

## **Chapter # 02**

### **Kinematics**

#### **Comprehensive questions:**

**Q#1. What is motion? Describe that motion is relative. How two observers in relative motion can have conflicting views about same object?**

**Ans: Motion:**

A body is said to be in state of motion if it changes its position with respect to its surroundings (or an observer).

**Examples:**

1. A flying bird
2. A moving car
3. A running boy, etc

**Rest and Motion are Relative:**

The rest and motion are not absolute. Both are relative because they need specification of observer.

**Explanation:**

Objects can be at rest and in motion at the same time. Sometimes it happens that a body "A" will be at rest with respect to body "B" but at the same time it will be in motion with respect to body "C". So for same events two observers can have different observations.

**Examples:**

1. For example, a person travelling by train is at rest with respect to its fellow passenger but the same person is in motion with respect to all the bodies outside the train. Thus, the motion and rest are not absolute but relative. This means that we have to specify the observer while telling about the rest or motion of the body.

2. Similarly, in the classroom, when teacher changes her position while the students are sitting on their chairs. According to the student observation, teacher is in motion whereas, the teacher while moving also observes the students to move as well because the distance between teacher and students in classroom is changing with respect to each other. This shows that rest and motion are relative.

**Q#2. Explain different types of motion and give an example of each.**

**Ans: Types of Motion:**

In general, there are three types of motion which are described below:

1. Translatory Motion
2. Rotatory Motion
3. Vibratory Motion

1. **Translatory Motion:** That type of motion in which all particles of the body move parallel to each other along any path, straight or curved is called translatory motion.

**Examples:**

1. Motion of a ball
2. A moving car, train, bus etc
3. A running boy

**2. Types of Translatory motion:**

There are further three types of translatory motion which are as follow:

**(i) Rectilinear Motion:**

The straight line motion of a body is called rectilinear motion.

**Example:**

Motion of free falling bodies.

**(ii) Curvilinear Motion:**

The motion of a body along a curved path is called curvilinear motion.

**Example:**

Motion of cricket ball in air.

**(iii) Random Motion:**

The irregular motion of a body is called random motion.

**Example:**

- Motion of gas molecules.
- Flight of butterfly

**2. Rotatory Motion:**

That type of motion in which all particles of a body moves around a fixed point or axis is called rotatory motion.

**Examples:**

1. Motion of the blades of a fan
2. Motion of a wheel.
3. Motion of hands of a clock.

**3. Vibratory Motion:**

The back and forth motion of a body along the same path about its mean position is called vibratory motion.

**Examples:**

1. Motion of a swing
2. Motion of pendulum
3. Motion of the strings of a guitar.

**Q#3. Define scalar and vector quantities. Explain with example the graphical representation of vector quantities.**

**Ans: Scalar Quantities:**

Those physical quantities which are completely described by their magnitude only are called scalar quantities or scalars.

The scalars can be added, subtracted, multiplied and divided by ordinary mathematical method.

**Examples:**

Speed, distance, temperature, energy, volume, power etc. are the examples of scalar quantities.

**Vector Quantities:**

Those physical quantities which are completely described by their magnitude as well as direction are called vector quantities or vectors.

The vectors can be added, subtracted, divided and multiplied by graphical or geometrical method.

**Examples:**

Force, velocity, acceleration, displacement etc. are the examples of vector quantities.

**Graphical Representation of Vector Quantities:**

Graphically, a vector is represented by an arrow where the length of arrow shows the magnitude (under certain scale) and the arrow head shows the direction of the vector.

The direction of the vector can either be represented by “**Geographical**” **Coordinate System (NEWS)**” or “**Cartesian Coordinate System**”.

**Steps to represent a vector:**

The following method is used to represent a vector.

1. Draw a coordinate system.
2. Select a suitable scale.
3. Draw a line in the specified direction. Cut the line equal to the magnitude of the vector according to the selected scale.
4. Put an arrow in the direction of the vector.

**Example:**

We can explain the graphical representation of a vector with the help of an example. Suppose a bus is moving towards east (direction) with a velocity of  $50\text{kmh}^{-1}$  (magnitude).

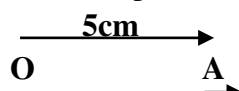
1. First of all, we specify the direction by drawing NEWS coordinate system as shown in figure.

Now, we select a suitable scale i.e.,

$$\text{Let, } 10\text{kmh}^{-1} = 1\text{cm}$$

$$\text{Then } 50\text{kmh}^{-1} = 5\text{cm}$$

2. Now, we draw the representative line  $\vec{OA}$  of 5cm towards east i.e.



In fig “B” the length of line  $\vec{OA}$  represents the magnitude of the given vector (velocity) and arrow head indicates the direction of given vector. This vector is infact  $50\text{ kmh}^{-1}$  and is directed towards East.

**Q#4. What is position. Explain the difference between distance traveled, displacement, and displacement magnitude.**

**Ans: Position:**

The location of an object relative to some reference point (origin) is known as position of that object.

