Motion in a straight line

Physics

02

2.1 Distance and displacement

Distance is a concept familiar to you. When you go from home to school, you have to travel a certain distance. Sometimes, there can be several paths you could use to travel between home and school. Some of them could be shorter and some longer.

Figure 2.1 shows several paths that a child could take, to travel from a point A to another point B.

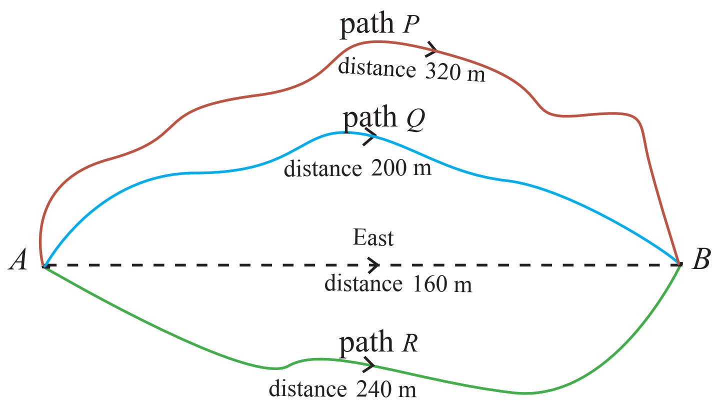


Figure 2.1 – Several paths between points A to B

If path P is used, the distance between point A to point B would be 320 m. If path Q is used, this distance would be 200 m. If path R is taken, the travel distance would be 240 m. This shows that the distance depends not only on the starting and the end points, but also on the path used to traverse the distance.

Whichever the path the child uses to reach B after starting from A, the ultimate result is that he has moved a distance of 160 m from A to B on a straight line towards the east . A change of position like this, that occurs from one point to another point in a particular direction is called **displacement**. The magnitude of the displacement is the shortest distance between the two points.

A physical quantity which can be described only by its magnitude is called a **scalar quantity**.

eg: speed, mass, time, distance

A physical quantity which can be described by its magnitude and direction is called a **vector quantity**.

eg: displacement, accelaration, velocity, weight

In the example above, the displacement of the child is 160 m to the east. Although the distance has changed according to the path taken, the displacement has remained the same.

In addition, there is another important difference between distance and displacement. Because we do not take the direction into account when measuring the distance, distance has only a magnitude. It does not have a direction. Therefore, distance is a scalar quantity. However, when measuring the displacement, the direction is important. In other words, the displacement has both a magnitude and a direction. Therefore it is a vector quantity.

Let us understand this concept further with following examples.

(i) Figure 2.2 shows the path taken by a child to travel from home to school.

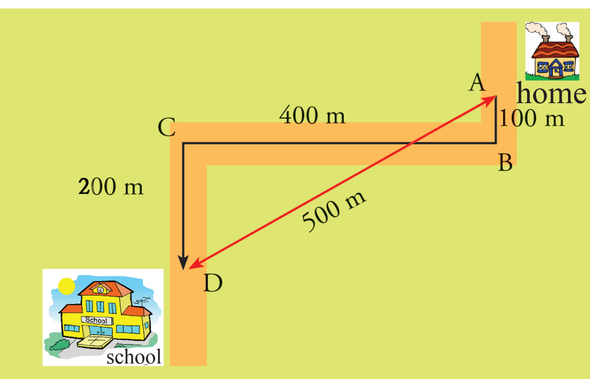


Figure 2.2 - Path taken by a child to travel from home to school

Total distance that the child has travelled between home and school is

$= AB + BC + CD = 100\text{ m} + 400\text{ m} + 200\text{ m} = 700\text{ m}$

However, the straight line distance from home to school is 500 m. This means that the magnitude of the displacement is 500 m while its direction is along *AD*.

(ii) Now consider Figure 2.3. A child starts from point A and reaches the point B along the path indicated by the arrows.

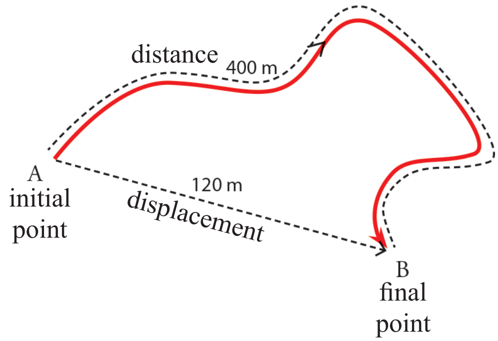


Figure 2.3 – A path between A and B

Even though the distance travelled by the child along this path is 400 m, the magnitude of his displacement is 120 m and the direction is along AB.

(iii) A 200 m running track used in track events is shown in Figure 2.4.

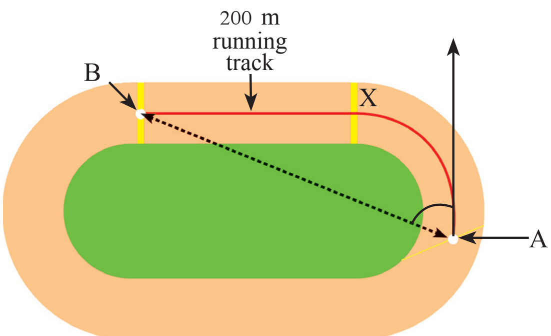


Figure 2.4 – A 200 m running track

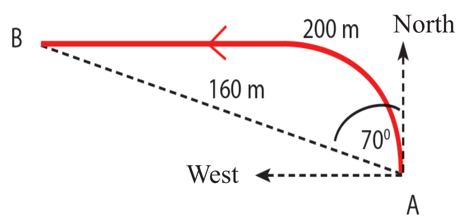


Figure 2.5 – Finding the direction of the athlete

An athlete who runs in this track from A to B reaches the point B after running a distance of 200 m. Then the displacement of the athlete can be indicated by the straight line AB. The magnitude of his displacement is 160 m. Its direction according to Figure 2.5 is 70° from the north to west. This displacement can be expressed in the following manner.

160 m in the direction 70^{0} from north to west.

(iv) Now consider a situation where a child is walking 60 m from A to B along the straight line path as shown in Figure 2.6.

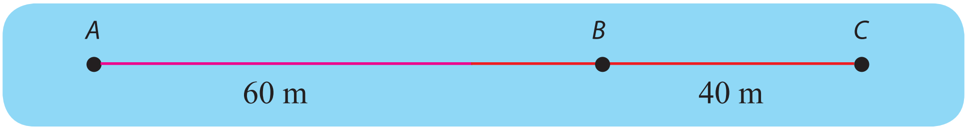


Figure 2.6 – Path of a child walking from A

The displacement of the child is 60 m along AB. Thereafter, if the child walks another 40 m along the same direction and reaches point C, what would be his total displacement?

