212en09

9

MOTION AND ITS DESCRIPTION

You must have seen number of things in motion. For example car, bicycle, bus moving on a road, train moving on rails, aeroplane flying in the sky, blades of an electric fan and a child on a swing. What makes things move? Are all the motions similar?

You might have seen that some move along straight line, some along curved path and some to and fro from a fixed position. How and why these motions are different? You will find answers to all such questions in this lesson. Besides studying about various types of motions, you will learn how to describe a motion. For this we will try to understand the concepts of distance, displacement, velocity and acceleration. We will also learn how these concepts are related with each other as well as with time. How a body moving with constant speed can acquire acceleration will also be discussed in this lesson.

OBJECTIVES

After completing this lesson you will be able to:

- *explain the concept of motion and distinguish between rest and motion;*
- *describe various types of motion – rectilinear, circular, rotational and oscillatory;*
- *define distance, displacement, speed, average speed, velocity and acceleration;*
- *describe uniform and uniformly accelerated motion in one dimension;*
- *draw and interpret the distance time graphs and velocity time graphs;*
- *establish relationship among displacement, speed, average speed, velocity and acceleration;*
- *apply these equations to make daily life situation convenient and*
- *explain the circular motion.*

9.1 MOTION AND REST

If you observe a moving bus you will notice that the position of bus is changing with time. What does this mean? This means that the bus is in motion. Now suppose you are sitting in a bus moving parallel to another bus moving in the same direction with same speed. You will observe that the position of the other bus with respect to your bus is not changing with time. In this case the other bus seems to be at rest with respect to your bus. However, both the buses are moving with respect to surroundings. Thus, an object in motion can be at rest with respect to one observer whereas for another observer, the same object may be in motion. Thus we can say that the motion is relative.

Let us understand the concept of relative motion. Suppose you are sitting in a vehicle waiting for traffic signal and the vehicle beside you just starts moving, you will feel that your vehicle is moving backward.

Suppose Chintu and Golu are going to the market. Golu is running and Chintu is walking behind him. The distance between the two will go on increasing, though both are moving in the same direction. To Golu it will appear that Chintu is moving away from him. To Chintu also, it will appear that Golu is moving ahead and away from him. This is also an example of relative motion. See Fig. 9.1.

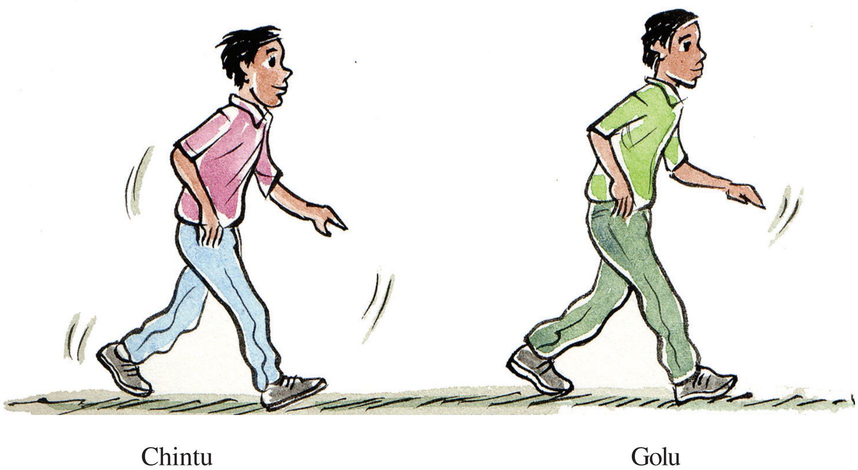


Fig. 9.1 *An example of relative motion*

Think and Do

One day, Nimish while standing on the bank of a river in the evening observed boats were approaching the bank, vehicles passing on the bridge, cattle going away from the bank of the river towards the village, moon rising in the sky, birds flying and going back to their nests, etc. Can you list some thoughts that could be emerging in the mind of the Nimish. What type of world Nimish has around him?

We can conclude that motion is a continuous change in the position of the object with respect to the observer. Suppose you are moving towards your friend standing in a field. In what way are you in motion? Are you in motion if you are observing yourself? Is your friend in motion with respect to you? Are you in motion with respect to your friend? Now you may have understood that observer with respect to itself can not be in motion. Thus, you are moving towards the object with respect to your friend and your friend is moving towards you with respect to you in opposite direction. In other words the change in position of the object with respect to observer decides whether object is in motion. This change should also be continuous. Let us take an interesting example to understand the concept of motion. There are five players participating in 200 metre race event. They are running in their lanes as shown in the Fig. 9.2. The players A, B, C, D and E runs 2, 3, 4, 3, 2 metre respectively in one second. Can you help the player to understand that which player is in motion with respect to which player and which player is at rest with respect to which player? Fill your responses in the table given below.

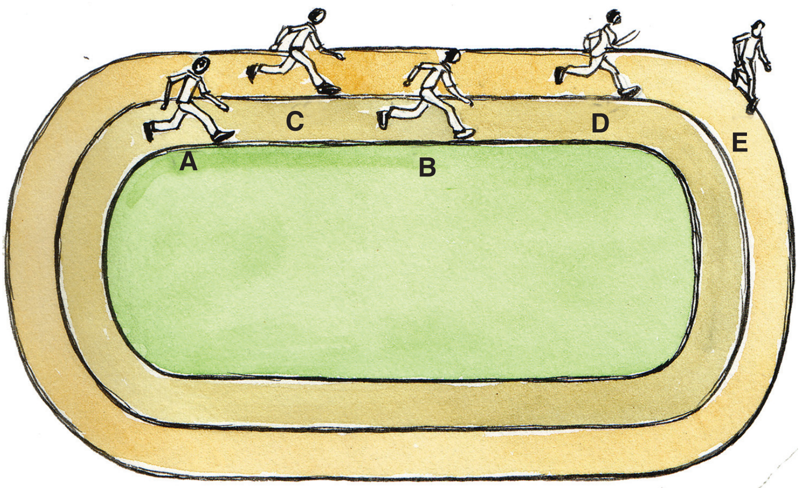


Fig. 9.2

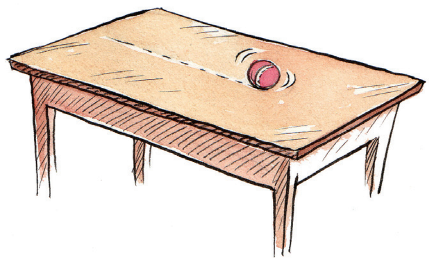
Table 9.1

Observer player	Player in motion	Player at rest	Remark
A	B, C, D	E	E is in rest with respect to A because change in position of A and E in 1second is zero while in other cases is not.
B			
C			
D			

Now you will be able to help Nimish to answer some of his questions.

9.1.1 Types of Motion

In our daily life we see many objects moving. Some objects moving in straight line and some are not. For example, a ball rolls on a horizontal surface, a stone falling from a building, and a runner on 100 m race track. In all these examples, you may notice that the position of moving objects is changing with respect to time along a straight line. This type of motion is called motion in a straight line or **rectilinear motion**.



(a) Ball rolling on horizontal surface

(b) Stone falling by hand

(c) A runner on a 100 m race track

Fig. 9.3 *Example of rectilinear motion*

Can you think at least two more other example of such motions. You might have observed the motion of time hands of a clock, motion of child sitting on a merry-go-round, motion of the blades of an electric fan. In such a motion, an object follows a circular path during motion. This type of motion is called **circular motion**.

ACTIVITY 9.1

(A) Suspend a small stone with a string (of length less than your height) with the help of your hand. Displace the stone aside from the position of rest and release.

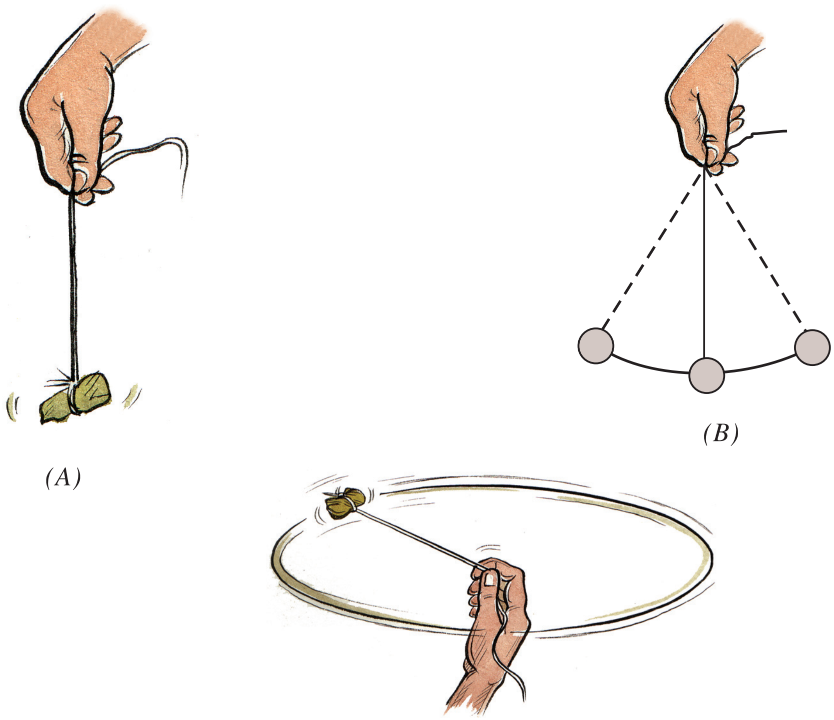
(B) Let the stone comes to rest and bring it to the point of suspension with the help of your hand and release it.

