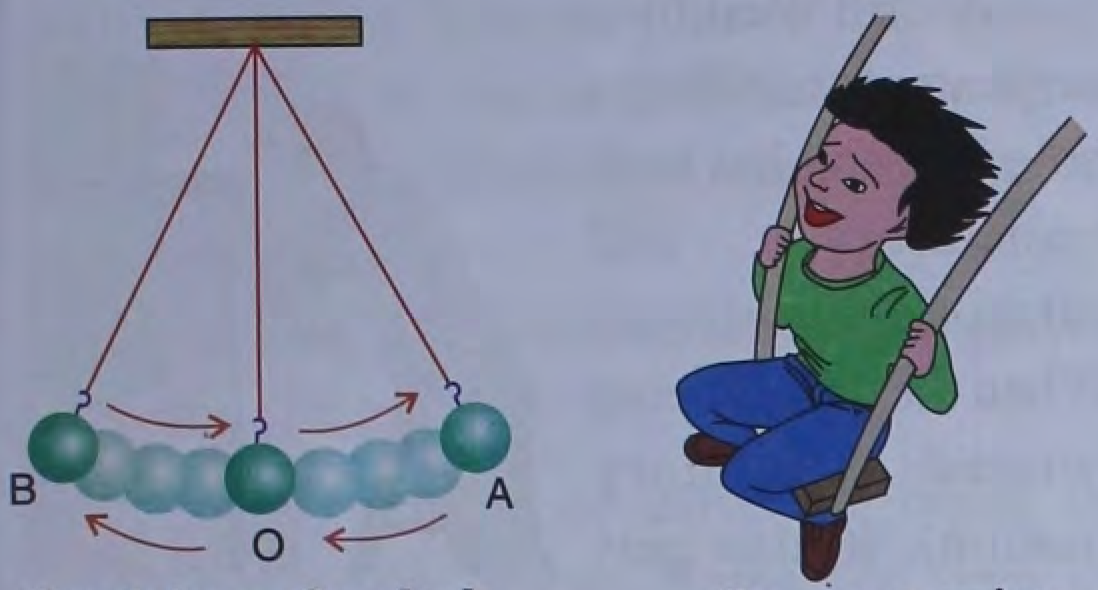
(c) Potter's wheel

(d) Ceiling fan

Fig. 2.5 Various types of rotatory motions

3. Oscillatory motion : Observe the motion of the pendulum of a wall clock. The to and fro motion of the bob is called *oscillatory motion.* The motion of a swing and the piston of an engine perform oscillatory motion.

The to and fro motion of a body along the same path about its mean position is called oscillatory motion. The oscillatory motion is a periodic motion.



Pendulum of a clock **Boy on a swing**

Fig. 2.6 Showing oscillatory motion

4. Vibratory motion : There is another type of oscillatory motion in which a certain part of the body always remains fixed while the rest of the body moves to and fro in a particular style about its mean position. This is called vibratory motion.

A metallic wire tied between two fixed rods on a table is stretched (Fig. 2.7). When the wire is plucked, it starts moving to and fro. It must be noted that during this motion, there is a change in the shape and size of the body. All musical instruments like guitar, violin, sitar, *etc*., have strings attached to them which produce vibratory motion.

When we breathe, our chest expands and contracts. This motion is also called **vibratory motion**.

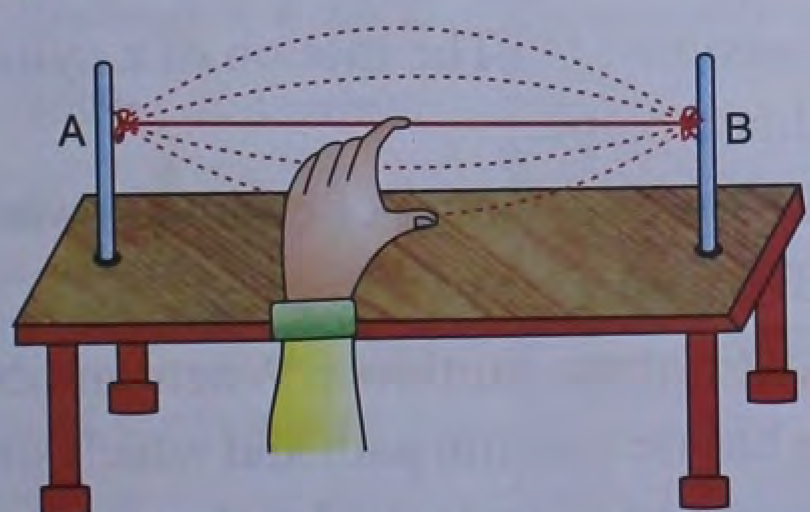


Fig. 2.7 Vibratory motion

5. Periodic motion : A motion which gets repeated after regular intervals of time is called a *periodic motion*. The earth moving around the sun takes 365 and $\frac{1}{4}$ days to complete one revolution and this motion gets repeated after every $365\frac{1}{4}$ days. Similarly, the swinging pendulum of a wall clock, the needle of a sewing machine and the heart beat of a normal person are examples of periodic motion.

Movement of the moon around the earth, a branch of a tree moving to and fro, the surface of the drums (tabla) being played are some more examples of periodic motion.

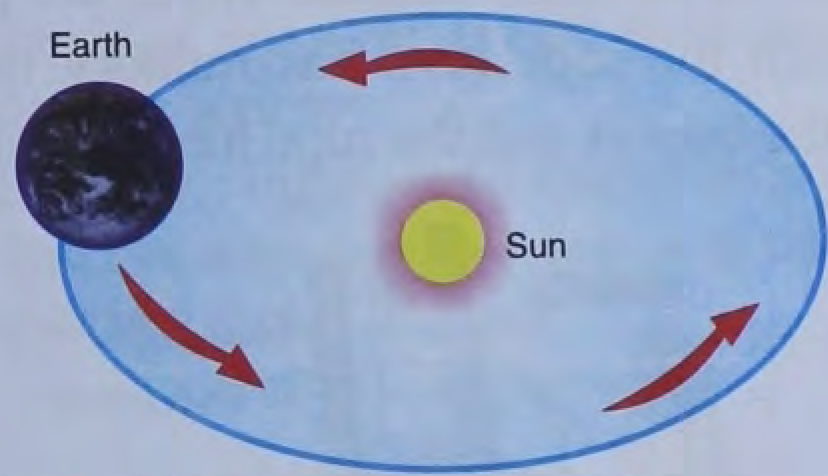


Fig. 2.8 Earth revolving around the sun

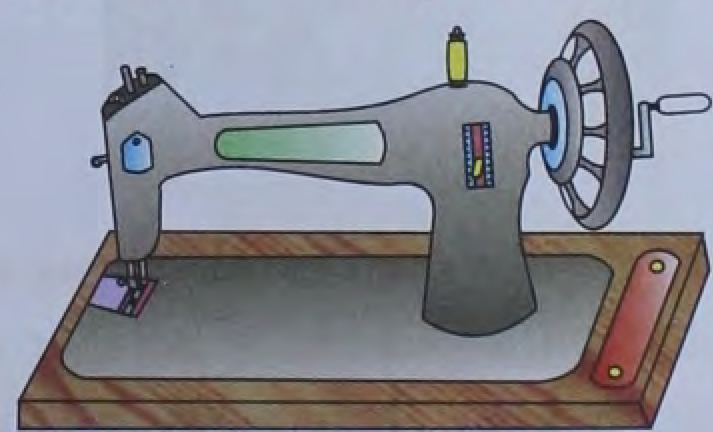


Fig. 2.9 Needle of a sewing machine

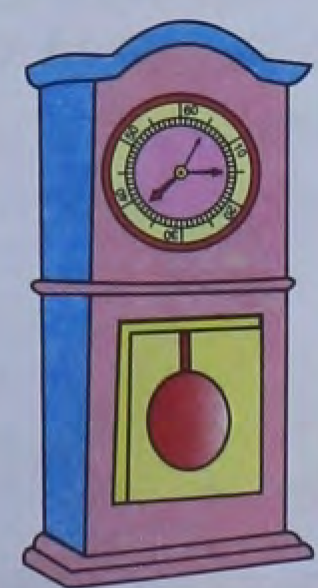


Fig. 2.10 Swinging pendulum of a wall clock

6. Non-periodic motion : The motion which does not repeat itself after regular interval of time is called non-periodic motion.

