Chapter – 8

Motion

Describing Motion

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

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

State of motion or rest: A body is in motion or rest depends on the reference point taken.

For example, a person sitting on a chair at his home is at rest with respect to the earth. When the reference point is the Sun, the person is in motion as the earth continuously revolve around the sun.

Example: If Rohan's school is 5 km in the west direction from his house and the bookstore is 2 km south from the house then what is the reference point in this case?

Solution: The Reference point (origin) and the direction are used to define the position of an object.

Here, we have specified the position of the school and the bookstore with respect to Rohan's house. Therefore, the house is the reference point in this case.

Scalar Quantity: The physical quantity that only has a magnitude and is independent of its direction, is called a scalar quantity.

Vector Quantity: The physical quantity that depends on both magnitude and direction is called a vector quantity.

Distance: The total path length travelled by an object from its initial position to its final position is called distance.

- Distance is a scalar quantity which means it only has magnitude and no direction is required to explain this term.

- Distance is always positive and never be 0 as it does not depend on the direction.

Displacement: It is the shortest distance between the initial position and final position of the journey.

- Displacement is a vector quantity.
- Displacement can be negative and 0.

Example: A car is moving on a circular track of radius 210 m. It takes 60 sec to complete one round of the circular track. Find the distance and displacement after 3 minutes.

Solution: The car completes one round of the circular track in 60 sec.

Number of rounds completed in 3 min = 3 x 60 sec = 3 complete rounds

The displacement of the car after 3 complete rounds is zero as the initial and the final position of the car is the same after 3 complete rounds. Therefore, the distance between the starting and ending point is zero.

The distance covered by a car in one round of the track = The circumference of the circular track.

Distance covered in one round = $2\Pi r$

Distance covered in 3 rounds = $3 \times 2\Pi r$

Distance covered in 3 rounds = $6 \times \frac{22}{7} \times 210$

Distance covered in 3 rounds = $6 \times 22 \times 30$

Distance covered in 3 rounds = 3960 m

Uniform Motion: If a body travels an equal distance in equal intervals of time, then it is said to be in uniform motion.

Non-uniform Motion: If a body covers unequal distances in an equal interval of time then it is said to be in non-uniform motion.

Measuring the Rate of Motion

Speed: The distance travelled by an object in unit time is known as its speed.

$$Speed = \frac{Total\ Distance\ Traveled}{Total\ Time\ Taken}$$

The SI unit of speed is meter per sec (ms^{-1}).

Speed is the scalar unit, it can be specified by its magnitude only.

Example: A bus going from Dehradun to Delhi covers a distance of 240 km in 4 hours and covers the remaining distance with a speed of 60 km/hr in 2 hours. Calculate the average speed of the bus.

Solution: The bus covers 240 km in the first 4 hours of the journey.

The bus covers the remaining distance with a speed of 60 km/hr in 2 hours.

Remaining Distance = Speed × time = 60 km/hr × 2 hr = 120 km

Average speed of the bus = $\frac{Total\ Distance\ Traveled}{Total\ Time\ Taken}$

Total distance covered = 240 km + 120 km = 360 km

Total time taken = 4 hr + 2 hr = 6 hr

Average speed of the bus = $\frac{360}{6}$ = 60 km/hr

∴ The average speed of the bus is 60 km/hr

Velocity: The speed of a body in a given direction is called velocity.

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

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

Velocity is a vector quantity. The velocity of a body changes when either its magnitude or direction changes.

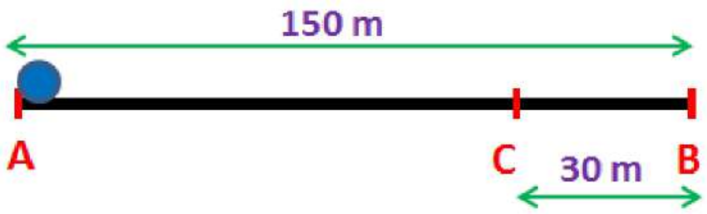
For uniformly changing velocity, the average velocity of the journey is:

$$Average\ Velocity = \frac{Initial\ Velocity + Final\ Velocity}{2}$$

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

Tip: While calculating average speed we consider total distance, while calculating average velocity we consider total displacement.

