MOTION

EDUMAX CLASSES

EDUCATION AT MAXIMUM

- **A Reference Point** is used to describe the location of an object. An object can be referred through many reference points.
- **Origin** – The reference point that is used to describe the location of an object is called **Origin**.
- **For Example**, a new restaurant is opening shortly at a distance of 5 km north from my house. Here, the house is the reference point that is used for describing where the restaurant is located.

What is motion?

If the location of an object changes with time the object is said to be in motion.

Motion in a Straight Line

Distance – 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. We do not mention the direction in which an object is travelling while mentioning about the distance covered by that object.

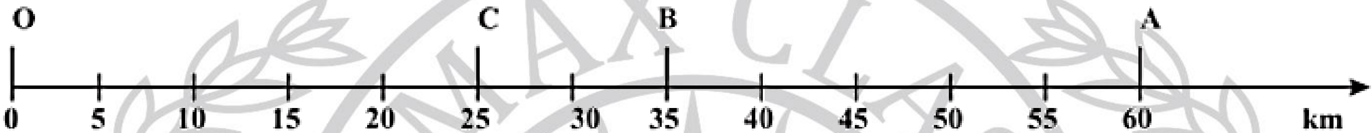


Figure 1 – Distance and Displacement

According to the figure 1 given above, if an object moves from point O to point A then total distance travelled by the object is given as 60 km.

Displacement – The shortest possible distance between the initial and final position of an object is called **Displacement**.

Consider the figure 1 given above, here the shortest distance between O and A is 60 km only. Hence, displacement is 60 km.

Displacement depends upon the direction in which the object is travelling.

Displacement is denoted by Δx.

$$\Delta x = x_f - x_0$$

Where,

x_f = Final position on the object

x_0 = Initial position of the object

Zero Displacement – When the first and last positions of an object are same, the displacement is zero.

For Example, consider the diagrams given below.

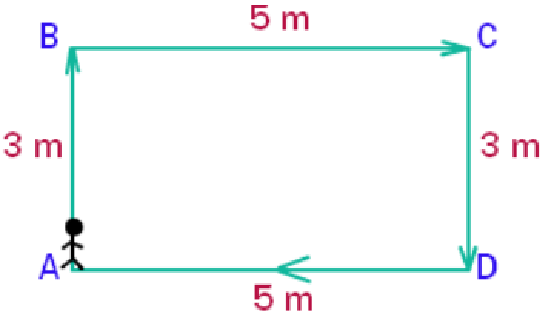


Figure 2 – Example for zero displacement

Displacement at point A = 0 because the shortest distance from A to A is zero.

Negative Displacement and Positive Displacement

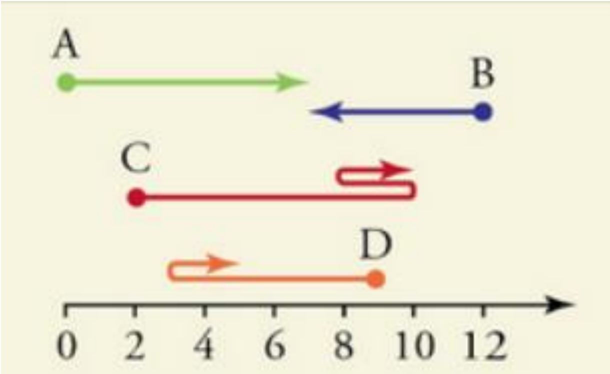


Figure 3 – Example for negative and positive displacement

Here, displacement of object B is negative

$\Delta B = B_f - B_0 = 7 - 12 = -5$

A negative sign indicates opposite direction here.

Also, displacement of object A is positive

$\Delta A = A_f - A_0 = 7 - 0 = 7$

What are Scalar and Vector Quantities?

- A **scalar** quantity describes a magnitude or a numerical value.
- A **vector** quantity describes the magnitude as well as the direction.
- Hence, distance is a scalar quantity while displacement is a vector quantity.

How is distance different from displacement?