**Explanation:**

Position of an object can be described in rectangular coordinate system where origin O can serve as a reference point. In the given figure, the position of an object at any point "P" is  $P(x, y)$  where  $x$  and  $y$  are known as coordinates of point P.

**1. Distance travelled:**

The length of actual path traveled by a body between two positions is called distance travelled.

The value of distance is always positive. Distance is a scalar quantity because it has magnitude only. It has no direction. Distance is usually denoted by  $\Delta x$ ,  $\Delta r$ ,  $\Delta s$ ,  $\Delta l$ , or  $\Delta d$  and its SI unit is meter (m).

**2. Displacement:**

The shortest directed distance between two positions is called displacement.

*Or*

Straight distance from one point to another is called displacement.

The value of displacement can be positive, negative or even zero. It is a vector quantity because it has magnitude as well as direction. Displacement is usually denoted by  $\Delta \vec{x}$ ,  $\Delta \vec{r}$ ,  $\Delta \vec{s}$ ,  $\Delta \vec{l}$  or  $\Delta \vec{d}$  and its SI unit is meter(m).

**3. Displacement Magnitude:**

The magnitude of displacement is the shortest distance between the two points.

The magnitude of displacement can be equal to the magnitude of distance when a body moves in a straight line. It is a scalar quantity rather than a vector because it has magnitude only and having no direction.

**For example:**

In the given figure, a body reaches from point “A” to ‘D’ through “B” and “C”. So, path “ABCD” represents the total path travelled by the body during its motion i.e. distance. While AD represents the shortest distance between A and D. So, it is known as displacement.

**Q#5. State and explain the terms:**

- a) Speed
- b) Velocity
- c) Acceleration

**a. Speed:**

The distance covered by a body in a unit time is called speed. It is denoted by “V”.

**Mathematical Form:**

Mathematically, it can be written as:

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

Or

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

Or

$$v = \frac{S_f - S_i}{t_f - t_i}$$

**Quantity and Unit:**

Speed is a scalar quantity and its SI unit is meter per second (m/s or  $\text{ms}^{-1}$ )

**Example:**

For example, a car is moving with a speed of 50m/s. This means that in every one second, it covers a distance of 50m.

**Types of Speed:**

The speed is categorized into following types:

**1) Uniform Speed (Constant Speed):**

If a body covers equal distances in equal intervals of time, then the body is said to be moving with uniform speed or constant speed.

**Mathematical Form:**

$$\text{Uniform speed} = \frac{\text{Equal distance covered}}{\text{equal interval of time}}$$

$$\text{Or } v = \frac{S}{t}$$

**2) Non-Uniform Speed (Variable Speed):**

If a body covers unequal distances in equal interval of time, then the body is said to be moving with non-uniform speed or variable speed.

**Mathematical Form:**

$$\text{Variable Speed} = \frac{\text{Unequal distance covered}}{\text{equal interval of time}}$$

**3. Average Speed:**

The total distance covered by a body divided by total time taken is called Average speed. It is denoted by “<math>\langle v \rangle</math>”.

**Mathematical Form:**

$$\text{Average Speed} = \frac{\text{Total distance}}{\text{Total Time}}$$

$$\text{Or } \langle v \rangle = \frac{s}{t}$$

**4. Instantaneous Speed:**

The speed of a body at any particular instant of time is called instantaneous speed.

For such speed, we take time interval “ $\Delta t$ ” to be very small such that limit “ $\Delta t$ ” approaches to zero i.e. limit  $\Delta t \rightarrow 0$ .

or

The speed for short time interval “ $\Delta t$ ” is called instantaneous speed.

**Mathematical Form:**

Mathematically, it can be written as:

$$\text{Instantaneous Speed} = \lim_{\Delta t \rightarrow 0} \frac{\text{short distance}}{\text{short time}}$$

$$\Delta t \rightarrow 0$$

Or

$$v = \lim_{\Delta t \rightarrow 0} \frac{\Delta s}{\Delta t}$$

**b. Velocity:**

The displacement (  $\Delta \vec{s}$  ) covered by a body in a unit time (  $\Delta t$  ) is called velocity. It is denoted by  $\vec{v}$ .

or

The speed of a body in a definite direction is called velocity.

**Example:**

For example, a car is moving with a velocity of 50m/s towards east. So, in case of velocity, we specify both magnitude (speed of car) and direction.

**Quantity and Unit:**

Velocity is a vector quantity and its SI unit is meter per second (m/s or  $\text{ms}^{-1}$ ).

**Mathematical Form:**

Mathematically, it can be written as:

$$\text{Velocity} = \frac{\text{displacement}}{\text{time}}$$

$$\text{Or } \vec{v} = \frac{\vec{\Delta s}}{\Delta t}$$

Or

$$\vec{v} = \frac{\vec{s}_f - \vec{s}_i}{t_f - t_i}$$

### **Types of Velocity:**

The velocity is categorized into following types.

#### **1. Uniform Velocity (constant velocity):**

If a body covers equal displacement in equal intervals of time, then the body is said to be moving with uniform velocity or constant velocity. In uniform velocity, the speed as well as direction of the body does not change with time.