Example: An object is moved from one end, A to the other end, B along a straight line of length 150 m in 50 sec. From point B the object is moved back along the same path to point C, 30 m away in 10 sec. Calculate the average velocity of the object.



Solution:

Distance between the ends A and B = 150 m

From point B the object is moved back along the same path to point C, 30 m away. So, Point C is the final position of the object.

Distance between the points C and A = 150 m – 30 m = 120 m

We know displacement is the shortest distance between the initial and the final position of the object.

Therefore, displacement of the object = 120 m

Total time = 50 s +10 s = 60 s

Average velocity of the object = $\frac{Displacement}{Time} = \frac{120}{60} = 2\ m/s$

Rate of Change of Velocity (Acceleration)

Acceleration: The rate of change of velocity per unit time is known as acceleration. The non-uniform motion is the accelerated motion.

$$Acceleration = \frac{Change\ in\ Velocity}{Time}$$

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

Where, is the initial velocity and $\boldsymbol{v}$ is the final velocity of the object.

The SI unit of acceleration is ms^{-2}.

Example: A bus moving with a velocity of 20 m/s decreases its velocity to 5 m/s in 20 seconds when its brakes are applied. Find the acceleration of the bus.

Solution: Here, the bus moving with a velocity of 20 m/s decreases its velocity to 5 m/s in 20 seconds.

Initial velocity, u = 20 m/s

Final velocity, v = 5 m/s

Time, t = 20 s

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

$$a = \frac{5-20}{20}$$

$$a = \frac{-15}{20}$$

$$a = -0.75\ ms^{-2}$$

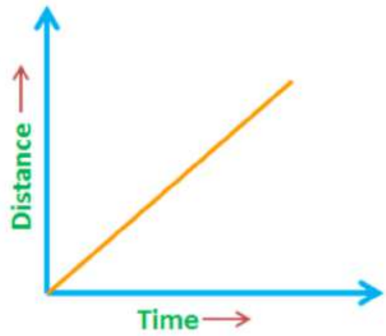
Here, the acceleration is negative which shows that the velocity is decreasing during the non-uniform motion.

Tip: The negative acceleration is called deceleration or retardation.

Graphical Representation of Motion

Distance-Time Graph:

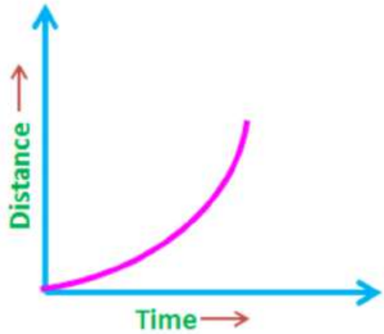
(a)



About: In this graph, the object covers equal distances in equal intervals of time and so its speed is uniform.

The straight line represents the uniform motion.

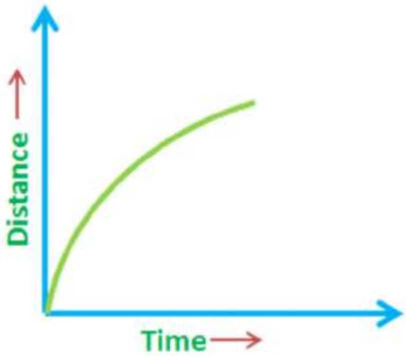
(b)



About: In this graph, the object not covers equal distances in equal intervals of time and so its speed is non-uniform.

The continuous increase in the slope indicates accelerated non-uniform motion.

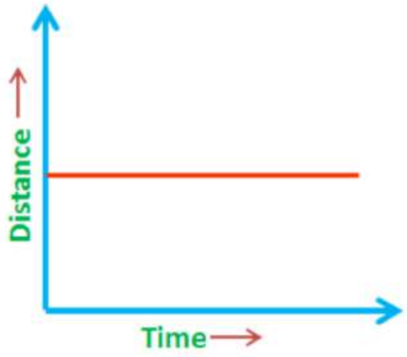
(c)



About: In this graph, the object not covers equal distances in equal intervals of time and so its speed is non-uniform.

The continuous decrease in the slope indicates retarded non-uniform motion.

