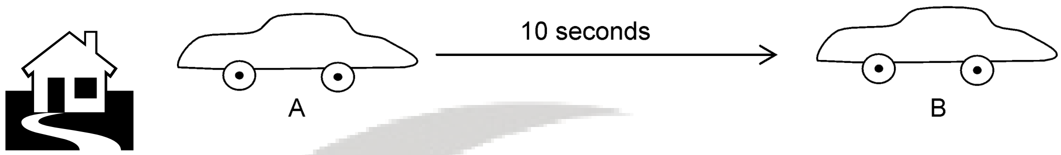
1. MOTION

The most important characteristic of all moving bodies is that they change their position with time.

A body is said to be in motion, when it changes its position continuously with respect to a stationary object taken as the standard or reference point.

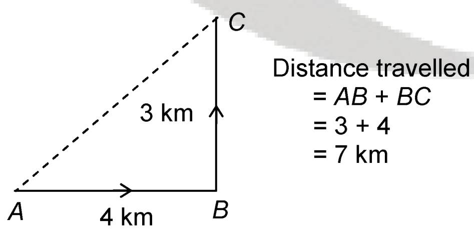
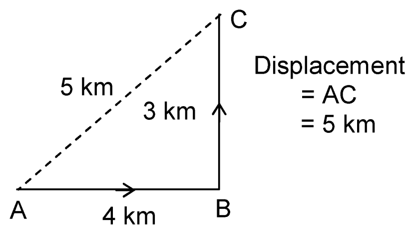


For example a car is in front of the hut at A. But after 10 seconds, it has changed its position to B. Here, the hut is a reference point and the car is changing its position with respect to this stationary object. Hence the car is said to be in motion. In order to study motion in depth we must know the meaning of the following terms.

2. SCALAR AND VECTOR QUANTITIES

Scalar Quantities	Vector Quantities
(a) Those physical quantities having magnitude but no direction are called scalar quantities. (b) For example Mass, Length (Distance), Time, Volume, Density, temperature and humidity etc.	Those physical quantities that have magnitude as well as direction are called vector quantities. For example displacement, velocity, acceleration, and force etc.

3. DISTANCE AND DISPLACMENT

Distance	Displacement
(a) The distance travelled by a body is the actual length of the path covered by a moving body irrespective of the direction in which the body travels (b) It is a scalar quantity therefore it has only magnitude 	When a body moves from one point to another, the shortest distance between the initial position and final position of the body, along with direction, is known as displacement. It is vector quantity therefore it has magnitude as well as direction. 

- Distance travelled by a moving body cannot be zero but the displacement of a moving body can be zero.
- With increase in time distance can not decrease but displacement can.

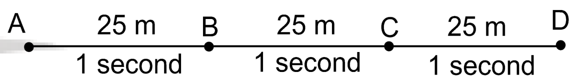
4. UNIFORM AND NON-UNIFORM MOTION

4.1 UNIFORM MOTION

A body is said to have uniform motion if it travels equal distances in equal intervals of time, howsoever small the time interval may be

For example

This body is travelling 25 m in the first second, 25 m in the second and 25 m in the third second. It is therefore undergoing uniform motion.

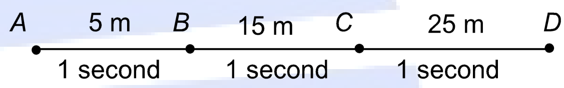


4.2 NON-UNIFORM MOTION

A body is said to have non-uniform motion if it travels unequal distances in equal intervals of time

For example

If a body starts at A and acted upon by a force it initially travels slowly then it gains speed. It travels 5 m in the first second, 15 m in the second and 25 m in the third. As these are unequal distances, it is known as non-Uniform motion.



5. SPEED, VELOCITY AND ACCELERATION

5.1 SPEED

The speed of a body tells us how slow or fast that body is moving. speed of a body is the distance travelled by it per unit time

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

Speed is represented by '*v*', distance by '*s*' and time by '*t*'.

