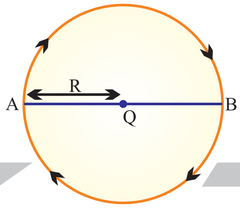


Chapter - 8

Motion

CHAPTER AT A GLANCE

Physical-State

- Rest
- Motion

Motion

- Uniform motion
- Non-uniform motion

Non-uniform Motion

- Accelerated motion
  - Uniformly accelerated motion
  - Non-uniformly accelerated motion
- Decelerated motion
  - Uniformly decelerated motion
  - Non-uniformly decelerated motion

Equations of Motion

- $v = u + at$ → First equation
- $s = ut + \frac{1}{2}at^2$ → Second equation
- $v^2 = u^2 + 2as$ → Third equation

Circular Motion → An-accelerated motion

Contents :

Rest : A body is said to be in a state of rest when its position does not change with respect to a reference point.

Motion : A body is said to be in a state of motion when its position change continuously with reference to a point.

Motion can be of different types depending upon the type of path by which the object is going through.

(i) Circulatory motion/Circular motion – In a circular path.

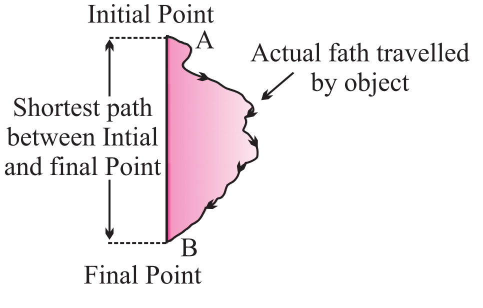
(ii) Linear motion – In a straight line path.

(iii) Oscillatory/Vibratory motion – To and fro path with respect to origin.

Scalar quantity : It is the physical quantity having own magnitude but no direction *e.g.,* distance, speed.

Vector quantity : It is the physical quantity that requires both magnitude and direction *e.g.,* displacement, velocity.

Distance and Displacement :



- The actual path or length travelled by a object during its journey from its initial position to its final position is called the distance.
- Distance is a scalar quantity which requires only magnitude but no

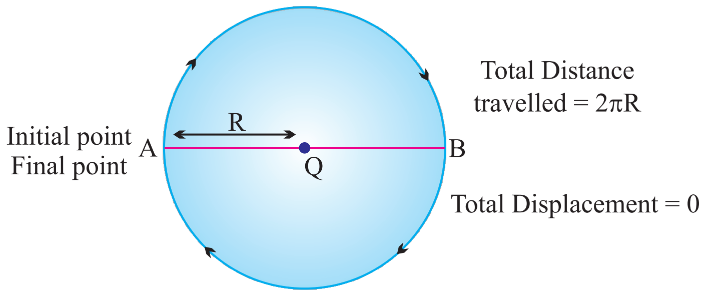
direction to explain it.

Example, Ramesh travelled 65 km. (Distance is measured by odometer in vehicles.)

- Displacement is a vector quantity requiring both magnitude and direction for its explanation.

  Example, Ramesh travelled 65 km south-west from Clock Tower.

- Displacement can be zero (when initial point and final point of motion are same) *Example,* circular motion.



Difference between Distance and Displacement

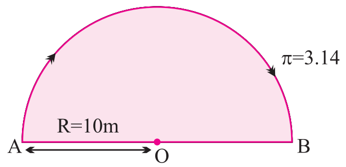
Distance	Displacement
1. Length of actual path travelled by an object.	1. Shortest length between initial point and far point of an object.
2. It is scalar quantity.	2. It is vector quantity.
3. It remains positive, can't be '0' or negative.	3. It can be positive (+ve), negative (-ve) or zero.
4. Distance can be equal to displacement (in linear path).	4. Displacement can be equal to distance or its lesser than distance.

Example 1. *A body travels in a semicircular path of radius 10 m starting its motion from point 'A' to point 'B'. Calculate the distance and displacement.*

Solution : Total distance travelled by body, S = ?

Given, $\pi = 3.14$, $R = 10$ m

$S = \pi R$



$= 3.14 \times 10$ m

$= 31.4$ m **Ans.**

Total displacement of body, D = ?