When two or more displacements occur along the same direction, they can be either added or subtracted using ordinary arithmatic.

Since the displacements in the above example are in the same direction, total displacement $= 60\text{ m} + 40\text{ m} = 100\text{ m}$

This means that the child is now at a point 100 m away on a straight line from the starting point.

Now suppose that the child walks back 40 m after reaching the point B, as shown in Figure 2.7, instead of walking forward. The displacement corresponding to 40 m is in the opposite direction to that of AB. Therefore, although the distance traversed in this case too is 100 m, his displacement would be 60 m + (–40 m). That is 20 m.

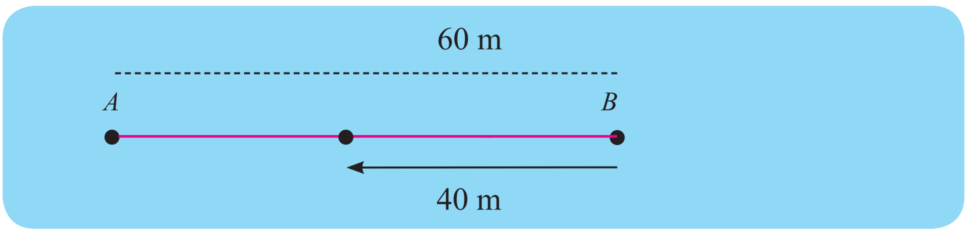


Figure 2.7 – Walking back 40 m after reaching point B

If he walked the same distance in the opposite direction after reaching the point B, his displacement would be 60 m + (–60 m). That is, a zero (0) displacement. From this we know that the child is back at the starting point.

Exercise 2.1

A child starts from a point A and walks 40 m to the East until he reaches another point B and from B he walks 30 m to the North to reach the point C as shown in Figure 2.8.

- What is the total distance traversed by the child?
- What is his displacement?

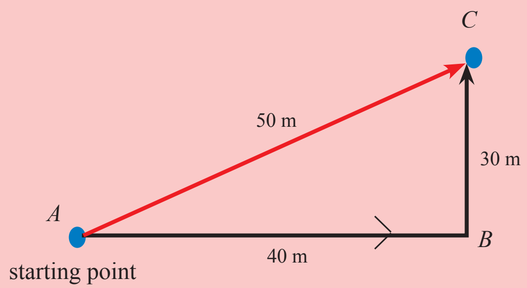


Figure 2.8 - A path walked by a child from A to C

2.2 Speed

We frequently hear about accidents caused by vehicles moving at high speeds.

Due to this reason, there are different regulatory speed limits assigned to different roadways. We should obey these speed limits in order to prevent accidents, particularly in highways with high speed limits.

What we mean by **speed** is the **rate** at which a given distance is traversed.

$$\textbf{speed} = \frac{\textbf{distance}}{\textbf{time}}$$

In other words, speed is the **distance traversed in a unit time.**

Vehicles moving in roadways cannot maintain the same speed throughout the travel time. The speedometer of a motor vehicle usually indicates only the speed of the vehicle at a particular instant. When there is heavy traffic, vehicles have to slow down, and when there are pedestrians crossing the road, the vehicles even have to stop. On the other hand, if there are only a few other vehicles in the road, the same speed can be maintained for a fairly long distance. Let us consider two such instances, one where the same speed is maintained, and the other where the speed changes with time, through the following examples.

The distance traversed by a certain object at different instances in time is shown in the table below.

Time t (s)	0	1	2	3	4	5	6
Distance traversed d (m)	0	3	6	9	12	15	18

According to these data,

Distance traversed by the object during the first second = (3 - 0) = 3 m

Distance traversed during the next second = (6 - 3) = 3 m

Similarly, the distances traversed during each of the third, fourth, fifth and sixth seconds is also 3 m.

That is, the object has traversed 3 m during each 1 s time interval. Therefore, in this case we can say that the object has moved at a **uniform or constant speed.**

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Since the time is given in seconds and the distance in meters, the speed has the unit m s^{-1}. Accordingly, the above object has a speed of 3 m s^{-1}.

Now let us consider the motion of another object described by the following data table.

Time t (s)	0	1	2	3	4	5	6
Distance traversed d (m)	0	3	5	9	12	16	18

The distance traversed by this object is 3 m in first second, 2 m in second second and 4 m in third second etc.

Therefore the distance traversed by this object during each interval of one second is not the same. That is, this object has not travelled with a uniform speed.

In such instances, where an object does not travel with a uniform speed, it is useful to calculate the **mean speed** of the object during a given time interval. The mean speed of an object can be calculated by dividing the total distance travelled, by the corresponding time interval. Mean speed is also known as the average speed.

$$\textbf{mean speed or average speed} = \frac{\text{total distance travelled}}{\text{total time duration}}$$

The total distance travelled by this object during 6 s is 18 m. Therefore, the average distance travelled during a second = $\frac{18}{6} = 3$ m.

That is, the mean speed or average speed of the object $= \frac{18\ \text{m}}{6\ \text{s}}$

$= 3\ \text{m s}^{-1}$

As another example, let us consider a vehicle that travelled a distance of 100 km from a location near Colombo to Peradeniya in 2 hours. In such a journey, a vehicle cannot maintain the same speed throughout the whole journey. However we could divide the total distance of 100 km by the total time duration of 2 hours as done above to calculate the average speed, which is 50 kilometers per hour.

2.3 Velocity

Because we calculate the speed in terms of distance, we do not consider the direction when we calculate the speed. Therefore, it must be clear to you by now, that the speed is a scalar quantity. The velocity however, is defined as the rate of change of the displacement. Therefore, it is a **vector quantity** that has both a magnitude and a direction.

The velocity of an object can be obtained by dividing its displacement by time.

$$\textbf{Velocity} = \frac{\textbf{displacement}}{\textbf{time}}$$

We learnt earlier that sometimes, bodies could move with uniform speeds while at other times they could move with non-uniform speeds. In a similar manner, the velocity of a body too can be uniform during certain time intervals while it can be non-uniform at other intervals.

The table below shows the displacement of a body along a specific direction, at the end of each 1 s time interval, as measured from the starting point.

Time t (s)	0	1	2	3	4
Displacement s (m)	0	3	5	9	12

Since the increase in the displacement of the body during each second is 3 m, the motion has taken place at a **constant or uniform velocity**.

When a body is moving at a constant velocity, neither the magnitude nor the direction of its velocity changes with time.

If a body moves along a straight line at a constant velocity of 6 m s^{-1}, then the change in the displacement during each 1 s interval is 6 m. The direction of the motion too remains constant. If the body moves at this constant velocity for 5 s,

then its displacement after 5 s = 6 m $s^{-1} \times$ 5 s = 30 m.