Distance	Displacement
Distance provides the complete details of the path taken by the object	Displacement does not provide the complete details of the path taken by the object
Distance is always positive	Displacement can be positive, negative or zero
It is a scalar quantity	It is a vector quantity
The distance between two points may not be unique	Displacement between two points is always unique

What is uniform motion?

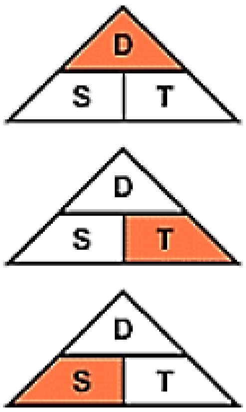
When an object travels equal distances in equal intervals of time the object is said to have a uniform motion.

What is non-uniform motion?

When an object travels unequal distances in equal intervals of time the object is said to have a non-uniform motion.

- **Speed** of an object is defined as the distance traveled by the object per unit time.

SI Unit: Meter (m)
Symbol of Representation: m/s or ms^{-1}
Speed = Distance/Time



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

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

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

- **Average Speed** – If the motion of the object is non-uniform then we calculate the average speed to signify the rate of motion of that object.

$$\text{Average Speed} = \frac{\text{Total Distance Travelled}}{\text{Total Time taken}}$$

For Example, If an object travels 10m in 3 seconds and 12m in 7 seconds. Then its average speed would be:

Total distance travelled = 10 m + 12 m = 22m

Total Time taken = 3s + 7s = 10s

Average speed = 22/10 = 2.2 m/s

- To describe the rate of motion in a direction the term **velocity** is used. It is defined as the speed of an object in a particular direction.

Velocity = Displacement/Time
SI Unit: Meter (m)
Symbol of Representation: M/s or ms^{-1}

Average Velocity (in case of uniform motion)-

Average Velocity = (Initial Velocity + Final Velocity)/2

Average Velocity (in case of non-uniform motion)-

Average Velocity = Total Displacement / Total Time taken

What are instantaneous speed and instantaneous velocity?

The magnitude of speed or velocity at a particular instance of time is called **Instantaneous Speed** or **Velocity**.

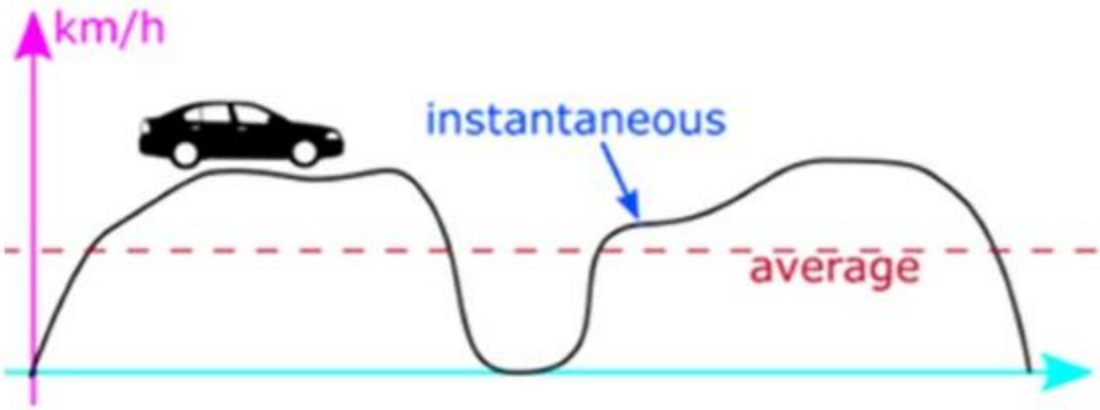
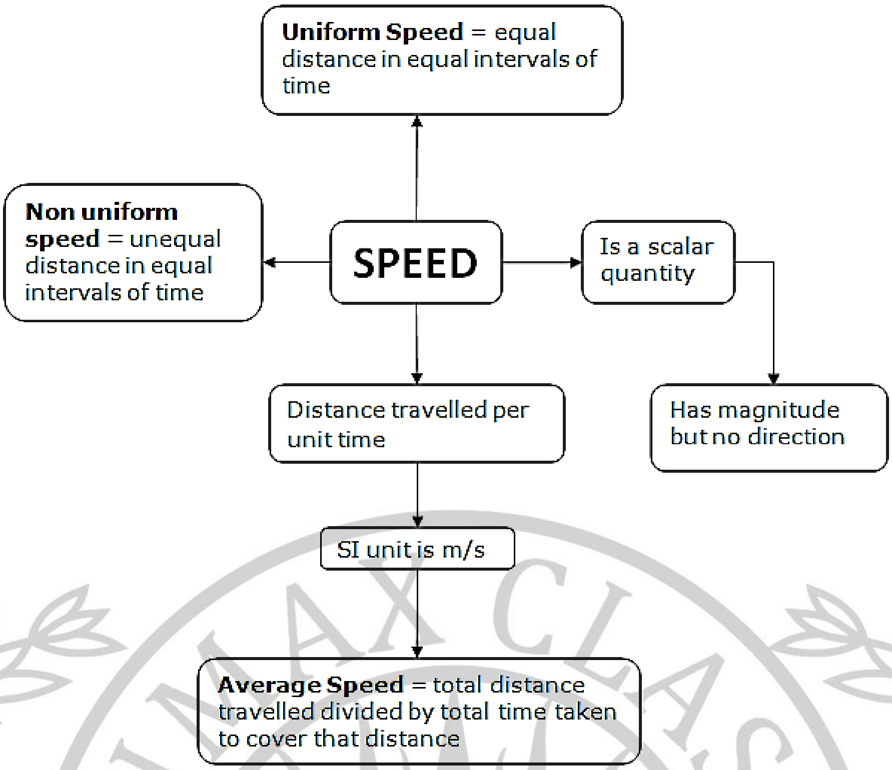


