Motion STD -9

Basic Concepts — A Flow Chart

Motion
Change in position of an object with respect to a fixed position with time

Measurement of rate of motion

Speed
- Distance travelled by the object in unit time (scalar quantity)
- Usually object are in non-uniform motion, therfore, calculate average speed
  Average speed (s) $= \frac{\text{Total distance travelled(s)}}{\text{Total time taken (t)}}$
- SI unit: ms^{-1} or m/s

Motion along straight line
- The actual path traversed by a body is its distance (scalar quantity)
- The shortest straight distance between the initial and final positions of a body is (vector quantity)

Motion along circular path
- When moving in a circular path with uniform speed, it is said to be uniform circular motion
- Direction changes continuously
- $v = \frac{2\pi r}{t}$

Uniform Motion
- The object covers equal distances in equal intervals of time
- E.g., car travelling 2 km in 2 min, 2 km in next 2 min.

Non-Uniform Motion
- The object covers unequal distances in equal intervals of time
- E.g., car moving in a crowded street

Velocity
- Speed of an object moving in a definite direction (vector quantity)
- Can be uniform or variable
- When speed is variable, expressed as average velocity
  Average velocity $= \frac{\text{Total distance travelled(s)}}{\text{Total time taken (t)}}$
- SI unit: ms^{-1} or m/s

Acceleration
- Rate of change of velocity with time (vector quantity)
- $a = \frac{v - u}{t}$
- SI unit: ms^{-2} or m/s

Uniform acceleration
Velocity of an object increases or dicreases by equal amounts in equal intervals of time.

Non- Uniform acceleration
Velocity of an object increases or dicreases by unequal amounts in equal intervals of time.

Graphical representation
- Pictorial representation or geometrical representation between two quantities on two axes

Distance-time graphs
- Time is taken on X-axis and distance travelled is taken on Y-axis
- Speed of a body = Slope of graph
- For uniform speed, slope is inclined straight line
- For non-uniform speed, slope is a curved line
- For stationary body, slope is a straight line parallel to time axis

Velocity-time graphs
- Time is taken on X-axis and velocity is taken on Y-axis
- Acceleration of body= Slope of graph
- Distance/displacement = Area under the curve
- For uniform accelerated motion slope is a straight line
- For non-uniform accelerated motion, slope is a curved line

Equation of motion

Velocity-time relation
- First equation of motion
  $v = u + at$

Velocity-time relation
- Second equation of motion
  $s = ut + \frac{1}{2}at^2$

Position-velocity relation
- Third equation of motion
  $v^2 = u^2 + 2as$

Motion means movement. That, of course, is the dictionary meaning. However, in physics too, Motion refers to the movement of an object. Movement can be seen every day. Plants show movement. Humans and all living beings move from one place to another place. Every day you see vehicular movement on the road.

To define in terms of physics, motion refers to the change of position of a body.

Types of Motion

1. Translatory Motion:

- The motion in which all the particles of a body move through the same distance in the same time is called translatory motion.
- This is further classified into **rectilinear** (straight path) and **curvilinear** (curved path) motions.
- **Example:** An athlete running on a straight path, a car running on a curved road.

2. Rotatory Motion:

- The motion in which a body moves about a fixed axis without changing the radius of its motion is called rotatory motion.
- Example: A ceiling fan.

3. Oscillatory Motion:

- The to and fro motion described by an object as a whole, along the same path, without any change in the shape of the object is called oscillatory motion.
- Example: The pendulum of a clock, a child on a swing.

4. Vibratory Motion:

- This is a kind of oscillatory motion in which the moving object undergoes a change in shape or size. In this motion, the body does not move as a whole.
- Example: The plucked string of a guitar.

5. Periodic Motion:

- A repetitive motion which repeats itself at regular intervals of time is called the periodic motion.
- Example: Earth revolving around the Sun.
- Every object **executing uniform circular motion** can be said to be executing **periodic** motion.

6. Non-periodic motion:

- A repetitive motion which repeats itself at irregular intervals of time is called non-periodic motion.
- Example: Tides in a sea.

7.Multiple Motion:

- Sometimes an object can display combinations of different types of motion.
- **Example**
  A moving car which moves straight on the road displays rectilinear motion but at the same time the wheels of the car which are moving in circles display circular motion. So a moving car displays both rectilinear and circular motion.
  In a sewing machine, the needle is in periodic motion whereas the wheels of the sewing machine are in circular motion. So a sewing machine displays circular and periodic motions.