(C) Now hold the stone firmly in your hand and whirl it over your head.

Write in table given below, what type of motion of stone you have observed in all the above three cases with justification.

Table 9.2

Case	Type of motion	Justification
A		
B		
C		



(A)

(B)

(C)

(A) A person suspend the stone attached to a string, (B) A person oscillate the stone attached to a string, (C) A person whirling the stone attached to a string

Fig. 9.4 (A), (B) (C)

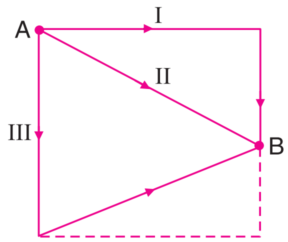
Have you ever noticed that the motion of the branches of a tree? They move to and fro from their central positions (position of rest). Such type of motion is called **oscillatory motion**. In such a motion, an object oscillates about a point often called position of rest or equilibrium position. The motion of swing and pendulum of wall clock are also oscillating motions. Can you think about the motion of the needle of a sewing machine? What type of motion is it? Now you can distinguish some of the motions viewed by Nimish.

9.2 DISTANCE AND DISPLACEMENT

For a moving object two points are significant. One is the point of start or origin where from the object starts its motion and the other is the point where it reaches after certain interval of time. Points of start and destination are connected by a path taken by the object during its motion. The length of the path followed by object is called distance. There may be a number of paths between the point of start and the point of destination. Hence the object may cover different distances between same point of start and destination. The unit of distance is metre (m) or kilometre (km).

ACTIVITY 9.2

An object moves from point A to B along three different paths. Measure the distance travelled by object along these three paths.



Take a scale 1 cm = 10 m

Fig. 9.5

In any motion, you will notice that object gets displaced while it changes its position continuously. **The change in position of the object is called displacement.** Basically, it is the shortest distance between initial and final position of the object. The path followed by the object between initial and final positions may or may not be straight line. Hence, the length of the path does not always represent the displacement.

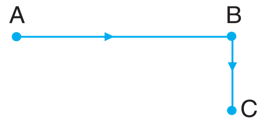
ACTIVITY 9.3

In the following cases measure the distance and displacement and write their values in the table given below:

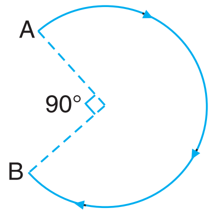
(a) A body moves from A to B

(b) A body moves from A to B then comes to C

(c) A body goes from position A to B and comes back to position A



(d) A body goes from posion A to B and then C



(e) A body moves from position A to B along a circular arc

Fig. 9.6

Table 9.3

Case	Distance	Displacement
(i)		
(ii)		
(iii)		
(iv)		
(v)		

Now you can conclude that:

(a) displacement is smaller or equal to the distance.

(b) displacement is equal to distance, if body moves along a straight line path and does not change its direction.

(c) if a body does not move along a straight line path its displacement is less than the distance.

(d) displacement can be zero but distance can not be zero.

(e) magnitude of displacement is the minimum distance between final position and initial position.

(f) distance is the length of the path followed by the body.

(g) distance is path dependent while displacement is position dependent.

Can you now, suggest a situation in which the distance is twice the displacement?

9.2.1 Graphical Representation of Distance and Displacement

Distance and displacement can also be shown by graphical representation. To draw a graph, follow the following steps:

(i) Analyse the range of variables (maximum and minimum values).

(ii) Select the suitable scale to represent the data on the graph line adequately.

(iii) Take independent quantity on x-axis and dependent quantity on y-axis.

Take distance on x-axis and displacement on y-axis. You know that for a motion along a straight line without changing its direction the distance is always equal to the displacement. If you draw the graph, you will find that the graph line is a straight line passing through origin making an angle of 45° with distance axis as shown in Fig 9.7.

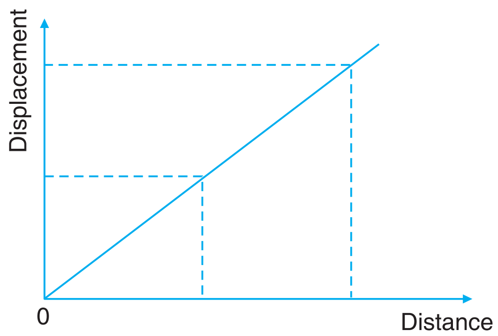


Fig. 9.7

Let us take another situation where an object moving from one position to another and coming back to the same position. In this case the graph line will be a straight line making an angle of 45° with distance axis upto its maximum value and then comes to zero as shown in Fig. 9.8.

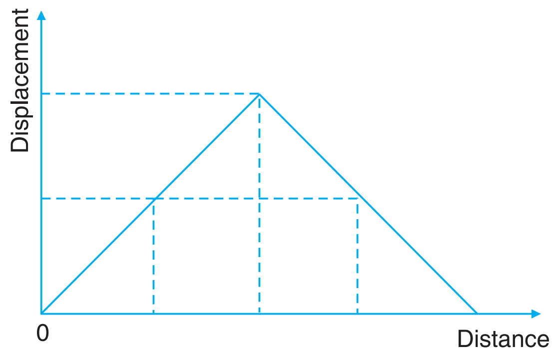


Fig. 9.8

Now you can infer that:

- If graph line is a straight line making an angle of 45° with x-axis or y-axis, the motion is straight line motion and distance is equal to the displacement.
- For same value of displacement, the distance travelled can be different.
- If graph line does not make an angle of 45° with x-axis or y-axis, the motion will not be straight line motion.

When an object moves along a circular path, the maximum displacement is equal to the diameter of the circular path and the distance travelled by object keeps on increasing with time as shown in Fig. 9.9.

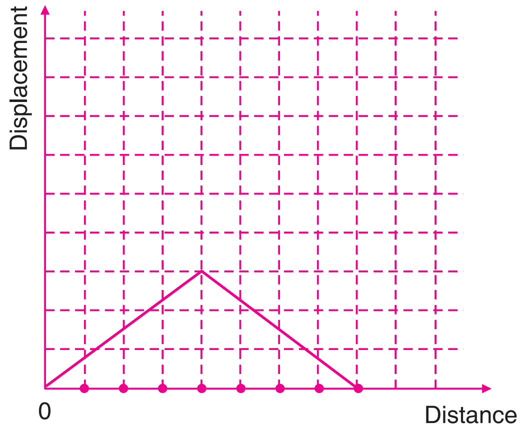


Fig. 9.9

INTEXT QUESTIONS 9.1

Choose the correct answer in the followings:

1. For an object moving along a straight line without changing its direction the
   - (a) distance travelled > displacement
   - (b) distance travelled < displacement
   - (c) distance travelled = displacement
   - (d) distance is not zero but displacement is zero
2. In a circular motion the distance travelled is
   - (a) always > displacement
   - (b) always < displacements
   - (c) always = displacement
   - (d) zero when displacement is zero

3. Two persons start from position *A* and reach to position *B* by two different paths *ACB* and *AB* respectively as shown in Fig. 9.10.

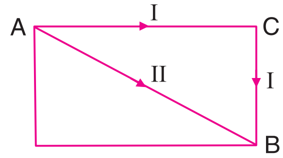


Fig. 9.10

   (a) Their distances travelled are same
   (b) Their displacement are same
   (c) The displacement of *I* > the displacement of II
   (d) The distance travelled by *I* < distance travelled by II

4. In respect of the top point of the bicycle wheel of radius *R* moving along a straight road, which of the following holds good during half of the wheel rotation.
   (a) distance = displacement
   (b) distance < displacement
   (c) displacement = 2*R*
   (d) displacement = πR

5. An object thrown vertically upward to the height of 20 m comes to the hands of the thrower in 10 second. The displacement of the object is
   (a) 20 m (b) 40 m (c) Zero (d) 60 m

6. Draw a distance-displacement graph for an object in uniform circular motion on a track of radius 14 m.

9.3 UNIFORM AND NON-UNIFORM MOTION

Let us analyze the data of the motion of two objects A and B given in the table 9.4.

