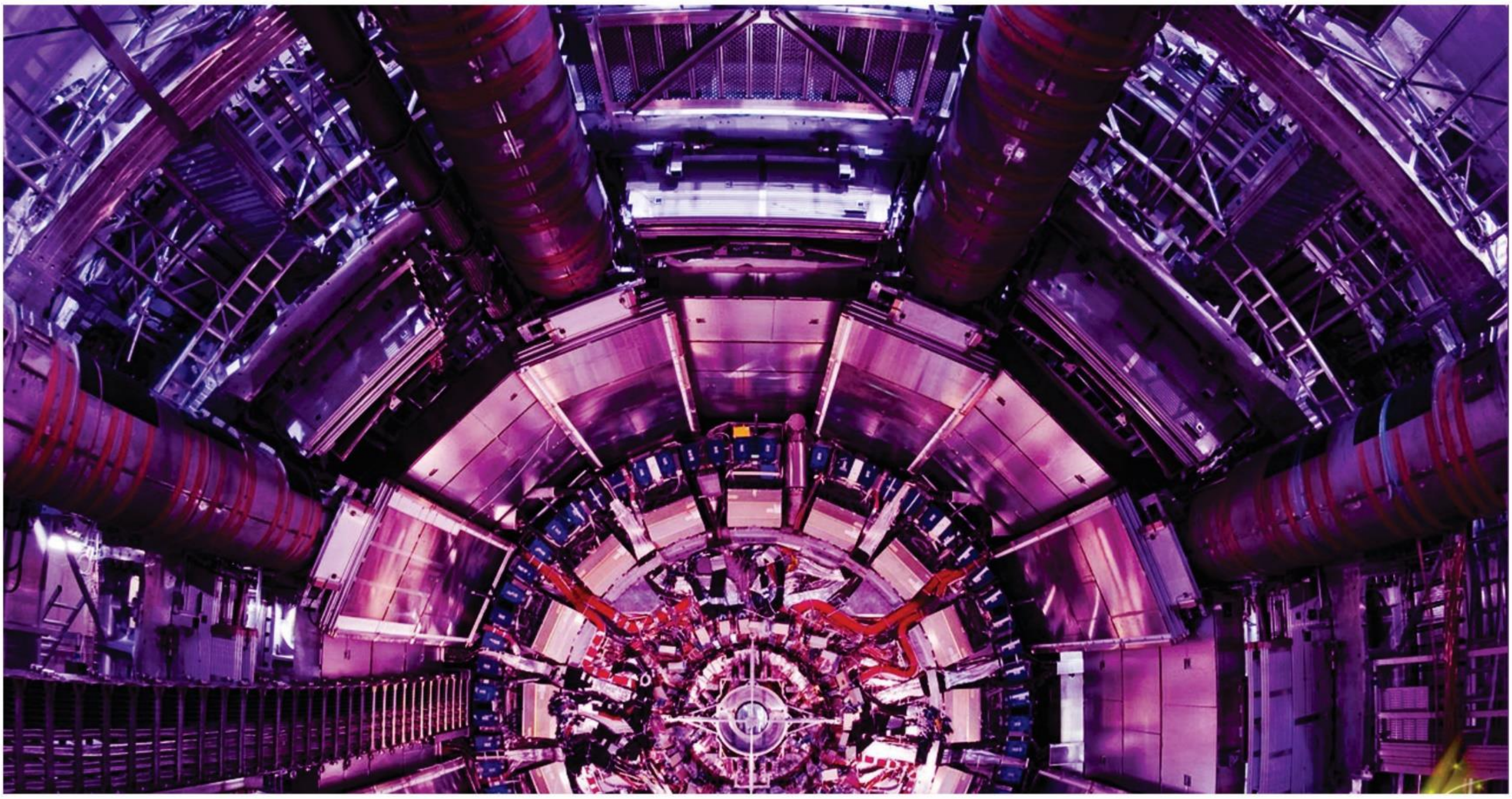

Concepts & Notes

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PHYSICS

Class - IX

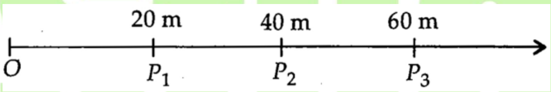
Motion

Introduction

Motion means the change in position of an object with respect to its surroundings in a given interval of time.
We see various things around us in motion, e.g. water flowing in a river, flowers nodding to blowing wind, birds flying in the sky, a player running in the playground and many more.
Motion is a relative phenomenon i.e. an object appearing to be in motion to one person can appear to be at rest to another person, e.g. to a person driving a car, trees on roadside might appear to move backward while same tree will appear to be at rest to a person standing on roadside. In this chapter we shall learn more about motion.

Describing Motion

Two different physical quantities the distance and the displacement, are used to describe the overall motion of an object and to locate its final position with reference to its initial position at a given time.
Since motion is a relative concept, we need a reference point to describe the position of an object. We call this reference point the origin.
Consider an object moving in a straight line. Let the object start from a point O. This starting point O is taken as the reference point. After 10 minutes it reaches the position P_3 through P_1 and P_2.