Scalar and Vector Quantities

- A physical quantity which has only magnitude but no specific direction is called a **scalar quantity**.
  Examples: length, distance, area, mass, time, energy, etc.
- A physical quantity which has both magnitude and direction is called a **vector quantity.**
  Examples: displacement, velocity, acceleration, force, weight, etc.

Distance and Displacement

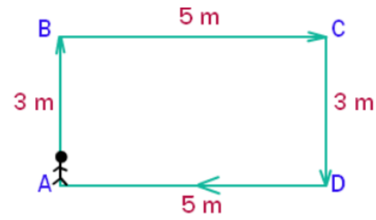
Distance

> Traveling in a circular path
>
> In this case, distance can be calculated by using formula for circumference of circle $=2\pi r$
>
> However, displacement will be zero if an object completes the full round of the circle

- The actual length of the path covered by a moving body, irrespective of the direction, is called the distance travelled by it.
- The distance covered by an object is described as the total path length covered by an object between two endpoints.
- Distance is a numerical quantity.
- Distance is a scalar quantity, as it has only magnitude and no direction.
- The SI unit of distance is the metre (m).

Displacement

- The shortest possible distance covered by a body between two points in a particular direction is known as its displacement.
- Displacement is a vector quantity, as it has both magnitude and direction.
- The SI unit of displacement is the metre (m).
- **Zero Displacement** – When the first and last positions of an object are same, the displacement is zero.
  For Example, consider the diagrams given below.



Note

It should be noted that distance can be greater than or equal to the magnitude of displacement.

Differences between distance and displacement:

1. Distance is the length of the actual path travelled by a body, whereas displacement is the shortest distance between the initial and final positions of a body.

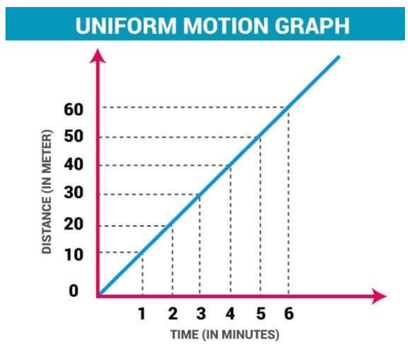
2. Distance is a scalar quantity whereas displacement is a vector quantity.

3. Distance is always positive, whereas displacement can be negative, zero or positive.

4. Distance never decreases with time. For a moving body, it is never zero. Displacement can decrease with time. For a moving body, it can be zero.

Uniform Motion:

- A body is said to have a uniform motion if it covers equal distances in equal intervals of time.
- This uniform motion is defined as the motion of an object in which the object travels in a straight line and its velocity remains constant along that line as it covers equal distances in equal intervals of time, irrespective of the duration of the time.

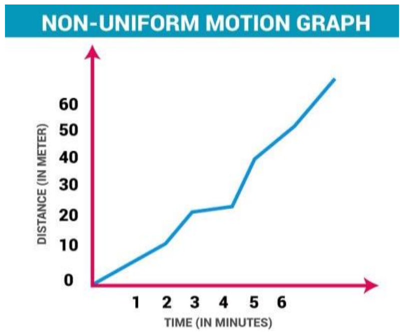


Example of Uniform Motion:

1. If the speed of a car is 10 m/s, it means that the car covers 10 meters in one second. The speed is constant in every second.
2. Movement of blades of a ceiling fan.

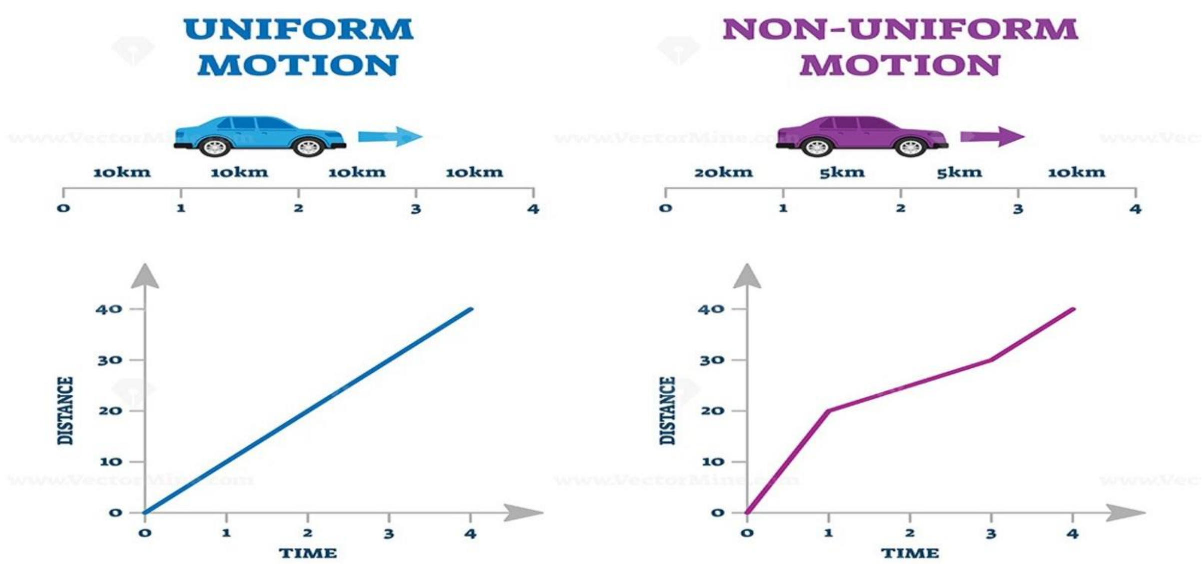
Non-uniform Motion:

- A body is said to have a non-uniform motion if it covers unequal distances in equal intervals of time.
- This non uniform of motion is defined as the motion of an object in which the object travels with varied speed and it does not cover same distance in equal time intervals, irrespective of the time interval duration.

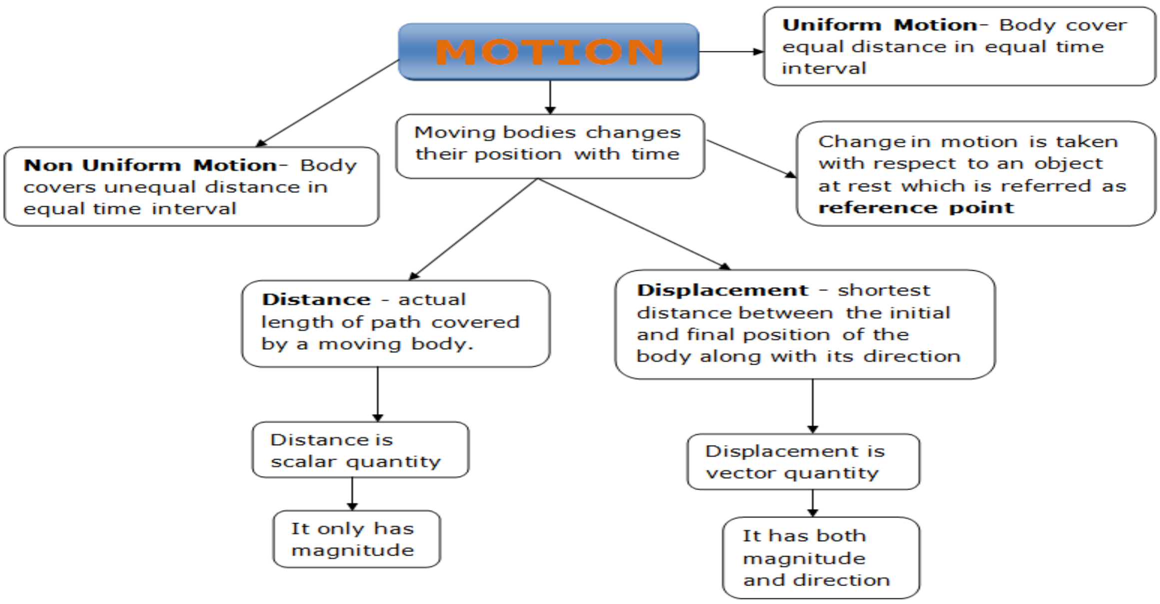


Example of Non Uniform Motion:

1. If a car covers 10 meters in first two seconds, and 15 meters in next two seconds.
2. The motion of a train.



Concept Map of Motion in General



Speed, Velocity and Acceleration

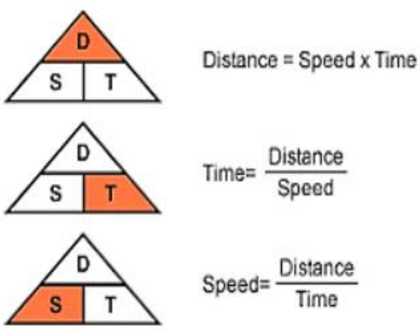
Speed:

> **Note**
>
> 1Km = 1000 meters
>
> 1 Meter = 100 centimeters

- The distance travelled by a body per unit time is called the speed of the body. Speed is a scalar quantity. The SI unit of speed is m/s.