Table 9.4

Time in seconds (t)	0	10	20	30	40	50
Position of A (x_1 in metre)	0	4	8	12	16	20
Position of object B (x_2 in metre)	0	4	12	12	12	20

Do you find any difference between the motion of object *A* and *B*? Obviously objects *A* and *B* start moving at the same time from rest and both objects travel equal distance in equal time. However, the object *A* has same rate of change in its position and object *B* has different rate of change in position. The motion in which an object covers equal distance in equal interval of time is called uniform motion whereas the motion in which distance covered by object is not equal in equal interval of time is called non-uniform motion. Thus, the motion of object *A* is uniform and of object *B* is non-uniform. You can draw the position-time graph for the motion of object *A* and *B* and observe the nature of the graph for both types of motion.

For the uniform motion of object *A* the graph is a straight line graph and for non-uniform motion of object *B* the graph is not a straight line as shown in the Fig. 9.11.

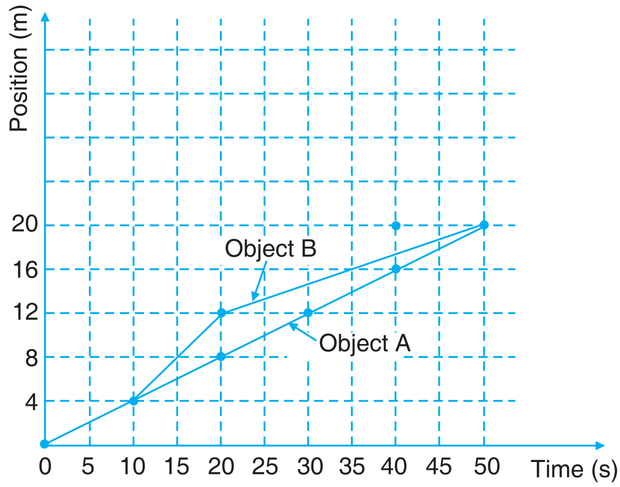


Fig. 9.11 *Graph representing uniform and non-uniform motion*

9.3.1 Speed

While you plan your journey to visit a place of your interest you intend to think about time of journey so that you can arrange needful things like eatables etc. for that period of time. How will you do it? For this you would like to know how far you have to reach and how fast you can cover the destination. The measure of how fast motion can take place is the speed. **Speed can be defined as the distance travelled by a body in unit time.**

Thus $$\text{speed} = \frac{\text{Distance travelled}}{\text{time taken}}$$

Its SI unit is metre per second which is written as ms^{-1}. The other commonly used unit is km h^{-1}.

i.e., $$1\ \text{kmh}^{-1} = \frac{1000\ \text{m}}{60 \times 60\ \text{s}} = \frac{5}{18}\text{ms}^{-1}$$

ACTIVITY 9.4

Here position of four bodies *A*, *B*, *C* and *D* are given after equal interval of time i.e. 2 s. Identify the nature of the motion of the bodies as uniform and non-uniform motion.

Table 9.5

Time (s) →	Bodies ↓	0	2	4	6	8
positions (m) →	A	0	4	8	12	16
	B	0	8	8	10	12
	C	4	8	12	16	20
	D	0	6	12	16	20

To identify the nature of the motion you can make a table as given below

Table 9.6

Time taken by body (s) → Distance covered by body (m) ↓	2 – 0 = 2	4 – 2 = 2	6 – 4 = 2	8 – 6 = 2
A	4 – 0 = 4	8 – 4 = 4	12 – 8 = 4	16 – 12 = 4
B	8 – 0 = 8	8 – 8 = 0	10 – 8 = 2	12 – 10 = 2
C	8 – 4 = 4	12 – 8 = 4	16 – 12 = 4	20 – 16 = 4
D	8 – 4 = 4	12 – 6 = 6	16 – 12 = 4	20 – 16 = 4

From the above table you can conclude that body *A* and *C* travel equal distances in equal interval of time so their motion is uniform. But the distances travelled by body *B* and *D* for equal intervals of time are not equal, hence their motion is non-uniform motion.

To analyze the motion as uniform motion or non-uniform motion, the motion can be represented by graph. The position-time graph of all the four bodies *A*, *B*, *C* and *D* is shown in Fig. 9.12.

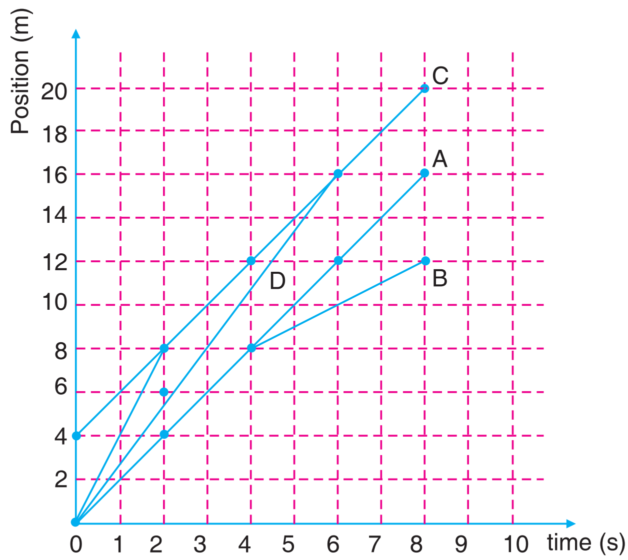


Fig. 9.12

Now you can see that the bodies having uniform motion e.g. *A* and *C* have their graph line straight and the bodies having non-uniform motion do not have their position time graph line straight. In this graphical representation on axis 1 div = 1s and on y-axis 1 div = 2m.

A graph drawn for different distances travelled by object with respect to time is called distance-time graph as shown in Fig. 9.13.

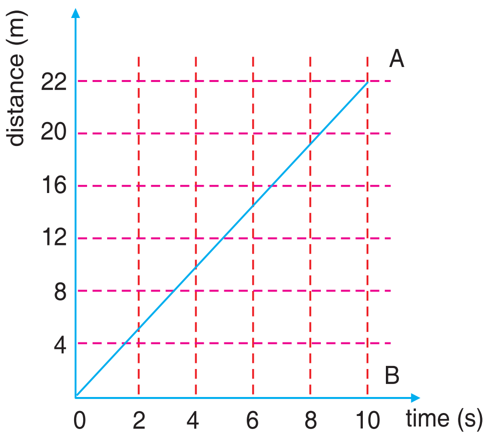


Fig. 9.13

In Fig. 9.13 distance travelled in 10 s is 22 m. Therefore, the speed of the object

$$= \frac{22(\text{m})}{10\ (\text{s})} = 2.2\ \text{ms}^{-1}$$

This motion can be represented by another way i.e., speed = $\frac{AB}{OB}$. This ratio is also known as slope of the graph line. Thus the speed is the slope of position-time graph.

Example 9.1 An object moves along a rectangular path of sides 20 m and 40 m respectively. It takes 30 minutes to complete two rounds. What is the speed of the object?

Solution: $$\frac{\text{Distance travelled}}{\text{time taken}} = \frac{2\times 2(20+40)\ \text{m}}{30\times 60\ \text{s}}$$

$$= \frac{4}{30}\text{ms}^{-1}$$

9.3.2 Velocity

If you are asked to reach a destination and you are provided three, four paths of different lengths, which of the path would you prefer? Obviously, the path of shortest length but not always. This is also called displacement. In the previous section you have learnt about distance. When motion is along the shortest path, it is directed from the point of start to the point of finish. How fast this motion is determines the velocity. The velocity is the ratio of length of the shortest path i.e. displacement to the time taken

$$\text{velocity} = \frac{\text{Displacement}}{\text{Time taken}}$$

Velocity has same unit as the unit of speed i.e., ms^{-1} (S.I. unit) or kmh^{-1}.

The shortest path or the displacement is directed from initial position of the object to the final position of the object. Hence, the velocity is also directed from initial position of the object to the final position of the object. Thus we can say that the velocity has direction. Speed does not have direction because it depends upon the total distance travelled by the object irrespective of the direction. The quantities which have direction are called vector and which do not have direction are called scalar quantity. Thus, velocity can also be expressed as

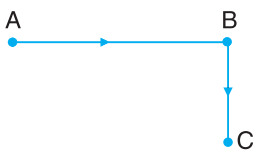
$$\text{velocity} = \frac{\text{Change in position}}{\text{Time taken}}$$

ACTIVITY 9.5

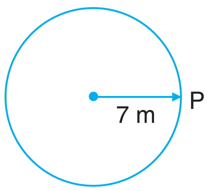
Observe the motion of an object in the following situations. Find speed and velocity in each situation and comment over the situation which you find different from other.

Object moves from A to B in time 10 s on the scale 1 cm = 10 m

Object moves from A to B than to C in 10 s on the scale 1 cm = 10 m



Object moves from A to B than to C in 20 s on the scale 1 cm = 10 m



Object completes a round of radius 7 m in 10 s

Fig. 9.14

Now you will be able to distinguish the speed and velocity. Magnitude of instantaneous velocity is the speed. Now you can understand the importance of preplanning your journey to save time, effort and fuel etc.