(time taken =10 min)
(time taken = 5 min)

In next 5 minutes it comes back to position P_2 (40 m away from O) and stops. So the total distance travelled by the object in these 15 minutes is $OP_3 + P_3P_2 = 60 + 20 = 80m$.
But the shortest distance between the initial and final positions of the object $= OP_2 = 40\,m$.
The shortest length of the path between initial and final positions is known as displacement.
So in the above example
Distance covered by the object = 80 m
Displacement of the object = 40 m right of 0.
Thus whereas distance is described with magnitude only, displacement requires both the magnitude and the direction. Physical quantities like distance, which can be described by magnitude only are called scalars, and the quantities are described using both magnitude and direction are called vectors. Hence distance is a scalar quantity and displacement is a vector quantity.

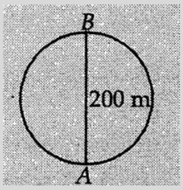
Do You Know

A vector is meaningful only if we know both magnitude and direction of vector. Without knowing direction, the description of a vector quantity is incomplete.

Illustration

1. An athlete completes a round of a circular track of diameter 200 m in 20 s. Calculate
(i) the distance travelled by the athlete and
(ii) the magnitude of the displacement of the athlete at the end of 1 minute and 10 seconds.

Sol. Here, diameter of circular track, D=200 m



$\therefore$ Length of circular track = circumference of the circular track

$$= 2\pi r = \pi(2r) = \pi D = \frac{22}{7} \times 200 = 628.57\text{m}$$

(i) Distance travelled in 20 s = length of circular track = 628.57 m

Distance travelled in 1 $s = \dfrac{628.57}{20} m$

$\therefore$ Distance travelled in 1 minute and 10 s (or 70 s) $= \dfrac{628.57}{20} m \times 70 = 2199.99 = 2200\text{m}$

(ii) Number of rounds completed in 20 s = 1
Number of rounds completed in 70 s $= \dfrac{1}{20} \times 70 = 3\dfrac{1}{2}$

When athlete completes 3 rounds, his displacement = zero

The position of the athlete in next $\dfrac{1}{2}$ round is just opposite to his starting point.

So, displacement of the athlete at the end of 1 minute and 10 s = diameter of the circular track = 200 m.

2. Are the following statements true or false
(a) Displacement cannot be zero
(b) The magnitude of displacement is greater than the distance travelled by the object.

Sol. (a) False, consider a boy who starts walking from a corner of a park along its perimeter and finally comes back to the initial point. As both starting and final positions of the boy are same. So his displacement is zero.
(b) False, since displacement is the length of shortest path between initial and final positions of the moving object, its magnitude can never be greater than the distance travelled.

Uniform and Non-uniform Motion

- **Uniform Motion**
  An object is said to be m uniform motion if it covers equal distances in equal intervals of time however big or small these time intervals may be.
  For example, suppose a car covers 60 km in first hour, another 60 km in second hour, again 60 km in the third hour and so on. The motion of the car is uniform motion. Let us now understand the meaning of the words, ('howsoever small the time interval may be') used in the definition. In this example, the car travels a distance of 60 km in each hour. In the stricter sense, the car should travel 30 km in each half hour ; 15 km in every 15 minutes ; 10 km is every 10 minutes, 5 km is every 5 minutes and 1 km in every one minute. Only then, the motion of the car can be said to be uniform. However, in broader sense, we do not mind even when time interval is big. The motion of the car is taken as uniform when it covers a distance of 60 km in every one hour.
- **Non-uniform Motion**
  Consider a bus starting from one stop. It proceeds slowly when it passes crowded area of the road. Suppose it manages to travel merely 100 m in 5 minutes due to heavy traffic. When it gets out and the road is clear, it speeds up and is able to travel about 2 km in 5 minutes. We say the motion of bus is non-uniform i.e. it travels unequal distances in equal intervals of time.
  Example of non-uniform motion is
  A speeding up or a slowing down vehicle.

Speed and Velocity

- **Speed**

Speed of a moving body gives us the idea about how fast or slow the body moves. In case of vehicles it is the quantity indicated by their speedometers.
Mathematically, it is the distance travelled by the object in unit time. We usually denote it by symbol v
$\therefore \upsilon =$ Distance travelled in unit time.
We also call it the instantaneous speed.
Its S.I. unit is meter per second represented by the symbol m/s or ms^{-1}. It is a scalar quantity as it requires magnitude only for its specification.
Many of the motions occurring around us are non - uniform motions. A train going from stop A to stop B, which are 100 km apart, may travel different intermediate intervals of path in different time spans. It will slow down or speed up at intermediate stops. Thus it does not move with a constant speed during its journey. We describe the rate of motion of such objects in terms of their average speed. Average speed is defined as the ratio of total distance travelled and total time taken.

$$\upsilon_{av} \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

Thus if the train discussed above travels first 25 km in 30 min, next 50 km in 40 min and the remaining 25 km in 30 min. The average speed of the train is

$$\upsilon_{av} = \frac{25\text{km}+50\text{km}+25\text{km}}{30\text{min}+40\text{min}+30\text{min}}$$

$$= \frac{100\,\text{km}}{100\,\text{min}} = \frac{1\text{km}}{\left(\frac{1}{60}\right)\text{h}} = 60\,\text{km/h}$$

An object undergoing a uniform motion is said to move with uniform speed while the object which is in non - uniform motion is said to be moving with a non - uniform speed.

