MOTION

INTRODUCTION

When a body does not change its position with time, we can say that the body is at **rest**. While if a body changes its position with time, it is said to be in **motion**.

❖ **Type of Motions**

(a) According to Directions

◆ **One Dimensional motion or Straight line motion** is the motion of a particle moving along a straight line.

◆ **Two dimensional motion or Planer motion** A particle moving along a curved path in a plane has 2-dimensional motion.

(b) According to state of motion

❖ **Uniform Motion**

◆ A body is said to be in a state of uniform motion if it travels equal distances in equal intervals of time.

◆ If the time distance graph is a straight line the motion is said to be uniform motion.

❖ **Non-uniform motion**

◆ A body has a non-uniform motion if it travels unequal distances in equal intervals of time. e.g. a freely falling body.

◆ Time - distance graph for a body with non-uniform motion is a curved line.

Distance & Displacement

◆ The path length between the initial and final positions of the particle gives the **distance** covered by the particle.

◆ The minimum distance between the initial and final positions of a body during that time interval is called **displacement**.

❖ **Difference between distance and displacement.**

◆ Distance travelled is a scalar quantity while displacement is a vector quantity.

eg. if a body moves along the circumference of a circle of radius r, then the distance travelled is given by $2\pi r$, while the displacement is given by zero.

◆ When a body continuously moves in the same straight line and in the same direction then displacement will be equal to the distance travelled. But if the body changes its direction while moving, then the displacement is smaller than the distance travelled.

$$\text{Displacement} \leq \text{Distance}$$

◆ Displacement in any interval of time may be zero, positive or negative.

Ex. A person travels a distance of 5 m towards east, then 4 m towards north and then 2 m towards west.

(i) Calculate the total distance travelled.

(ii) Calculate the resultant displacement.

Sol. (i) Total distance travelled by the person $= 5\text{ m} + 4\text{ m} + 2\text{ m} = 11\text{ m}$

(ii) To calculate the resultant displacement, we choose a convenient scale, where 1 cm represents 1 m. We draw a 5 cm long line AB towards east and then 4 cm long line BC towards north. Finally, a 2 cm long line CD towards west. The resultant displacement is calculated by joining the initial position A to the final position D. We measure AB = 5 cm.

Since 1 cm = 1 m

∴   5 cm = 5 m

Hence, the displacement of the person
= 5m towards AD.
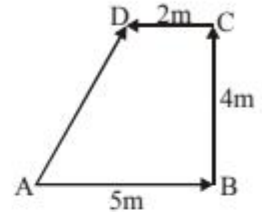
Speed and Velocity

◆ The 'distance' travelled by a body in unit time interval is called its **speed**. When the position of a body changes in particular direction, then speed is denoted by 'velocity'. i.e. the rate of change of displacement of a body is called its **velocity**.

◆ Speed is a scalar quantity while velocity is a vector quantity.

◆ Speed $= \dfrac{s_2 - s_1}{t_2 - t_2} = \dfrac{\Delta s}{\Delta t} = \dfrac{\text{Distance Travelled}}{\text{Time Taken}}$
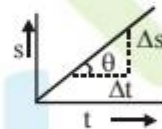
Where Δs = displacement in time interval Δt.

◆ Velocity $= \dfrac{\Delta s}{\Delta t}$;   Where Δs = distance travelled in time interval Δt.

◆ Unit : In M.K.S. system $= ms^{-1}$;   In C.GS. system $= ms^{-1}$

◆ If time distance graph is a straight line, then speed can be given by the slope of the line, i.e.

$v = \dfrac{\Delta s}{\Delta t} = \text{slope} = \dfrac{s_2 - s_1}{t_2 - t_1}$

If θ is more velocity will be more.

◆ The area of velocity time graph gives distance travelled.

Ex. The distance between two points A and B is 100 m. A person moves from A to B with a speed of 20 m/s and from B to A with a speed of 25 m/s. Calculate average speed and average velocity.