Example 9.2 In a rectangular field of sides 60 m and 80 m respectively two formers start moving from the same point and takes same time i.e. 30 minutes to reach diagonally opposite point along two different paths as shown in Fig. 9.15. Find the velocity and speed of both the formers.

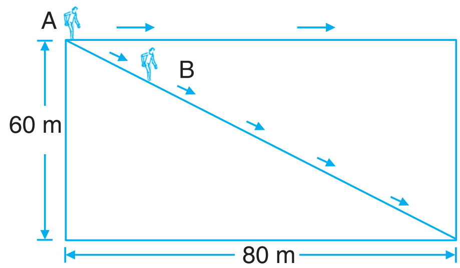


Fig. 9.15

Solution: The displacement of both the former in same i.e.,

$$\sqrt{60^2+80^2} = \sqrt{3600+6400} = \sqrt{10000} = 100 \text{ m}$$

$$\therefore \quad \text{Velocity } A \text{ and } B, \quad v = \frac{\text{displacement}}{\text{time taken}} = \frac{100 \text{ m}}{30 \times 60\text{s}} = \frac{1}{18} \text{ ms}^{-1}$$

$$\text{speed of } A = \frac{\text{Distance travelled}}{\text{time taken}} = \frac{(80+60)\text{m}}{30{\times}60\text{s}}$$

$$= \frac{140}{3800} \text{ ms}{-1} = \frac{14}{18} \text{ ms}^{-1}$$

$$\text{and} \quad \text{speed of } B = \frac{\text{Distance travelled}}{\text{time taken}} = \frac{100\text{s}}{30{\times}60\text{s}} = \frac{1}{18} \text{ ms}^{-1}$$

Note: In this example you can appreciate that the velocity of both the formers is same but not the speed.

9.3.3 Average speed and average velocity

Speed during a certain interval of time can not be used to determine total distance covered in given time of the journey and also the time taken to cover the total distance of journey. It is because a body does not always travel equal distance in equal interval of time. In most of the cases the body travels non-uniformly. Thus, in case of non-uniform motion to determine average speed is quite useful. The average speed can be determined by the ratio of total distance covered to the total time taken.

$$\text{Average speed} = \frac{\text{total distance covered}}{\text{total time taken}}$$

Similarly in case of average velocity in place of total distance covered you can take total displacement.

$$\therefore \qquad \text{Average speed} = \frac{\text{total displacement}}{\text{total time taken}}$$

Let us take few examples to understand the average speed and average velocity.

Example 9.3 If a body covers 50 m distance in 30 s and next 100 m in 45 s then total distance covered

$$= 50 + 100 = 150 \text{ m}$$

and $\qquad \text{total time taken} = 30 + 45 = 75 \text{ s}$

$$\therefore \qquad \text{Average speed} = \frac{150 \text{ m}}{75 \text{ s}} = 2\text{ms}^{-1}$$

Example 9.4 If an object moves with the speed of 10 ms^{-1} for 10 s and with 8 ms^{-1} for 20 s, then total distance covered will be the sum of distance covered in 10 s and the distance covered in 20 s = 10 × 10 + 8 × 20 = 260 m

$$\therefore \qquad \text{The average speed} = \frac{\text{total distance covered}}{\text{total time taken}}$$

$$= \frac{260 \text{ m}}{(10+20)\text{s}} = \frac{260 \text{ m}}{30 \text{ s}}$$

$$= 8.66 \text{ ms}^{-1}$$

Example 9.5 If a body moves 50 m with the speed of 5 ms^{-1} and then 60 m with speed of 6 ms^{-1}, then total distance covered

$$= 50 + 60 = 110 \text{ m}$$

and total time taken will be the sum of time taken for 50 m and 60 m = 20 s

Thus, $\qquad \text{average speed} = \frac{\text{total distance covered}}{\text{total time taken}}$

$$= \frac{110 \text{ m}}{20 \text{ s}} = 5.5 \text{ ms}^{-1}$$

Example 9.6 If an object moves 30 m toward north in 10 s and then 40 m eastward in next 10s, The displacement of the object will be OB

$$= \sqrt{30^2 + 40^2} = \sqrt{900+1600} = \sqrt{2500}$$

$$= 50 \text{ m}$$

$$\therefore \quad \text{The average velocity} = \frac{\text{total displacement covered}}{\text{total time taken}}$$

$$= \frac{50 \text{ m}}{(10+10)\text{ s}} = \frac{50 \text{ m}}{20 \text{ s}} = 2.5 \text{ ms}^{-1}$$

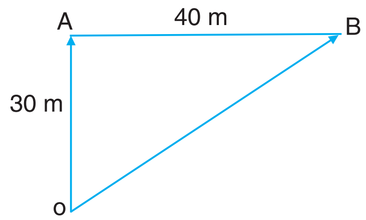


Fig 9.16

Example 9.7 If an object moves along a circular track of radius 14 m and complete one round in 20 s then for one complete round total displacement is zero and the average velocity will also be zero.

From these examples you can conclude that:

(i) Instantaneous speed is the magnitude of instantaneous velocity but average speed is not the magnitude of average velocity.

(ii) Average velocity is less than or equal to the average speed.

(iii) Average velocity can be zero but not average speed.

INTEXT QUESTIONS 9.2

1. Some of the quantities are given in column I. Their corresponding values are written in column II but not in same order. You have to match these values corresponding to the values given in column I:

Column I	Column II
(a) 1 kmh^{-1}	(i) 20 ms^{-1}
(b) 18 kmh^{-1}	(ii) 10 ms^{-1}
(c) 72 kmh^{-1}	(iii) 5/18 ms^{-1}
(d) 36 kmh^{-1}	(iv) 5 ms^{-1}

2. A cyclist moves along the path shown in the diagram and takes 20 minutes from point A to point B. Find the distance, displacement and speed of the cyclist.

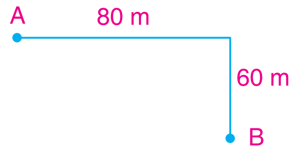


Fig. 9.17

3. Identify the situation for which speed and average speed of the objects are equal.
   (i) Freely falling ball
   (ii) Second or minute needle of a clock
   (iii) Motion of a ball on inclined plane
   (iv) Train going from Delhi to Mumbai
   (v) When object moves with uniform speed

4. The distance-time graph of the motion of an object is given. Find the average speed and maximum speed of the object during the motion.

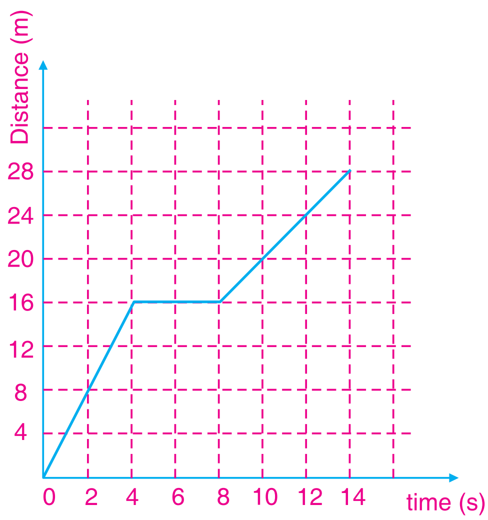


Fig. 9.18

5. The distance travelled by an object at different times is given in the table below. Draw a distance-time graph and calculate the average speed of the object. State whether the motion of the object is uniform or non-uniform.

Table 9.7

Time (s) →	0	10	20	30	40	50
Distance (m) →	0	2	4	6	8	10

6. A player completes his half of the race in 60 minutes and next half of the race in 40 minutes. If he covers a total distance of 1200 m, find his average speed.
7. A train has to cover a distance of 1200 km in 16 h. The first 800 km are covered by the train in 10 h. What should be the speed of the train to cover the rest of the distance? Also find the average speed of the train.
8. A bird flies from a tree *A* to the tree *B* with the speed of 40 km h^{-1} and returns to tree *A* from tree *B* with the speed of 60 km h^{-1}. What is the average speed of the bird during this journey?
9. Three players *P*, *Q* and *R* reach from point *A* to *B* in same time by following three paths shown in the Fig. 9.19. Which of the player has more speed, which has covered more distance?

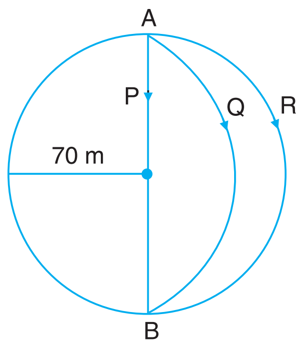


Fig. 9.19

9.4. GRAPHICAL REPRESENTATION OF MOTION

It shows the change in one quantity corresponding to another quantity in the graphical representation.