(d)

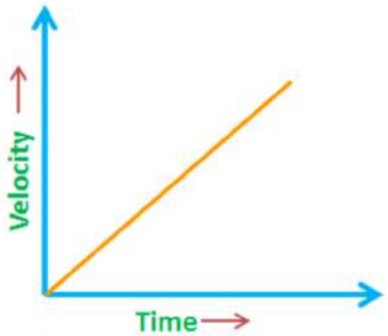


About: In this graph, an object is at rest as the distance remains constant with increase in time.

The parallel line to the x-axis(time) represents constant distance.

Velocity-Time Graph:

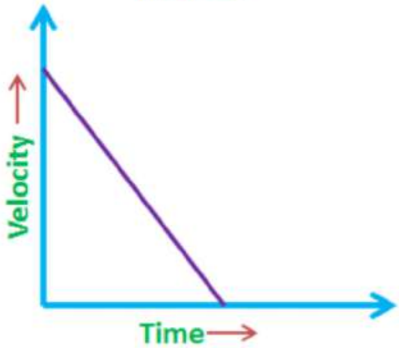
(a)



About: In this graph, the velocity of the object is increasing by equal amounts in equal intervals of time.

Therefore, the motion of the object is uniformly accelerated.

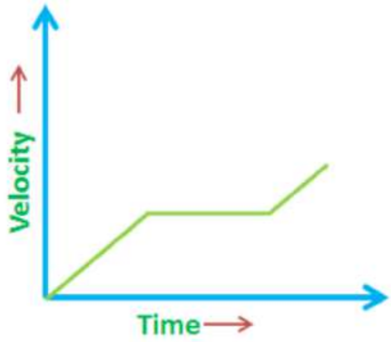
(b)



About: In this graph, the velocity of the object is decreasing by equal amounts in equal intervals of time.

Therefore, the motion of the object is uniformly decelerated.

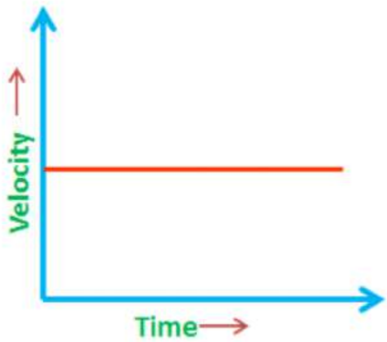
(c)



About: In this graph, the velocity of the object is increasing non - uniformly.

Therefore, the motion of the object is non-uniformly decelerated.

(d)



About: In this graph, the velocity of the object remains constant with time.

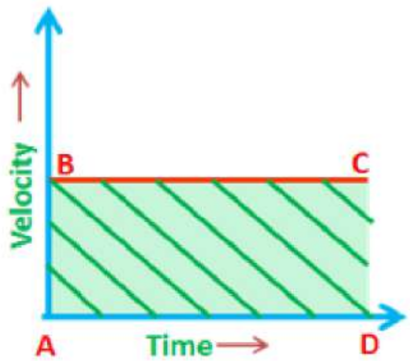
Therefore, we can say that the object is moving with constant velocity, that is, its acceleration is zero.

the velocity of the object is increasing non -uniformly.

Therefore, the motion of the object is non-uniformly decelerated.

Important Points:

- The area under velocity-time graph represents the displacement covered by the object.



Area of rectangle ABCD = AB x AD

Where AB is the velocity of the object and AD represents the time taken.

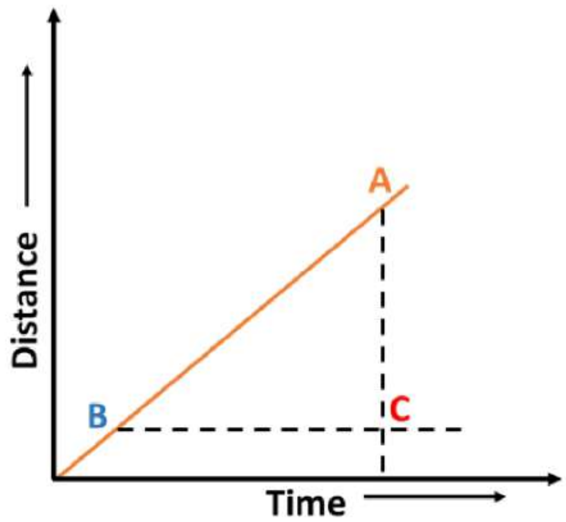
Area of rectangle ABCD = $v \times t$

As we know, velocity x time taken = magnitude of displacement

So, Area of rectangle ABCD = Displacement covered

- The slope (inclination with the x-axis) of the S-t graph represents the speed of the object.
- The slope (inclination with the x-axis) of the V-t graph represents the acceleration of the object.