  Speed = Distance travelled/Time taken.

- If a body covers equal distances in equal intervals of time, however small the intervals may be, it has **uniform speed**.

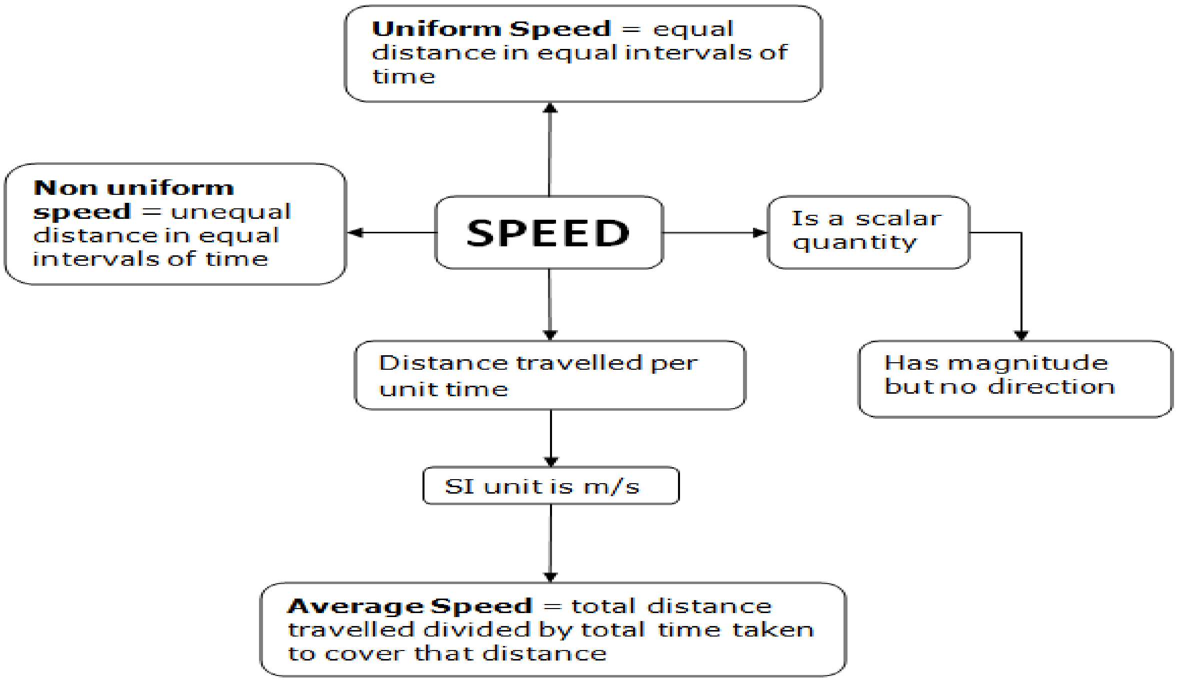


- If a body covers unequal distances in equal intervals of time, then it is said to be moving with **non-uniform speed**.
- The ratio of the total distance covered to the total time taken by the body gives its **average speed**.

  Average speed =**Total distance / Total time taken**

- The speed of a body at a given instant is its **instantaneous speed**.

Concept Map of Speed



Velocity:

- The rate of change of displacement of a body is called its velocity. Velocity can also be defined as displacement per unit time.
- In other words, the velocity of a body is the distance travelled by the body in unit time and in a given direction.
- The SI unit of speed is **m/s.**

Note : Automobiles are fitted with a device that shows the distance travelled. Such a device is known as an odometer.

Velocity = **Displacement/Time taken.**

- If a body has equal displacements in equal intervals of time, however small the intervals may be, it is said to be moving with **uniform velocity.**
- If the body is moving such that it has unequal displacements in equal intervals of time, it is said to be moving with **non-uniform velocity**.
- The ratio of total displacement to total time taken by the body gives its **average velocity**.