ILLUSTRATION

3. On a 60 km track, a train travels the first 30 km at a uniform speed of 30 km/h. How fast must the train travel the next 30 km so as to get an average of 40 km/h for the entire trip?

Sol. Total distance (d) = 60 km
Speed (υ_1) during the first half journey = 30 km/h
To calculate: Speed (υ_2) for the 2nd half =?

Now $\upsilon_{av} = \dfrac{\text{Total distance}}{\text{Total time}}$

or $\upsilon_{av} = \frac{\text{Total distance}}{t_1 + t_2}$ where $t_1 = \frac{30}{30} = 1hr$

According to question $40 = \frac{60}{1 + \frac{30}{\upsilon_2}}$ or

$40(\upsilon_2 + 30) = 60\upsilon_2 \Rightarrow \upsilon_2 = 60\,\text{km/hr}$

Velocity (Speed with Direction)

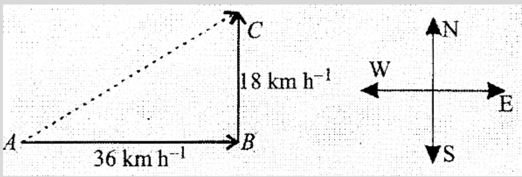
The distance covered by a body per unit time in a specified direction is called the velocity.
Thus the quantity that specifies both the speed and direction of an object is called velocity.
It is denoted by symbol v S.I. unit of velocity is m/s. larger unit such as km/h is also used.

- **Uniform Velocity**
  If the velocity of an object does not change as time passes, it is said to move with a uniform velocity. In such a case, both its speed and direction remain constant. This means that the object is moving along a straight line, without turning back, with a fixed speed. The displacement of the particle is equal in equal time intervals, however small a time interval we choose. We also say in this situation that the object is in uniform motion. If the object undergoes unequal displacement in equal time intervals, the motion is non uniform.
- **Non-Uniform Velocity**
  If the velocity of a moving body does not remain constant in a given interval of time, we say the body has a non-uniform velocity in that time interval. A body is said to have non-uniform velocity if
  (i) its speed i.e. magnitude of velocity changes and direction remains constant
  (ii) its direction of motion changes and speed remains constant, e.g. A boy running on a circular track with a constant speed of 2 m/s.
  (iii) both speed and direction change.
  Speed and velocity share similar relation as distance and displacement do.
  Thus speed $= \frac{\text{Distance travelled}}{\text{Time taken}}$ and velocity $= \frac{\text{Displacement}}{\text{Time taken}}$
  There are many instances when displacement of an object is zero while distance travelled is non-zero. Thus velocity of an object can be zero or have some other non-zero value (depending on displacement) different from its speed.

ILLUSTRATION

4. A car starts at 36 km/h towards east. After 10 minutes, it turns toward north and travels at a rate of 18 km/h for next 10 minutes. What is its average speed and velocity?

Sol.



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

$= \frac{\text{AB+BC}}{20\,\text{min}}$

$= \frac{(36\text{km/h})\times 10\text{min} + (18\text{km/h})\times 10\text{min}}{20\,\text{min}}$

$= \frac{[36\text{km/h}+18\text{km/h}]\times\left(\frac{10}{60}\text{h}\right)}{\left(\frac{20}{60}\right)\text{h}}$

$= \frac{[54\,\text{km/h}]}{2} = 27\,\text{km/h}$

Average velocity $= \frac{\text{Total displacement}}{\text{Total time taken}}$

$= \frac{AC}{20\text{min}} = \frac{\left(AB^2 + BC^2\right)^{\frac{1}{2}}}{20\text{min}}$

$= \frac{\left[(36)^2 + (18)^2\right]^{\frac{1}{2}} \times \left(\frac{10}{60}\right)\text{h}}{\frac{20}{60}\text{h}}$

$= \frac{1}{2}[40.25]\text{km/h}$ along AC.

= 20. 15 km/h along AC

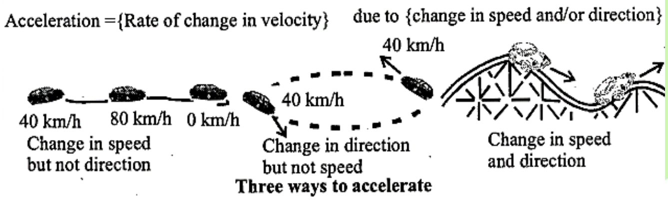
Acceleration

In non-uniform motion, velocity varies with time. The rate at which velocity varies is called acceleration. We can say that acceleration is the change in velocity per unit time.
If the velocity of an object from an initial value is u to the final value v in time t, then acceleration a is given by

$a = \frac{\upsilon - u}{t}$. This is also called **average acceleration.** As noted, velocity is a vector quantity, so is the acceleration. The S.I. unit of acceleration is s^{-2} or m/s^2.