Therefore $v = \frac{s}{t}$

The S.I. unit of speed is ms^{-1} (meter per second). It can also be represented as centimeter per second and kilometer per hour.

The speed of a running car is shown by an instrument called "SPEEDOMETER". The distance travelled by the car is measured by another instrument called ODOMETER.

5.1.1 Average Speed

The average speed of a body is the total distance travelled divided by the total time taken to cover that distance.

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

5.1.2 Uniform speed or constant speed

A body has a uniform speed if it travels equal distances in equal intervals of time, howsoever small the time intervals may be

For example

A —30 km, 1 hour— B —30 km, 1 hour— C —60 km, 2 hour— D

Speed (A to B) $= \frac{30}{1}$ = 30 km/hr Speed (B to C) $= \frac{30}{1}$ = 30 km/hr Speed (C to D) $= \frac{60}{2}$ = 30 km/hr

5.1.3 Non-uniform speed

A body has non-uniform speed if it travels unequal distances in equal intervals of time.

For example

A —30 km, 1 hour— B —20 km, 1 hour— C —10 km, 1 hour— D

Speed (A to B) $= \frac{30}{1}$ = 30 km/hr Speed (B to C) $= \frac{20}{1}$ = 20 km/hr Speed (C to D) $= \frac{10}{1}$ = 10 km/hr

5.2 VELOCITY

Velocity of a body is the distance travelled by it per unit time in the given direction

$$\text{Velocity} = \frac{\text{Displacement (Distance travelled in given direction)}}{\text{Time Taken}}$$

$$v = \frac{s}{t}$$

The S.I. unit of velocity is ms^{-1}

Therefore, 25 km/hr is SPEED and 25 km/hr towards North is VELOCITY.

The direction of velocity is the same as direction of displacement of the body.

5.2.1 Uniform velocity

A body is said to be in uniform velocity if it travels in a specified direction in a straight line and covers equal distances in equal intervals of time, howsoever small the time intervals may be.

Any change in velocity may occurs in three ways:

(a) by changing the speed of the body

(b) by keeping speed constant but changing the direction.

(c) by changing both speed and direction

5.2.2 Average velocity

If a body has changing velocity, but the change is uniform, the average velocity can be calculated as

$$\text{Average velocity} = \frac{\text{Initial velovity} + \text{Final velocity}}{2}$$

It is also represented as

$$\bar{v} = \frac{u+v}{2}$$

where, $\bar{v}$ = Average velocity
u = Initial velocity
v = Final velocity

5.3 ACCELERATION

We notice that bodies do change their speed or velocity. For example if we see the speedometer of a car, we will notice that the needle keeps on moving, that is the velocity of the car keeps on changing. The rate at which this change in velocity occur, is known as acceleration.

∴ Acceleration of a body can be defined as the rate of change of velocity with time

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

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

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

Where a = Acceleration of the body
v = Final velocity of the body
u = Initial velocity of the body
t = Time taken for this change in velocity

- S.I. unit of acceleration is ms^{-2} (meter per Second Square)
- Acceleration is a vector quantity
- When a body is moving with uniform velocity, its acceleration is zero (or no acceleration) This is because there is no change in velocity as initial velocity = Final velocity.
- A body moving with non-uniform velocity is said to be in accelerated motion.

5.3.1 Uniform acceleration

A body has uniform acceleration when it travels in a straight line and its velocity increases or decreases by equal amounts in equal intervals of time.

It can also be said that when the velocity of a body changes at a uniform rate, it is said to have uniform acceleration.

5.3.2 Non-uniform acceleration

A body is said to have non-uniform acceleration if its velocity increases or decreases by unequal amount in equal intervals of time

OR

When the velocity of a body changes at unequal rate or non-uniform rate.

5.3.3 Negative acceleration (retardation or deceleration)

Till now we have seen the case of increasing velocities. In many cases, there is also a decrease in velocity. For example when we apply brakes, the car stops after some time.

