Motion

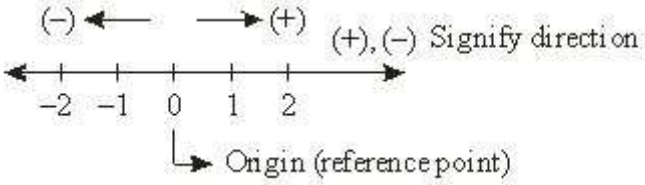
Motion
Movement of any object from one position to another position with respect to the observer is called as **Motion**.

Position: Motion of any object is defined by its position with respect to the observer. Position is the location of the object. If object changes its position with the passage of time, it is said to be in motion.

Reference point: It is the point from which the location of object is measured. It is often called as origin. Any object can be located only with the help of reference point and its direction.
Example: Suppose a person changes its position with respect to a tree(a reference point) with passage of time. In this example, person is an object and tree is a reference point. Direction is also necessary to locate an object.

Motion in straight line
When an object moves in straight line with respect to the observer then the motion is called straight line motion. For example, motion of lift.

Position in Straight line Motion:



Positive sign shows position in right (positive) direction.
Negative sign shows position in left (negative) direction.
Zero is usually considered as reference point or origin.
For example;
Position of X = +1m,
Position of Y = -3m.
Here + and – sign represent direction of object from origin. While 1m, 3m represent distance of object from origin.

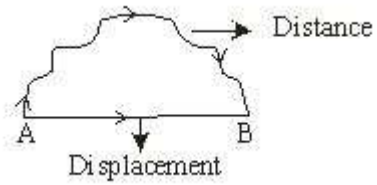
Vectors & Scalar
Vector is a quantity which have both magnitude and direction.
Examples: Force, position etc.
Scalar is quantity with which direction is not associated.

Examples: Temperature, mass etc.
Note: Magnitude of vector only represents numerical value of the vector without its direction.

Distance & Displacement

Distance is the actual path travelled by an object from its initial position to final position. It is a scalar quantity.

Displacement is the shortest straight line path between initial and final position.



- If the initial and final points are same then displacement will be zero.
- Distance depends on path but displacement does not.
- Distance is always greater than or equal to displacement. They are equal only in straight line motion without taking U- turn.

Uniform & Non – uniform Motion

Uniform motion is a motion in which equal distance is covered in equal time intervals.
Non Uniform motion is a motion in which unequal distance is covered in equal intervals of time.

Speed and Velocity

Speed is the distance travelled by object in unit time.

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

Average Speed: The ratio of total distance travelled to total time taken by the body gives its average speed.

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

It's a scalar quantity. SI unit of speed is metre/sec.

Velocity is the displacement of body in unit time.
Velocity is a vector quantity. SI unit of velocity is metre/sec.

$$\text{Velocity} = \frac{\text{Displacement of Object}}{\text{Time taken}}$$

Note:

- Velocity has both magnitude and direction while speed has only magnitude and no direction.
- Velocity has same direction as displacement.

Average Velocity: The ratio of total displacement travelled to total time taken by the body gives its average velocity.

$$\text{Average Velocity} = \frac{\text{Total Displacement}}{\text{Total time taken}}$$

- Average speed is always greater than average velocity except in case of straight line motion without u – turn when both are equal.
- If body returns to its initial position, average velocity will be zero but average speed will not be zero.
- When direction of motion changes, velocity also changes.

Instantaneous Speed and Velocity

Instantaneous speed is the speed of an object at a particular moment (instant) in time.
Instantaneous velocity is the velocity of an object in motion at a specific point in time.

Acceleration

Acceleration is measure of change of velocity with time. It is also called rate of change of velocity. SI unit is metre/sec^2. It is a vector quantity.

$$\text{Acceleration} = \frac{\text{Final Velocity} - \text{Initial Velocity}}{\text{Total time taken}}$$

If the velocity of an object changes from an initial value u to the final value v in time t, the motion is called acceleration motion. In this case, acceleration a is given by

$$a = \frac{V - U}{t}$$

Acceleration motion is a motion in which acceleration is not equal to zero.

- Acceleration has same direction as of velocity if velocity increases.
- Acceleration has opposite direction as of velocity if velocity decreases. In this case acceleration will be negative. Negative acceleration is also called **Retardation/ De – acceleration**.

Uniform and Non – uniform acceleration

- When velocity of body changes by equal amounts in equal time intervals, acceleration is said to be uniform.
- When velocity of body changes by unequal amounts in equal intervals if time, acceleration is said to be non – uniform.

Falling of ball is a uniform motion. Motion of car is a non – uniform motion.

Equations of Uniform Accelerated Motion

Relation among velocity, distance, time and acceleration is called equations of motion. There are three equations of motion for bodies moving with uniform acceleration.