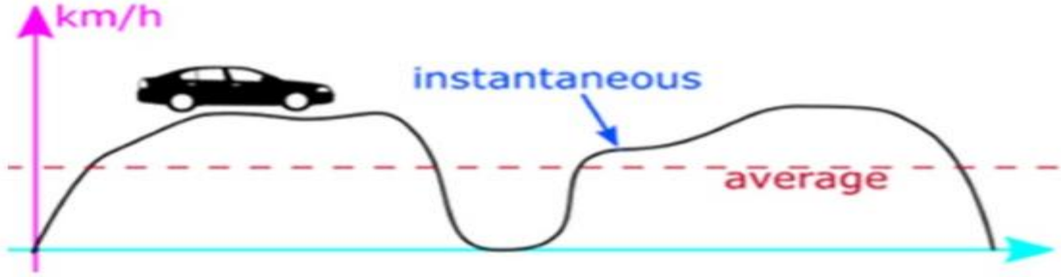
  Average velocity = **Total displacement / total time taken**

$$\text{Average velocity} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

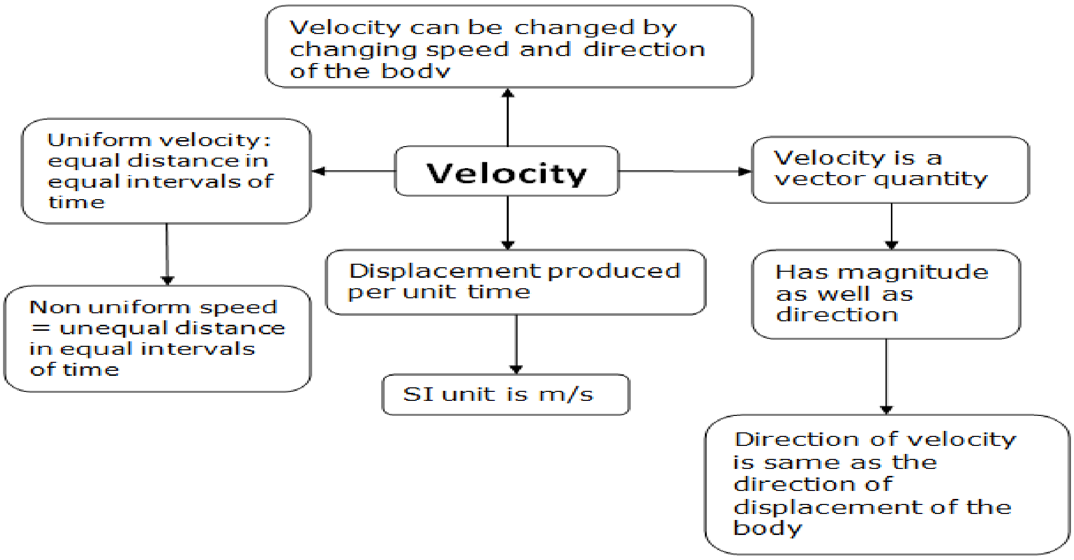
$$\therefore V_{av} = \frac{u+v}{2} \quad u = \text{initial velocity}$$

v = final velocity

- The velocity of a body at a given instant is called its **instantaneous velocity**.



Concept Map of Velocity



Differences between Speed and Velocity

1. Speed is defined as the rate of change of distance, whereas velocity is defined as the rate of change of displacement.
2. Speed is a scalar quantity whereas velocity is a vector quantity.
3. Speed is always positive whereas velocity can be positive, zero or negative.

<u>Acceleration:</u>

- The rate of change of velocity of a body is called its acceleration.
- The SI unit of acceleration is m/s^2 .
- Acceleration is a vector quantity.