#### **Mathematical Form:**

Mathematically, it can be written as:

$$\text{Uniform Velocity} = \frac{\text{Equal displacement covered}}{\text{Equal interval of time}}$$

#### **2. Non-uniform velocity (variable velocity):**

If a body covers unequal displacement in equal interval of time, then the body is said to be moving with non-uniform velocity or variable velocity.

In variable velocity, the speed or direction or both of a moving body changes with time.

#### **Mathematical Form:**

Mathematically, it can be written as:

$$\text{Variable Velocity} = \frac{\text{Unequal displacement covered}}{\text{Equal interval of time}}$$

#### **3. Average velocity:**

The total displacement covered by a body divided by the total time is called average velocity.

#### **Mathematical Form:**

Mathematically, it can be written as:

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

$$\vec{v} = \frac{\vec{S}}{t}$$

#### **4. Instantaneous velocity:**

The velocity of a body at any particular instant of time is called instantaneous velocity.

Or

The velocity for very short time interval  $\Delta t$  (very small such that limit " $\Delta t$ " approaching to zero) is called instantaneous velocity.

**Mathematical Form:**

Mathematically, it can be written as:

$$\text{Instantaneous velocity} = \lim_{\Delta t \rightarrow 0} \frac{\text{short displacement}}{\text{short time}}$$

$$\vec{v} = \lim_{\Delta t \rightarrow 0} \frac{\vec{\Delta s}}{\Delta t}$$

**c. Acceleration:**

The measure of change in velocity " $\Delta v$ " with the passage of time " $\Delta t$ " is called acceleration.

Or

Time rate of change of velocity is called acceleration.

**Mathematical Form:**

Mathematically, it can be written as:

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

Or

$$\vec{a} = \frac{\vec{\Delta v}}{\Delta t}$$

Or

$$\vec{a} = \frac{v_f - v_i}{t_f - t_i}$$

**Quantity and unit:**

Acceleration is a vector quantity and its SI unit is meter per second squared ( $\frac{m}{s^2}$  or  $ms^{-2}$ ).

**Type of Acceleration:**

The acceleration is categorized into following types.

**1. Uniform Acceleration (constant Acceleration):**

A body is said to be moving with uniform acceleration, if equal change occurs in velocity in equal intervals of time.

**2. Non-uniform or variable acceleration:**

A body is said to be moving with variable acceleration, if unequal change occurs in velocity in equal intervals of time.

**3. Average Acceleration:**

The total change in velocity of a body divided by the total time is called average acceleration. It is denoted by " $\langle \vec{a} \rangle$ ".

**Mathematical Form:**

Mathematically, it can be written as:

$$\text{Average Acceleration} = \frac{\text{Total change in velocity}}{\text{Total time}}$$



Or

$$\langle \vec{a} \rangle = \frac{\vec{v}}{t}$$

#### 4. Positive Acceleration:

If the magnitude of velocity increases with the passage of time, such type of acceleration is called positive acceleration. The positive acceleration is always in the direction of motion of a body.

#### Example:

For example, a car starts from rest and its speed increases along a straight line with the passage of time then the car is said to have positive acceleration.

#### 5. Negative Acceleration:

If the magnitude of velocity decreases with the passage of time, such type of **acceleration is called negative acceleration.**

Negative acceleration is also called **Retardation or deceleration.** The negative acceleration is always in the opposite direction of motion of a body.

#### Example:

For example, when a car is moving with a certain speed then brakes are applied which decreases the speed of car, then the car is said to have negative acceleration.

#### 6. Instantaneous Acceleration:

The Acceleration of a body at any particular instant of time is called instantaneous acceleration.

The value of instantaneous acceleration is obtained, if  $\Delta t$  is made smaller such that it approaches to zero.

#### Mathematical Form:

Mathematically, it can be written as:

$$\text{Instantaneous Acceleration} = \lim_{\Delta t \rightarrow 0} \frac{\text{short change in velocity}}{\text{short time}}$$

$$\vec{a} = \lim_{\Delta t \rightarrow 0} \frac{\vec{\Delta v}}{\Delta t}$$

**Q#6. Use velocity time graph to prove the following equations of motion.**

$$(a) v_f = v_i + at \quad (b) s = v_i t + \frac{1}{2} at^2 \quad (c) 2as = v_f^2 - v_i^2$$

(a) Derive 1<sup>st</sup> equation of motion

OR

Prove that  $v_f = v_i + at$

**Ans:** 1<sup>st</sup> equation of motion

Consider a body has initial velocity " $v_i$ " at point "A" and then its velocity changes with uniform acceleration from "A" to "B" in time interval "t" and its final velocity becomes " $v_f$ " as shown.