First Equation of Motion:

$$v = u + at \ldots (i)$$

Second Equation of Motion:

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

Third Equation of Motion:

$$v^2 = u^2 + 2as \ldots (iii)$$

Here,

v = final velocity of body
u = initial velocity of body
a = acceleration of body
t = time taken by body
s = distance travelled by body in time t.

Average Velocity in Uniform Accelerated Motion

If a body moves 's' distance in 't' time interval. Then,

$$\text{Average Velocity} = \frac{\text{Displacement}}{\text{Time}}$$

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

$$= \frac{ut + \frac{1}{2}at^2}{t} \qquad \left[\because s = ut + \frac{1}{2}at^2\right]$$

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

$$= ut + \frac{1}{2}(v-u) \qquad [\because v = u + at]$$

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

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

Here 'a' is uniform acceleration of body.

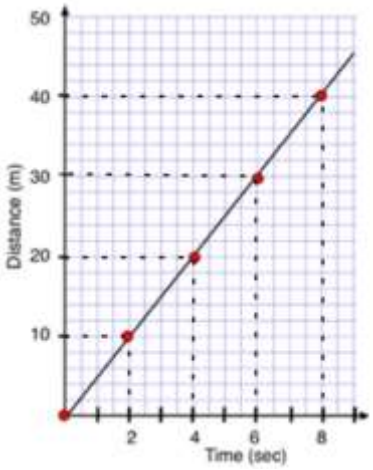
Graphical Representation of Motion

To describe the motion of an object, we can different graphs. Graphical representation of motion shows dependence of one physical quantity such as distance, velocity on other quantity such as time.

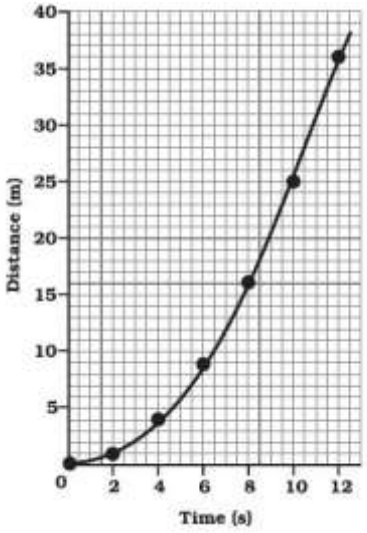
1. Distance Time Graphs:

The change in the position of an object with time can be represented on the distance – time graph. The distance time graph for a moving body can be used to calculate speed of the body.

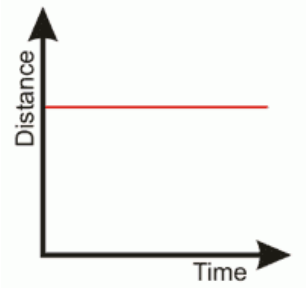
a. Straight line graph: The distance time graph for a body moving at uniform speed is always a straight line as body in uniform motion, body moves equal distance in equal time interval.



b. Curved graph: When graph of distance Vs time is plotted for an object moving with non uniform speed, the slope of graph will not be a straight line. The rising trend of slope shows the increasing trend of velocity.



c. The distance-time graph is parallel to time axis when the body is at rest.



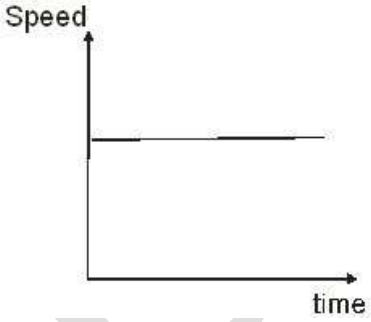
To calculate speed of body at any point say P, first draw two perpendiculars on time axis and distance axis say PA and PB respectively.

$$\text{Speed of object} = \frac{PA}{PB}$$

Here,
PA represents distance travelled by body and PB represents time taken by body.

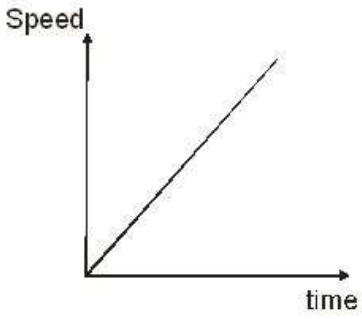
2. Velocity – time graph:

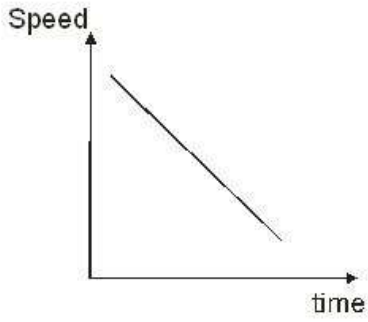
a. If a body moves with a **uniform velocity (no acceleration)** then speed time graph for this body would be straight line parallel to time axis.