Figure 4 - Instantaneous Speed / Velocity



Uniform Motion – In case of uniform motion the velocity of an object remains constant with change in time. Hence, the rate of change of velocity is said to be zero.

Non-uniform Motion – In case of non-uniform motion the velocity of an object changes with time. This rate of change of velocity per unit time is called **Acceleration**.

Acceleration = Change in velocity/ Time taken

SI Unit: m/s^2

Uniform Acceleration – An object is said to have a uniform acceleration if:

- It travels along a straight path
- Its velocity changes (increases or decreases) by equal amounts in equal time intervals

Non - Uniform Acceleration – An object is said to have a non-uniform acceleration if:

- Its velocity changes (increases or decreases) by unequal amounts in unequal time intervals

Acceleration is also a **vector quantity**. The direction of acceleration is the same if the velocity is increasing in the same direction. Such acceleration is called **Positive Acceleration**.

The direction of acceleration becomes opposite as that of velocity if velocity is decreasing in a direction. Such acceleration is called **Negative Acceleration.**

De-acceleration or Retardation – Negative acceleration is also called **De-acceleration** or **Retardation**

Graphical Representation of Motion

1. Distance – Time Graph

It represents a change in position of the object with respect to time.

The graph in case the object is stationary (means the distance is constant at all time intervals) – Straight line graph parallel to x = axis