Slope is the ratio of the physical quantity on y-axis to the physical quantity on x-axis.



$$Slope = \frac{AC}{BC}$$

Equation of motion

Equation of motion: There are three equations of motion that relate all the parameters like distance, time, velocity and acceleration.

1) $v = u + at$

Here u is the initial velocity of the object moving with uniform acceleration a in time t and v is the final velocity of the object.

This equation shows the relation between velocity and time.

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

Here u is the initial velocity of the object moving with uniform acceleration a in time t and s is the distance covered by the object in time t.

This equation shows the relation between position and time.

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

Here u is the initial velocity of an object moving with uniform acceleration a, v is the final velocity and s is the distance covered by the object in time t.

This equation shows the relation between position and velocity.

These equations are valid only if the object is moving with uniform acceleration. This set of equations are not valid if the object is not moving with uniform acceleration.

Tip: These equations can easily drive using the concept that the area under the V-t graph is equal to the magnitude of the displacement.

Example: A car starts from rest and moves with a uniform acceleration of 3 ms^{-2} to attain a speed of 15 m/s. Calculate the time taken by the car to attain the speed of 15 m/s and the distance covered by the bus at the same time.

Solution: The car starts from the rest, so initial velocity, $\boldsymbol{u} = \mathbf{0}$

Acceleration, $\boldsymbol{a} = \mathbf{3}$ ms^{-2}

Final velocity, $\boldsymbol{v} = \mathbf{15}$ m/s

Let $\boldsymbol{t}$ be the time taken by the car to attain the velocity of 15 m/s.

Using the velocity-time equation (1st equation of motion)

$$\boldsymbol{v = u + at}$$

$$\mathbf{15 = 0 + 3 \times \boldsymbol{t}}$$

$$\boldsymbol{t} = \frac{\mathbf{15}}{\mathbf{3}} = \mathbf{5\ s}$$

Time taken by the car to attain the velocity of 15 m/s is 5 s.

To calculate the distance covered by the car in 5 sec, we will use the position - time equation (2nd equation of motion)

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

$$s = 0 \times 5 + \frac{1}{2} \times 3 \times \ (5)^2$$

$$s = \frac{1}{2} \times 3 \times 25$$

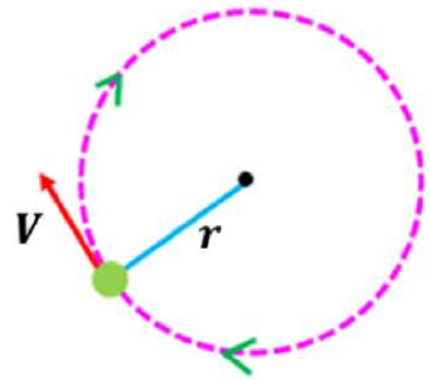
$$s = \frac{75}{2} = 37.5 \text{ m}$$

The distance covered by the bus in 5 sec is 37.5 m

Uniform Circular Motion

Uniform Circular Motion: If a body is moving around a circular path with uniform speed, then it is said to be in a uniform circular motion.

In this motion, the magnitude of velocity is the same throughout the motion, but its direction is different at each and every point of its motion due to continuous change in direction the uniform circular motion is an accelerated motion.



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

In a circular motion, the distance covered is equal to the circumference of the circle.

Distance = $2\Pi r$

$$v = \frac{2\Pi r}{t}$$

Example: Rita is cycling around a circular track of radius r. If the time taken by her to complete one round of the circular track is 10 sec. Find the speed of the cycle.

Solution: Radius of the circular track = r

Distance covered = 2πr

Time is taken by Rita to complete one round = 10 s

Using the relation,

$$v = \frac{2\Pi r}{t} = \frac{2\Pi r}{10} = \frac{\Pi r}{5}$$

Therefore, the speed of the cycle is $\frac{\Pi r}{5}$ m/s.