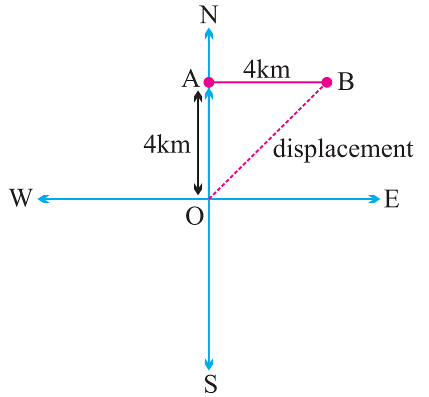
Given, R = 10 m

D = 2 × R

$= 2 \times 10$ m = 20 m **Ans.**

Example 2. *A body travels 4 km towards North then he turn to his right and travels another 4 km before coming to rest. Calculate (i) total distance travelled, (ii) total displacement.*

Solution :



Total distance travelled = OA + AB

= 4 km + 4 km

= 8 km **Ans.**

Total displacement = OB

$$OB = \sqrt{OA^2 + OB^2}$$

$$= \sqrt{(4)^2 + (4)^2}$$

$$= \sqrt{16+16}$$

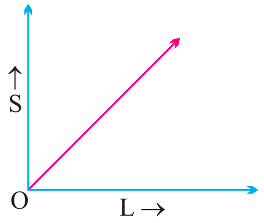
$$= \sqrt{32}$$

= 5.65 km **Ans.**

Uniform and Non-uniform Motions

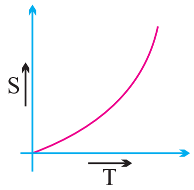
- ***Uniform Motion :***

  When a body travels equal distance in equal interval of time, then the motion is said to be uniform motion.

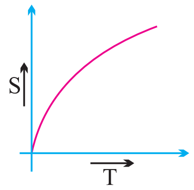


- **Non-uniform Motion :**

  In this type of motion, the body will travel unequal distances in equal intervals of time.



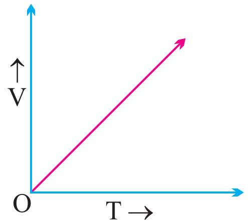
Continuous increase in slope of curve indicates accelerated non-uniform motion.



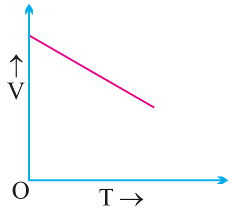
Continuous decrease in slope of curve indicates decelerate non-uniform motion.

Non-uniform motion is of two types :

(i) ***Accelerated Motion :*** When motion of a body increases with time.



(ii) ***De-accelerated Motion :*** When motion of a body decreases with time.



Speed : The measurement of distance travelled by a body per unit time is called speed.

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

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

- SI unit = m/s (meter/second)
- If a body is executing uniform motion, then there will be a constant speed or uniform motion.
- If a body is travelling with non-uniform motion, then the speed will not remain uniform but have different values throughout the motion of such body.
- For non-uniform motion, average speed will describe one single value of speed throughout the motion of the body.

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

Example : *What will be the speed of body in m/s and km/hr if it travels 40 kms in 5 hrs ?*

Solution : Distance (s) = 40 km

Time (t) = 5 hrs.

$$\text{Speed (in km / hr)} = \frac{\text{Total distance}}{\text{Total time}}$$

$$= \frac{40 \text{ km}}{5 \text{ hrs}}$$

= 8 km/hr **Ans.**

Speed (in m/s) = ?

40 km = 40 × 1000 m = 40,000 m

5 hrs = 5 × 60 × 60 sec.

$$= \frac{40 \times 1000 \text{ m}}{5 \times 60 \times 60 \text{ s}}$$

$$= \frac{80 \text{ m}}{36 \text{ s}}$$

= 2.22 m/s **Ans.**

Conversion Factor

Change from km/hr to m/s $= \dfrac{1000\text{ m}}{60 \times 60\text{ s}}$

$= \dfrac{5}{18}\text{ m/s}$

Velocity : It is the speed of a body in given direction.

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

- Velocity is a vector quantity. Its value changes when either its magnitude or direction changes.
- For non-uniform motion in a given line, average velocity will be calculated in the same way as done in average speed.

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

- For uniformly changing velocity, the average velocity can be calculated as follows :

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

$$V_{(avg)} = \frac{u+v}{2}$$

where, u = initial velocity, v = final velocity

SI unit of velocity = ms^{-1}

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

$\because$

- It can be positive (+ve), negative (-ve) or zero.