That is, for a body moving at a constant velocity, the displacement after a certain time interval can be obtained by multiplying the velocity by the relevant time interval.

$$\text{Displacement} = \text{velocity} \times \text{time}$$

The following table shows the displacement of another object moving on a straight line, as measured during each 1 s time interval.

Time t (s)	0	1	2	3	4
Displacement s (m)	0	4	7	9	12

The displacement of this object is 4 m in the first second, 3 m in the second second, and 2m in the third second etc. As the displacement is not the same in every second, the velocity of the object is not uniform. In such occasions we can calculate the **mean velocity.**

Mean velocity of the above object $= \dfrac{\text{displacement}}{\text{time}}$

$$= \frac{12 \text{ m}}{4 \text{ s}}$$

$$= \underline{\underline{3 \text{ m s}^{-1}}}$$

Example 1

The variation of the displacement, measured with respect to the starting point, of a child riding a bicycle on a straight path during each 1 s time interval is shown in the table below.

Time t (s)	0	1	2	3	4	5	6	7	8	9	10
Displacement s (m)	0	2	4	6	8	8	8	8	8	4	0

(i) What kind of motion has the child undergone during the first 4 s?

(ii) What is the rate of change of the displacement during the first 4 s?

(iii) Give one word to describe the rate of change of the displacement.

(iv) What can you say about the motion of the child during the time period from 4 s to 8 s?

(v) Describe the motion during the time interval from 8 s to 10 s

(vi) Find the velocity of the child during the last 2 s.

Answers

(i) The child has moved forward by 8 m at a uniform velocity during the first 4 s.

(ii) Rate of change of the displacement during the first 4 s $= \dfrac{\text{change of displacement}}{\text{time}}$

$$= \frac{(8\text{-}0) \text{ m}}{4 \text{ s}}$$

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

(iii) Rate of change of the displacement is the velocity.

(iv) The child has not moved during the time period from 4 s to 8 s.

(v) The displacement during the time interval from 8 s to 10 s has taken place in the opposite direction. He has come back to the starting point after 10 s.

(vi) Velocity of the child during the last 2 s $= \dfrac{\text{change of displacement}}{\text{time}}$

$$= \frac{(0 - 8)\text{ m}}{2\text{ s}}$$

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

That is, the velocity is 4 m s^{-1} in the opposite direction.

2.4 Acceleration

In everyday life we mostly encounter, objects that move with non-uniform velocities. Vehicles moving in roadways have to increase or decrease their velocities frequently. Sometimes they have to change their direction. The result of all these changes is the change of velocity.

The following table shows the manner in which the velocity of a body that travelled along a straight line varied with time.

Time t (s)	0	1	2	3	4	5	6
Velocity v (m s^{-1})	0	2	4	6	8	10	12

According to the above data, the velocity of the body has changed from 0 m s^{-1} to 12 m s^{-1} during a 6 s period

Change in the velocity during 6 s = velocity at the end of 6 s − initial velocity

When we divide the above velocity change (12 m s^{-1}) by the time duration for this change (6 s), we get the rate of change of the velocity.

The rate of change of the velocity is known as the **acceleration**. That is, the change in velocity per unit time is the acceleration.

We already know that the unit of the velocity is m s^{-1}. Since the acceleration is the velocity change in a second, the acceleration has the unit m s^{-2}.

Therefore we can calculate the acceleration of the above object in the following manner.

$$\text{Acceleration} = \frac{\text{change of velocity}}{\text{time}}$$

$$= \frac{(12 - 0) \text{ m s}^{-1}}{6 \text{ s}}$$

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

When a body has an acceleration of 2 m s^{-2}, it means that its velocity changes by 2 m s^{-1} during each second. If the acceleration has a positive value, it implies that the velocity is increasing. A negative acceleration means a decrease in the velocity.

Suppose that a body moving in a straight line had an initial velocity of 12 m s^{-1}, which later varied with time as shown in the following table.

Time t (s)	0	1	2	3	4
Velocity v (m s^{-1})	12	9	6	3	0

Here, the velocity has decreased. The acceleration of this body can be calculated in the following manner.

$$\text{Acceleration} = \frac{\text{change of velocity}}{\text{time}}$$

$$= \frac{(0 - 12) \text{ m s}^{-1}}{4 \text{ s}}$$

$$= -3 \text{ m s}^{-2}$$

Here, we have obtained a negative value for the acceleration. It means that the velocity has decreased by 3 m s^{-1} each second.

If the velocity is decreasing, the acceleration takes a negative value. A negative acceleration is known as a **deceleration**.

If a body has an acceleration of -3 m s^{-2}, it means that the body has a deceleration of 3 m s^{-2}.

If the velocity of a body either increases or decreases by the same amount every second, then that body is said to have a uniform acceleration or deceleration.

In order to find the displacement of a body moving at a uniform acceleration, we should find the mean velocity of the body and multiply it by the corresponding time.

Displacement = mean velocity × time

Example 1

A body that starts from rest, is subjected to a uniform acceleration for 6 s after which, it acquires a velocity of 12 m s^{-1}. What is the displacement of the body during this time interval?

Since the acceleration is uniform, we can find the mean velocity by dividing the sum of the initial and final velocities by two.

$$\begin{aligned}
\text{Displacement of the body} &= \text{mean velocity} \times \text{time} \\
&= \frac{(0 + 12)}{2}\ \text{m s}^{-1} \times 6\ \text{s} \\
&= 36\ \text{m}
\end{aligned}$$

Example 2

A body starting from rest, accelerates for 4 s and acquires a velocity of 12 m s^{-1}. Thereafter it moves at a constant velocity of 12 m s^{-1} for 4 s and ultimately comes to rest after decelerating for 2 s.

(i) Calculate the acceleration during the first 4 s.

(ii) Find the deceleration during the last 2 s.

(iii) What is the displacement of the body during the 10 s?

Answers

(i) Acceleration during the first 4 s $= \dfrac{(12-0)\text{ m s}^{-1}}{4\text{ s}}$

$= 3\text{ m s}^{-2}$

(ii) Acceleration during the last 2 s $= \dfrac{(0-12)\text{m s}^{-1}}{2\text{ s}}$

$= -6\text{ m s}^{-2}$

Deceleration $= 6\text{ m s}^{-2}$

(iii) Displacement during the first 4 s = mean velocity × time

$= \dfrac{(0+12)\text{ m s}^{-1}}{2} \times 4\text{ s}$

$= 24\text{ m}$

Displacement during the next 4 s = uniform velocity × time

$= 12 \times 4$

$= 48\text{ m}$

Displacement during last 2 s = mean velocity × time

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

$= 12\text{ m}$

Total displacement during the 10 s $= 24\text{ m} + 48\text{ m} + 12\text{ m}$

$= 84\text{ m}$

That is, the final position of the object after 10 s is 84 m away on a straight line from the starting point.