Sol. (i) Distance from A to B = 100 m

Distance from B to A = 100 m

Thus, total distance = 200 m

Time taken to move from A to B, is given by

$$t_1 = \dfrac{\text{distance}}{\text{velocity}} = \dfrac{100}{20} = 5 \text{ seconds}$$

Time taken from B to A, is given by

$$t_2 = \dfrac{\text{distance}}{\text{velocity}} = \dfrac{100}{25} = 4 \text{ seconds}$$

Total time taken $= t_1 + t_2 = 5 + 4 = 9$ sec.

∴ Average speed of the person $= \dfrac{\text{Total distance covered}}{\text{Total time taken}} = \dfrac{200}{9}$ m/s $= 22.2$ m/s

(ii) Since person comes back to initial position A, displacement will be zero, resulting zero average velocity.

Ex. A car moves with a speed of 40 km/hr for first hour, then with a speed of 60 km/hr for next half hour and finally with a speed of 30 km/hr for next $1\frac{1}{2}$ hours. Calculate the average speed of the car.

Sol. Distance travelled in first hour, is given by

$$s_1 = \text{speed} \times \text{time} = 40 \text{ km/hr} \times 1 \text{ hr} = 40 \text{ km}$$

Distance travelled in next half an hour, is given by

$$s_2 = \text{speed} \times \text{time} = 60 \text{ km/hr} \times \frac{1}{2} \text{ hr} = 30 \text{ km}$$

Distance travelled in last $1\frac{1}{2}$ hours, is given by

$$s_3 = \text{speed} \times \text{time} = 30 \text{ km/hr} \times \frac{3}{2} \text{hr} = 45 \text{ km}$$

Thus, total distance travelled $= s_1 + s_2 + s_3$
$$= 40 + 30 + 45 = 115 \text{ km}$$
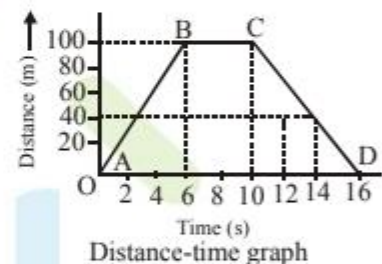
Total time taken $= 1 + \frac{1}{2} + 1\frac{1}{2} = 3$ hours

$$\therefore \text{ Average speed } = \frac{\text{Total distance covered}}{\text{Total time taken}} = \frac{115 km}{3 hrs} = 38.33 \text{ km/hr}$$

Ex. Figure shows time distance graph of an object. Calculate the following :
   (i) Which part of the graph shows that the body is at rest ?
   (ii) Average speed in first 10 s.

   (iii) Speeds in different parts of motion.

Distance-time graph

Sol. (i) The part BC shows that the body is at rest.
   (ii) In first 10 seconds, distance travelled $= 100$m

$$\therefore \text{ Thus, average speed} = \frac{\text{Distance covered}}{\text{Time taken}} = \frac{100}{10} = 10 \text{ m/s}$$

   (iii) Speed of the object in part AB is given by slope $= \frac{100}{6} = 50/3$ m/s

   Speed of object in part BC $= 0$ m/s

   Speed of object in part CD $= \frac{100-0}{16-10} = \frac{100}{6} = 50/3$ m/s

Ex. Figure shows the time-displacement graph of an object. Calculate the following:
   (i) Average velocity in the first 4s.
   (ii) Displacement at the end of 10s.
   (iii) After how much time, the object reaches its original position ?
   (iv) Velocity at t = 2 s, and at t = 6s

Sol. (i) Average velocity in first 4 s, is given by

$$v = \frac{\text{Total displacement(in 4 seconds)}}{4s} = \frac{20}{4} = 5 m/s$$

(ii) Displacement at the end of 10 s = 20 m

(iii) It is clear from the graph that the object comes to its original position.

i.e. displacement = 0, after 7 seconds and again after 13 seconds.