Analysis of the equation, $a=\frac{\upsilon-u}{t}$

- When a body moves in a straight line without reversing its direction.
  (i) From the above equation if v > u, a is positive.
  $\Rightarrow$ If final velocity is greater than initial velocity, i.e. if the velocity increases with time, the value of acceleration is positive.
  (ii) If v < u, a is negative.
  $\Rightarrow$ If final velocity is less than initial velocity, i.e. if the velocity decreases with time, the value of acceleration is negative.
  Note: Negative acceleration is called retardation or deceleration.
  If the acceleration has a value of-2 m s-^{2}, then we say that the retardation is 2 m/s^2 or deceleration is 2 m/s^2.
  (iii) If v = u, 'a = 0. Acceleration is zero when the final velocity is equal to initial velocity.
  Note 1: An acceleration of 2ms^{-2} means that a change of velocity of 2 m/s is taking place in 1 s,
  i.e. $2\text{ms}^{-2}=\frac{2\text{ms}^{-2}}{1\text{s}}$
  Note 2: For constant acceleration, the average velocity for a given time interval can be calculated by the formula,
  Average velocity $\upsilon_{av}=\frac{u+\upsilon}{2}$



ILLUSTRATION

5. A boy starting from rest, starts running and attains a velocity of 6 m s^{-1} in 30 s. Then he slows down uniformly to 4 m s^{-1} in next 5 s. Calculate his acceleration in both cases.

Sol. In the first case
Initial velocity u = 0 ;
Final velocity, v = 6 ms^{-1};
Time t = 30 s. $a=\frac{\upsilon-u}{t}$
Substituting the given values of u, v and t in the above equation, we get
As $a=\frac{\left(6\text{ms}^{-1}\text{-}0\text{ms}^{-1}\right)}{30\text{s}}=0.2\text{ms}^{-2}$
In the second case:
Initial velocity, $u=6\text{ms}^{-1}$
Final velocity, $u=4\text{ms}^{-1}$;
time, t = 5 s.
Then $a=\frac{\left(4\text{ms}^{-1}-6\text{ms}^{-1}\right)}{5\text{s}}=-0.4\text{s}^{-2}$

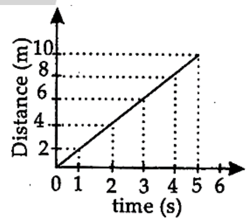
Study of Motion through Various Graphs

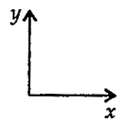
If information about various quantities related to motion is given in tabular form for various instants of time, it can be converted in graphical form. It makes easier for us to find out relation between various physical quantities.

Distance-Time Graphs

(i) Distance is taken along Y-axis and time along the X-axis. A convenient scale is chosen for both the axes. Consider the following data taken by an observer for a bus in 5 sec. using this data we can obtain the distance - time graph for the bus as shown

Distance (m)	Time (s)
0	0
2	1
4	2
6	3
8	4
10	5

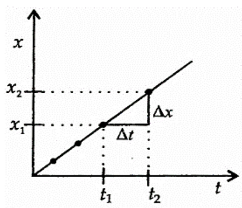




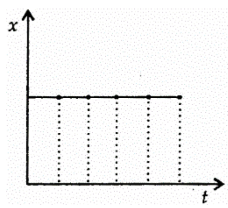
We see, the graph is a straight line passing through the origin (intersection of two axes). It is clear that the bus is travelling 2 m in each second, or the body has a constant speed Let us find out speed of the bus from above graph. By definition speed of a body is given by

$\upsilon=\frac{\text{total distance travelled}}{\text{total time taken}}$

Let us take any two instances t_1 and t_2 on the distance-time graph when the distance travelled by the bus are x_1 and x_2 respectively.



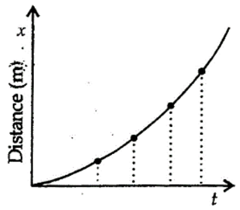
So the distance travelled between instances t_1 and t_2 is (x_2-x_1) and time taken is t_2-t_1



$\therefore$ speed $=\frac{x_2-x_1}{t_2-t_1}=\frac{\Delta x}{\Delta t}$ where $\frac{\Delta x}{\Delta t}$

is called the slope of distance time graph. In other words slope of the line obtained in a distance time graph gives the speed of the object.

(ii) If distance-time graph of an object is a straight line parallel to the time axis, as shown in graph, we say the position of the object does not change with time. Or the object remains at rest.



(iii) If we get a curved line in distance-time graph then, if we find slope for any two time intervals, it will not be same.

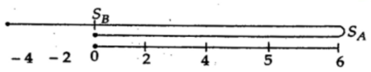
Or we say the object has a non-uniform speed i.e. the body is accelerated.

Displacement-Time Graph

As discussed earlier, we know that displacement of an object can be negative also while distance is always positive. Thus displacement time graph differs from distance-time graph in following manner.

First the objects moves with a constant velocity given by slope of line OA.

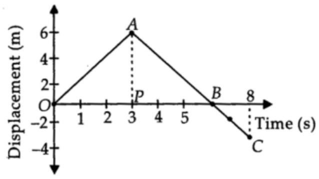
Velocity $= \dfrac{AP}{OP}$



After that object moves with a constant velocity given by slope of line AC.