Example : A footballer running on a field, application of brakes in a moving vehicle, a ball rolling down the ground gradually slows down and finally stops, motion of tides in the sea, *etc*.

7. Multiple motion : Sometimes, a moving object performs two or more types of motions simultaneously. Such a motion is called *multiple motion*. Some of the examples of multiple motion are :

A person drawing water from a well is an example of multiple motion. Here, the pulley on which the rope runs has rotatory motion while the bucket and the rope have translatory motion.

Fig. 2.11 Person drawing water from a well

A rider on a bicycle is another example of multiple motion. The wheels and the pedals perform rotatory motion and the bicycle as a whole moves in a curved or straight path (translatory motion).

Fig. 2.12 A rider on a bicycle

A drill used by a carpenter for drilling a hole in wood has both translatory and rotatory motions. When the drill is being rotated (rotatory motion), it also gets pierced into the wood (translatory motion).

Fig. 2.13 Drilling machine

Observe the motion of a ball on the ground. Here the ball is rolling on the ground – rotating as well as moving forward on the ground. Thus, the ball undergoes a rectilinear motion as well as rotational motion.

The earth rotates about its axis (rotatory motion) and at the same time it revolves around the sun in a curved path (curvilinear motion) in a fixed time interval (periodic motion).

8. Rolling motion : The motion in which a body undergoes both translatory as well as rotatory motion is called rolling motion.

When a spin bowler (in the game of cricket) delivers a ball, the ball has a motion of spin (rotatory motion) while it moves towards the batsman (translatory or curved motion).

Example : (1) The motion of a cylinder on an inclined plane.

(2) The movement of a bicycle wheel.

(3) Movement of a drill.

9. Random motion : When an object in motion has no specific path and which suddenly changes its motion is said to have a **random motion**. Some examples are given below.

(i) A mosquito while flying has translatory motion at one moment and rotatory motion at another moment.

(ii) A flying kite may have translatory motion at one instant and may have rotatory motion at the very next moment.

(iii) Motion of a football or hockey player on the ground.

Some examples of different types of motion are given below. Name the type of motion in each case.

Examples of motion	Type of motion
Soldiers in a march past	....
Bullock cart moving on a straight road	....
Hands of an athlete in a race	....
Pedal of a bicycle in motion	....
Motion of the earth around the sun	....
Motion of a swing	....
Motion of a pendulum	....
A stone falling from certain height	....
A plucked string of a sitar	....
Tip of the hand of a clock	....
A car moving on a curved path	....
Motion of a train on a straight bridge	....
Motion of hands while running	....
The movement of the wheel of a cycle	....
The movement of our chest while breathing	....

Intext Questions

1. Define rotatory motion. Give *one* example.
2. How is rotatory motion different from a translatory motion ?
3. Define periodic motion. Give *one* example.
4. Define multiple motion. Give *one* example.
5. Define random motion. Give *one* example.

UNIFORM AND NON-UNIFORM MOTION

Uniform motion : If an object covers equal distances in equal intervals of time, we say that the object is in **uniform motion**.

When the motion is uniform, the body remains at a constant speed throughout the period of its journey.

Example : Figure 2.14 shows the positions of a cyclist who is covering a distance of 2 metres in every 1 second.

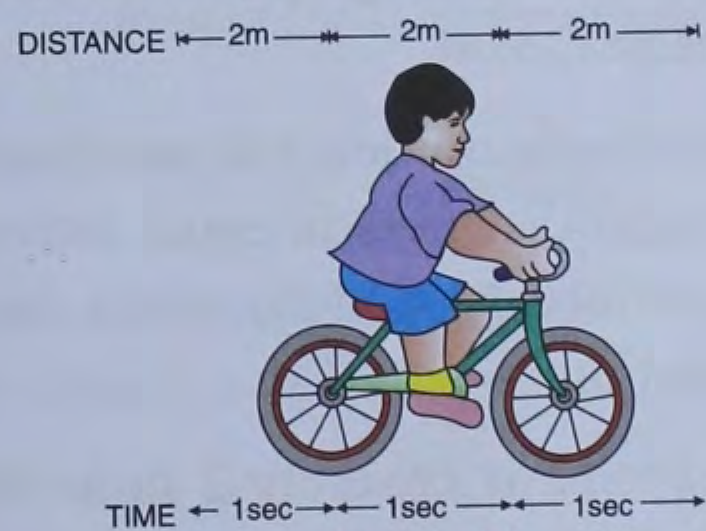


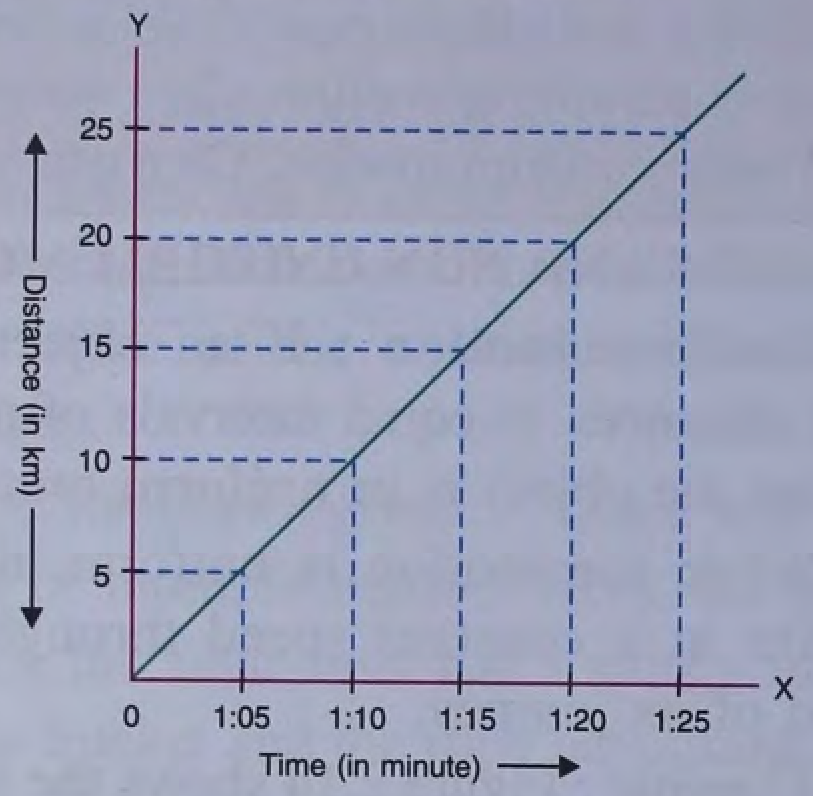
Fig. 2.14

Example : A flying aeroplane in a particular direction at a constant speed, a train moving straight in a particular direction at constant speed.

Look at the following table which displays the distance covered by a car in given time.

Time	Time taken	Total distance	Distance covered in equal interval
1:00 pm		0	
1:05 pm	5 min	5 km	5 – 0 = 5 km
1:10 pm	5 min	10 km	10 – 5 = 5 km
1:15 pm	5 min	15 km	15 – 10 = 5 km
1:20 pm	5 min	20 km	20 – 15 = 5 km
1:25 pm	5 min	25 km	25 – 20 = 5 km

The table shows that the car is moving with a constant speed. It is covering 5 km in every 5 minutes. We can also say that it is covering 1 km in every 1 minute.