(iv) At t = 2 s, v = slope = $\dfrac{0-20}{3-1} = \dfrac{-20}{2} = -10$ m/s

At t = 6 s, $\qquad$ v = $\dfrac{0-20}{7-5} = \dfrac{-20}{2} = -10$ m/s

Acceleration

◆ Rate of change of velocity is called acceleration

◆ The change in velocity may be in magnitude or in direction or both. i.e. $a = \dfrac{v-u}{t}$

◆ Unit of acceleration = m/s^2 or ms^{-2}

◈ **Types of acceleration : Uniform & Non uniform acceleration**

◆ **Uniform acceleration :** If a body travels in a straight line and its velocity increases by equal amounts in equal intervals of time then it is said to be in state of uniform acceleration e.g. motion of a freely falling body.

◆ **Non uniform acceleration :** A body has a non-uniform acceleration if its velocity increases by unequal amounts in equal intervals of time.

◆ **Average acceleration :** $a_{av} = \dfrac{v_2 - v_1}{t_2 - t_1} = \dfrac{\Delta v}{\Delta t}$

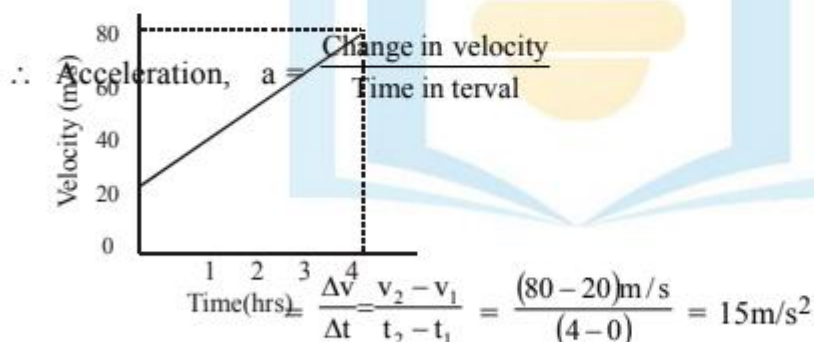[here it is assumed that acceleration remains the same during the time interval Δt.]

Ex. Time-velocity graph of a body is shown in the fig. Find its acceleration in m/s^2.

Sol. As it is clear from the figure,

At t = 0 s, $\qquad$ v = 20 m/s

At t = 4 s, $\qquad$ v = 80 m/s

∴ Acceleration, $a = \dfrac{\text{Change in velocity}}{\text{Time interval}}$

$\dfrac{\Delta v}{\Delta t} = \dfrac{v_2 - v_1}{t_2 - t_1} = \dfrac{(80-20)\,\text{m/s}}{(4-0)} = 15\,\text{m/s}^2$

Ex. Starting from rest, Deepak paddles his bicycle to attain a velocity of 6 m/s in 30 seconds then he applies brakes so that the velocity of the bicycle comes down to 4 m/s in the next 5 seconds. Calculate the acceleration of the bicycle in both the cases.

Sol. (i) Initial velocity, u = 0, final velocity, v = 6 m/s, time, t = 30 s

Using the equation v = u + at,

we have $\qquad a = \dfrac{v-u}{t}$

substituting the given values of u, v and t in the above equation, we get

$$a = \frac{6-0}{30} = 0.2 \text{ m/s}^2 ; \quad \text{which is positive acceleration.}$$

(ii) Initial velocity, u = 6 m/s, final velocity, v = 4 m/s, time, t = 5 s, then

$$a = \frac{v-u}{t} = \frac{4-6}{5} = -0.4 \text{ m/s}^2 ; \qquad \text{which is retardation.}$$

Note : The acceleration of the case (i) is positive and is negative in the case (ii).

Equations of Motion

◈ **Motion under uniform acceleration**

Suppose a body starts with initial velocity u, moving with an acceleration attains a velocity v after time t travels a distance s, then motion can be described by following equations.