Exercise 2.2

1. If the velocity of an object increased uniformly from 0 to 12 m s^{-1} during 6 s, find the acceleration of the object.
2. If the velocity of an object decreased uniformly from 16 m s^{-1} to 4 m s^{-1} during 4 s, calculate the deceleration of the object.
3. Starting from rest, if an object travelled with an acceleration of 0.5 m s^{-2}, for 10 s find the velocity of the object at the end of 10 s period.
4. The velocity of an object moving on a straight line was 2 m s^{-1} at a certain instant. Its velocity changed to 6 m s^{-1}, after accelerating for 4 s. Find the acceleration during the 4 s period.

2. 5 Displacement-time graphs

Graphs that illustrate how the displacement of a body varies with time are known as displacement - time graphs. These graphs are plotted by marking the time on the *x*-axis and the displacement on the *y*-axis.

The following table shows the variation of the displacement of a body with time.

Time t (s)	0	1	2	3	4	5
Displacement s (m)	0	3	6	9	12	15

The displacement - time graph for the above data set is shown in Figure 2.9.

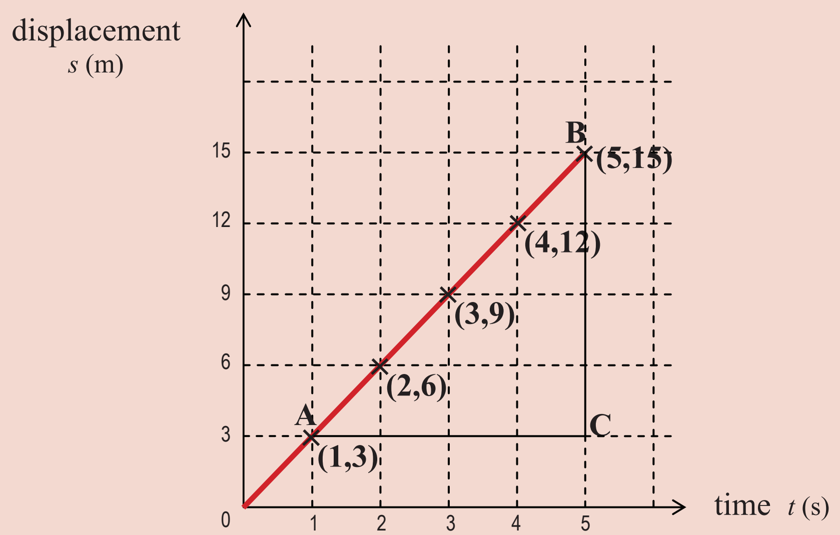


Figure 2.9 - A displacement - time graph

Since the velocity is uniform in this case, we get a straight line for the graph. For a body with the non - uniform velocity, we get a curve for the graph. The velocity can be obtained by determining the gradient of the graph.

The gradient of a straight line can be calculated by dividing the difference between the y-coordinates of any two points on that line by the difference between the corresponding x-coordinates of the two points. However, if two distant points are chosen to find the gradient the result will be more accurate.

Since the x-axis represents time, the difference between the x-coordinates of two points is a time interval. The corresponding difference between the y-coordinates is the displacement of the body during that time interval. What we get when the displacement is divided by time is a velocity.

$$\text{Gradient} = \frac{\text{difference between } y \text{ - coordinates}}{\text{difference between } x \text{ - coordinates}}$$

$$= \frac{\text{displacement}}{\text{time}} = \text{velocity}$$

Therefore, the velocity can be calculated by choosing two fairly distant points A and B on the above graph and by calculating the gradient as shown below.

$$\text{Gradient} = \frac{BC}{AC}$$

$$= \frac{(15\text{-}3)\text{m}}{(5\text{-}1)\text{ s}} = \frac{12\text{m}}{4\text{ s}} = 3\text{ m s}^{-1}$$

Therefore, the velocity of the motion represented by the above graph is 3 m s^{-1}.

2.6 Velocity-time graphs

In order to represent the variation of velocity with time, velocity-time graphs are used. In velocity-time graphs, the time is plotted on the x-axis while the velocity is plotted on the y-axis.

The table below gives the variation of velocity with time for the motion of an object.

Time t (s)	0	1	2	3	4	5	6
Velocity v (m s^{-1})	0	3	6	9	12	15	18

A velocity - time graph plotted using the above data is shown in Figure 2.10.

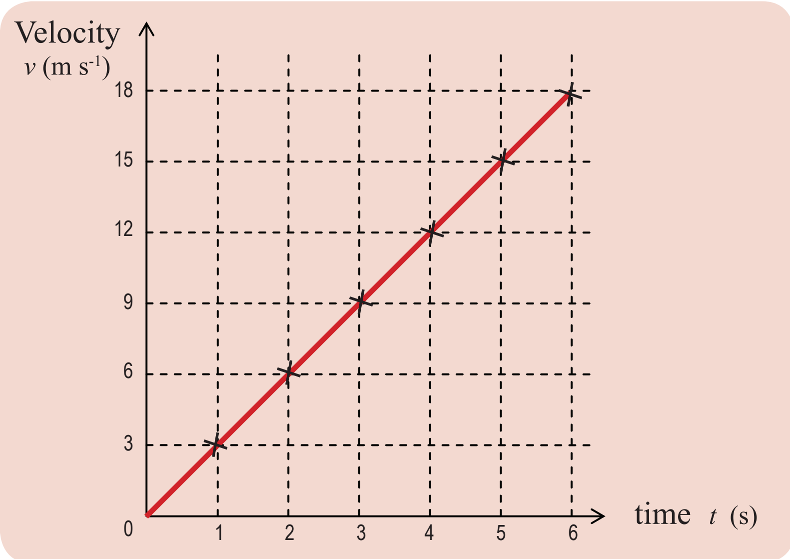


Figure 2.10 - A velocity - time graph

This graph is a straight line, because the increase in the velocity during each 1 s interval is the same. This represents a motion with a uniform (constant) acceleration.

As mentioned before, the gradient of the straight line can be obtained by dividing the difference between the y-coordinates of any two points on the graph by the difference between the corresponding x-coordinates.

In this graph also, the x-axis represents time. Therefore, the difference between x coordinates gives a time interval. The corresponding difference in the y coordinates gives the velocity difference during this time interval. Velocity difference divided by time gives an acceleration.

$$\text{Gradient} = \frac{\text{difference between velocities}}{\text{time}}$$
$$= \text{acceleration}$$

For the above graph,

$$\text{Acceleration} = \frac{(18 - 0)\text{ m s}^{-1}}{6\text{ s}}$$

$$= 3\text{ m s}^{-2}$$

Figure 2.11 shows the velocity - time graph for the motion of a body moving at a constant velocity of 6 m s^{-1}. Since the velocity remains the same in a motion taking place with a constant velocity, this graph is a straight line parallel to the *x*-axis.