Acceleration = **Change in velocity/Time.**

a= v-u /t

where v=final velocity

u=initial velocity

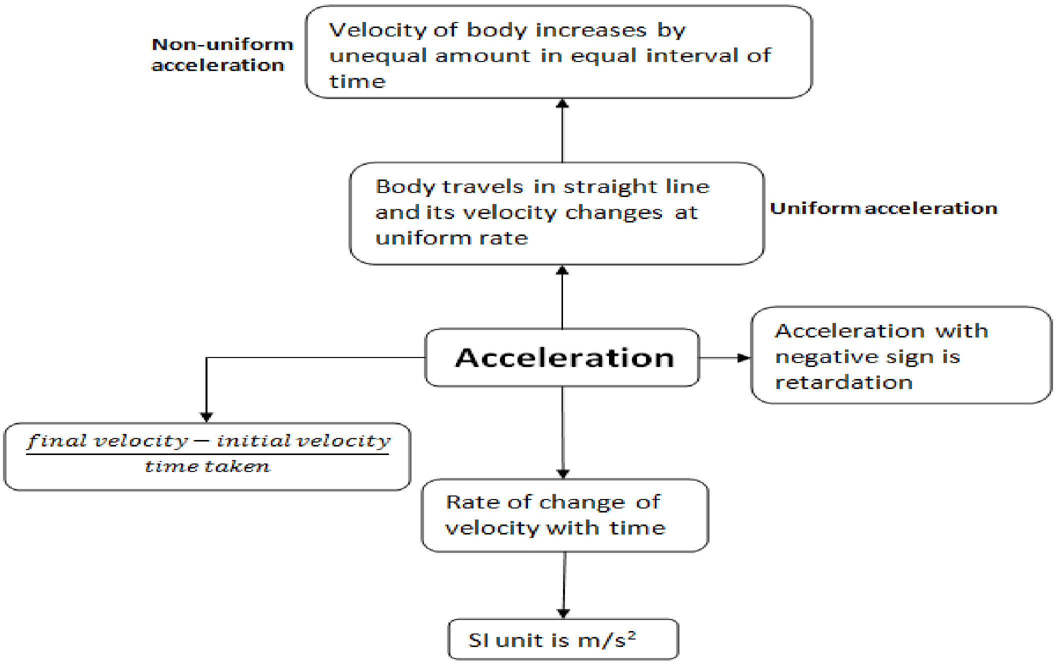
t= time taken

Note
A body moving with uniform velocity has zero acceleration.

Acceleration is regarded as **positive** if the velocity of the object is increasing and is considered to be **negative** if the velocity is decreasing.

- The negative acceleration is called **retardation or deceleration**.
- A body is considered to be moving with uniform acceleration if its rate of change of velocity with time is constant.

Concept Map of Acceleration



Acceleration due to Gravity:

- If a body is released from a height its velocity gradually increases during its fall, i.e., it has an acceleration. This is due to gravity and hence called acceleration due to gravity.
- It is generally denoted by the letter g.
- The acceleration due to gravity is defined as the increase in velocity of a freely falling body due to gravity in one second.
- Its value on Earth's surface is 9.8 m/s^2.
- If a body falls down, its velocity increases with time, so the acceleration is +g, while if a body moves vertically upwards, its velocity decreases with time, so the acceleration is -g (or the retardation is g).

Graphical representation of motion

- A graph is a pictorial representation of the relation between two sets of data of which one set is of dependent variables and the other set is of independent variables.

- To describe the motion of an object, we can use line graphs. In this case, line graphs show dependence of one physical quantity, such as distance or velocity, on another quantity, such as time.

Distance - Time Graphs

- The change in the position of an object with time can be represented on the distance-time graph.
- In this graph, time is taken along the x-axis and distance is taken along the y-axis.
- Distance time graphs of a moving body can be used to calculate the speed of the body as they specifically represent velocity.
- The distance time graph for a body moving at uniform speed is always a straight line as distance travelled by the body is directly proportional to time as shown below in the figure 1.
- The distance time graph for a body moving with non-uniform speed is a curve and is shown below in the figure 2.

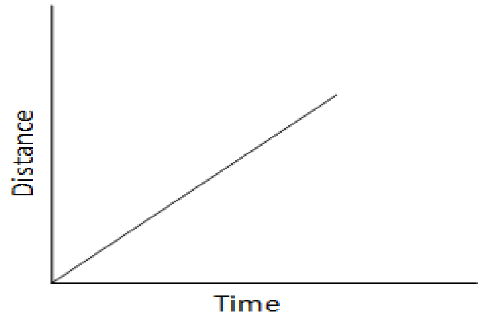


Figure 1: - Distance time graph for uniform speed

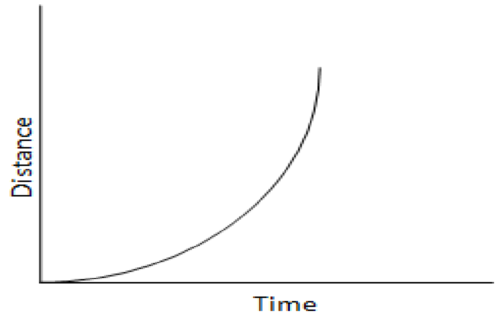


Figure 2: - Distance time graph for non uniform speed

- The distance time graph is parallel to time axis when the object is at rest and is shown below in figure 3