9.4.1 Position-time Graph

It is easy to analyze and understand motion of an object if it is represented graphically. To draw graph of the motion of an object, its position at different times are shown on y-axis and time on x-axis. For example, positions of an object at different times are given in Table 9.8.

Table 9.8 Position of different objects at different time

Time (s)	0	1	2	3	4	5	6	7	8	9	10
Position (m)	0	10	20	30	40	50	60	70	80	90	100

In order to plot position-time graph for data given in Table 9.8, we represent time on horizontal axis and position on vertical axis drawn on a graph paper. Next, we choose a suitable scale for this.

For example, in Fig. 9.20 one division on horizontal axis represents 1 s of time interval and one division on vertical axis represents in 10 m, respectively. If we join different points representing corresponding position time data, we get straight line as shown in Fig. 9.20. This line represents the position-time graph of the motion corresponding to data given in Table 9.8.

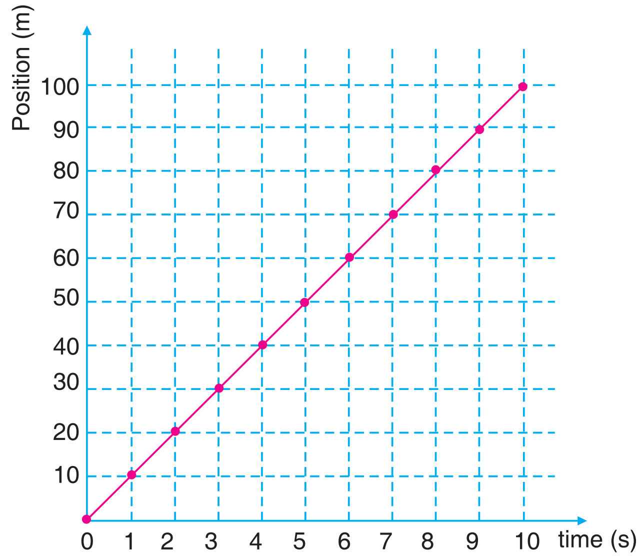


Fig. 9.20 *Position-time graph for the motion of a particle on the basis of data given in table*

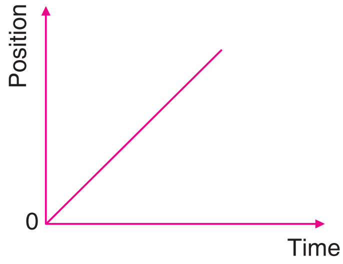
We note from the data that displacement of the object in 1^{st} second, 2^{nd} second,....., 10^{th} second is the same i.e., 10 m. In 10 second, the displacement is 100 m. Therefore, velocity is $\frac{100\text{ m}}{10\text{ s}} = 10\text{ ms}^{-1}$ for the whole course of motion. Velocity during 1^{st} second = 10 ms^{-1} and so on.

Thus, velocity is constant i.e., equal to 10 ms^{-1} throughout the motion. The motion of an object in which velocity is constant, is called **uniform motion.**

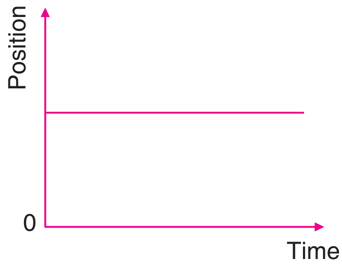
As you see Fig. 9.20, for uniform motion position-time graph is a straight line.

Like position-time graph, you can also plot displacement-time graph. Displacement is represented on the vertical axis and time interval on the horizontal axis. Since displacement in each second is 10 m for data in table, the same graph (Fig. 9.20) also represents the displacement-time graph if vertical axis is labeled as displacement.

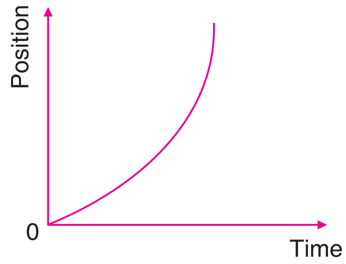
For good understanding you can observe the following graphs.



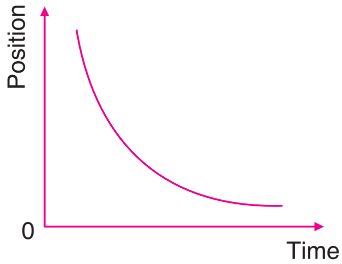
(A) Uniform motion



(B) Object is at rest



(C) Non-uniform motion, rate of change in position is increasing



(D) Non-uniform motion, rate of change in position is decreasing

Fig. 9.21 *Graph (A), (B), (C), (D)*

9.4.2 Velocity-Time Graph

Take time on the horizontal axis and velocity on the vertical axis on a graph paper. Let one division on horizontal axis represent 1 s and one division on vertical axis represent 10 ms^{-1}. Plotting the data in Table 9.9 gives us the graph as shown in Fig. 9.22.

Table 9.9 Velocity-time data of objects *A* and *B*

Time (s)	0	1	2	3	4	5	6	7	8
Velocity of *A* (ms^{-1})	0	10	20	30	40	50	60	70	80
Velocity of *B* (ms^{-1})	0	10	10	10	10	10	10	10	10

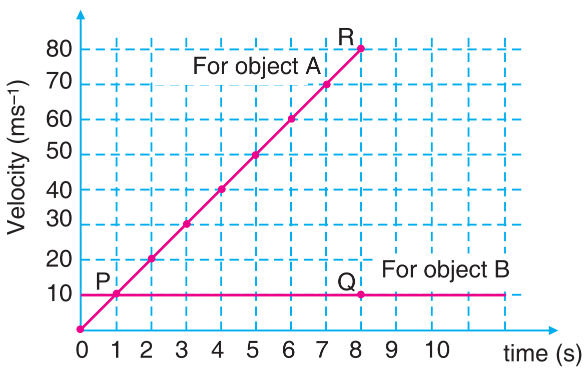


Fig. 9.22 *Velocity-time graph for the motion of object A and B on the basis of data given in table*

Lines *OR* and *PQ* represent the motion of object *A* and *B* respectively. Thus, we see that the velocity-time graph of motion represented in Table 9.9 is a straight line and parallel to time axis for object *B*. This is so because the velocity is constant throughout the motion. The motion is uniform. Consider the area under the graph in Fig. 9.22 for object *B*.

Area = (8s) × (10 ms^{-1}) = 80 m. This is equal to the displacement of the object B in 8 s.

Area under velocity-time graph = Displacement of the object during that time interval

Similarly for object *A* area under the graph in Fig. 9.22.

$$= \frac{1}{2}(8\ s)\times(80-0)\ ms^{-1}$$

$$= \frac{1}{2}(8)\times(80)\ m\ = 320\ m$$

This is equal to the displacement of object *A* in 8 s.

Though, we obtained this result for object *B* for a simple case of uniform motion, it is general result.

Let x be displacement of an object in time t, moving with uniform velocity v, then

$$x = vt \text{ (for uniform motion)}$$

You may have seen the motion of objects moving differently. Can you think what make this difference? Observe the motion of a ball on a floor. The ball slows down and finally comes to rest. This means that the velocity during different time intervals of motion is different. In other words velocity is not constant. Such a motion is called accelerated motion.

9.5 ACCELERATION

In the previous section we have learnt about the non-uniform motion in which the change in velocity in different intervals of motion is different. This change in velocity with time is called **acceleration.** Thus, the acceleration of an object is defined as the change in velocity divided by the time interval during which this occurs.

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

Its unit is ms^{-2}. It is specified by direction. Its direction is along the direction of change in velocity. Suppose the velocity of an object changes from 10 ms^{-1} to 30 ms^{-1} in a time interval of 2 s.

Fig. 9.23 *Changing velocity*

The acceleration, $a = \dfrac{30\ \text{ms}^{-1} - 10\ \text{ms}^{-1}}{2.0\text{s}} = 10\ \text{ms}^{-2}$

This means that the object accelerates in +x direction and its velocity increases at a rate of 10 ms^{-1} in every second.

If the acceleration of an object during its motion is constant, we say that object is moving with **uniform acceleration**. The velocity-time graph of such a motion is straight line inclined to the time axis as shown in Fig. 9.24.

For a given time interval, if the final velocity is more than the initial velocity, then according to Fig. 9.24, the acceleration will be positive. However, if the final velocity is less than the initial velocity, the acceleration will be negative.

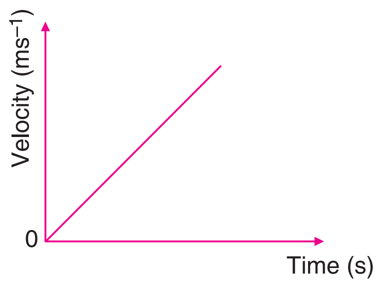


Fig. 9.24 *velocity-time graph of an object moving with uniform acceleration*

When velocity of the object is constant, acceleration will be zero. Thus, for uniform motion, the acceleration is zero and for **non-uniform** motion, the acceleration is non-zero.