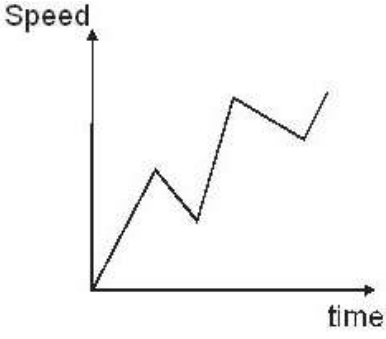
b. If body moves with a **non uniform velocity (uniform acceleration)** then speed time graph would be a straight line. The pattern of slope of the graph depends on sign of velocity.

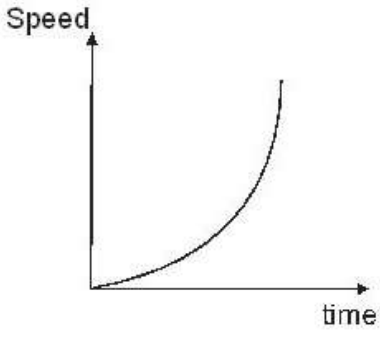
If velocity increases (positive uniform acceleration) with time, graph would be a straight upward slope. If velocity decreases (negative uniform acceleration) with time, graph would be a straight downward slope.





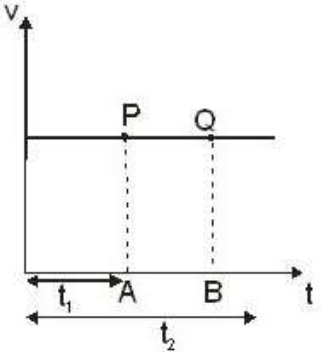
c. Zig – zag graph and curved graph show that the object is moving with **non-uniform velocity (with non-uniform acceleration)**.





We can find out the magnitude of displacement (distance) and acceleration of body using the velocity time graph.

The distance travelled by moving body in a given time will be equal to area under speed time graph.



For above graph,

Distance travelled = area of triangle PQBA = PQ x QB

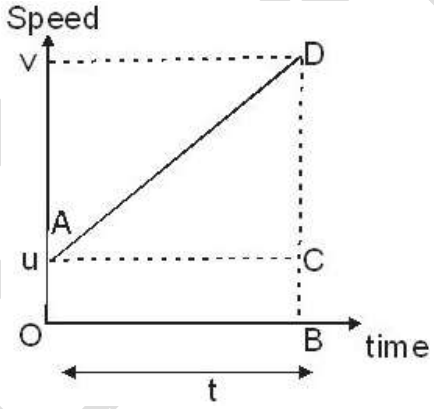
$$s = v\,(t_2 - t_1)$$

Acceleration of body = $\dfrac{\text{Change in velocity}}{\text{time taken}}$

As in above graph, velocity is constant, so in this case acceleration will be zero.

Derivation of Equations of Motion using graphs

Let an object moves from A to D in time interval t.



1. Acceleration of moving object = $\dfrac{V_2 - V_1}{t_2 - t_2}$

If initial velocity is u and final velocity is v then

=> $a = \dfrac{V - U}{t - 0}$

=> $at = v - u$

=> $v = u + at$ **Hence Proved**

2. Distance travelled by object = area under graph

= area of rec. ACBO + area of triangle ADC

$= (OA)(OB) + \dfrac{1}{2}(AC)(CD)$

$= ut + \dfrac{1}{2}(OB)(BD - BC)$

$= ut + \dfrac{1}{2}t(v-u)$

$= ut + \dfrac{1}{2}t(at)$

$s = ut + \frac{1}{2} at^2$ **Hence Proved**

3. Distance travelled by object = area under graph

$S = \frac{1}{2}$ (Sum of || sides) x t

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

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

=> $\frac{v-u}{a} = t \ldots (2)$

Equating equations (1) and (2)

$$\frac{2s}{u+v} = \frac{v-u}{a}$$

=> $2as = (v - u)(v + u) = v^2 - u^2$

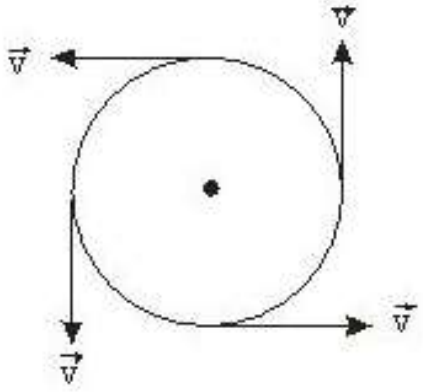
=> $v^2 = u^2 + 2as$ **Hence Proved**

Circular Motion

Uniform circular motion is the motion in which an object moves on a circular path with constant speed. For example: watch, moon revolve around earth etc.

Non uniform circular motion is the motion in which an object is moves on circular path with varying speed.

When an object is in circular motion, direction of its velocity keeps on changing.



Speed in the case of circular motion

Suppose a body is moving in a circular path of radius r.

Speed (v) = $\frac{\text{distance}}{\text{time}}$

= $\frac{\text{circumstance of circle}}{\text{time}}$

= $\frac{2\pi r}{t}$