(a) $v = u + at$

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

(c) $v^2 = u^2 + 2as$

◆ The equations of motion under gravity can be obtained by replacing acceleration by acceleration due to gravity (g) and can be written as follows :

◆ When the body is coming towards the centre of earth

(a) $v = u + gt$;

(b) $h = ut + \frac{1}{2}gt^2$;

(c) $v^2 = u^2 + 2gh$

◆ When a body is thrown upwards with some initial velocity, then a retardation produced due to attraction of the earth. In equations of motion, a is replaced by (–g) and thus equations become.

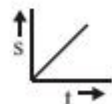**(a)** $v = u - gt$;

(b) $h = ut - \frac{1}{2}gt^2$;

(c) $v^2 = u^2 - 2gh$

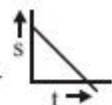◆ Distance covered by a body in n^{th} sec. i.e. $s_n = u + \frac{1}{2}a(2n - 1)$

Various Graphs Related to Motion

◈ **Displacement- time graph :**

◆ The straight line inclined to time axis in s-t graph represents constant velocity.

◆ The straight line inclined to time axis in s-t graph represents constant negative velocity.
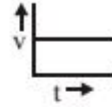
◆ Body with accelerated motion (velocity increasing)

◆ Body with decelerated motion(velocity decreasing)
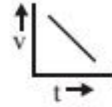
❖ **Velocity -time graph :**

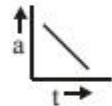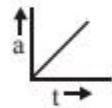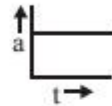◆ For the body having constant velocity or zero acceleration.

◆ The body is moving with constant retardation and its initial velocity is not zero.

❖ **Acceleration time graph :**

◆ Acceleration is constant

◆ Acceleration is increasing and is +ve

◆ Acceleration is decreasing and is –ve

Circular Motion

When a body moves in such a way that its distance from a fixed point always remains constant, then its motion is said to be the circular motion.

❖ **Uniform circular motion :**

◆ If the partical travels out equal angles in equal times, then its motion is said to be uniform circular motion.

◆ In uniform circular motion speed remains const.
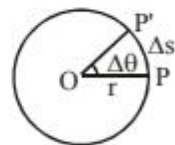
❖ **Linear velocity (v) :**

It is defined as distance travelled per unit time on a circular path.

❖ **Angular velocity (ω) :**

It is defined as angle travelled per unit time on a circular path.

$$\omega = \frac{\Delta\theta}{\Delta t}$$

◆ Unit is Radian/sec. or rad/s

◆ $v = r\omega$ where   r = radius of the circle.

    v = Linear velocity

    w = Angular velocity

❖ **Centripetal acceleration**

◆ In uniform circular motion the particle experiences an acceleration called the centripetal acceleration.

◆ $a_c = \dfrac{v^2}{r}$

◆ The direction of centripetal acceleration is along the radius towards the centre.

◈ **Centripetal force :**

   ◆ Always acts towards centre.

   ◆ Centripetal force is required to move a particle in a circle.

   ◆ Because F_c is always perpendicular to velocity or displacement, hence the work done by this force will always be zero.

   Note :

   ◆ Circular motion in horizontal plane is usually uniform circular motion.

   ◆ Remember that equations of motion are not applicable for circular motion.

◈ **Time period :**

   ◆ It is the time taken to complete one complete revolution.

   ◆ In one revolution, angle subtended is 2π and if T is time period, then the angular velocity is given by

   $$\omega = \frac{2\pi}{T}$$

   or $$T = \frac{2\pi}{\omega}$$

◈ **Frequency :**

   ◆ Frequency is defined as the no. of revolutions per second.

   i.e. $n = \dfrac{1}{T} = \dfrac{\omega}{2\pi}$

Ex. The length of second's needle in a watch is 1.2 cm. Calculate the following :

   (i) Angular velocity and

   (ii) Linear velocity of the tip of the needle.

Sol. (i) We know that the second's needle in a watch completes one revolution in 60 seconds.