**In the figure**Initial velocity =  $v_i = OA = DC$ Final velocity =  $v_f = BC$ Time =  $t = OC = AD$ Acceleration =  $a = AB$ **From the graph**

$$BC = BD + DC \text{ ----- (i)}$$

Put the values of "BC" and "DC" in equation (i)

$$V_f = BD + v_i \text{ ----- (ii)}$$

As we know that the slope of velocity-time graph is equal to acceleration, then

$$AB = \frac{BD}{AD}$$

$$a = \frac{BD}{t}$$

$$at = BD$$

Put it in eq (ii)

$$V_f = at + V_i$$

$$V_f = V_i + at \quad \text{(Proved)}$$

**(b) Derive 2<sup>nd</sup> equation of motion****OR**

$$\text{Prove that } S = v_i t + \frac{1}{2} at^2$$

**Ans: 2<sup>nd</sup> equation of motion**

Consider a body is moving with initial velocity " $v_i$ " and covered distance " $S$ " in time " $t$ ".

The distance covered by a body is equal to the area between velocity-time graph "AB" and time axis "OC" which is equal to the area of "OABC".

**In the figure**Initial velocity =  $v_i = OA = DC$ Final velocity =  $v_f = BC$ Time =  $t = OC = AD$ Acceleration =  $a = AB$ Distance =  $S$ **From the figure**

Distance travelled = Area of figure OABC

$$S = \text{Area of Rectangle OADC} + \text{Area of Triangle ABD}$$

$$S = (\text{Length} \times \text{Breadth}) + \frac{1}{2}(\text{Length} \times \text{Breadth})$$

$$S = (OC \times OA) + \frac{1}{2}(AD \times BD)$$

By putting the values we get

$$S = (t \times v_i) + \frac{1}{2} (t \times BD) \text{ ----- (i)}$$

As

$$AB = \frac{BD}{AD}$$

$$a = \frac{BD}{t}$$

$$at = BD$$

Put it in eq (i)

$$S = + V_i t + \frac{1}{2} (t \times at)$$

$$S = v_i t + \frac{1}{2} at^2$$

(Proved)

(c) Derive 3<sup>rd</sup> equation of motion

OR

$$\text{Prove that } 2aS = v_f^2 - v_i^2$$

**Ans:** 3<sup>rd</sup> equation of motion

Consider a body is moving with initial velocity “ $v_i$ ” covered distance “ $S$ ” in time “ $t$ ”.

The distance covered by a body is equal to of “OABC” which is known as Trapezium.

and

the area

**In the figure**

$$\text{Initial velocity} = v_i = OA = DC$$

$$\text{Final velocity} = v_f = BC$$

$$\text{Time} = t = OC = AD$$

$$\text{Acceleration} = a = AB$$

$$\text{Distance} = S$$

**From the figure**

Distance travelled = Area of figure OABC

$$S = \text{Area of Trapezium OABC}$$

$$S = \frac{(\text{Sum of parallel sides}) \times \text{height}}{2}$$

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

$$S = \frac{(v_i + v_f) \times t}{2}$$

$$S = \frac{(v_f + v_i)}{2} \times t \text{ ----- (i)}$$

As from 1<sup>st</sup> equation of motion

$$V_f = V_i + at$$

OR

$$t = \frac{v_f - v_i}{a}$$

Put it in eq (i)

$$S = \left(\frac{v_f + v_i}{2}\right) \left(\frac{v_f - v_i}{a}\right)$$

$$S = \frac{v_f^2 - v_i^2}{2a}$$

$$2aS = v_f^2 - v_i^2 \quad (\text{proved})$$

**Q#7. What is free fall? what is its value near the surface of earth. Explain with example that rock and sheet of paper will fall at the same rate without air resistance.**

**Ans: Free Fall:**

The motion in which air resistance is neglected and the acceleration is nearly constant is known as free-fall.

**Explanation:**

The acceleration produces in a freely falling body due to attraction of earth is called acceleration due to gravity or gravitational acceleration. It is denoted by “g”.

According to famous scientist Galileo, In the absence of air resistance, when bodies of different masses (light or heavy) are dropped at the same time from the same height then they fall towards earth with the same acceleration.

Furthermore, if the distance of the fall is small compared to the radius of earth, the acceleration can be considered constant throughout its fall.

**Value of “g”:**

The value of “g” near the earth’s surface is approximately “9.8 m/s<sup>2</sup>” or “32.2Ft/s<sup>2</sup>” and its value is constant for all bodies. It is directed downward towards the centre of the earth.

**Example:**

If we drop a rock and sheet of paper from the top of tube at the same time. It is found that in the presence of air resistance, rock is falling faster than a sheet of paper. The effect of air resistance is responsible for slower fall of the paper. When air is removed from the tube, both the rock and the paper have exactly the same acceleration due to the gravity. So, in the absence of air, the rock and the paper fall freely as shown in figure.

**Acceleration due to gravity and three equations of motion:**

For freely falling bodies, we can use the equations of motion by replacing “a” with “g” and distance “S” with height “h”. Then, the equations become:

$$v_f = v_i + gt \quad \text{(i)}$$

$$h = v_i t + \frac{1}{2}gt^2 \quad \text{(ii)}$$

$$2gh = v_f^2 - v_i^2 \quad \text{(iii)}$$

**Conditions:** While using these equations of motion there are two conditions.

1. If a body is thrown vertically downward, its initial velocity ( $v_i$ ) will be zero and the value of “g” will be positive.