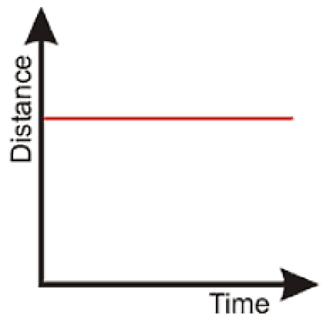


Figure 5 - Distance-time Graph in case of Stationary object

The graph in case of uniform motion – Straight line graph

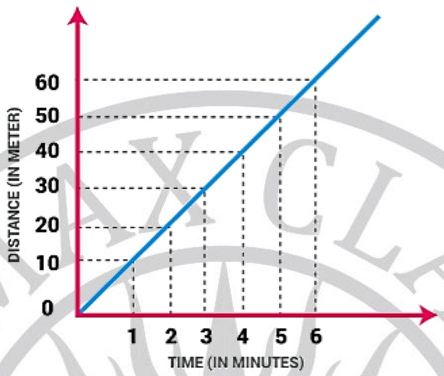


Figure 6 - Distance-time Graph in Uniform Motion

The graph in case of non-uniform motion – Graph has different shapes

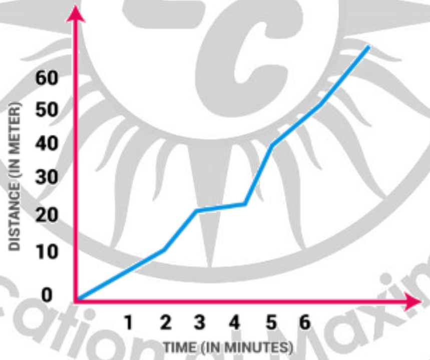
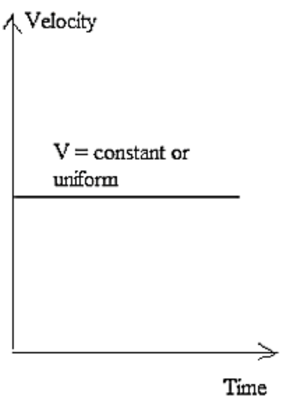


Figure 7- Distance-time Graph in Non-Uniform Motion

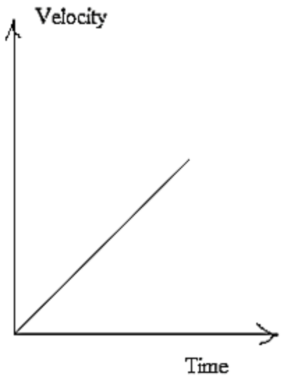
2. Velocity – Time Graphs

Constant velocity – Straight line graph, velocity is always parallel to the x-axis

Uniform Velocity / Uniform Acceleration – Straight line graph

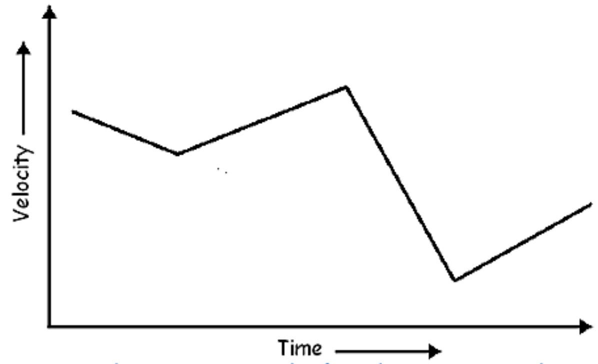


(A) v-t Ccurve for uniform velocity



(B) v-t curve for uniform acceleration

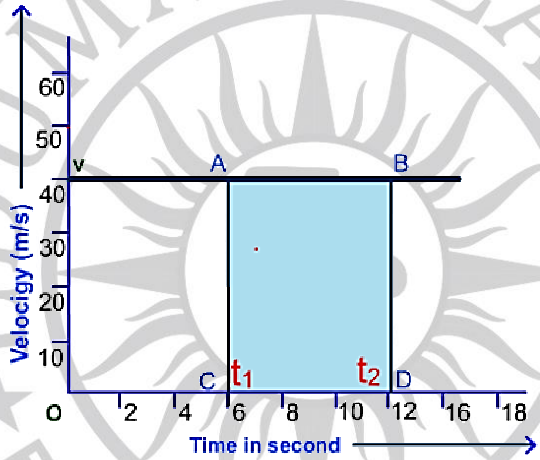
Non-Uniform Velocity / Non-Uniform Acceleration – Graph can have different shapes



Velocity - Time Graph of an object moving with Non-uniform velocity

Calculating Displacement from a Velocity-time Graph

Consider the graph given below. The area under the graph gives the distance traveled between a certain interval of time. Hence, if we want to find out the distance traveled between time interval t_1 and t_2, we need to calculate the area enclosed by the rectangle ABCD where area (ABCD) = AB * AC.