The graph shows that when we plot a uniform motion on a graph it is always a straight line.

Non-uniform motion : If an object does not cover equal distances in equal intervals of time, the object is said to move in **non-uniform motion.**

If the cyclist is covering 2 m in the first second, 3 m in the next second and 4 m in the next second, then the motion of the cyclist is non-uniform.

Example : Figure 2.15 shows the positions of a cyclist who is covering a distance of 2 m in the first second, 3 m in the next second and so on. Since there are variations in the distance covered in the fixed time intervals, the object is said to be in non-uniform motion.

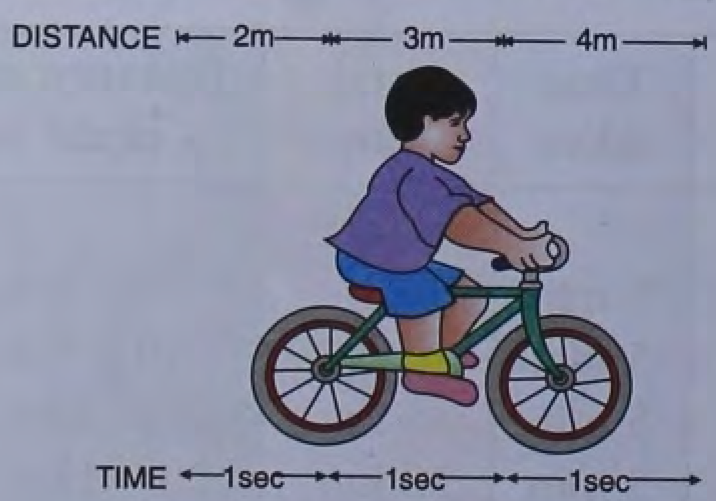
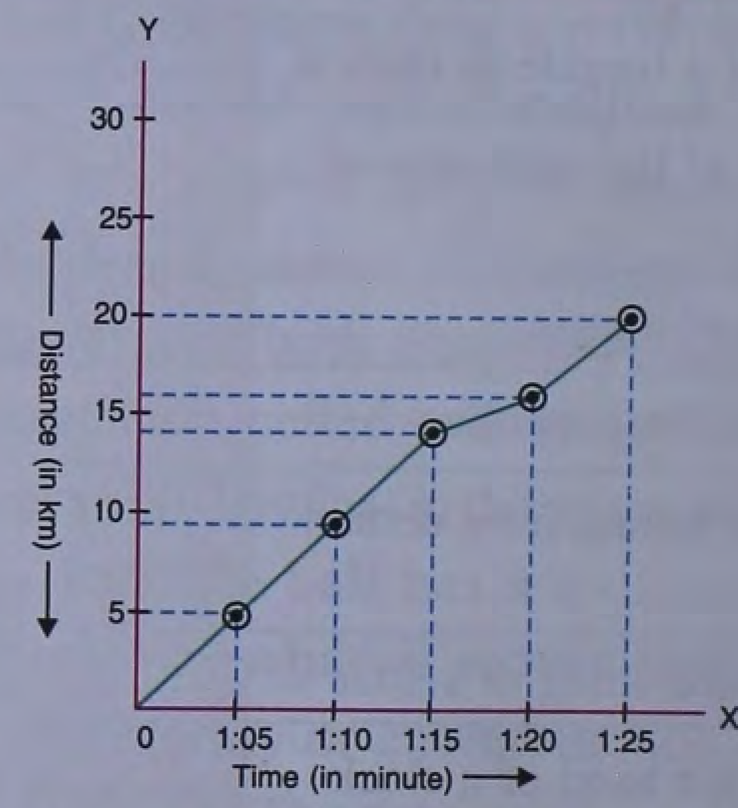


Fig. 2.15

Look at the following table which displays the distance covered by a car in given intervals of time.

Time	Time taken	Total distance	Distance covered in equal interval
1:00 pm	0	0	
1:05 pm	5 min	5 km	5 – 0 = 5 km
1:10 pm	5 min	9 km	9 – 5 = 4 km
1:15 pm	5 min	14 km	14 – 9 = 5 km
1:20 pm	5 min	16 km	16 – 14 = 2 km
1:25 pm	5 min	20 km	20 – 16 = 4 km



The above mentioned table clearly shows that the car is covering unequal distances in equal intervals of time *i.e.* 5 minutes. It means the car is in non-uniform motion.

SIMPLE PENDULUM

An ideal simple pendulum consists of a small metal ball called the bob suspended from a rigid support by a weightless and inextensible string. But practically, we cannot construct a simple pendulum with weightless string. Therefore, in reality, a simple pendulum consists of a heavy bob suspended from a fixed point by a light inextensible string (Fig. 2.16). When the pendulum moves, we say it constitutes an oscillatory motion.

Fig. 2.16 Simple pendulum at rest

In Fig. 2.17, O is known as its **rest or mean position while,** A and B are known as **extreme positions** on either side. When the bob is slightly pushed from its rest position to the other side and then released, it begins to move to and fro about its mean position O and thus begins to oscillate. Following are the terms related to the pendulum when it is oscillating.

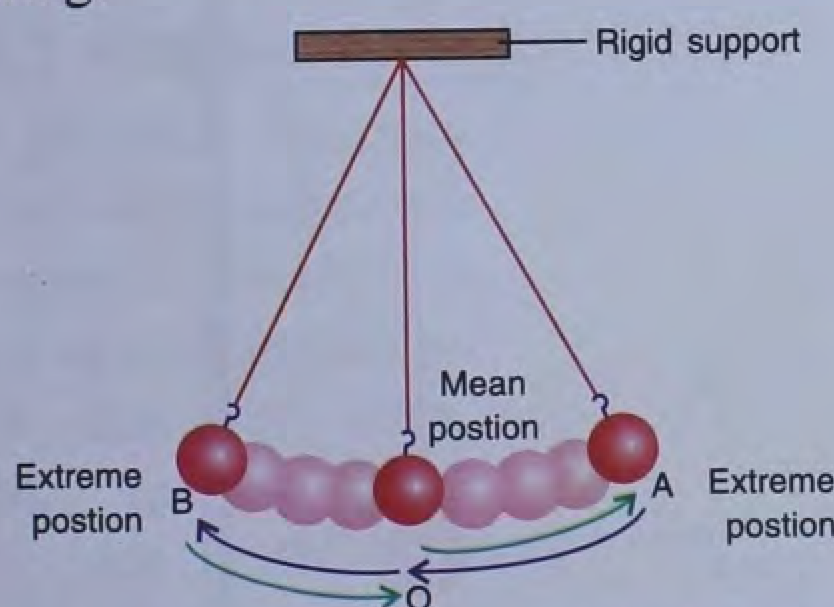


Fig. 2.17 Different position of the bob of an oscillating pendulum

(a) Oscillation : When a pendulum completes one to and fro motion, it is considered to have completed one oscillation. According to Fig. 2.17, when the pendulum starts from O, moves to A, then from A to B and back to O, it completes one oscillation.

(b) Amplitude (A) : The maximum displacement of the bob on either side of its mean position is called the *amplitude of oscillation*. According to the figure, OA and OB both are amplitudes.

(c) Time period (T) : The time taken by the bob to complete one oscillation is called its time period. It is denoted by T and is measured in seconds.

(d) Frequency (ν) : The number of complete oscillations executed by the bob in one second is called its *frequency*. It is denoted by ν or f. Its unit is *Hertz* (Hz) or cycles/second.