Example 9.8 Find the distance and displacement from the given velocity-time graph in Fig. 9.25.

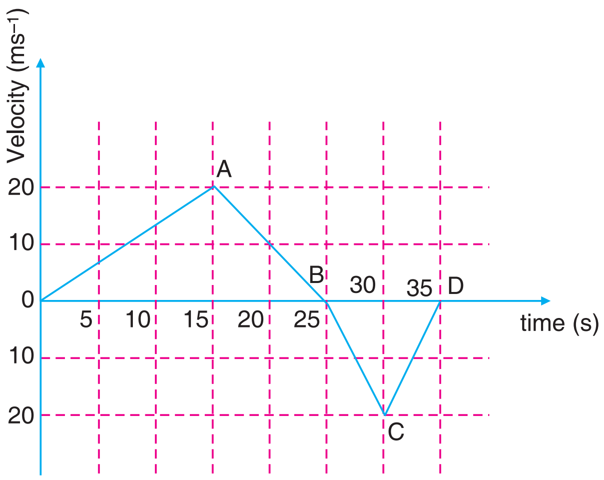


Fig. 9.25

Solution:

$$\text{Distance travelled} = \text{Area of } \Delta OAB + \text{Area of } \Delta BCD$$

$$= \frac{1}{2}(25) \times (20) + \frac{1}{2}(10) \times (20)$$

$$= 250 + 100 = 350 \text{ m}$$

$$\text{Displacement} = \text{Area of } \Delta OAB - \text{Area of } \Delta BCD$$

$$= \frac{1}{2}(25) \times (20) - \frac{1}{2}(10) \times (20)$$

$$= 250 - 100 = 150 \text{ m}$$

Example 9.9 From the given velocity-time graph obtain the acceleration-time graph.

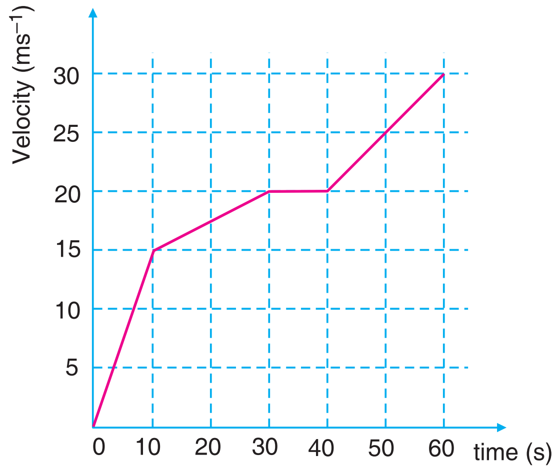


Fig. 9.26

Solution: From the given graph acceleration for 0 – 10 s time interval

$$= \frac{15-0}{10-0} = 1.5 \text{ ms}^{-2}$$

acceleration for 10 – 20s time interval in same as for 20 – 30s time interval

$$= \frac{20-15}{30-10} = \frac{5}{20} = 0.25 \text{ ms}^{-2}$$

acceleration for 30 – 40s time interval $= \dfrac{20-20}{40-30} = 0$

acceleration for 40 – 50 and 50 – 60s interval $= \dfrac{30-20}{60-40} = \dfrac{10}{20} = 0.5 \text{ ms}^{-2}$

For all the above time intervals the acceleration-time graph can be drawn as shown in Fig. 9.27.

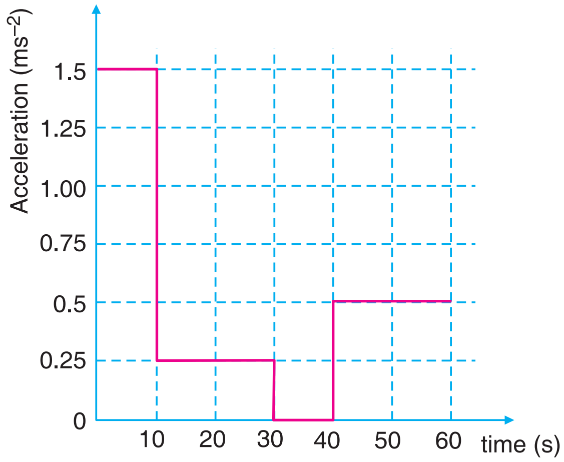


Fig. 9.27

INTEXT QUESTIONS 9.3

1. Describe the motion of an object shown in Fig. 9.28.

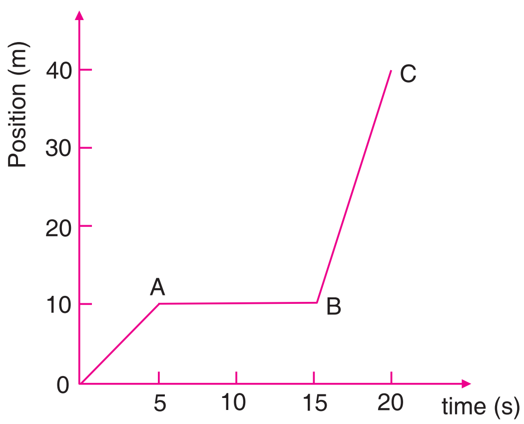


Fig. 9.28 *Position-time graph of an object*

2. Compare the velocity of two objects where motion is shown in Fig. 9.29.

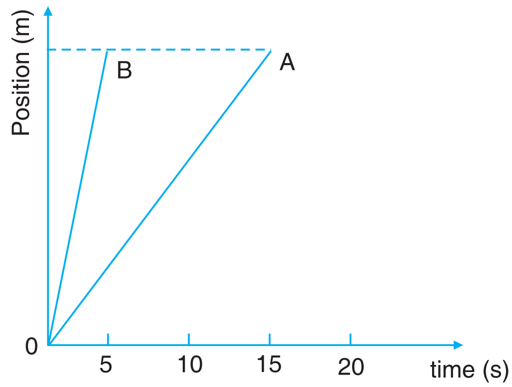


Fig. 9.29 *Position-time graph for object A and B.*

3. Draw the graph for the motion of object *A* and *B* on the basis of data given in Table 9.10.

Table 9.10

Time (s)	0	10	20	30	40	50
Position (m) for *A*	0	5	5	5	5	5
Position (m) for *B*	0	2	4	6	8	10

4. A car accelerates from rest uniformly and attains a maximum velocity of 2 ms^{-1} in 5 seconds. In next 10 seconds it slows down uniformly and comes to rest at the end of 10^{th} second. Draw a velocity-time graph for the motion. Calculate from the graph (i) acceleration, (ii) retardation, and (iii) distance travelled.

5. A body moving with a constant speed of 10 ms^{-1} suddenly reverses its direction of motion at the 5^{th} second and comes to rest in next 5 second. Draw a position-time graph of the motion to represent this situation.

9.6 EQUATIONS OF MOTION

Consider an object moving with uniform acceleration, *a*. Let *u* be the initial velocity (at time $t = 0$), *v*, velocity after time *t* and *S*, displacement during this time interval. There are certain relationships between these quantities. Let us find out.

We know that

$$\text{Acceleration} = \frac{\text{Chnage in velocity}}{\text{Time interval}}$$

$$\therefore \quad a = \frac{v-u}{t}$$

or

$$v = u + at \qquad \text{...(9.1)}$$

This is called as the first equation of motion.

Also, we know that

$$\text{Displacement} = (\text{average velocity}) \times (\text{time interval})$$

or $$s = \left(\frac{v+u}{2}\right)t = \left(\frac{u+at+u}{2}\right)t \qquad (\because\ v = u + at)$$

or $$s = ut + \frac{1}{2}at^2 \qquad ...(9.2)$$

This is called the second equation of motion.

If object starts from rest, $u = 0$ and

$$s = 0 \times t + \frac{1}{2}at^2$$

or $$s = \frac{1}{2}at^2$$

Thus, we see that the displacement of an object undergoing a constant acceleration is proportional to t^2, while the displacement of an object with constant velocity (zero acceleration) is proportional to t.

Now, if we take $a = \frac{v-u}{t}$ and $s = \left(\frac{v+u}{2}\right).t$ and multiply them, we find that

$$a.s = \frac{(v-u)}{t}\left(\frac{v+u}{2}\right)t = \frac{v^2-u^2}{2}$$

or $$2a.s = v^2 - u^2$$

or $$v^2 = u^2 + 2as \qquad ...(9.3)$$

This is called as third equation of motion. In case of motion under gravity 'a' can be replaced by 'g'.

INTEXT QUESTIONS 9.4

1. A ball is thrown straight upwards with an initial velocity 19.6 ms^{-1}. It was caught at the same distance above the ground from which it was thrown:

   (i) How high does the ball rise?