2. If a body is thrown vertically upward, its final velocity “ $v_f$ ” will be zero and the value of “g” will be

negative because with altitude, the value of “g” decreases.

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## TOPIC WISE QUESTIONS

### Q#1. Define Kinematics.

#### Ans: Kinematics:

Kinematics is the branch of physics which deals with the study of motion without going into detail of what causes the motion.

### Q#2. Define Rest.

#### Ans: Rest:

When a body does not change its position with respect to its surrounding (or an observer), then the body is said to be in the state rest.

#### Examples:

1. A bird sitting on a branch of a tree.
2. A student sitting on a chair.

### Q#3. What is meant by graph and discuss how the slope of a graph can be calculated?

#### Ans: Graph:

A graph is a straight or curved line which shows a relationship between two physical quantities.

#### Explanation:

Usually, a graph contains horizontal and vertical lines at equal distances and coordinate systems to show relationship in various quantities. The horizontal lines are called x-axis while the vertical lines are called y-axis. The point of intersection of these two lines are called origin "O".

#### Slope of Graph:

The slope of graph means vertical coordinate difference divided by horizontal coordinate difference.

#### Mathematical Form:

Mathematically, it can be written as:

$$\text{Slope} = \frac{\Delta y}{\Delta x}$$

Or

$$\text{Slope} = \frac{y_f - y_i}{x_f - x_i}$$

#### Calculation of slope of a graph:

The slope of a graph in Cartesian coordinate system can be calculated as,

1. Pick two points  $P_i$  and  $P_f$  on the line.
2. Determine the coordinates i.e.  $P_i (x_i, y_i)$  and  $P_f (x_f, y_f)$  by drawing perpendicular on  $x$  and  $y$ -axis from both points.
3. Determine the difference between  $x$ -coordinates ( $\Delta x = x_f - x_i$ ) and  $y$ -coordinates ( $\Delta y = y_f - y_i$ .)
4. Dividing the difference in  $y$ -coordinates by difference in  $x$ -coordinates gives slope. i.e.

$$\text{Slope} = \frac{\Delta y}{\Delta x} = \frac{y_f - y_i}{x_f - x_i}$$

**Q#4. Discuss the distance time graph with different cases.**

**Ans: Distance- Time Graph:** The graph plotted between distance (s) and time (t) is called distance-time graph.

**Explanation:** In this graphical analysis, the distance is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis). Distance time graph is always in the positive xy plane, as with the passage of time, distance never goes to negative axis, irrespective of the direction of motion. The slope of distance time curve only gives speed.

$$\text{Slope} = \frac{\Delta s}{\Delta t} \quad \text{Or}$$

$$\text{Slope} = \frac{s_f - s_i}{t_f - t_i}$$

**Distance time graph with different cases:**

**1. When there is no motion (zero speed):**

When there is no change in distance with the passage of time, then the body is at rest. So, the speed is zero. In such conditions, graph will be a straight horizontal line as shown in figure.

**When the body is moving with uniform speed:** When a body covers equal distance in equal interval of time, then the body is said to be moving uniform speed, In such conditions the graph will be a straight line with a constant slope. i.e. the higher is the slope, greater will be the speed.

**When the body is moving with variable speed:** When a body covers unequal distance in equal interval of time, then it is said to be moving with variable speed. In such conditions, the slope does not remain constant as shown in figure.

to

**Q#5. Define speed-time graph? Show that how**

**(a) Slope or gradient of speed-time graph gives magnitude of acceleration?**

**(b) Area under the gives distance travelled?**

**Ans: Speed-Time Graph:** The graph plotted between speed (v) and time (t) is called speed-time graph.

In this graphical analysis, the speed is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis).

**(a) Slope of speed-time graph gives magnitude of acceleration:** The slope of speed-time graph will give the magnitude of acceleration i.e.

$$\text{Slope} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

**Explanation:** Consider the motion of the object which speeds up from 0 m/s to 8m/s in 4 seconds.

Now, the slope of the graph is given by:

$$\text{Slope} = \frac{\Delta v}{\Delta t}$$

Whereas,  $\Delta v = v_f - v_i$  And  $\Delta t = t_f - t_i$

$$\text{Slope} = \frac{v_f - v_i}{t_f - t_i}$$

So, eq (i) becomes

Slope = Magnitude of acceleration |a|

So,

$$a = \frac{8-0}{4-0}$$

$$a = \frac{8}{4}$$

$$a = 2\text{m/s}^2$$

Thus, the slope of speed time graph gives the magnitude of acceleration.

**(b) Area under speed time graphs represent the distance travelled:** In speed time graph, the area enclosed by the speed time curve and the time axis gives us the distance travelled by the body.

As we know that,

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

Or

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

By cross-multiplication

$$\Delta s = v \times \Delta t - (i)$$

Now, to find out the distance travelled by calculating the area of rectangle for the speed time graph, consider the motion of the object which speeds up from 0 m/s to 8 m/s in 4 sec.