Since the velocity of the motion described by the above graph is 6 m s^{-1}, you can calculate the displacement as shown below, using the formula you learnt in section 2.3.

$$\text{Velocity} = \frac{\text{displcement}}{\text{time}}$$

$$\text{Displacement} = \text{velocity} \times \text{time}$$

$$= 6\text{ m s}^{-1} \times 8\text{ s}$$

$$= 48\text{ m}$$

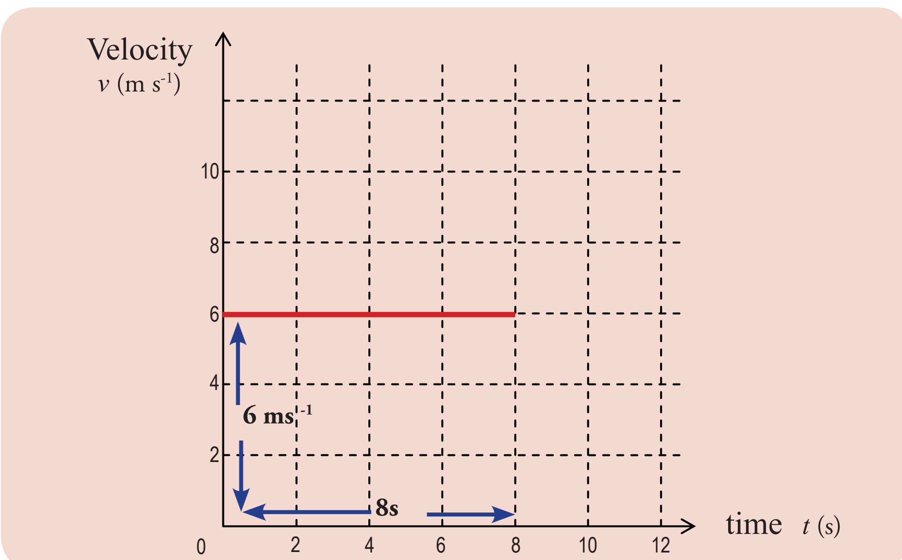


Figure 2.11 - Velocity - time graph of a body moving at a constant velocity

As shown in Figure 2.11 , the area under the straight line is $6 \times 8 = 48$ m. This area is calculated by multiplying the length along the x-axis (time) by the length along the y-axis (velocity).

That is, the displacement is equal to the area under the velocity - time graph.

Let us now consider how we could find the displacement of a body moving at a uniform acceleration using its velocity - time graph.

A body starting from rest, acquires a velocity of 12 m s^{-1} after moving at a constant acceleration for 4 s. A velocity - time graph plotted for this motion is shown in Figure 2.12.

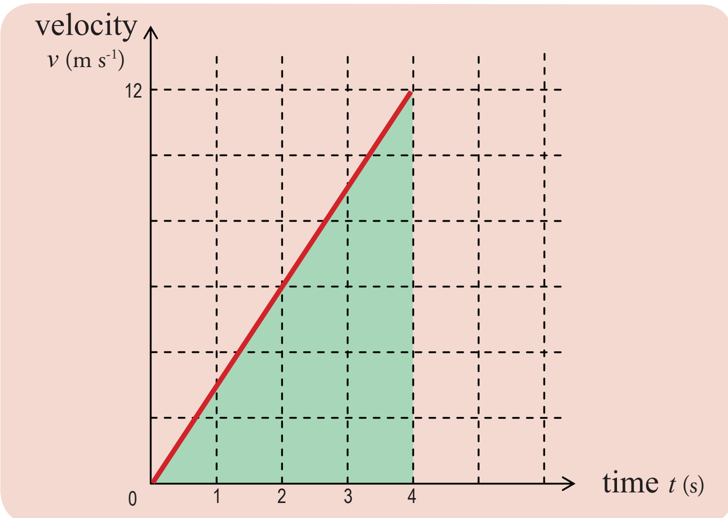


Figure 2.12 - A velocity - time graph of a body moving at a uniform acceleration

According what we learnt in section 2.4, the displacement of a body moving with a uniform acceleration can be found using the formula,

$$\text{Displacement} = \text{mean velocity} \times \text{time}$$

Therefore, for the motion shown in Figure 2.12,

$$\begin{aligned} \text{Displacement} &= \frac{12 \text{ m s}^{-1}}{2} \times 4 \text{ s} \\ &= 24 \text{ m} \end{aligned}$$

The shaded area of the region below the graph of Figure 2.12,= $\frac{1}{2} \times 12 \times 4 = 24$

Again see how this area was calculated.

$$\frac{12 \times 4}{2}$$

12/2 is the mean velocity.

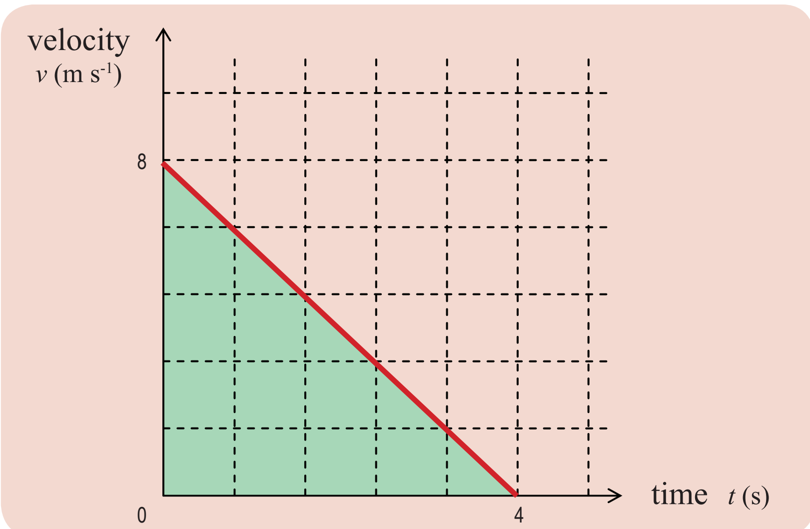
Displacement = mean velocity × time

That is, the displacement of a body moving at a uniform acceleration is equal to the magnitude of the area under the velocity-time graph.

This graphical method provides you with another way of finding the displacement of an object.

Example

A body with an initial velocity of 8 m s^{-1} moves under a constant deceleration, and comes to rest after 4 s. Plot the velocity - time graph for this motion and find the displacement during the 4 s.