1 Hz = 1 cycle per second

The relation of time period and frequency is written as :

$$\text{Frequency} = \frac{1}{\text{Time Period}}; \; \nu = \frac{1}{T}$$

and, $$\text{Time period} = \frac{1}{\text{Frequency}}; \; T = \frac{1}{\nu}$$

Factors Affecting the Time Period of a Simple Pendulum

The time period of a simple pendulum is neither affected by the mass of the bob nor by the amplitude of oscillation. However, it is affected by the length of the pendulum. These facts give rise to the following laws of simple pendulum.

1. Law of mass : The time taken for one oscillation by a pendulum of given length does not change with the change in the mass of the bob. A bob of mass 10 g will take the same time for one oscillation as much a bob of mass of 20 g or more for length of string.

2. Nature of material of the bob : The time period of a simple pendulum is independent of the nature of material of the bob.

3. Law of amplitude : The time period of a simple pendulum is independent of its amplitude of oscillation.

4. Law of length : The time period of a simple pendulum is directly proportional to the square root of its effective length *i.e.*

$$T \propto \sqrt{l} \quad (l \text{ is the effective length})$$

It is observed that if the length of a pendulum is made four times, its time period becomes double, *i.e.*, it takes twice the time to complete one to and fro oscillation, compared to previous time.

5. Law of gravity : The time period of a simple pendulum at a given place is inversly proportional to the square root of the acceleration due to gravity at that place

i.e. $T \propto \frac{1}{\sqrt{g}}$.

Combining the above two laws :

$$T \propto \sqrt{\frac{l}{g}} \text{ or } T = K\sqrt{\frac{l}{g}}.$$

Where K is the proportionality constant and has a value of 2π.

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

Finding the time period of a simple pendulum

Apparatus : We need a metallic bob suspended by a strong but thin thread of about 100 cm in length; an iron clamp stand; a cork cut into two halves; a metre scale and a stop watch.

Procedure : Measure the diameter of the metallic bob by keeping it over a metre scale and holding it tight with two wooden blocks. Calculate the radius of the bob *R* by dividing the diameter by 2. Set up the pendulum as shown in Fig. 2.18, such that the length l_1 of its string is equal to, say (60 – R) cm. The length of pendulum 'l' from the point of suspension to the centre of the bob will now be 60 cm. Adjust the clamp in such a way that the bob is a little above the floor. Pull the pendulum to one side such that it makes an angle of about 15° to 20° with the vertical. Release the pendulum and simultaneously start the stop watch. Find the time for 20 complete oscillations of pendulum and record it. Let the time be *t* seconds.

∴ Time to complete one oscillation

(time period) $T = \frac{t}{20}$ seconds.

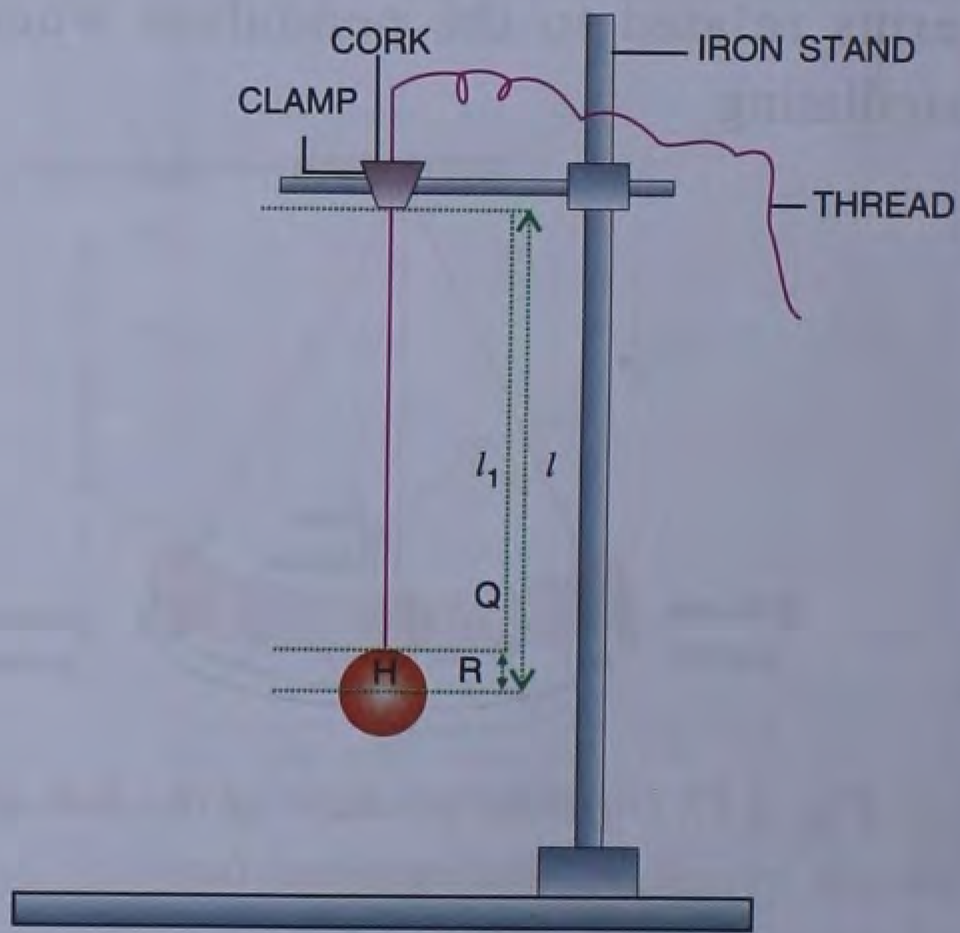


Fig. 2.18

Since time period of a simple pendulum is very small, so time for one oscillation cannot be accurately recorded. Thus, for accuracy, we find the time for 20 oscillations or more and then calculate the mean time for one oscillation.

Second's Pendulum : A simple pendulum which has a time period of two seconds is known as a **second's pendulum.**

To make a second's pendulum, take a thread of 100 cm length. Tie one end of the thread to a rigid support. At the other end of this thread, tie a heavy metallic bob and suspend it. Now calculate the time period of the pendulum by finding the time for 20 oscillations. You will find that the average time period of an oscillation is 2 seconds. Repeat this experiment by changing the lengths of the pendulum and calculating the time period in each case. You will observe that as the length of the pendulum increases, the time of oscillation also increases and vice-versa. The time period of a second's pendulum is independent of its amplitude of oscillation.

$$\text{Its frequency } (\nu) = \frac{1}{\text{Time Period}}$$

$$= \frac{1}{2\text{ sec}} = 0{\cdot}5\text{ Hz.}$$

SCALAR AND VECTOR QUANTITIES

A physical quantity which has only magnitude but no specific direction is called a **scalar quantity**. Length, distance, area, volume, mass, time, energy, *etc*., are the examples of scalar quantities.

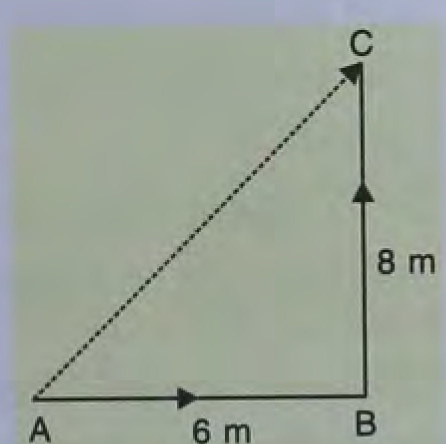


Fig. 2.19

A physical quantity having magnitude as well as specific direction is called a **vector quantity**. Displacement, velocity, acceleration force, weight, *etc*., are all examples of vector quantities.

DISTANCE AND DISPLACEMENT

Distance

Irrespective of the direction, the actual length of the path covered by a moving body is known as the **distance** travelled by the body.

It is a scalar quantity because it is described completely by its magnitude. Suppose an object first moves from A to B through 6 m and then from B to C through 8 m.