   ∴ Time period, T = 60 s

   Angular velocity,

   $$\omega = \frac{2\pi}{T} = \frac{2\pi}{60} = \frac{\pi}{30} \text{ rad/s}$$

   (ii) Length of the needle = 1.2 cm = Radius of the circle

   Linear velocity of the tip of the needle is given by

   $$v = r\omega = 1.2 \times \frac{\pi}{30} = \frac{\pi}{25}$$

   or $v = \dfrac{\pi}{25} = 1.266 \times 10^{-1}$ cm/sec.

Ex. Earth revolves around the sun in 365 days. Calculate its angular velocity.

Sol. Time period,

   T = 365 days

   $= 365 \times 24 \times 60 \times 60$ seconds

   ∴ Angular velocity,

   $$\omega = \frac{2\pi}{T} = \frac{2\pi}{365 \times 24 \times 60 \times 60} \text{ rad/s} = 1.99 \times 10^{-7} \text{ rad/s}.$$

EXERCISE - 1

VERY SHORT ANSWER TYPE QUESTION.

Q.1 What does the slope of time distance graph represent ?

Q.2 What does the slope of time-velocity graph represent ?

Q.3 What is the acceleration of a body moving with constant velocity ?

Q.4 What is the unit of acceleration in MKS system ?

Q.5 What does area under time-velocity graph represent ?

Q.6 Define uniform circular motion.

Q.7 What is the relation between linear velocity and angular velocity ?

Q.8 Define velocity.

SHORT ANSWER TYPE QUESTION

Q.9 A body falls from a height of 500 m. In how much time, will it strike the ground ?

Q.10 Differentiate between the following :

(i) speed and velocity,

(ii) distance and displacement

Q.11 A body starts moving with an initial velocity 50 m/s and acceleration 20 m/s^2. How much distance it will cover in 4s ? Also, calculate its average speed during this time interval.

Q.12 A body is moving with a speed of 20 m/s. When certain force is applied, an acceleration of 4 m/s^2 is produced. After how much time its velocity will be 80 m/s ?

Q.13 A body starts from rest and moves with a constant acceleration. It travels a distance s_1 in first 10 s, and a distance s_2 in next 10 s. Find the relation between s_2 and s_1.

Q.14 A train is moving with a velocity 400 m/s. With the application of brakes a retardation of 10 m/s^2 is produced. Calculate the following :

(i) After how much time it will stop ?

(ii) How much distance will it travel before it stops ?

Q.15 A body is thrown vertically upwards with an initial velocity of 19.6 m/s. If g = –9.8 m/s^2. Calculate the following :

(i) The maximum height attained by the body.

(ii) After how much time will it come back to the ground ?

Q.16 From the top of a tower of height 490 m, a shell is fired horizontally with a velocity 100 m/s. At what distance from the bottom of the tower, the shell will hit the ground ?

Q.17 The brakes applied to a car produce a negative acceleration of 6 m/s^2. If the car takes 2 seconds to stop after applying the brakes, calculate the distance it travels during this time.

Q.18 A particle moves in a circle of radius 2 m and completes 5 revolutions in 10 seconds. Calculate the following :

   (i) Angular velocity and   (ii) Linear velocity.

EXERCISE- 2

SINGLE CORRECT ANSWER TYPE QUESTIONS

Q.1 A car increases its speed from 36 km/hr to 72 km/hr in 10 s. Its acceleration is

(A) 1 m/s^2 (B) 2 m/s^2

(C) 3.6 m/s^2 (D) 5 m/s^2

Q.2 The rate of change of displacement with time is called

(A) speed   (B) velocity

(C) angular velocity   (D) acceleration

Q.3 The velocity of an object is directly proportional to the time elapsed. The object has

(A) uniform speed

(B) uniform velocity

(C) uniform acceleration

(D) variable acceleration

Q.4 A body whose speed is constant

(A) has a constant velocity

(B) must be accelerated

(C) might be accelerated

(D) can not be accelerated

Q.5 An object is moving with a constant velocity of 10 m/s, then its acceleration is

(A) zero   (B) 10 m/s^2

(C) 5 m/s^2 (D) 20 m/s^2

Q.6 A particle moves with a uniform positive acceleration. Its velocity-time graph is a