As,

Distance travelled = Area of Rectangle –

(ii)

And we know that

Area of Rectangle = length x width

Area of Rectangle =  $l \times w$

So, eq (i) becomes,

Area of Rectangle =  $\Delta x \Delta t$

Where as  $\Delta t = t_f - t_i$ ,  $\Delta v = v_f - v_i$

So,

Area of rectangle =  $(t_f - t_i) \times (v_f - v_i)$

By putting values,

Area of rectangle =  $(4-0) \times (8-0)$   
 $= 4 \times 8$

Area of Rectangle = 32m

This shows that area under the graph gives us distance travelled.

**Q#6. Discuss the slopes of speed-time graph in following cases.**

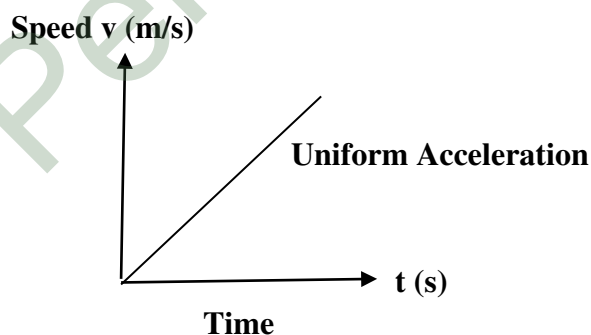
(a). When Acceleration is uniform

(b). When Acceleration is variable (non-uniform)

(c). When there is no Acceleration.

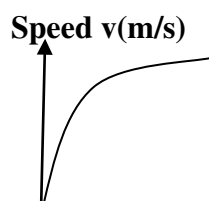
**a. When Acceleration is uniform:**

When the speed of a moving body increases by equal amounts in equal intervals of time then the speed-time graph of the body will be straight line with a constant slope as shown in figure. The slope of straight line shows uniform acceleration of the moving body.



**b. When acceleration is variable (non-uniform):**

When a body covers unequal distance in equal intervals of time then the body is said to be moving with variable speed. In such case, variable acceleration is produced and the slope of the body is a curved lined. So, the curved line shows the variable acceleration of the moving body as shown in figure.

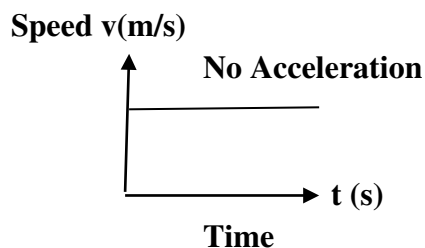


### Variable Acceleration



#### C. When there is no Acceleration:

When the speed of a moving body does not change with the passage of time then there is no acceleration produced in it. So, the speed remains constant and in such condition, the graph will be a straight horizontal line as shown in figure.



### “CONCEPTUAL QUESTIONS”

Give a brief response to the following questions.

**Q#1. Is it possible that displacement is zero but not the distance? Under what condition displacement will be equal to distance.**

**Ans:(a)**

Yes, it is possible that the displacement is zero but not the distance if the initial and final point of a moving body are at the same place.

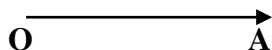
**For example:**



In figure ABCD, displacement is zero because starting and ending point is same i.e. “A” but distance covered by the body is ABCD which is the actual path of the body.

**(b)** The magnitude of distance and displacement will be equal when a body moves in a straight line because displacement is the shortest distance between two points in a straight line.

**For Example:**



In the given figure, a body moves from point “O” to “A”. Now, in this case distance and displacement are equal.

**Q#2. Does a speedometer measure a car's speed or velocity?**

**Ans:** As we know that speed is a scalar quantity. It has magnitude only but having no direction while velocity is a vector quantity and it has magnitude as well as direction. The speedometer of a car displays only magnitude i.e. speed of a car but it does not tell us about the direction of the car. Thus, the speedometer measures only the speed of the car but not its velocity.

**Q#3. Is it possible for an object to be accelerating and at rest at the same time? Explain with example.**

**Ans:** Yes, it is possible for an object to be accelerating and at rest at the same time.

**For example:**

If a body of mass "m" is thrown vertically upwards with initial velocity " $v_i$ " then it comes to rest after reaching at highest point. So, at that point, its final velocity " $v_f$ " becomes zero but forces acting on it will not be zero and still the body possess certain acceleration which is known as acceleration due to gravity i.e.  $g = -9.8 \text{ m/s}^2$ . In such case, the acceleration will be negative because it is opposite to the direction of velocity.

**Q#4. Can an object have zero acceleration and non-zero velocity at the same time? Give example.**

**Ans:** Yes, an object can have zero acceleration and non-zero velocity at the same time.

As we know that

$$\vec{a} = \frac{\Delta \vec{v}}{t} \text{ - (i)}$$

Eq (i) shows that acceleration depends upon rate of change in velocity of a body. If there is no change in velocity then, body will have zero acceleration but its velocity is not zero.

**Example:**

For example, if a car of mass "m" is moving along a smooth straight path "AB" with uniform velocity. In this case, the acceleration of the car is zero but its velocity is non zero.