Now slope of line $AC = \dfrac{S_A - S_B}{t_A - t_B}$

$= \dfrac{6-0}{3-6} = -\dfrac{6}{3} = -2$ It is negative.



We say the object moves with velocity -2 m/s i.e. with a velocity 2 m/s in opposite direction. It comes to original position in 6 sec (Zero Displacement) and then moves to the other side maintaining its velocity.

The distance-time and displacement-time graphs of a moving body are similar only when the body moves along a straight line in its positive direction without changing its direction.

Velocity-Time Graphs

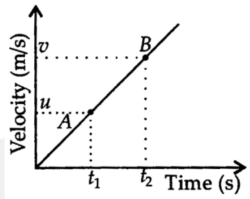
In these graph, variation of velocity of an object with time is shown. Time is taken along x-axis while velocity is taken along y-axis.

- **Velocity- time graph for uniformly accelerated motion:**

  Consider the velocity time graph shown.

  It is a straight line with a positive slope passing through the origin.

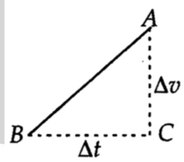
  Consider any two positions A and B of the object at instants t_1 and t_2 when the object has velocities u and v respectively.



  Now according to definition of acceleration

  $a = \dfrac{\Delta \upsilon}{\Delta t} = \dfrac{\upsilon - u}{t_2 - t_1}$ ....(i)

  $= \dfrac{BC}{AC} =$ slope of the straight line



  Thus slope of the graph obtained in a velocity time graph gives the acceleration of the object. Now for a straight line, the slope will be same for any two points considered. Or we can say acceleration will remain constant or uniform.

  Thus a uniform accelerated motion is shown by a straight line having a positive slope in a velocity time graph.

  Consider equation (i) above once more.

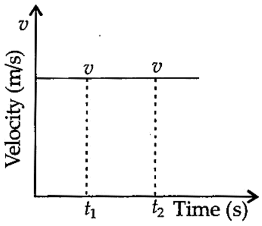
  $a = \dfrac{\upsilon - u}{t_2 - t_1}$ Let $t_2 - t_1 = t \Rightarrow a = \dfrac{\upsilon - u}{t}$ or $\upsilon = u + at$

  Which is one of the very important equation of motion.

- **Velocity time graph for a uniform motion:**

  When an object is in uniform motion, it will have a constant velocity at every instant, i.e. velocity won't change with time. Or we can say that velocity time graph is a straight line parallel to time-axis.

  Now acceleration between any two instants t_1 and t_2 is $a = \dfrac{\Delta \upsilon}{\Delta t} = \dfrac{\upsilon - u}{t_2 - t_1} = 0$



Thus acceleration is zero for an object having uniform motion.

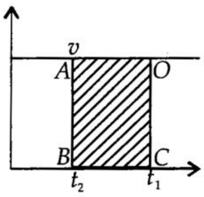
Also according to the definition of velocity

Average velocity $= \dfrac{\text{total displacment}}{\text{total time taken}}$

Again taking same time interval between two instants t_1 and t_2

$$\upsilon = \frac{s}{t_2 - t_1} \Rightarrow s = \upsilon \times (t_2 - t_1) = AB \times BC$$

= Area of the shaded region shown in adjacent graph.



Thus distances of the object is given by the area enclosed by velocity time graph and the time axis.

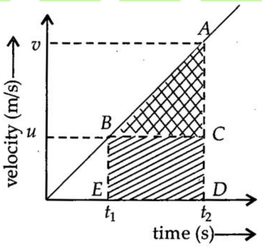
Distance can also be obtained for a uniformly accelerated motion using same method.

Total distance = Area of trapezium ABEDC

s = Area of rectangle BCDE + Area of triangle ABC.

$$= BE \times ED + \frac{1}{2} \times AC \times BC$$

$$= u \times (t_2 - t_1) + \frac{1}{2}(\upsilon - u) \times (t_2 - t_1)$$



Let time interval $t_2 - t_1 = t$

$$\Rightarrow \quad s = ut + \frac{1}{2}(v-u)t$$

Using equation, v = u + at, we get

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

This is second equation of motion.

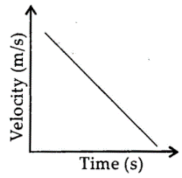
Consider the figure given above once again,

s = Area of trapezium ABEDC

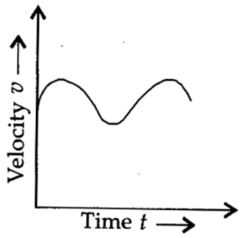
$$= \frac{1}{2} \times ED(BE + AD) = \frac{1}{2}t(u + \upsilon)$$

$$= \frac{1}{2}\frac{(\upsilon - u)a}{ }(\upsilon + u) = \frac{1}{2a}(\upsilon^2 - u^2)$$

- **Uniformly retarded motion:** For this velocity- time graph is a straight line having a negative slope as shown



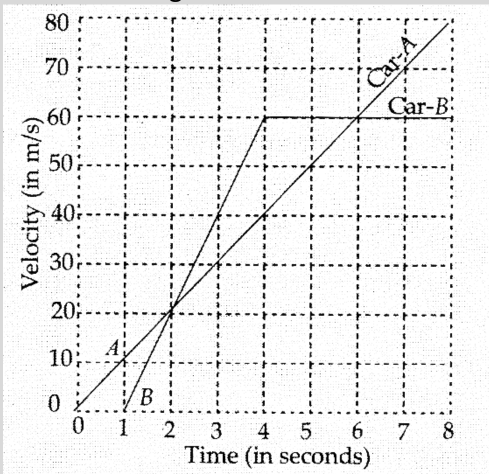
- **Non- uniformly acceleration motion:** For this velocity time graph can have any shape depending upon how the velocity varies. Here Time(s) acceleration will be different between different instants as the slope does not remain constant.