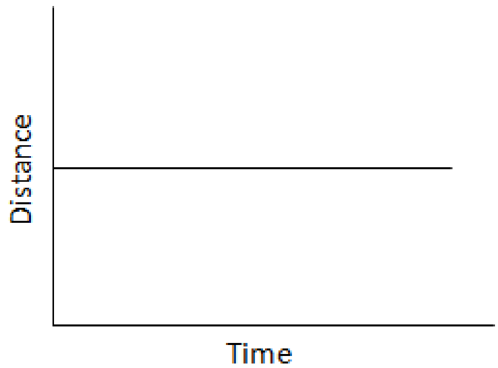


Figure 3: - Distance time graph for objects at rest

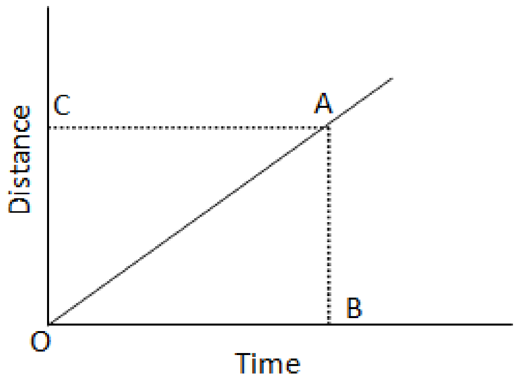


Figure 4: - Calculation of speed from distance time

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- To calculate speed of the body from distance time graph say at point A first draw a perpendicular AB on time axis and a perpendicular AC on distance axis so that AB represents the distance travelled by the body in time interval OB and since we know that

$$speed = \frac{distance\ travelled}{time\ taken} = \frac{AB}{OB}$$

Velocity - time graphs

- The variation in velocity with time for an object moving in a straight line can be represented by a velocity-time graph.
- In this graph, time is represented along the x-axis and the velocity is represented along the y-axis.
- The product of velocity and time give displacement of an object moving with uniform velocity. The area enclosed by velocity-time graph and the time axis will be equal to the magnitude of the displacement.
- If a body moves with a constant velocity, then velocity time graph for this body would be straight line parallel to time axis as shown below in the figure 5

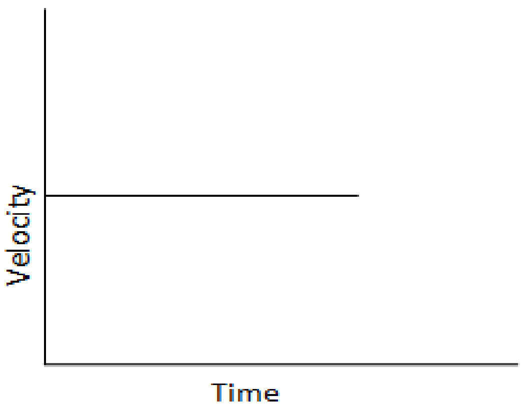


Figure 5: - Velocity time graph when speed remains constant (no acceleration)

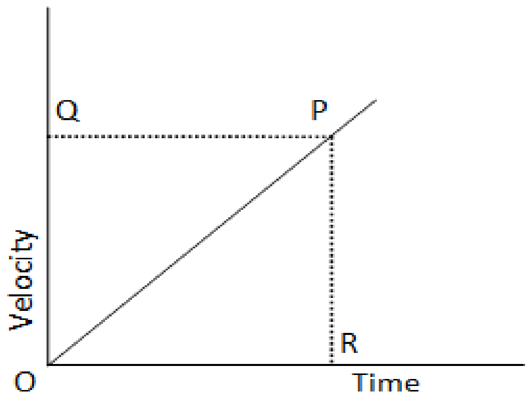


Figure 6: - Velocity time graph showing uniform acceleration

- The velocity time graph of uniformly changing velocity is shown in figure 6 and is a straight line. We can find out the value of acceleration using the velocity time graph.
- For calculating acceleration at time corresponding to point R draw a perpendicular RP from point R as shown in figure 6 and we know that

$$a = \frac{change\ in\ velocity}{time\ taken}$$

Here change in velocity is represented by PR and time taken is equal to OR. So,

$$Acceleration = \frac{PR}{OR}$$

which is equal to the slope of velocity time graph. So we conclude that slope of velocity time graph of moving body gives its acceleration.

- The distance travelled by moving body in a given time will be equal to area of triangle OPR as shown in figure 6

$$Distance\ travelled = Area\ of\ triangle\ OPR = \frac{1}{2} area\ of\ rectangle\ ORPQ$$

so,

$$Distance\ travelled = \frac{1}{2} \times OQ \times OR$$

- When the velocity of a body changes in an irregular manner then velocity time graph of the body is a curved line.