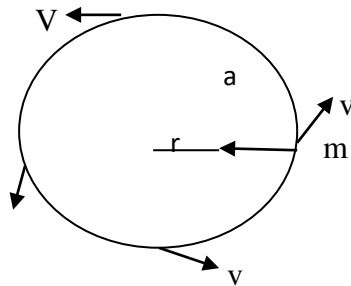
**Q#5. A person standing on a roof of a building throws a rubber ball down with a velocity of 8.0 m/s. What is the acceleration (magnitude and direction) of the ball?**

**Ans:** When a person throws a ball from the top of a building, the ball will fall towards earth due to force of gravity. According to famous scientist Galileo, all bodies falling towards earth with a constant acceleration of  $g=9.8\text{m/s}^2$ . So, if we ignore the air resistance, then the ball will fall freely with acceleration due to gravity "g". Its magnitude will be  $9.8 \text{ m/s}^2$  and it will be directed towards earth.

**Q#6. Describe a situation in which speed of an object is constant while velocity is not.**

**Ans:** A situation in which the speed of an object is constant while the velocity is not constant may be that of circular motion. For example, a body moving along a circular path may have a

constant (uniform) speed. But its velocity is not constant because the direction of velocity changes at each point continuously during circular motion.



**Q#7. Can an object have a northward velocity and a southward acceleration? Explain.**

**Ans:** Yes, it is possible for an object to have northward velocity and a southward acceleration in the following situations.

1. When a body is coming to the rest.
2. When the speed of a body is decreasing.

**Example:**

If a car is moving towards north and gradually its velocity decreases by applying breaks. Then, negative acceleration (deceleration) will produce which is opposite to the direction of the velocity. In this case, the acceleration produced will be acting towards south.

**Q#8. As a freely falling object speeds up, what is happening to its acceleration does it increase, decrease, or stay the same?**

**Ans:** In the absence of air resistance, all bodies falling towards earth with a constant acceleration. So, for freely falling objects, the speed of the body increases uniformly at the rate of  $9.8 \text{ m/s}^2$ . Thus, the acceleration of the body does not increase, or decrease but remains constant during free-fall motion. i.e. we take  $g=9.8 \text{ m/s}^2$  as a constant value for free-fall objects.

**Q#9. A ball is thrown upward with an initial speed of 5m/s. What will be its speed when it returns to starting point?**

**Ans:** If a ball is thrown vertically upward with an initial speed of 5m/s, then in the absence of air resistance, the ball will return back to its starting point with the same speed of 5m/s. Because, in upward and a downward, the only force acting on ball is gravitational pull of earth.

**“NUMERICAL QUESTIONS”**

1. A squash ball makes contact with a squash racquet and changes velocity 15m/s west to 25m/s east in 0.10s. Determine the vector acceleration of the squash ball.

**Data:**

Initial velocity (west) =  $\vec{v}_i = -15\text{m/s}$  (negative sign is used with  $\vec{v}_i$  because it is opposite to  $\vec{v}_f$ )

Final velocity (East) =  $\vec{v}_f = 25\text{m/s}$

Time =  $t = 0.10\text{s}$

**Find:**

Acceleration =  $\vec{a} = ?$

**Solution:**

As, we know that

$$\vec{a} = \frac{v_f - v_i}{t}$$

By putting values

$$\vec{a} = \frac{25 - (-15)}{0.10}$$

$$\vec{a} = \frac{25 + 15}{0.10}$$

$$\vec{a} = \frac{40}{0.10}$$

$$\vec{a} = 400 \text{ m/s}^2$$

**Result:**

So, the acceleration produced by squash ball is  $400 \text{ m/s}^2$  in the direction of east.

2. A golf ball that is initially traveling at 25m/s hits a sand trap and slows down with an acceleration of  $-20\text{m/s}^2$ . Find its displacement after 2.0s.

**Data:** Initial velocity =  $v_i = 25\text{m/s}$

Acceleration =  $a = -20\text{m/s}^2$  (deacceleration)

Time =  $t = 2\text{s}$

**Find:** Displacement =  $S = ?$

**Solution:** By using second equation of motion

$$S = v_i t + \frac{1}{2} a t^2$$

By putting values,

$$S = 25 \times 2 + \frac{1}{2} \times (-20) \times (2)^2$$

$$S = 25 \times 2 + \frac{1}{2} \times -20 \times 4$$

$$S = 50 + \frac{1}{2} \times -20 \times 4$$

$$S = 50 + \frac{1}{2} \times -80$$

$$S = 50 - 40$$

$$S = 10\text{m}$$

3. A bullet accelerates the length of the barrel of a gun 0.750m long with a magnitude of  $5.35 \times 10^5 \text{m/s}^2$ . With what speed does the bullet exit the barrel?