Therefore, if the velocity of the body increases, Acceleration is said to be **Positive Acceleration**

And if the velocity of a body decreases, acceleration is said to be **Negative Acceleration**, which is also called as **Retardation** or **Deceleration**.

Retardation is measured in the same way as acceleration.

$$\text{Retardation} = \frac{v-u}{t}$$

- S.I. unit of retardation is ms^{-2}
- Value of retardation is always negative as in this case '*u*' is always larger than '*v*'

6. EQUATIONS OF UNIFORMLY ACCELERATED MOTION

When the body is moving along a straight line with uniform acceleration, a relation can be established between velocity of the body, acceleration of the body and the distance travelled by the body in a specific time by a set of equation. These equations are called equations of motion.

The three equations are:

First Equation of motion : $v = u + at$

Second Equation of motion: $s = ut + \frac{1}{2}at^2$

Third Equation of motion : $v^2 - u^2 = 2as$

Where u = initial velocity of the body
v = final velocity of the body
a = uniform acceleration of the body
t = time taken
s = distance travelled

7. GRAPHICAL REPRESENTATION OF MOTION

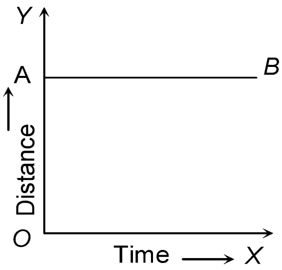
A Graph represents the relation between two variable quantities in pictorial form. A graph is plotted between two variable quantities. The quantity that is made to alter at will is called independent variable. The other quantity, which varies as a result of this change is called the dependent variable. These graphs are used to calculate speed, acceleration and distance. For the purpose of graphical representation speed and velocity are taken in the same meaning.

There are two types of graphs we draw

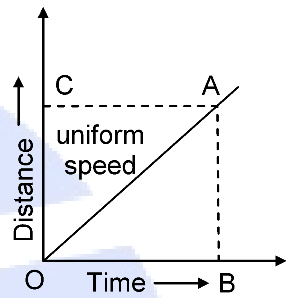
1. Distance –Time graph
2. Speed – Time graph or Velocity-Time graph

7.1 DISTANCE –TIME GRAPH

(a) When we draw Distance –Time Graphs, time is always taken on the x-axis and distance on the y-axis.
In this graph AB is a straight line parallel to x-axis. In this graph, the distance travelled is not increasing with time. This is a graph of stationary object.



(b) The Distance-Time graph of a body moving at uniform speed is represented by a straight line OA as shown in figure. It can be used to calculate the speed of the body by finding the slope of the graph

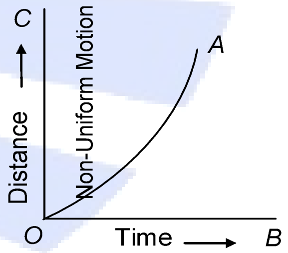


$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$\text{Speed} = \frac{AB}{OB}$$

$\frac{AB}{OB}$ is also taken as the slope of the graph, which indicates the speed of the body.

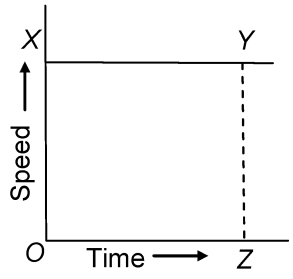
(c) When the Speed – Time graph is a curve, it represents non-uniform motion. This curved line is called a PARABOLA



7.2 SPEED-TIME GRAPH

7.2.1 When speed remains constant (zero Acceleration)

If the speed-time graph of a body is a straight line parallel to the time axis, then speed of the body is constant (uniform)



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

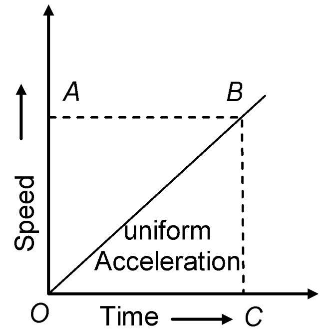
$$\text{Distance} = \text{Speed} \times \text{Time}$$

$$= YZ \times OZ$$

Therefore, the area enclosed by the speed-time graph and the x-axis(time-axis), represents the Distance travelled by the body.