The graphs discussed above can also be used to make a comparative study of motion of two or more objects. Consider the illustration given.

ILLUSTRATION

6. The velocity-time graph of two cars A and B, which start from the same place and move along a straight road in the same direction, as shown in diagram. Calculate



(i) the acceleration of car A.

(ii) the acceleration of car B between 2 s to 4 s.

(iii) the points of time at which both the cars have the same velocity

(iv) which of the two cars is ahead after 8 seconds and by how much?

Sol. (i) Acceleration of car A

(ii) Acceleration of car B $a = \dfrac{80}{8} = 10\,\text{ms}^{-2}$

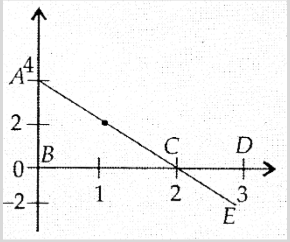
(iii) After 2 seconds and 6 seconds from start.

(iv) Distance travelled by car

$A=\frac{1}{2}\times 80\,m/s=320\,m$ and distance travelled by car $B=\frac{1}{2}\times(7+4)s\times 60\,m/s=330\,m$

$\therefore$ Car B is ahead by 330 – 320 = 10 m.

7. Find the displacement of a car between t = sec to t = 3 sec for the given velocity time graph.



Sol. As discussed earlier, the area between velocity-time graph and the time axis gives the displacement.

$\therefore$ Required displacement

= Area of ΔABC + Area of ΔDCE

$=\frac{1}{2}AB\times BC+\frac{1}{2}CD\times DE$

$s=\frac{1}{2}\times(4m/s)\times 2s+\frac{1}{2}(1s)\times(-2m/s)$

$=4m-1m$

S=3 m, So total displacement = 3 m.

If we study this graph carefully, it is a uniformly retarded motion. Initially at t = 0 sec, object has a velocity 4 m/s. It decreases uniformly till it becomes zero at t = 2 sec i.e. the object momentarily comes to rest at t =2 sec. Velocity still continues to decrease at the same rate i.e. the object now starts moving in opposite direction or we say the velocity now has a negative value. It is for this reason that displacement corresponding to ΔACB is taken as positive and for ΔDCE as negative.

Equations of Motion for Uniformly Accelerated Motion

The three important equations of motion, which we have derived in last section also, are given below:

(i) $\upsilon=u+at$

(ii) $s=ut+\frac{1}{2}at^2$

(iii) $2as=\upsilon^2-u^2$

Illustration based on these equations are as follows.

ILLUSTRATION

8. A bus starting from rest moves with a uniform acceleration of 0.1 ms^{-2} for 2 minutes. Find (a) the speed acquired, (b) the distance travelled.

Sol. Here, u = 0,

A = 0.1 ms^{-2}, t = 2 minutes = 120 s

(a) Using, $\upsilon=u+at, \upsilon=0+0.1\times 120=12\,ms^{-1}$

$\therefore$ speed acquired $=12\,ms^{-1}$

(b) Using, $s=ut+\frac{1}{2}at^2$, we get

$s=0+\frac{1}{2}\times 0.1\times 120\times 120=720\,m$

$\therefore$ Distance travelled = 720 m.

A bus decreases its speed from 80 km h^{-1} to 60 km h^{-1} in 5 s. Find the retardation of the bus.

Sol. Here, u = 80 km h^{-1} = $80\times\frac{5}{18}ms^{-1}$

$=22.22\,ms^{-1}$ $\upsilon=60\,km\,h^{-1}=60\times\frac{5}{18}ms^{-1}$

$=16.67\,ms^{-1}$ t = 5 s

$\therefore$ retardation,

$a=\frac{\upsilon-u}{t}=\frac{(16.67-22.22)ms^{-1}}{5s}$

$a=\frac{-5.55\,ms^{-1}}{5s}=1.11\,ms^{-2}$

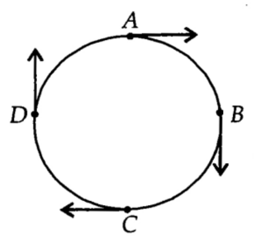
Uniform Circular Motion

If an object moves in a circular path with uniform speed, its motion is called uniform circular motion.

A circular path can be made up of an indefinite number of small sides, and a body moving along such a circular path changes its direction of motion continuously.

Therefore, if you run on a circular track, you change your direction infinite times in one round.