Then the total distance travelled by the body will be

$$AB + BC = 6\text{ m} + 8\text{ m} = 14\text{ m.}$$

Therefore, 14 m is the **distance** travelled by the body between A and C.

In S.I. system, the unit of distance is metre (m). The other units are centimetre (cm) and kilometre (km). The relation is,

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

$$1\text{ km} = 1000\text{ m or } 1\text{ m} = \frac{1}{1000}\text{ km} = 10^{-3}\text{ km}$$

Displacement

When a body moves from one point to another point, the shortest distance between the two points, *i.e.*, from initial point to the final point, in a particular direction is called its displacement. It is a vector quantity. Displacement is also measured in metre, centimetre or kilometre. Figure 2.19 shows that the shortest possible distance between A to C is AC. To calculate AC, we will have to use Pythagorus theorem.

$$\therefore \text{ Displacement AC} = \sqrt{AB^2 + BC^2}$$

$$= \sqrt{6^2 + 8^2} = \sqrt{100} = 10\text{ m}$$

Therefore, **displacement** of the object between the points A and C is 10 m.

Note that a body moving along a circular path and completing its one full rotation has a displacement equal to zero because the initial position and the final position of the body in one rotation of a circular path are the same.

Example 1 : An object moves from A to B, 4 km due west and then from B to C, 3 km due north. Find the distance and the displacement covered by the object.

Solution : Distance = AB + BC

= 4 + 3 = 7 km.

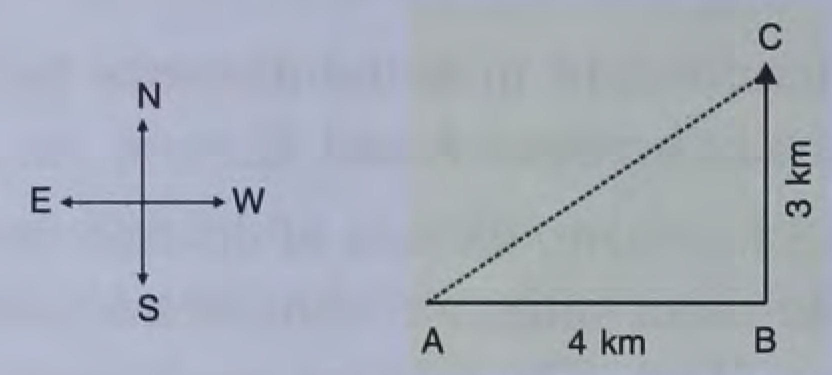


Fig. 2.20

Therefore, 7 km is the distance travelled by the body to reach at C.

$$\text{Displacement AC} = \sqrt{AB^2 + BC^2}$$

$$= \sqrt{4^2 + 3^2} = \sqrt{16+9}$$

$$= \sqrt{25} = 5 \text{ km.}$$

Therefore, the displacement of the body is 5 km while the distance covered by the body is 7 km.

Distinction between distance and displacement

Distance	Displacement
1. It is the length of actual path travelled by the object in a certain time.	1. It is the shortest path travelled by an object in a certain time.
2. It depends on the path followed by the object.	2. It does not depend on the path followed by the object.
3. It is always positive.	3. It can be positive, negative or zero.
4. It can be more than or equal to the magnitude of displacement.	4. Its magnitude can be less than or equal to the distance.
5. It is a sclar quantity.	5. It is a vector quantity.

SPEED AND VELOCITY

Speed

Speed is a physical quantity which gives us an idea about the motion of a body or how fast a body moves. Suppose we want to compare the motions of a car and a horse-cart on the road. We see that car travels greater distance than the horse-cart in the same time period. Hence, we say that the car moves faster than the horse-cart.

The distance travelled by a body per unit time is known as the **speed** of a body.

$$\text{Speed (s)} = \frac{\text{Distance travelled (d)}}{\text{Time taken (t)}}$$

Speed is a scalar quantity, and is denoted by the symbol s.

Knowledge bank

Speedometer displays the speed of moving vehicles. It consists of a needle that moves over the marked digits. If the needle points to 50, it means the vehicle is moving with speed of 50 km/h.

Odometer displays the distance covered by the vehicle in kilometer.

Fastest speed that some animals can attain.

S.No.	Name of the object	Speed in km/h	Speed in m/s
1.	Falcon	320	$\frac{320\times1000}{60\times60}$ or 889
2.	Cheetah	112	31.11
3.	Blue fish	40-46	11.11-12.8
4.	Rabbit	56	15.6
5.	Squirrel	19	5.3
6.	Human	40	11.11
7.	Giant tortoise	0·27	0.075
8.	Domestic mouse	11	3.05

Unit of speed : In S.I. system, distance is measured in metre and time in seconds, so the

S.I. unit of speed is metre/second. Its symbol is m/s or m s^{-1}.

Sometimes, we express speed in cm/s and m/min too. However, if the body is covering a long distance, it is expressed in km/hr. It is the conventional unit of speed.

Example 2 : A car covers a distance of 210 km in 7 hours of time. Calculate the speed of the car.

Solution : Distance = 210 km, time = 7 hr

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

$$s = \frac{210\text{ km}}{7\text{ hr}} = 30\text{ km/hr}$$

$\therefore$ The speed of car is 30 km/hr.

Example 3 : A train takes 4 hours to travel from Agra to Delhi with a uniform speed of 80 km/hr. Find the distance between the two cities.

Solution :

$$\text{Distance} = \text{Speed of the train} \times \text{Time taken}$$
$$= 80 \times 4 = 320\text{ km.}$$

Example 4 : A child covers a distance of 40 metres in 2 minutes. What is the speed of the child ?

Solution : Distance covered = 40 m

Time taken = 2 min or 120 sec.

$$\text{Speed of child} = \frac{\text{Distance covered}}{\text{Time}}$$

$$= \frac{40}{120} = 0{\cdot}33\text{ m/s.}$$

Example 5 : Rajdhani Express moves at a speed of 150 km/h. How long will it take to cover a distance of 25 km ?

Solution : Distance covered = 25 km

Speed = 150 km/hr

$$= \frac{150}{60}\text{ km/min} = 2{\cdot}5\text{ km/min}$$

$$\text{Time} = \frac{\text{Distance covered}}{\text{Speed}}$$

$$= \frac{25\text{ km}}{2{\cdot}5\text{ km/min.}} = 10\text{ min.}$$

Example 6 : A motor cycle is running at a constant speed of 20 m/s. How much distance will it cover in 60s ?

Solution : Speed of motor cycle = 20 m/s

Time = 60s

$\therefore$ Distance covered in 60s

$$= \text{Speed} \times \text{Time}$$
$$= 20 \times 60 = 1200\text{ m.}$$

Example 7 : A train takes 3 hr to reach from station A to station B and then 5 hr to return from station B to station A. The distance between the two stations is 400 km. Calculate the average speed of the train.

Solution : Average speed of the train

$$= \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

$$= \frac{[400+400]\text{ km}}{[3+5]\text{ h}} = \frac{800\text{ km}}{8\text{ h}} = 100\text{ km/h.}$$

Velocity

When we describe the motion of a body from its initial position to its final position, we should not only know its speed but also the direction in which the body has to move, *i.e.*, we must know the velocity of the body.

The **velocity** of a body is *the distance travelled by the body in unit time and in a* *given direction.* **Velocity can also be defined as displacement per unit time.**

$$\text{Velocity} = \frac{\text{displacement}}{\text{time taken}}$$

Velocity is a vector quantity. The S.I. unit of velocity is metre per second (m/s).

Differences Between Speed and Velocity

Figure 2.21 shows that two cars (1) and (2) are moving in two different directions. Car (1) travels a distance of 50 km from point A towards east and reaches the point B in 1 hour. Car (2) travels from point A towards west and reaches the point C at the same distance as point B and in the same time period. The speed of the two cars is same *i.e.* 50 km/h but they have different velocities since they are travelling in different directions. Thus, we say that when two bodies with the same speed are moving in different directions, they have different velocities.