7.2.2 When speed increases at uniform rate (uniform Acceleration)

The speed –time graph for uniformly changing speed will be a straight line.



Acceleration $= \frac{\text{change in speed}}{\text{Time Taken}}$

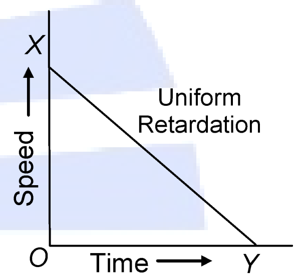
Acceleration $= \frac{BC}{OC}$

Therefore acceleration of a body is given by the slope of the graph $\left(\text{i.e.} \frac{BC}{OC}\right)$

The distance travelled = Area under ΔOBC = $\frac{1}{2} \times OC \times BC$

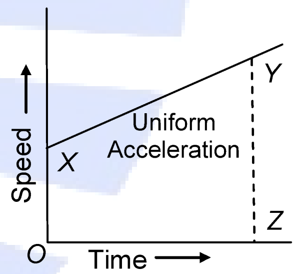
7.2.3 When speed decreases at uniform rate(Retardation)

In speed time graphs, a straight line sloping downwards indicates uniform retardation.



7.2.4 When initial speed of the body is not zero

When the initial speed of the body is not zero, the speed-time graph is represented as a straight line forming a trapezium with the time-axis.



Distance travelled = Area of Trapezium *OXYZ*

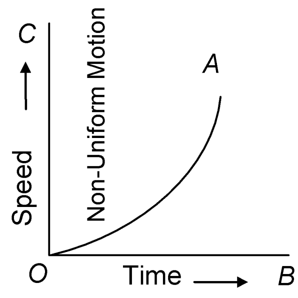
$= \frac{1}{2}$ (sum of parallel sides) (Height)

$= \frac{1}{2}(OX + YZ)(OZ)$

$= \frac{1}{2}(u + v)(t)$

7.2.5 When speed changes at non-uniform rate

Speed-time graph of non-uniform speed (non-uniform acceleration) is a curved line.



8. DERIVATION OF EQUATIONS OF MOTION BY GRAPHICAL METHOD

8.1 TO DERIVE *v* = *u* + *at* BY GRAPHICAL METHOD

This is a graph of uniform acceleration with '*u*' as initial velocity and '*v*' as final velocity.

Initial velocity = *u* = *OP*

Final velocity = *v* = *RN*

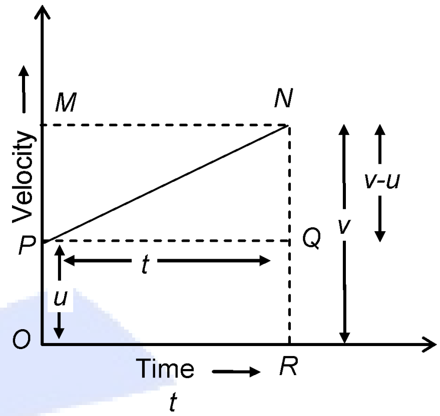
= *RQ* + *QN*

v = *u* + *QN* .....(i)

Acceleration, a = slope of line *PN*

$$a = \frac{QN}{PQ} = \frac{QN}{t}$$

$QN = at$ .....(ii)



Putting the value of *QN* from equation (ii) into equation (i), we get *v* = *u* + *at*

8.2 TO DERIVE $s = ut + \frac{1}{2}at^2$ BY GRAPHICAL METHOD

In the above speed-time graph, the distance travelled is given by

Distance travelled = Area of figure *OPNR*

= Area of Δ*PNQ* + Area of rectangle *OPQR*

(1) Area of triangle *PNQ* = $\frac{1}{2} \times \text{base} \times \text{height}$