Example 1 : *During first half of a journey by a body it travel with a speed of 40 km/hr and in the next half it travels with a speed of 20 km/hr. Calculate the average speed of the whole journey.*

Solution : Speed during first half (v_1) = 40 km/hr

Speed during second half (v_2) = 20 km/hr

$$\text{Average speed} = \frac{v_1 + v_2}{2}$$

$$= \frac{40+20}{2} = \frac{60}{2}$$

= 30 km/hr

Average speed by an object (body) = 30 km/hr. **Ans.**

Example 2 : *A car travels 20 km in first hour, 40 km in second hour and 30 km in third hour. Calculate the average speed of the train.*

Solution : Speed in Ist hour = 20 km/hr, *Distance travelled during 1st hr = 1×20= 20 km*

Speed in IInd hour = 40 km/hr, *Distance travelled during 2nd hr = 1×40= 40 km*

Speed in IIIrd hour = 30 km/hr, *Distance travelled during 3rd hr = 1×30= 30 km*

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

$$= \frac{20+40+30}{3} = \frac{90}{3} = \frac{20+40+30}{1+1+1}$$

= 30 km/hr **Ans.**

Acceleration : Acceleration is seen in non-uniform motion and it can be defined as the rate of change of velocity with time.

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

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

where, v = final velocity, u = initial velocity

If $v > u$, then 'a' will be positive (+ve).

Retardation/Deaceleration : Deaceleration is seen in non-uniform motion during decrease in velocity with time. It has same definition as acceleration.

$$\text{Deaceleration} = \frac{\text{Change in velocity}}{\text{Change in time}}$$

$$a' = \frac{v-u}{t}$$

Here $v < u$, 'a' = negative (-ve).

Example 1 : *A car speed increases from 40 km/hr to 60 km/hr in 5 sec. Calculate the acceleration of car.*

Solution : $u = \frac{40\text{ km}}{\text{hr}} = \frac{40 \times 5}{18} = \frac{100}{9} = 11.11\text{ ms}^{-1}$

$v = \frac{60\text{ km}}{\text{hr}} = \frac{60 \times 5}{18} = \frac{150}{9} = 16.66\text{ ms}^{-1}$

$a = ?$ $t = 5$ sec.

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

$$= \frac{16.66 - 11.11}{5}$$

$$= \frac{5.55}{5}$$

$= 1.11\text{ ms}^{-2}$ **Ans.**

Example 2. *A car travelling with a speed of 20 km/hr comes into rest in 0.5 hrs. What will be the value of its retardation ?*

Solution : $v = 0$ km/hr

$u = 20$ km/hr

$t = 0.5$ hrs

Retardation, $a' = ?$

$$a' = \frac{v-u}{t}$$

$$= \frac{0-20}{0.5}$$

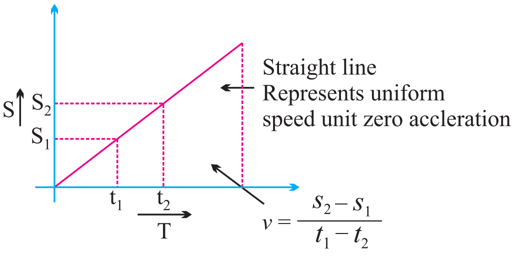
$$= -\frac{200}{5}$$

$= -40\text{ km/hr}^2$ **Ans.**

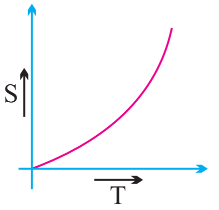
Graphical Representation of Equation

(i) Distance-Time Graph : *s/t* graph :

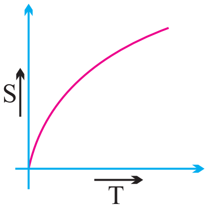
(a) *s/t* graph for uniform motion :



(b) *s/t* graph for non-uniform motion :

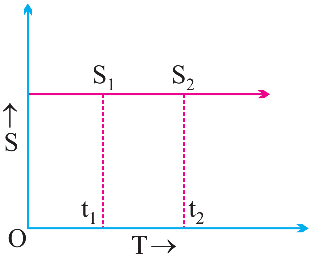


Continuous increase in slope of curve indicates accelerated non-uniform motion.



Continuous decrease in slope of curve indicates decelerate non-uniform motion.