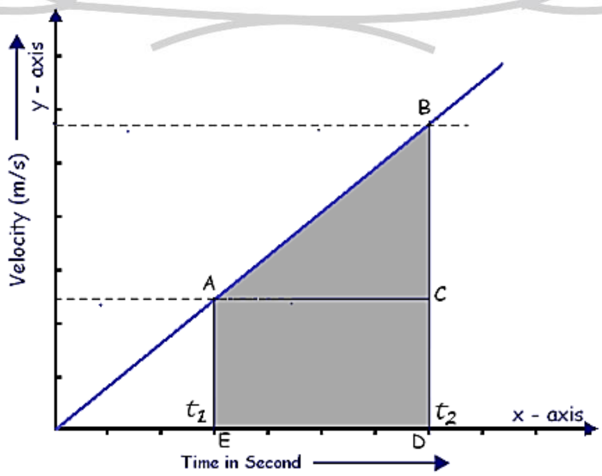


Velocity - Time Graph of an object moving with constant velocity

Similarly, to calculate distance traveled in a time interval in case of uniform acceleration, we need to find out the area under the graph, as shown in the figure below.

To calculate the distance between time intervals t_1 and t_2 we need to find out area represented by ABED.

Area of ABED = Area of the rectangle ABCD + Area of the triangle ADE = AB × BC + 1/ 2 * (AD × DE)



Velocity - time graph of an object moving with uniform acceleration

Equations of Motion

The equations of motion represent the relationship between an object's acceleration, velocity and distance covered if and only if,

- The object is moving on a straight path
- The object has a uniform acceleration

Three Equations of Motion

1. The Equation for Velocity – Time Relation

$v = u + at$

2. The Equation for Position – Time Relation

$s = ut + 1/2\ at^2$

3. The Equation for the Position – Velocity Relation

$2a\ s = v^2 – u^2$

Where,

u: initial velocity
a: uniform acceleration
t: time
v: final velocity
s: distance traveled in time t

Deriving the Equations of Motion Graphically

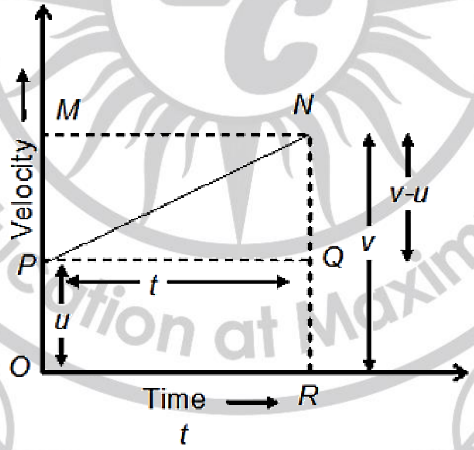


Figure 12

Study the graph above. The line segment PN shows the relation between velocity and time.

Initial velocity, u can be derived from velocity at point P or by the line segment OP

Final velocity, v can be derived from velocity at point N or by the line segment NR

Also, NQ = NR – PO = v – u

Time interval, t is represented by OR, where OR = PQ = MN

1. Deriving the Equation for Velocity – Time Relation

Acceleration = Change in velocity / time taken

Acceleration = (final velocity – initial velocity) / time a = (v – u)/t

so, at = v – u

v = u + at

2. Deriving Equation for Position – Time Relation

We know that, distance travelled by an object = Area under the graph

So, Distance travelled = Area of OPNR = Area of rectangle OPQR + Area of triangle PQN

s = (OP * OR) + (PQ * QN) / 2

s = (u * t) + (t * (v – u) / 2)

s = ut + 1/2 at^2 [because at = v – u]

3. Deriving the Equation for Position – Velocity Relation

We know that, distance travelled by an object = area under the graph

So, s = Area of OPNR = (Sum of parallel sides * height) / 2

s = ((PO + NR)* PQ)/ 2 = ((v+u) * t)/ 2

2s / (v+u) = t [equation 1]

Also, we know that, (v – u)/ a = t [equation 2]