(A) straight line parallel to time axis

(B) straight line parallel to velocity axis

(C) straight line inclined to time axis

(D) parabola

Q.7 A ball is thrown vertically upwards, It rises to a height of 20 m and comes back to the same place, then the

(A) total distance covered by the ball is zero

(B) net displacement of the ball is zero

(C) displacement is 40 m

(D) both distance moved and displacement are 40 m each

Q.8 A body moves with a constant acceleration upto 10s. It travels a distance s, in first 5s and a distance s_2 in next 5s, then

(A) $s_2 = s_1$ (B) $s_2 = 2s_1$

(C) $s_2 = 3s_1$ (D) $s_2 = 4s_1$

Q.9 The slope of speed-time graph gives

(A) displacement   (B) velocity

(C) acceleration   (D) momentum

Q.10 A particle moves in a straight line. It travels for first half time with a velocity v_1 and for next half

time with a velocity v_2. The average velocity over the complete path is

(A) $\dfrac{v_1 + v_2}{2}$

(B) $\dfrac{2v_1 v_2}{v_1 + v_2}$

(C) $\dfrac{v_1 - v_2}{2}$

(D) $v_1 + v_2$

Q.11 A particle is thrown vertically up with some initial velocity and comes back to the ground. Its velocity-time graph is represented by
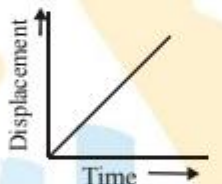
(A)

(B)

(C)

(D)
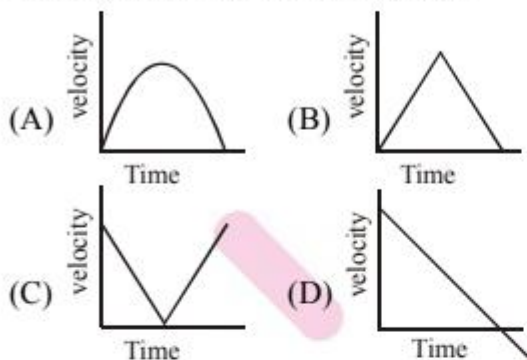
Q.12 The following time-displacement graph (fig.) represents

(A) zero velocity

(B) constant velocity

(C) increasing velocity

(D) decreasing velocity
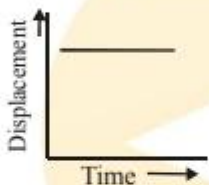
Q.13 The following time-displacement graph (fig.)

(A) zero velocity

(B) constant velocity

(C) increasing velocity

(D) decreasing velocity

Q.14 The following time-velocity graph (fig.) represents

(A) zero acceleration

(B) constant acceleration

(C) increasing acceleration

(D) decreasing acceleration
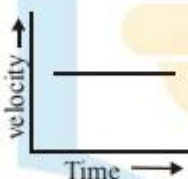
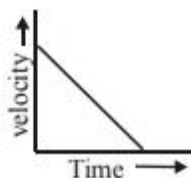

Q.15 The following time-velocity graph (fig) represents

(A) zero acceleration

(B) positive acceleration

(C) negative acceleration

(D) variable acceleration

Q.16 The following time-velocity graph (fig.) represents

(A) zero acceleration

(B) positive acceleration

(C) negative acceleration

(D) variable acceleration

Q.17 The following time-velocity graph (fig.) represents

(A) zero acceleration

(B) constant acceleration

(C) increasing acceleration

(D) decreasing acceleration

Q.18 Which of the following quantities is a vector quantity ?

(A) time   (B) distance

(C) speed   (D) velocity

Q.19 Which of the following quantities is/are a vector quantity ?

(A) Mass   (B) Length

(C) work   (D) Momentum

Q.20 Which of the following is incorrect statement ?

(A) speed is a scalar quantity while velocity is a vector quantity

(B) speed may be positive or negative but velocity is always positive.

(C) The change in the position of a body in a particular direction is called   displacement.

(D) displacement can be positive as well as negative.