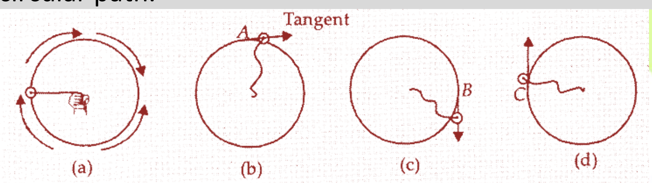
Four arbitrary points on the circular path and the direction of motion of the body at these points are shown. Since the direction of motion changes, uniform circular motion is a case of accelerated motion.



ACTIVITY CORNER

Take a small stone and tie it with one end of a strong thread. Now, move the stone in a circular path by holding the other end of the thread in your hand as shown in figure

(a). Leave the thread, when the stone is at position A on the circular path as shown figure (b). You will find that the stone moves in a straight line which the tangent to the position A on the circular path. Again, move the stone in the circular path and leave the thread, when stone is at position B as shown in figure (c). Once again, you will find that the stone moves in a straight line which is the tangent to the position B on the circular path. Repeat the activity and leave the thread, when the stone is at different position on the circular path.



From this simple activity, we conclude that the direction of motion of a body moving in a circular path is always along the tangent to a point on the circular path. Thus, the direction of motion of a body moving in a circular path is different at different positions of the circular path.

Note:

If a body moves around a circular path of radius r in the time t then the distance covered by the body is equal to the circumference of the circle, i.e., $2\pi r$. In such a case the velocity v is given by $\upsilon = \frac{2\pi r}{t}$

Examples for circular motion

- **A stone tied to a thread and whirled in a circular path.**
- **Wheels of various vehicle rotating about their axles.**
- **A satellite revolving around the Earth in a circular path, at constant speed.**
- **The Moon revolving around the Earth in a circular path at constant speed.**

  In the above examples, the speed is uniform, but the velocity is variable due to continuous change in direction. Thus, the bodies have an accelerated motion.