Fig. 2.21

Figure 2.22 shows a car moving along a curvy path at a constant speed of 20 m/s. The arrows in the diagram show the direction of motion of car at various intervals. We see that the direction of motion of car changes as it

Fig. 2.22

moves along the curve. Hence the velocity of car is continously changing although its speed is constant.

Therefore, constant speed is not the same as the constant velocity. **A body is said to have a constant velocity if its speed as well as the direction of motion do not change with time.**

The velocities of two bodies are different if they move with the same speed but in different directions. But if two bodies move with the same speed and in the same direction, then the bodies have the same velocity.

Distinction between speed and velocity

Speed	Velocity
1. The distance travelled by a moving object in one second is called its speed.	1. The distance travelled by a moving object in a particular direction in one second is called its velocity.
2. It is a scalar quantity.	2. It is a vector quantity.
3. Speed of a moving body is always positive.	3. Velocity of a moving body can be positive, negative or zero.

Acceleration

A car starts from rest and attains a constant velocity, say, 50 km/hr. It runs at that velocity for sometime. The driver now wants to slow down the car and hence reduces the velocity, so that finally it becomes zero. The various changes in velocity with time are expressed in terms of acceleration.

Acceleration is, therefore, defined as *the rate of change of velocity of a body*.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time}}$$

or $$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}}$$

or $$\boxed{\text{Acceleration} = \frac{v-u}{t}}$$

$$\text{Unit of Acceleration} = \frac{\frac{\text{m}}{\text{s}}}{\text{s}}$$

$$= \frac{\text{m}}{\text{s}} \times \frac{1}{\text{s}} = \frac{\text{m}}{\text{s}^2} \text{ or m s}^{-2}$$

Acceleration is regarded as **positive** if the velocity of the object is increasing and is considered to be **negative** if the velocity is decreasing. However, we limit the word acceleration to a situation when velocity is increasing with respect to time. If velocity is decreasing with respect to time, then we use the term **deceleration** or **retardation.**

e.g., if $u = 35$ m s^{-1}, $v = 75$ m s^{-1} and $t = 8$ sec

$$\text{Then } a = \frac{(75-35)\,\text{m s}^{-1}}{8\,\text{s}} = \frac{40\,\text{m s}^{-1}}{8\,\text{s}} = 5 \text{ m s}^{-2}$$

Thus, 5 m s^{-2} is the acceleration.

If $v = 35$ m s^{-1}, $u = 75$ m s^{-1} and $t = 8$ sec

$$\text{Then } a = \frac{(35-75)\,\text{m s}^{-1}}{8\,\text{s}} = \frac{-40\,\text{m s}^{-1}}{8\,\text{s}} = -5 \text{ m/s}^2$$

Since acceleration is negative *i.e.*, –5, hence we say that retardation is 5 m s^{-2}.

Equations of Motion

An equation of motion is an equation that relates the initial velocity, acceleration, time interval, final velocity and displacement of a moving body.

If the motion is uniformly accelerated, then the initial velocity 'u', the final velocity 'v', the uniform acceleration 'a', the time 't' and the displacement 'S' are related by three equations known as the *equations of motion*. These equations are as follows :

$$v = u + at \quad \text{.............(i)}$$

$$S = ut + \frac{1}{2}at^2 \quad \text{...........(ii)}$$

$$v^2 = u^2 + 2aS \quad \text{..........(iii)}$$

However, if the body is retarding *i.e.* the acceleration is negative, the equations take the following forms.

$$v = u - at \quad \text{...........(iv)}$$

$$S = ut - \frac{1}{2}at^2 \quad \text{............(v)}$$

$$v^2 = u^2 - 2aS \quad \text{..........(vi)}$$

The above six equations are applicable if the body is getting displaced in a straight path or **horizontally**.

Each of the equations of motion has four quantities out of v, u, a, t and S. If any three of these four quantities are known, we can calculate the remaining quantities.

Note, in these equations, the initial velocity is denoted by u and the final velocity by v.

Example 8 : A car starts from rest and is accelerated at the rate of 3 m s^{-2} for 8 seconds. Find the velocity of the car at the end of 8 seconds.

Solution : Given : $u = 0$, $a = 3$ m s^{-2}, $t = 8$ sec, $v = ?$

Since, $v = u + at$

$$\therefore \quad v = 0 + 3 \text{ m s}^{-2} \times 8 \text{ s}$$

$$= \mathbf{24 \text{ m s}^{-1}}$$

Example 9 : A motor bike is moving with a velocity of 8 m s^{-1}. It is accelerated at a rate of 0·8 m s^{-2} for 20s. Find the final velocity of motor bike.

Solution : Given : $u = 8 \text{ m s}^{-1}$, $a = 0{\cdot}8 \text{ m s}^{-2}$, $t = 20$ s

From the relation $v = u + at$

Putting values we get, $v = 8 + 0{\cdot}8 \text{ m s}^{-2} \times 20 \text{ s}$

$$v = 8 + 16 \text{ m s}^{-1}$$

$$= 24 \text{ m s}^{-1}$$

Example 10 : A body is initially moving with a velocity of 0·5 m/s. Its velocity decreases at a rate of 0·05 m/s^2. How much time it will take to stop ?

Solution :

Given $u = 0{\cdot}5$ m/s $\quad v = 0$

$a = -0{\cdot}05$ m/s^2 $\quad t = ?$

$$v = u + at$$

$$0 = 0{\cdot}5 - 0{\cdot}05 \times t$$

$$\Rightarrow 0{\cdot}05\, t = 0{\cdot}5$$

$$t = \frac{0{\cdot}5}{0{\cdot}05} = \frac{5}{0{\cdot}5} = \frac{50}{5} = \mathbf{10 \text{ s}}$$

Example 11 : A body initially at rest travels a distance of 100 m in 5 seconds with constant acceleration. Calculate : (i) the acceleration and (ii) final velocity at the end of 5 seconds.

Solution :

$u = 0$, S = 100 m, $t = 5$ sec.

$a = ?$, $v = ?$

(i) $$S = ut + \frac{1}{2}at^2$$

$$100 = 0 + \frac{1}{2} \times a \times (5)^2$$

$$100 = \frac{25}{2}a$$

$$\therefore \quad a = \frac{100 \times 2}{25} = \mathbf{8 \text{ m/s}^2}$$

(ii) $$v = u + at$$

$$v = 0 + 8\frac{m}{s^2} \times 5 \text{ s}$$

$$v = \mathbf{40 \text{ m/s}}$$

Example 12 : A body moves from rest with uniform acceleration of 5 m/s^2 for 10 seconds. How much distance it covers in 10 seconds.

Solution :

$u = 0$, $a = 5$ m/s^2, $t = 10$ s, S = ?

$$S = ut + \frac{1}{2}at^2$$

$$S = 0 + \frac{1}{\cancel{2}} \times 5\frac{m}{\cancel{s^2}} \times \overset{50}{\cancel{100}}\,\cancel{s^2}$$

$$= \mathbf{250 \text{ m}}$$

Acceleration Due to Gravity

If a body is released from a certain height, its velocity gradually increases *i.e.* the body has an acceleration as it approaches the earth's surface. This acceleration is due to the earth's gravity and so it is called *acceleration due to gravity*. Thus, acceleration due to gravity is defined as the rate of increase in velocity of a freely falling body due to gravity. Its value for the earth's surface is 9·8 m s^{-2}. This means that a body falling from a height will increase its velocity at a rate of 9·8 metre every second.

Due to various factors, the acceleration due to gravity changes for different heavenly bodies. *For example*, acceleration due to gravity on the surface of the moon is only 1·63 m s^{-2} which is about one-sixth of the value at the surface of the earth.