   (ii) How long does the ball remain in air? (g = 9.8 ms^{-2})

2. A brick is thrown vertically upwards with the velocity of 192.08 ms^{-1} to the labourer at the height of 9.8 m. What are its velocity and acceleration when it reaches the labourer?
3. A body starts its motion with a speed of 10 ms^{-1} and accelerates for 10 s with 10 ms^{-2}. What will be the distance covered by the body in 10 s?
4. A car starts from rest and covers a distance of 50 m in 10 s and 100 m in next 10 s. What is the average speed of the car?

9.7 UNIFORM CIRCULAR MOTION

You may have seen the motion of the bicycle on a straight level road. Do all movable parts of the bicycle move alike? If not, then how are they moving differently? Does the peddling make a difference in these motions? Like Nimish, number of questions you may have in your mind. Let us try to answer these questions. Bicycle is moving on a straight road so its motion is rectilinear motion.

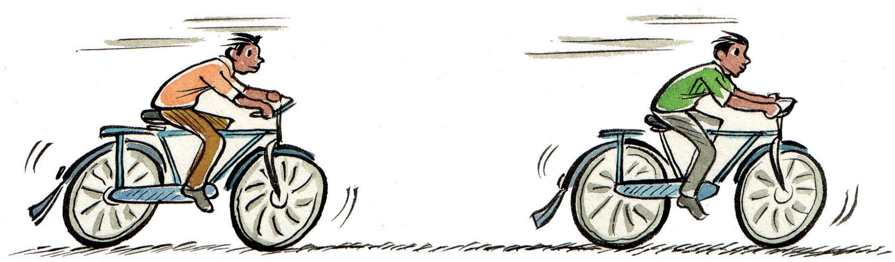


Fig. 9.30 *Bicycle moving on a road*

Now look at the wheels of the bicycle. Any point on the wheel of the bicycle always remains at a constant distance from the axis of the wheel and moves around the fixed point i.e., axis of the wheel. On the basis of this description of motion of the wheel you can decide very obviously that this motion is circular motion.

Similarly, can you think about the motion of the flywheel of the bicycle? During non-peddling, there is no circular motion of flywheel and it moves in a straight line thus, its motion is rectilinear motion. But during the peddling its motion is circular motion can you think about the motion of any part of the bicycle which has two types of motion at the same time? Yes, during the circular motion of the wheel or flywheel, they are also advancing in forward direction on a straight road. Thus, there motion is circular motion as well as rectilinear motion at the same time.

Now consider the motion of an object along a circular track of radius R through four points *A*, *B*, *C* and *D* on the track as shown in Fig. 9.31. If object completes each round of motion in same time, than it covers equal distance in equal interval of time and its motion will be uniform motion. Since during this uniform motion equal distance is being covered in equal interval of time, therefore, the ratio of distance covered to the time taken i.e., speed will remain constant. It means **in uniform circular motion speed remains constant.**

Now think about velocity, velocity remains along the direction of motion. In Fig. 9.31 you can see the direction of motion changes at every point as shown at point *A*, *B*, *C* and *D*. Since there is a change in direction of motion, therefore, the direction of velocity also changes. We can say that in uniform circular motion, velocity changes due to change in direction of motion and the motion of the object is accelerated motion. This acceleration is due to change in the direction of motion. But in this motion speed remains constant. How interested this motion is because a body moving with constant speed acquires acceleration.

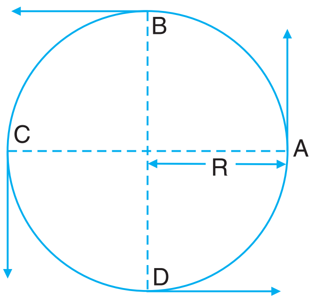


Fig. 9.31 *Circular motion*

Think and Do

K	I	L	O	M	E	T	R	E	T	O
S	P	E	E	D	T	O	N	C	N	E
O	N	D	I	S	T	A	A	N	O	E
P	D	I	S	P	L	A	C	D	I	A
A	N	S	V	E	L	O	C	I	T	Y
T	A	P	P	E	E	R	C	S	A	N
K	A	L	U	D	I	N	E	T	R	A
T	E	A	M	Y	O	Y	L	A	E	D
M	A	C	H	I	N	E	E	N	L	L
E	P	E	P	T	A	D	R	C	E	K
T	O	M	F	T	R	E	A	E	C	D
R	N	E	N	G	I	N	T	G	C	Q
E	E	N	K	L	O	M	E	T	A	R

In the above word grid identify the meaningful words, related to description of motion, in horizontal or vertical columns in sequence and define them (at least three).

INTEXT QUESTIONS 9.5

1. In circular motion the point around which body moves
   - (a) always remain in rest
   - (b) always remain in motion
   - (c) may or may not be in motion
   - (d) remain in oscillatory motion
2. In uniform circular motion
   - (a) speed remain constant
   - (b) velocity remain constant
   - (c) speed and velocity both remain constant
   - (d) neither speed nor velocity remain constant
3. A point on a blade of a ceiling fan has
   - (a) always uniform circular motion
   - (b) always uniformly accelerated circular motion
   - (c) may be uniform or non-uniform circular motion
   - (d) variable accelerated circular motion

WHAT YOU HAVE LEARNT

- If a body stays at the same position with time, it is at rest.
- If the body changes its position with time, it is in motion.
- Motion is said to be rectilinear if the body moves in the same straight line all the time. e.g., a car moving in straight line on a level road.
- The motion is said to be circular if the body moves on a circular path; e.g. the motion of the tip of the second needle of a watch.
- The total path length covered by a moving body is the distance travelled by it.
- The distance between the final and initial position of a body is called its displacement.
- Distance travelled in unit time is called speed, whereas, displacement per unit time is called velocity.

- Position-time graph of a body moving in a straight line with constant speed is a straight line sloping with time axis. The slope of the line gives the velocity of the object in motion.
- Velocity-time graph of a body in straight line with constant speed is a straight line parallel to time axis. Area under the graph gives distance travelled.
- Velocity-time graph of a body in straight line with constant acceleration is a straight line sloping with the time axis. The slop of the line gives acceleration.
- For uniformly accelerated motion

$$v = u + at$$

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

and $$v^2 = u^2 + 2as$$

where u = initial velocity, v = final velocity, and s = distance travelled in t seconds

TERMINAL EXERCISE

1. An object initially at rest moves for t seconds with a constant acceleration a. The average speed of the object during this time interval is

   (a) $\frac{a \cdot t}{2}$; (b) $2a \cdot t$; (c) $\frac{1}{2}a \cdot t^2$; (d) $\frac{1}{2}a^2 \cdot t$

2. A car starts from rest with a uniform acceleration of 4 ms^{-2}. The distance travelled in metres at the ends of 1s, 2s, 3s and 4s are respectively,

   (a) 4, 8, 16, 32 (b) 2, 8, 18, 32

   (c) 2, 6, 10, 14 (d) 4, 16, 32, 64

3. Does the direction of velocity decide the direction of acceleration?
4. Establish the relation between acceleration and distance travelled by the body
5. Explain whether or not the following particles have acceleration:

   (i) a particle moving in a straight line with constant speed, and

   (ii) a particle moving on a curve with constant speed.

6. Consider the following combination of signs for velocity and acceleration of an object with respect to a one dimensional motion along x-axis and give example from real life situation for each case:

Table 9.11

Velocity	Acceleration	Example
(a) Positive	Positive	Ball rolling down on a slope like slide or ramp
(b) Positive	Negative	
(c) Positive	Zero	
(d) Negative	Positive	
(e) Negative	Negative	
(f) Negative	Zero	
(g) zero	Positive	
(h) Zero	Negative	

7. A car travelling initially at 7 ms^{-1} accelerates at the rate of 8.0 ms^{-2} for an interval of 2.0 s. What is its velocity at the end of the 2 s?

8. A car travelling in a straight line has a velocity of 5.0 ms^{-1} at some instant. After 4.0 s, its velocity is 8.0 ms^{-1}. What is its average acceleration in this time interval?

9. The velocity-time graph for an object moving along a straight line has shown in Fig. 3.32. Find the average acceleration of this object during the time interval 0 to 5.0 s, 5.0 s to 15.0 s and 0 to 20.0 s.

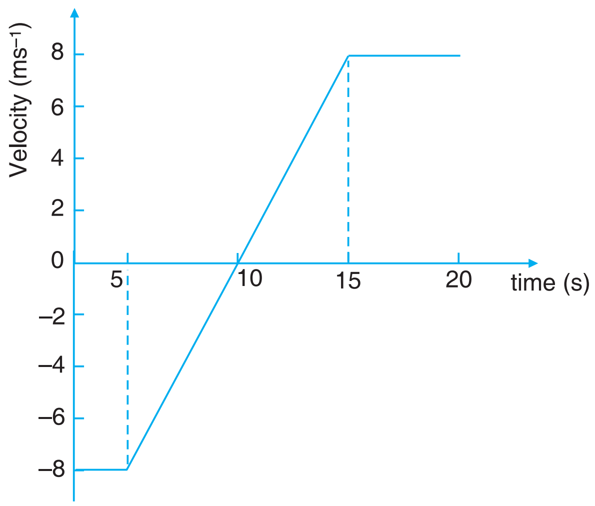


Fig. 9.32

10. The velocity of an automobile changes over a period of 8 s as shown in the table given below:

Table 9.12

Time (s)	Velocity (ms^{-1})	Time (s)	Velocity (ms^{-1})
0.0	0.0	5.0	20.0
1.0	4.0	6.0	20.0
2.0	8.0	7.0	20.0
3.0	12.0	8.0	20.0
4.0	16.0		

(i) Plot the velocity-time graph of motion.