Q.21 The acceleration versus time graph of a particle moving in a straight line is shown in the figure. The velocity-time graph of the particle would be–
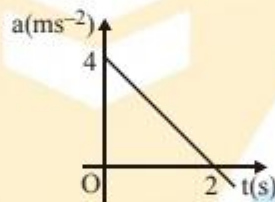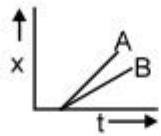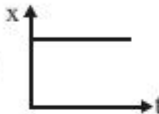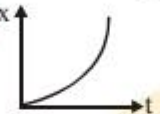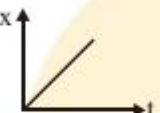

(A) a straight line   (B) a parabola

(C) a circle   (D) an ellipse

Q.22 The acceleration versus time graph of a particle is as shown in figure. The respective v–t graph of the particle is–
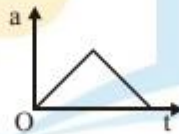
(A)   (B)

(C)   (D)

Q.23 The displacement of a particle is proportional to the cube of time. Then magnitude of its acceleration–

(A) increases with time

(B) decreases with time

(C) constant but not zero

(D) zero

Q.24 Figure shows two displacement-time graphs for particles A and B. Their relative velocity-

(A) zero

(B) non-zero but constant

(C) continuously decreases

(D) continuously increases

Q.25 Which of the following distance-time graphs represents one dimensional uniform motion?

(A)   (B)

(C)   (D)

Q.26 A stone falls from the top of the tower in 8 sec. How much time will it take to cover the first quarter of the distance starting from the top ?

(A) 4s   (B) 2s   (C) 1s   (D) none

Q.27 The slope of the velocity-time graph for retarded motion is–

(A) positive   (B) negative

(C) zero   (D) infinite

Q.28 A car travels along a straight line with speed V_1 from A to B and returns back from B to A with speed V_2. The average speed of the car during its journey is given by–

(A) $\dfrac{V_1 + V_2}{2}$ (B) $\dfrac{2V_1V_2}{V_1 + V_2}$

(C) $\dfrac{V_1V_2}{V_1 + V_2}$ (D) $\sqrt{V_1V_2}$

Q.29 A particle moves on a circular path with constant speed. What is the nature of its acceleration–

(A) it is zero

(B) it is uniform

(C) its direction changes

(D) its magnitude changes

Q.30 A stone thrown upward with a speed u from the top of the tower reaches the ground with the velocity 3u. The height of the tower is–

(A) $3u^2/g$ (B) $4u^2/g$

(C) $6u^2/g$ (D) $9u^2/g$

Q.31 The velocity of a body depends on time according to the equation $v = 20 + 0.1t^2$. The body is undergoing–

(A) Uniform acceleration

(B) Uniform retardation

(C) Non-uniform acceleration

(D) Zero acceleration

Q.32 A driver applies the brakes on seeing traffic signal 400 m ahead. At the time of applying the brakes vehicle was moving with 15 ms^{-1} and retarding with 0.3 ms^{-2}. The distance of vehicle after 1 minute from the traffic light is–

(A) 25m   (B) 375m

(C) 360m (D) 40 m

Q.33 Choose the wrong statement–

(A) zero velocity of a particle does not necessarily mean that its acceleration is zero.

(B) zero acceleration of a particle does not necessarily mean that its velocity is zero.

(C) if speed of a particle is constant, its acceleration must be zero.

(D) none of these

Q.34 Which statements can be impossible cases in one/two dimensional motion–

(A) A body has zero velocity and still be accelerating

(B) The velocity of an object reverses direction when acceleration is constant

(C) An object be increasing in speed as its acceleration decreases.

(D) None of these

Q.35 A body falling for 2 sec covers a distance 'S' which is equal to that covered in next 1 sec. If g = 10 m/sec^2 the distance S is –

(A) 30 m   (B) 10 m

(C) 60 m   (D) 20 m

Q.36 Which of the following graphs represents the uniform motion–

(A)   (B)

(C)   (D)