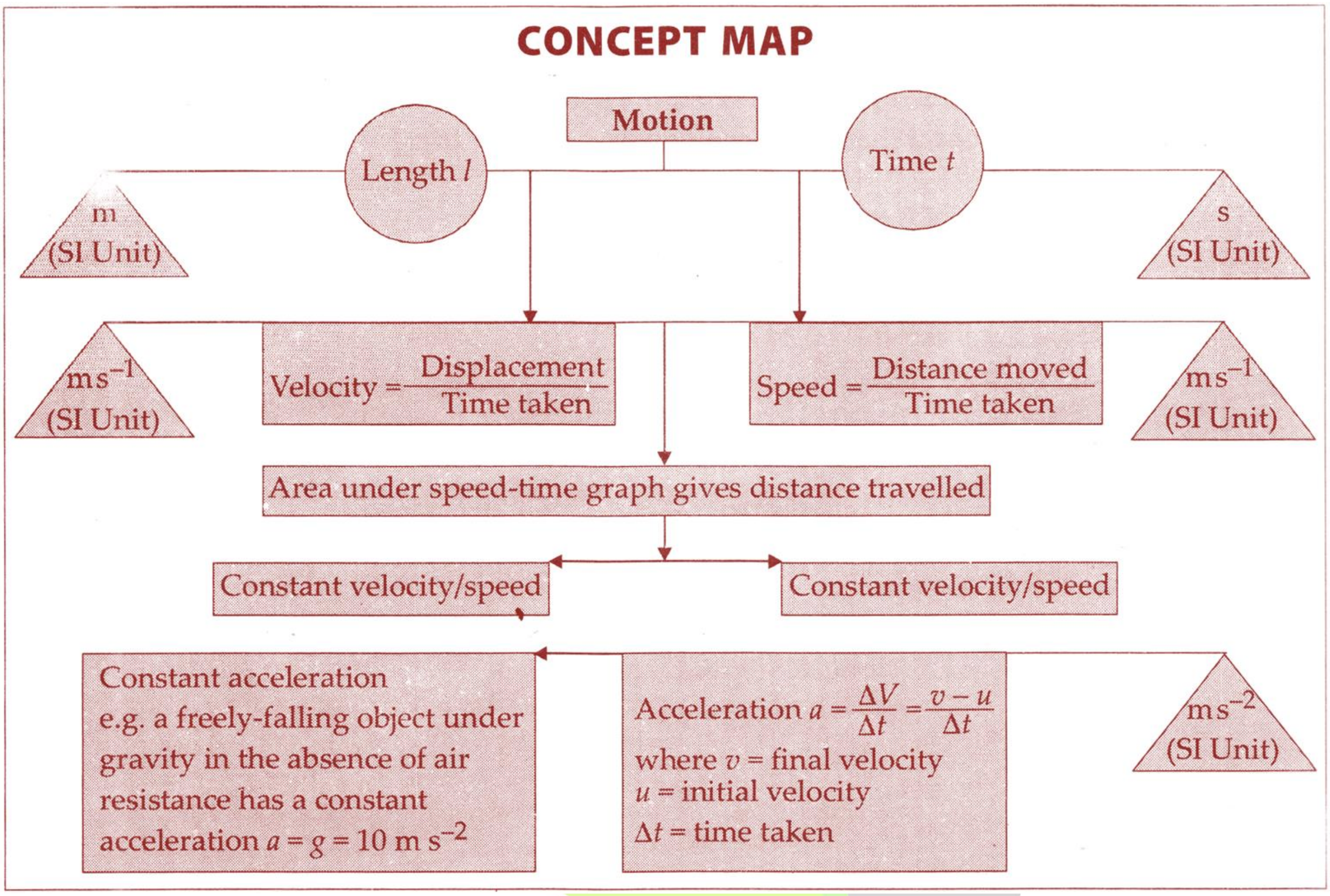
ESSENTIAL POINTS For COMPETITIVE EXAMS

- **Rest:** When a body does not change its position with respect to time and its surroundings, the body is said to be at rest.
- **Motion:** When a body continuously changes its position with respect to time and its surroundings, the body is said to be in motion.
- **Characteristics (properties) of a moving body:**

  (i) There must be a reference point (a stationary object) to describe the position of a given body.

  (ii) The position of the given body must continuously change with time and with respect to reference point.
- **Distance:** It is the actual length of the path travelled by a moving body, irrespective of the direction of motion of the body.
- **Displacement:** The shortest distance of a moving body from the point of reference (initial position of the body) in a specified direction is called displacement.
- **Uniform motion:** When a body covers equal distances in equal intervals of time, however small may be time intervals, the body is said to be uniform motion.
- **Non-uniform motion:** When a body covers unequal distances in equal intervals of time, it is said to be moving with non-uniform motion.
- **Speed:** The rate of change of motion is called the speed.
- **Mathematical expression for speed:** Speed = Distance ÷ Time. S.I. unit of speed is metre per second (ms^{-1} or m/s)
- **Uniform speed:** When a body covers equal distances in equal intervals of time, however small may be the time intervals, the body is said to be moving with uniform speed.
- **Variable speed:** When a body covers unequal distances in equal intervals of time, the body is said to be moving with a variable speed.
- **Average speed:** The total distance covered by a body per unit time is called average speed.

- **Velocity:** The distance covered by a body per unit time in a specified direction is called velocity. It is a vector quantity and has same units as speed.
- **Uniform velocity:** When a body covers equal distances in equal intervals of time (however small may be the time intervals) in a specified direction, the body is said to be moving with uniform velocity.
- **Variable velocity or Non-uniform velocity:** When a body covers unequal distances in equal intervals of time in a specified direction or when a body covers equal distances in equal in - tervals of time, but its direction changes, then the body is said to be moving with a variable velocity.
- **Acceleration:** The rate of change of velocity of a moving body is called acceleration. It is a vector quantity and its unit is metre per second square ($m\ ms^{-1}$ or m/s^2)
- **Positive acceleration:** The rate of change of velocity of a moving body, when the velocity is increasing is called positive acceleration.
- **Negative acceleration:** The rate of change of velocity of a moving body, when the velocity is decreasing is called negative acceleration or retardation.
- **Distance - time graph:**
  (a) The distance-time graph of an object moving with a uniform speed is a straight line. Conversely, if the distance-time graph of an object is a straight line, the object is moving with a uniform speed.
  (b) The slope of the distance-time graph of an object equals its speed.
  (c) If an object moves with no uniform speed, its distance-time graph is not a straight line.
- **Displacement-time graph:**
  (a) The displacement-time graph of an object moving with a uniform velocity is a straight line.
  (b) The slope of the displacement-time graph of an object equals its velocity.
- **Speed-time graph:**
  (a) If an object moves with a constant speed, its speed-time graph is a straight line parallel to the time-axis.
  (b) The area under the speed-time graph gives the distance traversed by the object in the corresponding time interval.
- **Velocity-time graph:**
  (a) If an object moves with a constant acceleration in a straight line, its velocity-time graph is a straight line.
  (b) The slope of the velocity-time graph gives the acceleration of the object.
  (c) The area under a velocity-time graph gives the displacement of the object.
- **Circular motion:**
  A particle moving in a circular path changes its direction continuously, and hence, is accelerated.
- **Mathematical equations :**
  s = vt s = distance, v = speed (assumed constant), t = time v = u + at u = velocity at t = 0, v = velocity at time t, a = acceleration (assumed constant). $s = ut + \frac{1}{2}at^2$ s = displacement during time 0 to t.
  u = velocity at t = 0, a = acceleration (assumed constant) $v^2 = u^2 + 2as$
  Symbols have the same meaning as in the above equations.


CONCEPT MAP
Motion
Length l
Time t
m (SI Unit)
s (SI Unit)
ms^{-1} (SI Unit)
Velocity = $\frac{\text{Displacement}}{\text{Time taken}}$
Speed = $\frac{\text{Distance moved}}{\text{Time taken}}$
ms^{-1} (SI Unit)
Area under speed-time graph gives distance travelled
Constant velocity/speed
Constant velocity/speed
Constant acceleration e.g. a freely-falling object under gravity in the absence of air resistance has a constant acceleration $a = g = 10\ m\ s^{-2}$
Acceleration $a = \frac{\Delta V}{\Delta t} = \frac{v-u}{\Delta t}$
where v = final velocity
u = initial velocity
Δt = time taken
ms^{-2} (SI Unit)