On equating equations 1 and 2, we get,

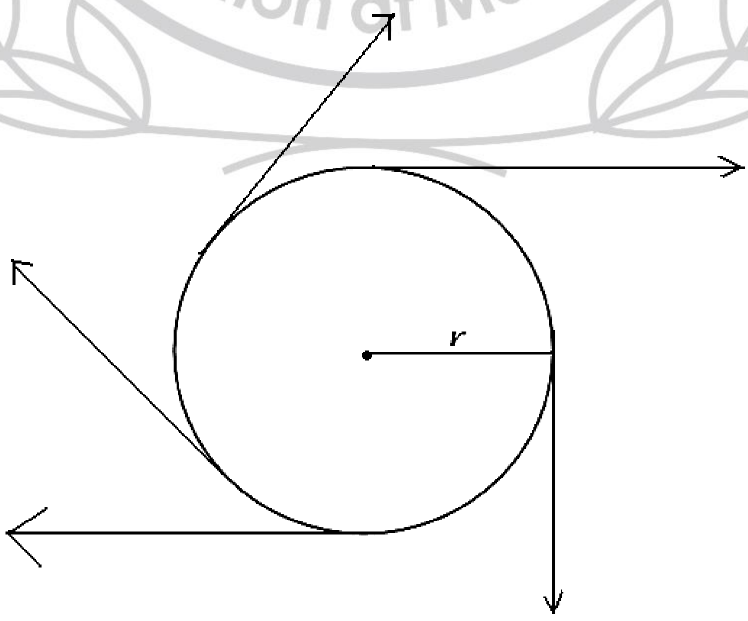
2s / (v + u) = (v – u)/ a

2as = (v + u) (v – u)

2 a s = $v^2 - u^2$

Uniform Circular Motion

If an object moves in a constant velocity along a circular path, the change in velocity occurs due to the change in direction. Therefore, this is an **accelerated motion**. Consider the figure given below and observe how directions of an object vary at different locations on a circular path.



Direction at different point while circular motion

Uniform Circular Motion – When an object travels in a circular path at a uniform speed the object is said to have a uniform circular motion.

Non-Uniform Circular Motion – When an object travels in a circular path at a non-uniform speed the object is said to have a non-uniform circular motion

Examples of uniform circular motion:

- The motion of a satellite in its orbit
- The motion of planets around the sun

Velocity of Uniform Circular Motion

Velocity = Distance/ Time = Circumference of circle / Time

v = 2πr/ t

where,

v: velocity of the object
r: radius of the circular path
t: time taken by the object

MCQS for practice

1. If the displacement of an object is proportional to square of time, then the object moves with:

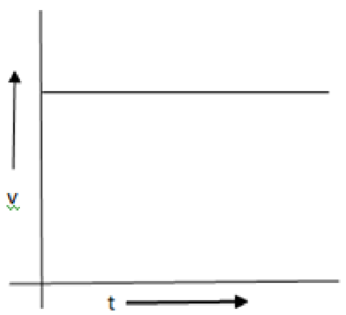
(a) Uniform velocity

(b) Uniform acceleration

(c) Increasing acceleration

(d) Decreasing acceleration

2. From the given v-t graph, it can be inferred that the object is



(a) At rest

(b) In uniform motion

(c) Moving with uniform acceleration

(d) In non-uniform motion

3. Suppose a boy is enjoying a ride on a marry-go-round which is moving with a constant speed of 10 m/s. It implies that the boy is:

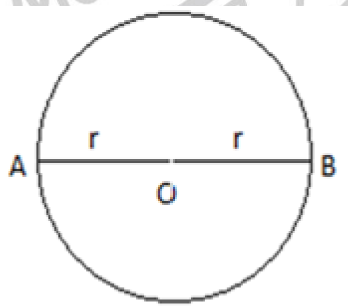
(a) At rest

(b) Moving with no acceleration

(c) In accelerated motion

(d) Moving with uniform velocity

4. A particle is moving in a circular path of radius r.



The displacement after half a circle would be:

(a) Zero

(b) πr

(c) 2r

(d) 2πr

5. Which of the following can sometimes be 'zero' for a moving body?

i. Average velocity

ii. Distance travelled

iii. Average speed

iv. Displacement

(a) Only (i)