Equations of Motion

A relation between the initial and final velocities, time interval and acceleration of a moving body is called an equation of motion.
Consider a body moving with an initial velocity u and final velocity v, uniform acceleration a, time t and displacement S.
Then the equations of motion are given as follows:

v = u + at,
$S = u.t + ½ at^2$,
$v^2 = u^2 + 2aS$

Equations of motion by graphical method

We already know about equations of motion when an object moves along straight line with uniform acceleration. We already know how to derive them but these equations can also be derived by graphical method.

a. Equation for velocity time relation

- Consider the velocity-time graph of an object that moves under uniform acceleration as shown below in the figure 7.
- From this graph, you can see that initial velocity of the object is u (at point A) and then it increases to v (at point B) in time t. The velocity changes at a uniform rate aa.
- Again from figure it is clear that time t is represented by OC, initial velocity u by OA and final velocity of object after time t by BC.

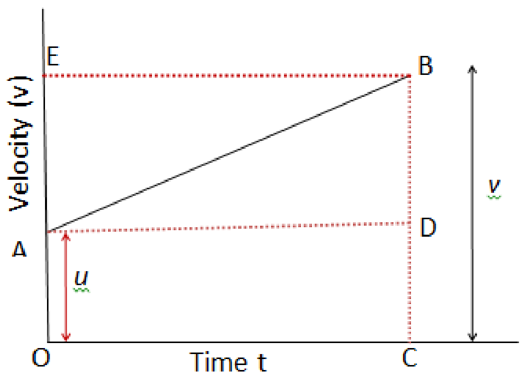


Figure 7:- v-t graph to derive equations of motion

- From graph as given in figure 7 it is clear that BC=BD+DC=BD+OA.
  So we have
  v=BD + u (1)
- We should now find out the value of BD. From the velocity-time graph (Fig. 7), the acceleration of the object is given by

$$a = \frac{change\ in\ velocity}{time\ taken} = \frac{BD}{AD} = \frac{BD}{OC} = \frac{BD}{t}$$

which gives, BD=at
putting this value of BD in equation 1 we get
v = u + at
which is the equation for velocity time relation.

b. **Equation for position time relation**

- Let us consider that the object has travelled a distance s in time t under uniform acceleration a. In Fig. 7, the distance travelled by the object is obtained by the area enclosed within OABC under the velocity-time graph AB.
- Thus, the distance s travelled by the object is given by
s = area OABC (which is a trapezium)
s= area of the rectangle OADC + area of the triangle ABD
So,
s=OA×OC + ½ ×AD × BD
Substituting OA=u , OC=AD=t and BD=at, we get
s=(u × t)+1/2×(t × at)
or,
$s = ut + 1/2\ at^2$
which is the equation of position time relation

c. **Equation for position velocity relation**

- Again consider graph in figure 7. We know that distance travelled s by a body in time t is given by the area under line AB which is area of trapezium OABC. So we have

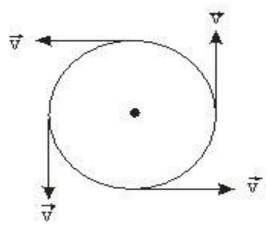
$$distance\ travelled = s = Area\ of\ trapezium\ OABC$$

$$s = \frac{(sum\ of\ parallel\ sides) \times height}{2} = \frac{(OA + CB) \times OC}{2}$$

Since OA+CB=u + v and OC=t , we thus have
s=(u + v)t × ½ 1
From velocity time relation
t=(v−u) ×1/a 2
putting this t in equation for s we get
s=(u+ v)/2 × (v−u /a)
or we have
$v^2=u^2+2as$
which is equation for position velocity relation.

Uniform circular motion

- When an object moves in a circular path at a constant speed then motion of the object is called **uniform circular motion**.
- In our everyday life, we came across many examples of circular motion for example cars going round the circular track and many more. Also earth and other planets revolve around the sun in a roughly circular orbits



- If the speed of motion is constant for a particle moving in a circular motion still the particles accelerates because of constantly changing direction of the velocity.
- If an object moves in a circular path with uniform speed, its motion is called **uniform circular motion**
- Here in circular motion, we use angular velocity in place of velocity we used while studying linear motion.
- Force which is needed to make body travel in a circular path is called **centripetal force.**
- We know that the circumference of a circle of radius r is given by 2πr. If the body takes t seconds to go once around the circular path of radius r, the velocity v is given by
  $v=2\pi r/t$
- One thing we must keep in mind is that uniform linear motion is not accelerated but uniform circular motion is **accelerated motion**.
- Examples of uniform circular motion are
  (a) Motion of artificial satellites around the earth
  (b) Moon, the natural satellite of earth, moves in uniform circular motion round the earth.
  (c) Cyclist moving on a circular track with a constant speed exhibits uniform circular motion.

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