(ii) Determine the distance the car travels during the first 2 s.

(iii) What distance does the car travel during the first 4 s?

(iv) What distance does the car travel during the entire 8 s?

(v) Find the slope of the line between t = 5.0 s and t = 7.0 s. What does the slope indicate?

(vi) Find the slope of the line between t = 0 s to t = 4 s. What does this slope represent?

11. The position-time data of a car is given in the table given below:

Table 9.13

Time (s)	Position (m)	Time (s)	Position (m)
0	0	25	150
5	100	30	112.5
10	200	35	75
15	200	40	37.5
20	200	45	0

(i) Plot the position-time graph of the car.

(ii) Calculate average velocity of the car during first 10 seconds.

(iii) Calculate the average velocity between t = 10 s to t = 20 s.

(iv) Calculate the average velocity between t = 20 s and t = 25 s. What can you say about the direction of the motion of car?

12. An object is dropped from the height of 19.6 m. Draw the displacement-time graph for time when object reach the ground. Also find velocity of the object when it touches the ground.

13. An object is dropped from the height of 19.6 m. Find the distance travelled by object in last second of its journey.

14. Show that for a uniformly accelerated motion starting from velocity u and acquiring velocity v has average velocity equal to arithmetic mean of the initial (u) and final velocity (v).

15. Find the distance, average speed, displacement, average velocity and acceleration of the object whose motion is shown in the graph (Fig. 9.33).

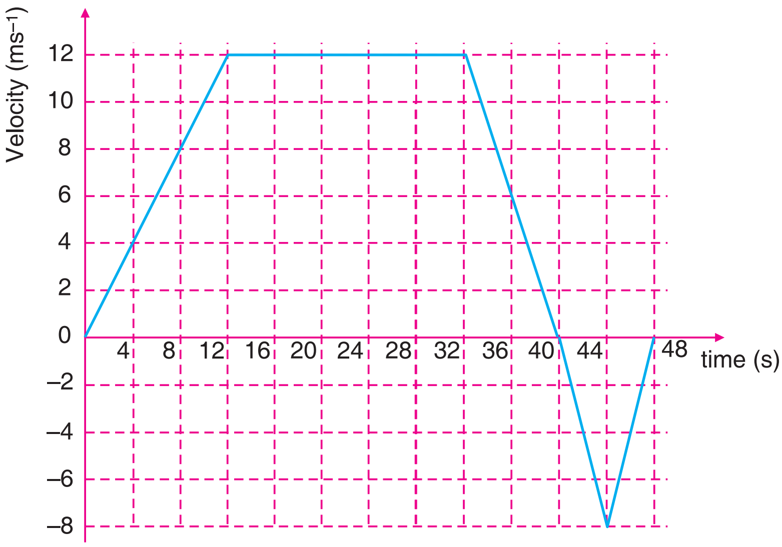


Fig. 9.33

16. A body accelerates from rest and attains a velocity of 10 ms^{-1} in 5 s. What is its acceleration?

ANSWERS TO INTEXT QUESTIONS

9.1

1. (c) 2. (a) 3. (b) 4. (a) 5. (c)

6.

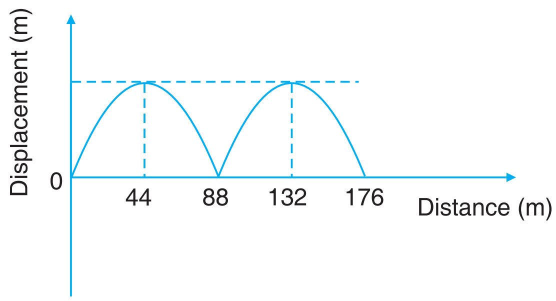


Fig. 9.34

Notes

9.2

1. (a) (iii) (b) (iv) (c) (i) (d) (ii)
2. Distance = 140 m, Displacement = 100 m, Speed = 7 ms^{-1}
3. When object moves with uniform speed
4. 2ms^{-1}, 5 ms^{-1}
5. Average speed = 0.2 ms^{-1}, motion is uniform motion

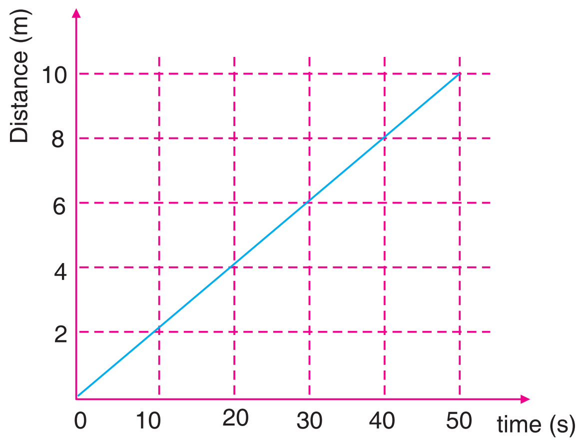


Fig. 9.35

6. 0.2 ms^{-1} 7. 63 km h^{-1} 8. 48 km h^{-1} 9. R, R

9.3

1. For first five seconds object moves with constant speed i.e. 2ms^{-1}. From 5 to 15 second it remains at rest and then from 15 to 20 seconds it moves with constant speed 2 ms^{-1}.

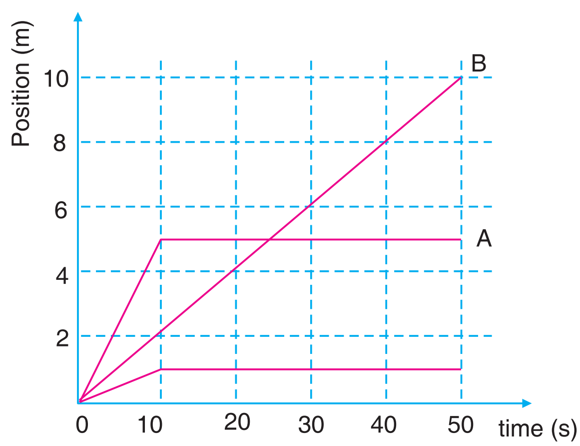
   The motion of the object is not uniform.
2. Velocity of object *A* is 4 times the velocity of *B*.
3. 

Fig. 9.36

4.

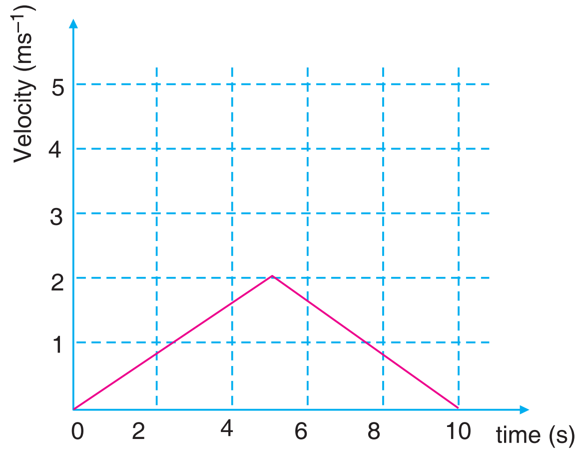


Fig. 9.37

(i) $a = 0.4\ \text{ms}^{-2}$, (ii) $-a = 0.4\ \text{ms}^{-2}$, (iii) 10 m

5.

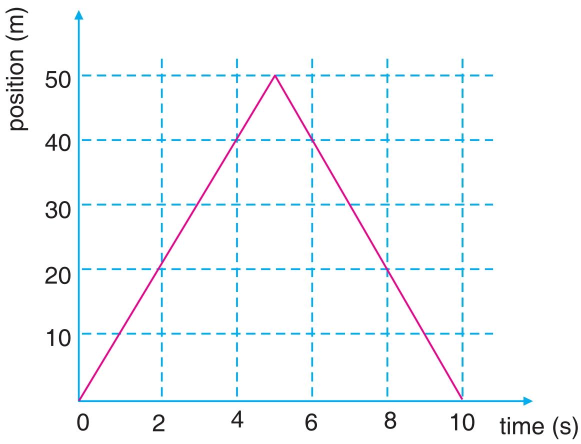


Fig. 9.38

9.4

1. (i) 19.6 m, (ii) 4 s
2. Zero and $9.8\ \text{ms}^{-2}$
3. 600 m
4. $7.5\ \text{ms}^{-1}$

9.5

1. (a)
2. (a)
3. (b)