(c) *s/t* graph for a body at rest :



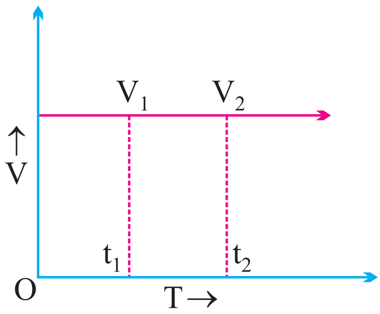
$$v = \frac{s_2 - s_1}{t_2 - t_1}$$

But, $s_2 = s_1$

$$\therefore \quad v = \frac{0}{t_2 - t_1} \quad \text{Or} \quad v = 0$$

(ii) Velocity-Time Graph : *v/t* graph :

(a) *v/t* graph for uniform motion :



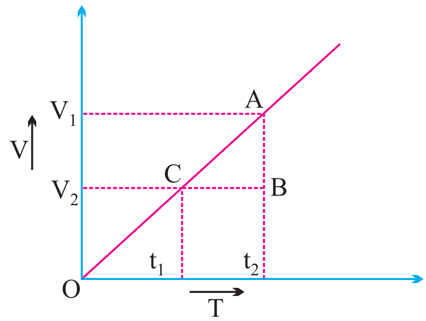
$$a = \frac{v_2 - v_1}{t_2 - t_1}$$

But, $v_2 = v_1$

$$\therefore \quad a = \frac{0}{t_2 - t_1} \quad \text{Or} \quad a = 0$$

(b) *v/t* graph for non-uniform motion :

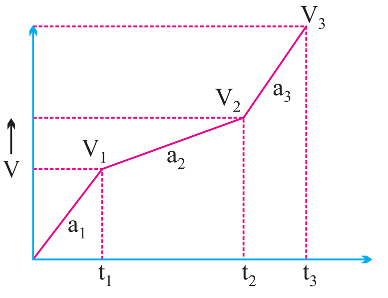
(A) *v/t* graph for accelerated (uniform) motion :



$$a = \frac{v_2 - v_1}{t_2 - t_1}$$

In uniformly accelerated motion, there will be equal increase in velocity in equal interval of time throughout the motion of body.

(B) *v/t* graph for accelerated (non-uniform) motion :



Here if, $t_2 - t_1 = t_2 - t_3$

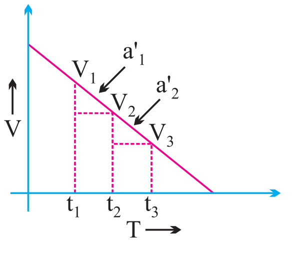
Then, $v_2 - v_1 \neq v_3 - v_2$

$$\frac{v_2 - v_1}{t_2 - t_1} \neq \frac{v_3 - v_2}{t_3 - t_2}$$

Or

Or $a_2 \neq a_1$

(C) *v/t* graph for decelerated (uniform) motion :



Here, $v_2 - v_1 = v_3 - v_2$

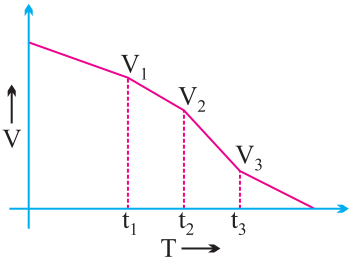
If $t_2 - t_1 = t_3 - t_2$

$$\frac{v_2 - v_1}{t_2 - t_1} = \frac{v_3 - v_2}{t_3 - t_2}$$

Then,

Or $a'_1 = a'_2$

(D) *v/t* graph for decelerated (non-uniform) motion :



Here, $v_2 - v_1 \neq v_3 - v_2$

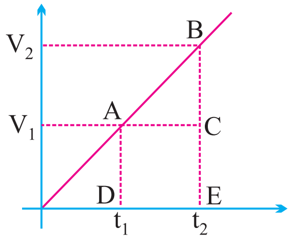
If $t_2 - t_1 = t_3 - t_2$

$$\frac{v_2 - v_1}{t_2 - t_1} \neq \frac{v_3 - v_2}{t_3 - t_2}$$

Then,

Or $a'_1 \neq a'_2$

Note : *The area enclosed between any two time intervals is '$t_2 - t_1$' in v/t graph will represent the total displacement by that body.*

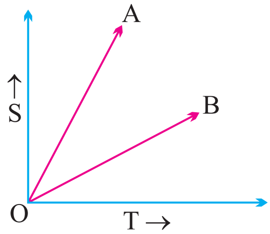


Total distance travelled by body between t_2 and t_1, time intervals

= Area of ΔABC + Area of rectangle ACDB

$= ½ \times (v_2 - v_1) \times (t_2 - t_1) + v_1 \times (t_2 - t_1)$

Example : *From the information given in s/t graph, which of the following body 'A' or 'B' will be more faster ?*



Solution : $V_A > V_B$

Equation of Motion (For Uniformly Accelerated Motion)

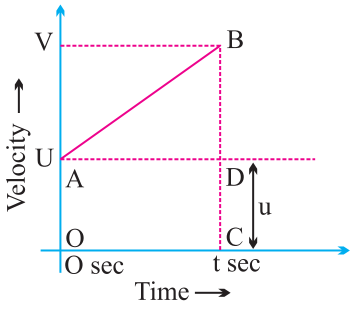
(i) First Equation

$$v = u + at$$

Or Final velocity = Initial velocity + Acceleration × Time

Graphical Derivation :

Suppose a body has initial velocity 'u' (*i.e.,* velocity at time $t = 0$ sec.) at point 'A' and this velocity changes to 'v' at point 'B' in 't' secs. *i.e.,* final velocity will be 'v'.