Unit of acceleration due to gravity is same as that of acceleration *i.e.* m/s^2 ($m\ s^{-2}$) in S.I. or M.K.S. system and cm/s^2 ($cm\ s^{-2}$) in C.G.S. system.

Acceleration and acceleration due to gravity can also be expressed in km/hr^2 ($km\ hr^{-2}$). Since, acceleration has magnitude as well as direction, hence it is a **vector quantity.**

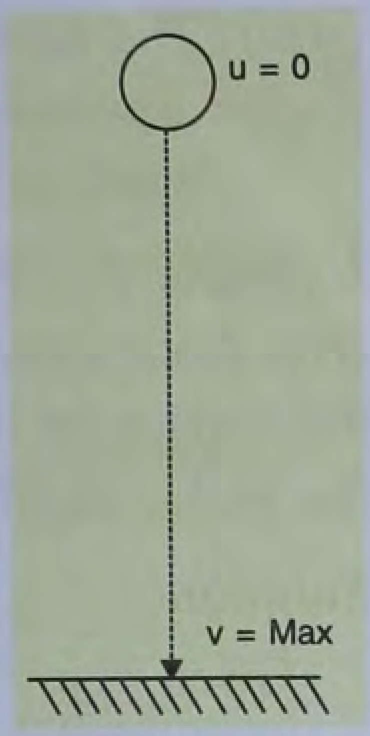


Fig. 2.23

A body moving with a uniform velocity has zero acceleration or no acceleration.

Uniform Acceleration

A body is considered to be moving with uniform acceleration if its rate of change of velocity with time is constant. We write it as

$$\text{acceleration } (a) = \frac{\text{change in velocity}}{\text{time } (t)}$$

i.e. $$a = \frac{v-u}{t}$$

$$\Rightarrow \quad v = u + at$$

where 'v' is the final velocity, 'u' is the initial velocity, 'a' is the acceleration and 't' is the time.

The above equation is for a uniformly accelerated body. Infact, in every equation of motion, the acceleration is uniform.

Further, if the body is moving vertically downward under the action of acceleration due to gravity, then in place of 'a', we use the value 'g' and equations take the following forms.

$$v = u + gt \qquad \text{.............(i)}$$

$$H = ut + \frac{1}{2}gt^2 \qquad \text{............(ii)}$$

$$v^2 = u^2 + 2gH \qquad \text{..........(iii)}$$

In case the body is moving vertically upwards against the acceleration due to gravity, then in place of 'a', we use '$-g$' and so the equations are written as,

$$v = u - gt \qquad \text{.............(iv)}$$

$$H = ut - \frac{1}{2}gt^2 \qquad \text{............(v)}$$

$$v^2 = u^2 - 2gH \qquad \text{..........(vi)}$$

Consider the following examples to understand these equations.

Example 1 : A car, starting from rest, attains a velocity of 50 m s^{-1} in 25 seconds. Find the acceleration of the car.

Solution : Given : $u = 0$, $v = 50\ m\ s^{-1}$,

$t = 25$ sec, $a = ?$

Using $v = u + at$

$$v - u = at$$

or $$a = \frac{v-u}{t}$$

$$= \frac{50\ m\ s^{-1} - 0}{25\ s} = 2\ m\ s^{-2}.$$

Hence, the acceleration of the car is 2 m s^{-2}.

Example 2 : An object starting from rest accelerates at the rate of 20 m s^{-2} in 5 seconds. Calculate the displacement of the body.

Solution : Given : $u = 0$, $a = 20\ m\ s^{-2}$,

$t = 5$ sec, $S = ?$

Using $S = ut + \frac{1}{2}at^2$

$$= 0 \times 5 + \frac{1}{2} \times 20\frac{m}{\cancel{s^2}} \times 25\cancel{s^2}$$

$$= 0 + 10\ m \times 25 = 250\ m$$

Therefore, the displacement is 250 m.

Example 3 : A body, starting from rest, acquires a velocity of 50 m s^{-1} to cover a distance of 25 m. Calculate the acceleration.

Solution : Given : $u = 0, v = 50 \text{ m s}^{-1}$,

$$S = 25 \text{ m}, a = ?$$

$$\text{Using } v^2 = u^2 + 2aS$$

$$\text{or} \quad v^2 - u^2 = 2aS$$

$$\text{or} \quad a = \frac{v^2 - u^2}{2S}$$

$$= \frac{50 \text{ m s}^{-1} \times 50 \text{ m s}^{-1} - 0}{2 \times 25 \text{ m}}$$

$$= \frac{50 \times 50}{50} \text{ m s}^{-2}$$

$$= 50 \text{ m s}^{-2}$$

Therefore, the acceleration of the body is 50 m s^{-2}.

Example 4 : A ball is thrown vertically upwards. It goes to a height 19.6 m and then returns back to the ground. Find :

(i) the initial velocity of the ball

(ii) the total time of journey

(iii) the final velocity of the ball when it strikes the ground.

Solution : $S = 19{\cdot}6$ m, $g = 9{\cdot}8$ m/s^2, $v = 0$

(i)

$$v^2 = u^2 + 2\,gS$$

$$0 = u^2 + 2 \times (-9{\cdot}8) \times 19{\cdot}6$$

$$0 = u^2 - 19{\cdot}6 \times 19{\cdot}6$$

$$u^2 = 19{\cdot}6^2$$

$$u = \pm 19{\cdot}6 \text{ m/s} = 19{\cdot}6 \text{ m/s}$$

(negative value is not considered)

(ii)

$$v = u + gt$$

$$0 = 19{\cdot}6 + (-9{\cdot}8 \times t)$$

$$\frac{-19{\cdot}6}{-9{\cdot}8} = t$$

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

$\therefore$ Total time = Time taken to go upwards + time taken to come downwards $= 2 + 2 = 4$ s

(iii) The final velocity when the body reaches the ground will be same as the velocity with which it starts *i.e.* 19·6 m/s.

Example 5 : A stone is dropped freely in a river from a bridge. It takes 5 seconds to touch the surface of the river. Calculate the height of the bridge from the water level (g = 9·8 m/s^2).

Solution :

Given $u = 0, a = g = 9{\cdot}8$ m/s^2

$$t = 5 \text{ s}, h = ?$$

$$h = ut + \frac{1}{2}gt^2$$

$$h = 0 + \frac{1}{2} \times 9{\cdot}8\frac{m}{s^2} \times (5)^2 \text{ m}$$

$$= \frac{1}{2} \times 9{\cdot}8\frac{m}{s^2} \times 25 \text{ s}^2$$

$$= 4{\cdot}9 \times 25 \text{ m} = \mathbf{122{\cdot}5 \text{ m}}$$

Example 6 : A body is dropped from a tower. It acquires a velocity 20 m/s on reaching the ground. Calculate the height of the tower (g = 10 m/s).

Solution :

Given $u = 0, v = 20$ m/s, $g = 10$ m/s^2

$$h = ?$$

$$v^2 = u^2 + 2gh$$

$$v^2 - u^2 = 2gh$$

$$h = \frac{v^2 - u^2}{2g} = \frac{(20 \text{ m/s})^2 - 0}{2 \times 10 \text{ m/s}^2}$$

$$= \frac{40\cancel{0} \text{ m}^2/\text{s}^2}{2\cancel{0} \text{ m/s}^2} = \mathbf{20 \text{ m}}$$

Intext Questions

1. Define the terms speed and velocity.
2. What do you mean by time period in a simple pendulum.
3. What is frequency ? Give its unit.
4. What are the *two* factors which affect the time period of a simple pendulum.