The velocity - time graph is shown in the figure. The displacement is equal to the area of the shaded region.

$$\text{Displacement of the body} = \frac{8 \times 4}{2}$$

$$= 16 \text{ m}$$

- Now consider the following problem.

An object starting from rest, acquires a velocity of 15 m s^{-1} after moving for 6 s under a uniform acceleration. Then the object moves with that velocity for 6 s and comes to rest after decelerating for 3 s.

(i) Plot the velocity - time graph for this motion.

(ii) Find the acceleration during the first 6 s.

(iii) What is the displacement during these 6 s?

(iv) What is the distance travelled under the uniform velocity?

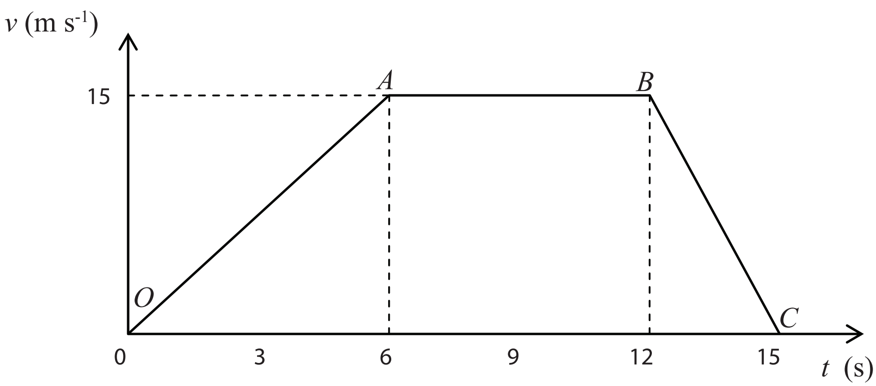
(v) What is the deceleration during the last 3 s?

(vi) What is the distance traversed during the last 3 s?

(vii) (a) Write down an expression in order to find the total distance travelled by the object during the complete motion, using the velocity - time graph.

(b) Find the total distance travelled using the above expression.

Answer



(i) The velocity - time graph is shown in the above figure .

(ii) Acceleration during the first 6 s = Gradient of the *OA* part of the graph

$$= \frac{15 \text{ m s}^{-1}}{6 \text{ s}}$$

$$= 2.5 \text{ m s}^{-2}$$

(iii) Displacement during the first 6 s = Area of the graph below *OA*

$$= \frac{15 \times 6}{2}$$

$$= 45 \text{ m}$$

(iv) Distance traversed at uniform speed = Area of the graph below AB

$$= 15 \text{ m s}^{-1} \times 6 \text{ s}$$
$$= 90 \text{ m}$$

(v) Acceleration during the last 3 s $= \dfrac{(0 - 15) \text{ m s}^{-1}}{3 \text{ s}}$

$$= -5 \text{ m s}^{-2}$$

That is, deceleration $= 5 \text{ m s}^{-2}$

(vi) Distance traversed during the last 3 s = Area of the graph below BC

$$= \frac{15 \text{ m s}^{-1}}{2} \times 3 \text{ s}$$
$$= 22.5 \text{ m}$$

(vii) (a) Total distance travelled = Area of the trapezoid $OABC$

(b) Total distance travelled $= \dfrac{(OC + AB)}{2} \times 15 \text{ m s}^{-1}$

$$= \frac{(15 + 6)\text{s}}{2} \times 15 \text{ m s}^{-1}$$
$$= \frac{21\text{s}}{2} \times 15 \text{ m s}^{-1}$$
$$= 157.5 \text{ m}$$

- During the periods of heavy traffic, vehicles have to reduce the speed frequently. When the vehicles begin to move again, the engine has to produce extra power. This process causes an energy loss. Such losses can be minimized by travelling during hours of low traffic whenever possible.

2.7 Gravitational acceleration

By experience we know that when a body falls, its velocity increases gradually. That is, the body accelerates. In order to give rise to an acceleration, a **force** must act on the body. The force that acts on a falling body is the gravitational force exerted by the earth. The acceleration caused by the earth's gravitational attraction is known as the gravitational acceleration. Its symbol is g.

The average value for the gravitational acceleration at sea level is about 9.8 m s^{-2}.

This means that the velocity of a free falling body increases by 9.8 m s^{-1} every second.

When a body is moving vertically upwards, the velocity decreases by 9.8 m s^{-1} every second. Therefore, the gravitational acceleration of a body moving vertically upwards is, –9.8 m s^{-2}.

Suppose that a body falling vertically down after starting from rest takes 4 s to reach the ground. Its velocity change during each second can be stated as follows.

Initial velocity = 0

Velocity at the end of 1 s = 9.8 m s^{-1}

Velocity at the end of 2 s = 19.6 m s^{-1}

Velocity at the end of 3 s = 29.4 m s^{-1}

Since it took 4 s to fall to the ground, the velocity upon reaching the ground, that is the velocity at the end of 4 s = 39.2 m s^{-1}

$$\begin{aligned}\text{Height that the body fell during 4 s} &= \text{mean velocity} \times \text{time}\\ &= \frac{(0 + 39.2)\ \text{m s}^{-1}}{2} \times 4\ \text{s}\\ &= 78.4\ \text{m}\end{aligned}$$

The velocity - time graph for the above motion is shown in Figure 2.13.