For such a body there will be an acceleration.

$$a = \frac{\text{Change in velocity}}{\text{Change in time}}$$

$$a = \frac{\text{OB} - \text{OA}}{\text{OC} - 0} = \frac{v - u}{t - 0}$$

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

Or

Or $\quad v = u + at$

(ii) Second Equation

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

Distance travelled by object $= \text{Area of OABC (trapezium)}$

$= \text{Area of OADC (rectangle)} + \text{Area of } \Delta\text{ABD}$

$= \text{OA} \times \text{AD} + \frac{1}{2} \times \text{AD} \times \text{BD}$

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

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

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

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

(iii) Third Equation

$v^2 = u^2 + 2as$

$s = \text{Area of trapezium OABC}$

$$s = \frac{(\text{OA} + \text{BC}) \times \text{OC}}{2}$$

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

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

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

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

Or $$v^2 = u^2 + 2as$$

Example 1. *A car starting from rest moves with uniform acceleration of 0.1 ms^{-2} for 4 mins. Find the speed and distance travelled.*

Solution : $u = 0$ ms^{-1} $\quad\because$ car is at rest.

$a = 0.1$ ms^{-2}

$t = 4 \times 60 = 240$ sec.

$v = ?$

From, $v = u + at$

$v = 0 + 0.1 \times 240$

Or $v = 24$ ms^{-1} **Ans.**

Example 2. *The brakes applied to a car produces deceleration of 6 ms^{-2} in opposite direction to the motion. If car requires 2 sec. to stop after application of brakes, calculate distance travelled by the car during this time.*

Solution : Deceleration, $a = -6$ ms^{-2}

Time, $t = 2$ sec.

Distance, $s = ?$

Final velocity, $v = 0$ ms^{-1} $\quad\because$ car comes to rest.

Now, $v = u + at$

Or $u = v - at$

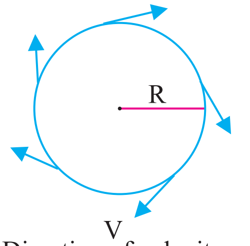
Or $u = 0 - (-6) \times 2 = 12$ ms^{-1}

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

$= 12 \times 2 + \frac{1}{2} \times (-6) \times (2)^2$

$= 24 - 12 = 12$ m **Ans.**

Uniform Circular Motion



Direction of velocity (Tangential)

If a body is moving in a circular path with uniform speed, then it is said to be executing uniform circular motion.

In such a motion the speed may be same throughout the motion but its velocity (which is tangential) is different at eact and every point of its motion. Thus, uniform circular motion is an accelerated motion.

QUESTIONS

VERY SHORT ANSWER TYPE QUESTIONS (1 Mark)

1. Change the speed 6 m/s into km/hr.
2. What do speedometer and odometer used for ?
3. What is the other name of negative acceleration ?
4. What does the slope of distance-time graph indicate ?
5. What can you say about the motion of a body if its speed-time graph is a straight line parallel to the time axis ?
6. What does the slope of speed-time graph indicate ?
7. Name the physical quantity which gives an idea of how slow or fast a body is moving ?

SHORT ANSWER TYPE QUESTIONS (2 Marks)

1. A tortoise moves a distance of 100 m in 15 minutes. What is its average speed in km/hr ?
2. If a bus travelling at 20 m/s is subjected to a steady deceleration of 5 m/s^2, how long will it take to come to rest ?
3. What is the difference between uniform linear motion and uniform circular motion ?
4. Explain why the motion of a body which is moving with constant speed in a circular path is said to be accelerated.

LONG ANSWER TYPE QUESTIONS (5 Marks)

1. Derive the equations $v = u + at$, $s = ut + ½at^2$ and $v^2 = u^2 + 2as$ graphically.
2. What is uniform circular motion ? Give two examples which force is responsible for that.

HOTS

1. What can you say about the motion of a body if its displacement-time graph and velocity-time graph both are straight line ?