= $\frac{1}{2} \times PQ \times NQ = \frac{1}{2} \times t \times (v - u)$

= $\frac{1}{2} \times t \times at$ [As *v* = *u* + *at* and *v* − *u* = *at*]

Area of Δ*PNQ* = $\frac{1}{2}at^2$

(2) Area of rectangle *OPQR* = *OP* × *PQ*

= *u* × *t*

= *ut*

Distance travelled = Area of Δ*PNQ* + Area of rectangle *OPQR*

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

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

8.3 TO DERIVE $v^2 - u^2 = 2aS$ BY GRAPHICAL METHOD

In the above speed time graph distance travelled (S) = Area of trapezium *OPNR*

$S = \frac{1}{2} \times$ (sum of parallel sides) × height

$S = \frac{1}{2} \times (OP + RN) \times OR$

$S = \frac{1}{2} \times (u + v) \times t$

$S = \frac{1}{2} \times (v + u)\, t$ …(i)

But v = u + at

at = v − u

$t = \left(\frac{v-u}{a}\right)$ … (ii)

Putting this value of '*t*' from equation (ii) into equation (i) we get that ___

$S = \frac{1}{2} \times (v + u) \left(\frac{v-u}{a}\right)$

$S = \frac{(v+u)(v-u)}{2a}$

$S = \frac{v^2 - u^2}{2a}$ [As $(a + b)(a - b) = a^2 - b^2$]

$2as = v^2 - u^2$

$v^2 - u^2 = 2as$

9. CIRCULAR MOTION

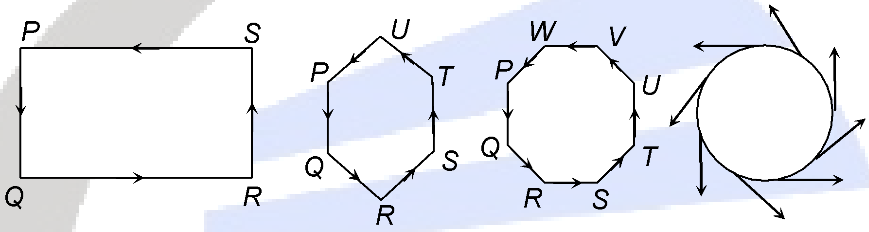
When a body or an object moves in a circle, its motion is called circular motion. In other words, motion in a circle is circular motion.

When a body (or object) is moving along a circular path, then its direction of motion (or direction of speed) keeps changing continuously.

Since the velocity changes (due to continuous change in direction), therefore, the motion along a circular path is said to be accelerated.

When a body moves in a circular path with uniform speed (constant speed), its motion is called uniform circular motion.

Figure (a) shows the path of an athlete along a rectangular track *PQRS*. The athlete changes his direction of motion at the four corners *P, Q, R, S* of the rectangular track, in every round. Figure (b) shows a hexagonal path where in every round, the direction of motion is changed at the six corners *P, Q, R, S, T, U* and *P*. In figure (c) the track is a regular octagon. In every round, the athlete has to change the direction of motion at eight corners *P, Q, R, S, T, U, V, W* of the octagon; and so on. We observe that as number of sides of track increase, athlete has to take turn more and more number of times. If we go on increasing the number of sides of the track indefinitely, we find that the shape of the track approaches the shape of a circle. The length of each side tends to be zero. Along the circle, the athlete has to change his direction of motion at each point. Therefore, the effective direction of motion is along the tangent to the circular path at that point as shown in figure (d).



(a) (b) (c) (d)

The force which is needed to make an object travel in a circular path is called **centripetal force**.

Artificial satellites move under uniform circular motion around the earth.

The earth moves around the sun in uniform circular motion

The tip of a seconds' hand of a watch exhibits uniform circular motion on the circular dial of the watch.

$$\text{speed} = \frac{\text{Distance}}{\text{Time}} \qquad v = \frac{2\pi r}{t}$$

where v = speed

(pi) $\pi = \frac{22}{7}$ (It is a constant)

r = radius of circular path

and t = time taken for one round of circular path