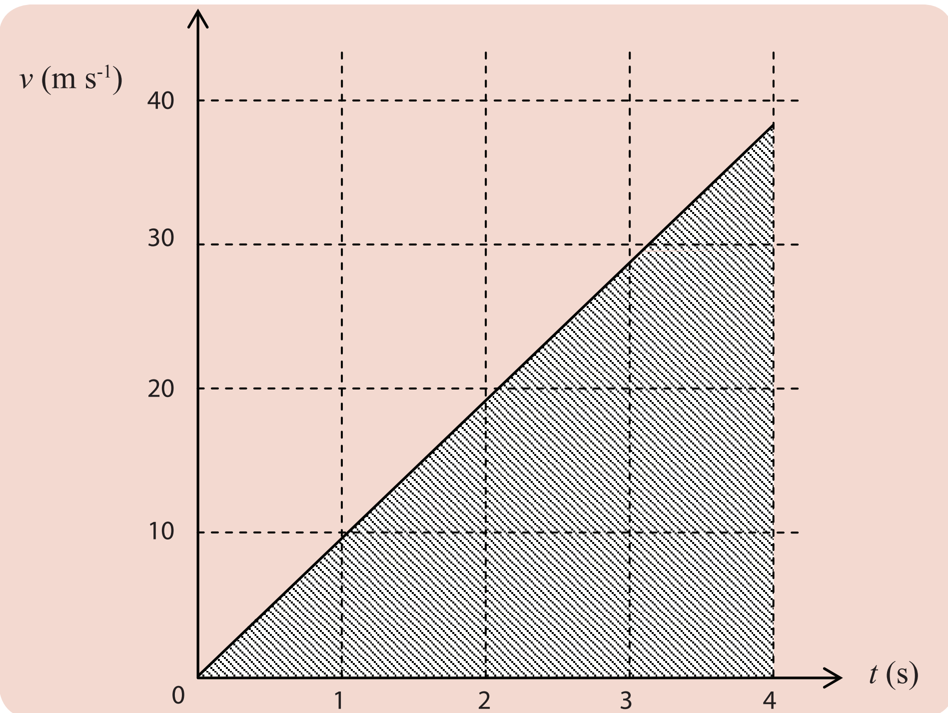


Figure 2.13 - Velocity - time graph of a body falling vertically down

Distance fallen during the 4 s $= $ Shaded area below the graph

$$= \frac{39.2\ \mathrm{m\ s^{-1}} \times 4\ \mathrm{s}}{2}$$

$$= 78.4\ \mathrm{m}$$

Let us next plot a velocity - time graph for a body reaching the maximum height after being initially projected vertically upwards with a velocity of 20 m s^{-1} (Take g = 10 m s^{-2} for conveniance of the calculations)

The change in the velocity with time is shown in the table below, and the corresponding velocity - time graph is shown in Figure 2.14.

t (s)	0	1	2
v (m s^{-1})	20	10	0

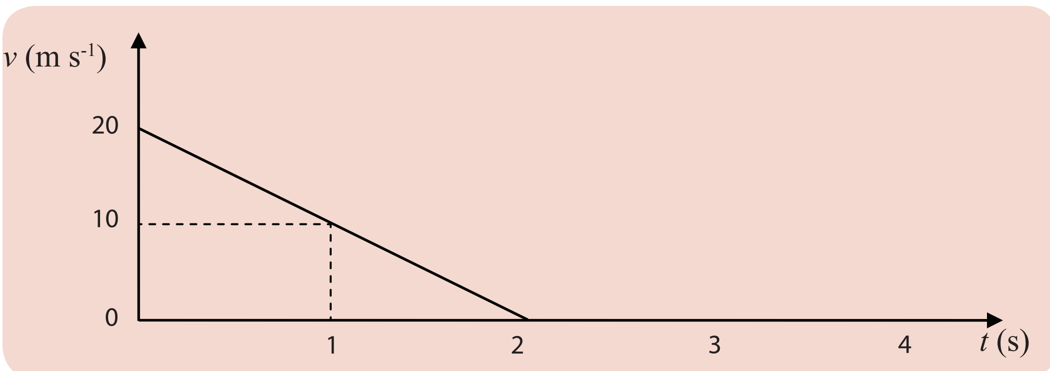


Figure 2.14 - Velocity - time graph of a body reaching its maximum height after being projected vertically upward

In plotting the above graph, velocities directed upwards have been taken as positive. Therefore this graph shows gravitational acceleration as a negative acceleration.

Example

An object was projected vertically upward at a velocity of 30 m s^{-1}.

(i) Prepare a velocity - time data table indicating the variation of the velocity with time from the moment the object was projected until it reaches the maximum height.

(ii) Sketch a velocity - time graph to describe the motion.

(iii) Find the maximum height reached by the object.

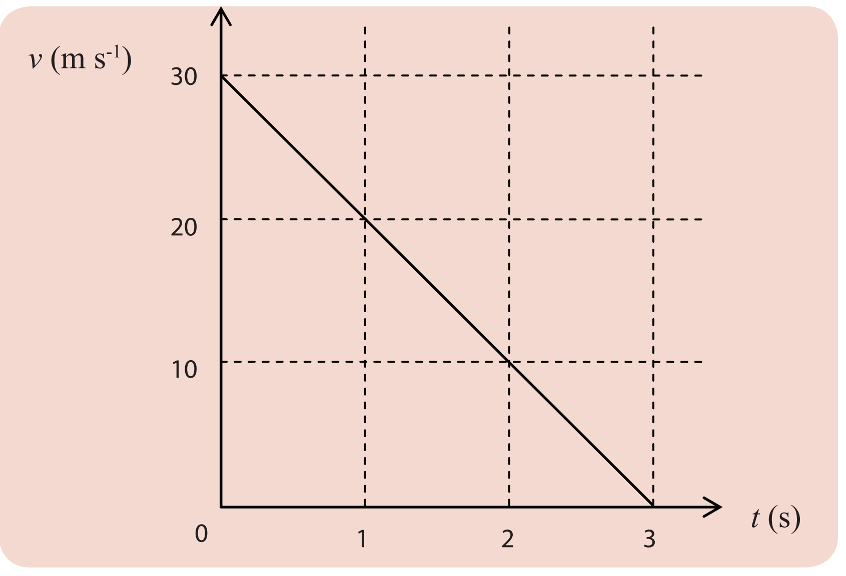
Take $g = 10 \text{ m s}^{-2}$ for convenience of the calculations

Answer

(i) Velocity-time data table is shown below.

Time t (s)	0	1	2	3
Velocity v (m s^{-1})	30	20	10	0

(ii) Velocity-time graph is shown in the figure below.



(iii) Maximum distance reached by the object = Area under the graph

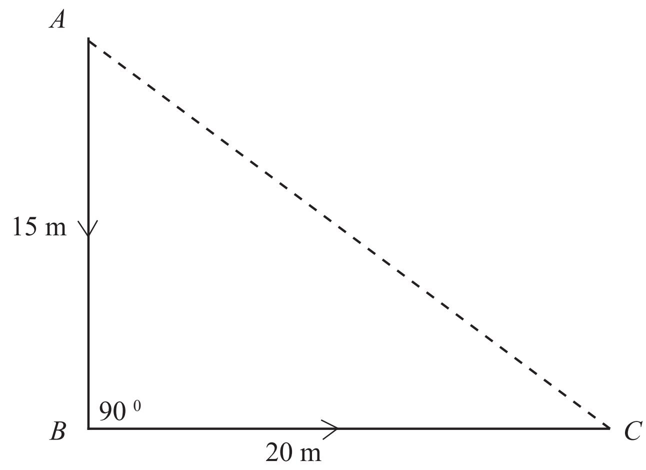
$$= \frac{30 \text{ m s}^{-1}}{2} \times 3 \text{ s}$$

$$= 45 \text{ m}$$

Miscellaneous exercises

1. (i) Explain the difference between distance and displacement.

   (ii) The path taken by a child in order to walk from a point A to a point C is shown in the figure below.



   (a) What is the total distance traversed by the child?