(b) (i) and (ii)

(c) (i) and (iv)

(d) Only (iv)

6. Which of the following statement is correct regarding velocity and speed of a moving body?

(a) Velocity of a moving body is always higher than its speed

(b) Speed of a moving body is always higher than its velocity

(c) Speed of a moving body is its velocity in a given direction

(d) Velocity of a moving body is its speed in a given direction

7. When a car driver travelling at a speed of 10 m/s applies brakes and brings the car to rest in 20 s, then the retardation will be:

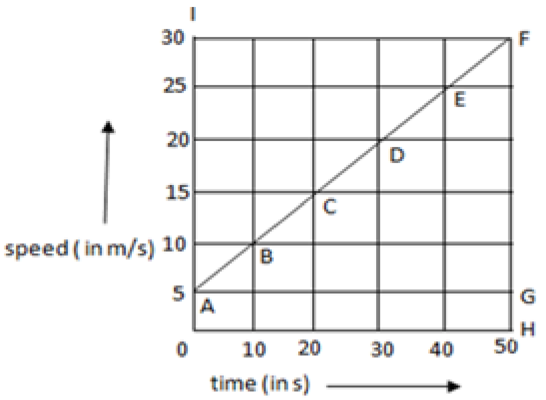
(a) + 2 m/s^2

(b) − 2 m/s^2

(c) − 0.5 m/s^2

(d) + 0.5 m/s^2

8. The speed - time graph of a car is given here. Using the data in the graph calculate the total distance covered by the car.



(a) 1250 m

(b) 875 m

(c) 1500 m

(d) 870 m

9. A car of mass 1000 kg is moving with a velocity of 10 m/s. If the velocity-time graph for this car is a horizontal line parallel to the time axis, then the velocity of the car at the end of 25 s will be:

(a) 40 m/s

(b) 25 m/s

(c) 10 m/s

(d) 250 m/s

10. Which of the following is most likely not a case of uniform circular motion?

(a) Motion of the earth around the sun

(b) Motion of a toy train on a circular track

(c) Motion of a racing car on a circular track

(d) Motion of hours' hand on the dial of a clock

11. In which of the following cases of motions, the distance moved and the magnitude of the displacement are equal?

i. If the car is moving on a straight road

ii. If the car is moving in circular path

iii. The pendulum is moving to and fro

iv. The earth is moving around the sun

(a) only(ii)

(b) (i) and (iii)

(c) (ii) and (iv)

(d) only (i)

12. A car is travelling at a speed of 90 km/h. Brakes are applied so as to produce a uniform acceleration of – 0.5 m/s^2. Find how far the car will go before it is brought to rest?

(a) 8100 m

(b) 900 m

(c) 625 m

(d) 620 m

13. In a free fall the velocity of a stone is increasing equally ion equal intervals of time under the effect of gravitational force of the earth. Then what can you say about the motion of this stone? Whether the stone is having:

(a) Uniform acceleration

(b) Non-uniform acceleration

(c) Retardation

(d) Constant speed

14. The numerical ratio of displacement to distance for a moving object is:

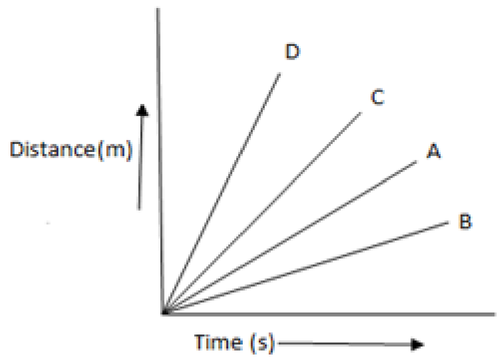
(a) Always less than 1

(b) Equal to 1 or less than 1

(c) Always more than 1

(d) Equal to 1 or more than one

15. Four cars A, B, C and D are moving on a levelled, straight road. Their distance time graphs are shown in the figure below. Which of the following is the correct statement regarding the motion of these cars?



(a) Car A is faster than car D

(b) Car B is the slowest

(c) Car D is faster than car C

(d) Car C is the slowest