TEST YOURSELF

A. Choose the most appropriate answer :

1. A book lying on a table is an example of
   (a) a body at rest
   (b) a body in motion
   (c) a body neither at rest nor in motion
   (d) none of these
2. The motion of a pendulum is
   (a) rotatory (b) oscillatory
   (c) curvilinear (d) rectilinear
3. A car moving on a straight road is an example of
   (a) rotatory motion (b) rectilinear motion
   (c) oscillatory motion (d) periodic motion
4. The time taken by the bob of a pendulum to complete one oscillation is called its
   (a) time period (b) frequency
   (c) amplitude (d) oscillation
5. A body moving with a constant velocity will have
   (a) constant retardation
   (b) zero acceleration
   (c) constant acceleration
   (d) variable acceleration
6. Displacement is a
   (a) scalar quantity (b) vector quantity
   (c) normal quantity (d) none of these
7. The quantity which gives us the distance travelled by an object in a certain time is called
   (a) speed (b) velocity
   (c) acceleration (d) none of these
8. If two bodies are moving with the same speed and in the same direction, then they will have
   (a) same acceleration
   (b) different velocities
   (c) same velocities
   (d) none of these
9. The average value of acceleration due to gravity for the earth is
   (a) $8{\cdot}9$ m s^{-2} (b) $9{\cdot}7$ m s^{-2}
   (c) $9{\cdot}0$ m s^{-2} (d) $9{\cdot}8$ m s^{-2}
10. Which of the following is a combination of rectilinear and rotational motion ?
    (a) spin ball in cricket
    (b) a hard kicked football
    (c) heart beat of a healthy man
    (d) curvilinear motion of a car

B. Fill in the blanks :

1. A tree in a park is in a state of ....
2. Motion of the earth around the sun is ....
3. The maximum displacement of the bob from its mean position is called its ....
4. The frequency of a second's pendulum is ....
5. A passenger standing in a stationary bus is likely to fall .... as the bus starts suddenly.
6. The .... of a body is the shortest possible path covered by it.
7. Making one complete round, the displacement is ....
8. The S.I. unit of velocity is ....
9. If a body is dropped from a certain height, its velocity increases due to ....
10. The unit of frequency is ....
11. A body undergoing both translatory and rotatory motions is said to be ....

C. Write true or false. Rewrite the false statement correctly.

1. A motion which repeats itself after a fixed interval of time is called vibratory motion.
2. A ball thrown by a boy from a roof-top has oscillatory motion.
3. If the length of a pendulum decreases, the time period of the simple pendulum increases.
4. The unit of frequency is hertz.
5. Velocity is the displacement per unit time.
6. Displacement is a scalar quantity.
7. The S.I. unit of acceleration is m s^{-2}.
8. A body can change its state of rest at its own.

9. Fruit falls from a tree when its branches are shaken.
10. Negative acceleration is called retardation.

D. Match the following :

1. Velocity	(a) m
2. Displacement	(b) sec.
3. Time	(c) m s^{-2}
4. Acceleration	(d) m s^{-1}

E. Short Answer Questions

1. Distinguish between scalar and vector quantities.
2. Define the terms rest and motion.
3. Name the different kinds of motion.
4. What is oscillatory motion ? Give two examples.
5. What is translatory motion ? Name two kinds of translatory motions.
6. Give an example to show that rest and motion are relative terms.
7. What is a simple pendulum. What kind of motion does it have ?
8. Explain the term time period of a simple pendulum. In what unit is it measured ?
9. What is a second's pendulum ? What is its length ?
10. Define the term displacement. State its S.I. unit.
11. Explain the difference between speed and velocity. Give their S.I. units.

F. Long Answer Questions

1. Define the following :
   (a) Speed (b) Velocity
   (c) Retardation (d) Displacement
2. Define (a) acceleration (b) acceleration due to gravity. Give the numerical value of acceleration due to gravity on earth's surface.
3. What do you understand by the terms (a) uniform velocity (b) variable velocity ? Give one example of each.
4. The length of a second's pendulum is shortened by 30 cm. How this change in length will affect the time period of the pendulum ?
5. Explain what it means when we say one oscillation of a simple pendulum.
6. Draw a diagram of a simple pendulum and show on the diagram, the rest or mean position, one oscillation and amplitude of oscillation.
7. Differentiate between distance and displacement. Give one example each in support of your answer.
8. Explain the meanings of (a) rectilinear motion and (b) curvilinear motion. Give *one* example of each.
9. How does the time period of a pendulum depend on (a) length of pendulum, (b) mass of the bob ?
10. Give two examples of each —
    (a) Rectilinear motion
    (b) Oscillatory motion
    (c) Periodic motion
    (d) Curvilinear motion
    (e) Non-uniform motion

G. Solve the following numericals :

1. What is the speed of a car moving 160 km in 4 hours ? **Ans.** 40 km/hr
2. A train running with a constant speed of 60 km/hr covers 300 km. How much time does it take to do so ? **Ans.** 5 hr
3. A car is running with a speed of 60 km/hr for 3 hours. What distance does it cover ? **Ans.** 180 km
4. A car starting from rest acquires a velocity of 30 m s^{-1} in 15 seconds. Find the acceleration of the car. **Ans.** 2 m s^{-2}
5. A runner starting from rest accelerates at the rate of 0·5 m s^{-2} for 20 seconds. What is the velocity achieved by him ? **Ans.** 10 m s^{-1}
6. A car changes its velocity from 2 m/s to 42 m s^{-1} at the rate of 5 m s^{-2}. How much time is required ? **Ans.** 8 sec.
7. A body starting from rest, picks up a velocity of 80 m s^{-1} to cover a distance of 320 metres. Find the acceleration. **Ans.** 10 m s^{-2}

8. A ball is thrown vertically upwards with an initial velocity of 49 m s^{-1}. Calculate the maximum height attained by the ball if $g = 9{\cdot}8$ m s^{-2}.

[At the maximum height, the velocity of the ball is zero *i.e.*, $v = 0$. Use the equation : $v^2 = u^2 - 2gh$]

Ans. 122·5 m

RECAPITULATION

- A body is said to be at rest if it does not change its position with respect to a fixed point in its surroundings.
- A body is said to be in motion, if it changes its position with respect to a fixed point in its surroundings.
- A body is said to move in translatory motion if each part of the body moves through the same distance in the same interval of time.
- Translatory motion along a straight line is called rectilinear motion and its motion along a curved line is called curvilinear motion.
- A body is said to be in rotatory motion if it moves about a fixed point without changing the radius of its motion.
- A body is said to be in oscillatory motion if it moves to and fro about its mean position.
- A body is said to be in vibratory motion if the body moves to and fro in a particular style.
- One complete to and fro motion constitutes an oscillation of a pendulum.
- The maximum displacement on either side of a mean position is called amplitude.
- When an object moves in two or more types of motions at the same time, it is called multiple motion.
- A motion which repeats itself at regular intervals of time is called periodic motion.
- A physical quantity which has only magnitude and no specific direction is called a scalar quantity.
- A physical quantity which has magnitude as well as direction is called a vector quantity.
- Irrespective of direction, the actual length of the path covered by a moving body is known as the distance covered by the body. It is a scalar quantity.
- Time taken by a pendulum to complete one oscillation is known as its time period.
- The shortest possible distance between the two positions of a moving body is called its displacement. Displacement is a vector quantity.
- Speed is the distance travelled per unit time. It is a scalar quantity.
- The displacement per unit time is known as the velocity of the body. It is a vector quantity.
- Acceleration is the rate of change of velocity. It is a vector quantity.
- Unit of frequency is Hertz.
- Frequency is the number of complete oscillations in one second.
- If a body covers equal distances in equal intervals of time, the motion is uniform.

Let us imagine ourselves to be sitting inside a compartment of a running train. Take a situation when everybody in the compartment is sitting at rest. Then, each passenger is at rest relative to the compartment as well as with respect to the other passengers. But, if we consider any point outside the compartment, say, platform, as a reference point, then the compartment, as well as all the passengers in it are in motion. So, we can say that rest and motion are relative.