   (b) What is the displacement of the child?

   (c) If the child walked from A to C via B in 5 s, without stopping, find the

      (i) mean speed

      (ii) mean velocity of the child.

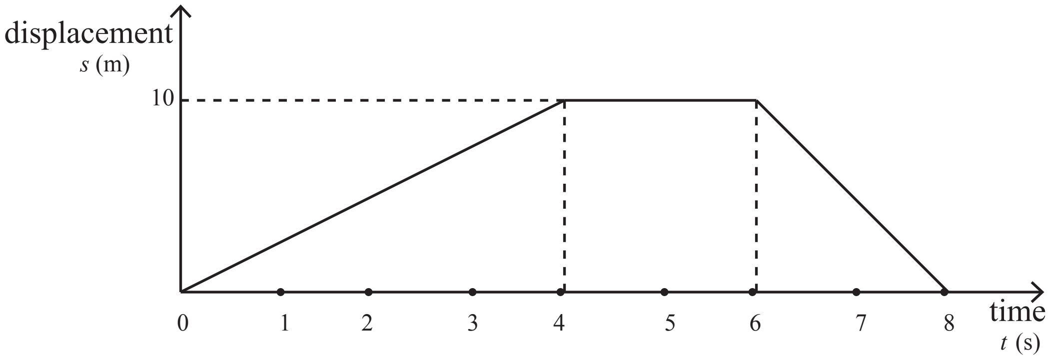
   over the 5 s period.

2. (i) Briefly explain the difference between scalars and vectors.

   (ii) Classify the following physical quantities as scalars or vectors.

   Distance, displacement, speed, velocity

   (iii) The displacement-time graph of an object moving along a straight line is shown in the figure below .



(a) How far has the object moved after starting from rest?

(b) How long has it taken to travel the above distance?

(c) Find the maximum velocity of the object during that period.

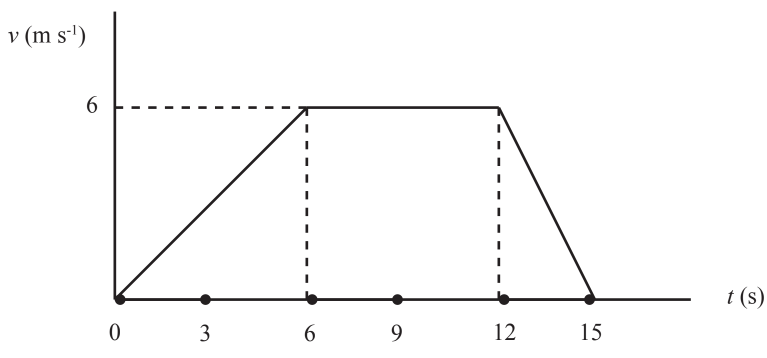
(d) What can you say about the motion during the interval from 4 s to 6 s?

(e) Comment on the motion during the interval from 6 s to 8 s.

3. (i) If the velocity of a body varied uniformly from 10 m s^{-1} to 25 m s^{-1} during a time interval of 5 s what was the acceleration of the body?

(ii) Sketch the velocity - time graph for the above motion and find the distance travelled during the 5 s.

(iii) The variation of the velocity of a certain object that travelled along a straight line is shown in the graph below .



(a) Find the acceleration of the object during the first 6 s.

(b) Find the distance traversed by the object during the first 6 s.

(c) What is the distance traversed at a uniform velocity?

(d) Find the deceleration during the last 3 s.

4. An object starting from rest and moving on a straight line at a constant acceleration acquires a velocity of 12 m s^{-1} in 8 s. Thereafter it moves for another 4 s at a uniform velocity of 12 m s^{-1}. Ultimately it decelerates for 4 s and comes to rest.

   (i) Sketch the velocity - time graph for the above motion.
   (ii) What is the acceleration of the object during the first 8 s?
   (iii) What is the distance traversed by the object during the first 8 s?
   (iv) What is the distance travelled at uniform velocity?
   (v) What is the deceleration of the object during the interval from 12 s to 16 s?
   (vi) What is the displacement of the object after 16 s?

5. An object starting from rest and travelling along a straight line takes 8 s to acquire a veloctity of 16 m $s^{-1.}$ Next, it moves at a uniform velocity for 4 s and ultimately decelerates for 4 s before coming to rest.

   (i) Sketch a velocity-time graph for the above motion.
   (ii) Find the deceleration during the first 8 s.
   (iii) What is the distance traversed by the object during the first 8 s?
   (iv) What is the distance traversed at a uniform velocity of 16 m s^{-1} ?
   (v) Find the deceleration during the last 4 s.
   (vi) What is the distance moved during the last 4 s?

6. (i) A fruit in a tree that detaches from the stalk takes 4 s to fall to the ground
   (a) What is its velocity when it reaches the ground?
   (b) What is the height that it fell from?

   (ii) An object is projected vertically upwards at an initial velocity of 30 m s^{-1}.

   (a) Find the time taken by the object to reach its maximum height.
   (b) What is the maximum height reached by the object?
   (c) Sketch the velocity-time graph for the motion of the object from the time it was projected until it reaches the maximum height.

Summary

- The distance traversed by a body to move from a certain point to another point depends on the path taken. But its displacement depends only on the initial and final points.

- Distance has a magnitude only. It is a scalar quantity.

- Displacement is a vector quantity. The magnitude of the displacement is the straight line distance between the initial and final points. Its direction is the direction of the straight line segment drawn from the initial to the final point.

- The rate of change of distance or the distance traversed in a unit time is known as the speed of an object. Speed is a scalar quantity.

- $\text{speed} = \dfrac{\text{distance}}{\text{time}}$

- The rate of change of displacement is known as the velocity. It is a vector quantity.

- $\text{velocity} = \dfrac{\text{displacement}}{\text{time}}$

- The rate of change of the velocity is known as the acceleration. A negative acceleration is known as a deceleration. Both acceleration and deceleration are vector quantities.

- $\text{acceleration} = \dfrac{\text{change of velocity}}{\text{time}}$

Technical terms		
Distance	දුර	தூரம்
Displacement	විස්ථාපනය	இடப்பெயர்ச்சி
Object	වස්තුව	பொருள்
Vector quantity	දෛශික රාශිය	காவிக் கணியம்
Scalar quantity	අදිශ රාශිය	எண்ணிக் கணியம்
Speed	වේගය	கதி
Velocity	ප්‍රවේගය	வேகம்
Acceleration	ත්වරණය	ஆர்முடுகல்
Retardation / (Deceleration)	මන්දනය	அமர்முடுகல்
Acceleration due to gravity-	ගුරුත්වජ ත්වරණය	புவியீர்ப்பினாலான ஆர்முடுகல்