**Data:** Initial velocity =  $v_i = 0 \text{m/s}$

Distance covered =  $S = 0.750\text{m}$

Acceleration =  $\vec{a} = 5.35 \times 10^5 \text{m/s}^2$

**Find:** Final velocity =  $v_f = ?$

**Solution:**

By using 3<sup>rd</sup> equation of motion

$$2aS = v_f^2 - v_i^2$$

Or

$$v_f^2 = 2aS + v_i^2$$

By putting values

$$v_f^2 = 2 \times 5.35 \times 10^5 \times 0.750 + (0)^2$$

$$v_f^2 = 8.025 \times 10^5 + 0$$

$$v_f^2 = 8.025 \times 10^5$$

Taking square root on both sides

$$\sqrt{v_f^2} = \sqrt{8.025 \times 10^5}$$

$$v_f = \sqrt{80.25 \times 10^{-1} \times 10^5}$$

$$v_f = \sqrt{80.25 \times 10^{5-1}}$$

$$v_f = \sqrt{80.25 \times 10^4}$$

$$v_f = \sqrt{80.25} \times \sqrt{10^4}$$

$$v_f = \sqrt{80.25} \times \sqrt{(10^2)^2}$$

$$v_f = 8.958 \times 10^2 \text{ m/s}$$

$$v_f = 8.96 \times 10^2 \text{ m/s}$$

Or

$$v_f = 896 \times 10^{-2} \times 10^2 \text{ m/s}$$

$$v_f = 896 \times 10^{-2+2}$$

$$v_f = \mathbf{896 \text{ m/s}}$$

4. A driver is travelling at 18m/s when she sees a red light ahead. Her car is capable of decelerating at a rate of 3.65 m/s<sup>2</sup>. If she applies brakes when she is only 20.0m from the intersection when she sees the light, will she be able to stop in time.

**Data:**

Initial velocity =  $v_i = 18 \text{ m/s}$

Final velocity =  $v_f = 0 \text{ m/s}$       Acceleration =  $a = -3.65 \text{ m/s}^2$  (negative sign shows deceleration because velocity of car decreases)

Distance b/w car and red light =  $S_1 = 20 \text{ m}$

**Find:**

Actual distance covered =  $S_2 = ?$

Further distance covered =  $S = ?$

**Solution:** First, we calculate actual distance covered " $S_2$ " with deceleration by using 3<sup>rd</sup> equation of motion.

$$2aS_2 = v_f^2 - v_i^2$$

Or

$$S_2 = \frac{v_f^2 - v_i^2}{2a}$$

$$S_2 = \frac{(0)^2 - (18)^2}{2 \times -3.65}$$

$$S_2 = \frac{0 - 324}{-7.3}$$

$$S_2 = \frac{-324}{-7.3}$$

$$S_2 = 44.38 \text{ m}$$

Or

$$S_2 = \mathbf{44.4 \text{ m}}$$

Here the distance covered by the car with given deceleration is 44.4m which is greater than the remaining distance i.e 20m between the car and red light.

Thus, the driver will unable to stop the car with in 20m.

Now, For finding further distance covered "S"

$$S = S_2 - S_1$$

$$S = 44.4 - 20$$

$$S = 24.4\text{m}$$

So, she will go 24.4m past the light.

**Q#5. An antelope moving with constant acceleration  $2\text{m/s}^2$  covers crosses a point where its velocity is  $5\text{m/s}$ . After  $6.00\text{s}$  how much distance it has covered and what is its velocity.**

**Data:**

$$\text{Acceleration} = a = 2\text{m/s}^2$$

$$\text{Initial velocity} = v_i = 5\text{m/s}$$

$$\text{Time} = t = 6\text{s}$$

**Find:**

$$\text{Distance covered} = S = ?$$

$$\text{Final velocity} = v_f = ?$$

**Solution:**

For finding "S", we use 2<sup>nd</sup> equation of motion

$$S = v_i t + \frac{1}{2} a t^2$$

By putting values

$$S = 5 \times 6 + \frac{1}{2} \times 2 \times (6)^2$$

$$S = 30 + \frac{1}{2} \times 2 \times 36$$

$$S = 30 + 36$$

$$S = 66\text{m}$$

Now, for finding "v<sub>f</sub>", we use 1<sup>st</sup> equation of motion

$$v_f = v_i + at$$

By putting values

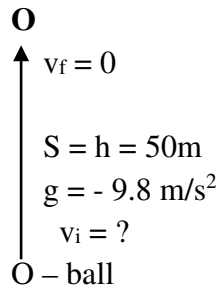
$$v_f = 5 + (2 \times 6)$$

$$v_f = 5 + 12$$

$$v_f = 17\text{ m/s}$$



**Q#6. With what speed must a ball be thrown vertically from ground level to rise a maximum height of 50m?**



**Data:**

Final velocity =  $v_f = 0$  m/s

Height =  $h = 50$  m

Acceleration due to gravity =  $g = -9.8$  m/s<sup>2</sup> [for upward motion,  $g$  is  $-9.8$  m/s<sup>2</sup>]

**Find:**

Initial velocity =  $v_i = ?$

**Solution:**

By using 3<sup>rd</sup> equation of motion

$$2gh = v_f^2 - v_i^2$$

By putting values

$$2 \times (-9.8) \times 50 = 0 - v_i^2$$

$$-980 = -v_i^2$$

$$980 = v_i^2$$

Or

$$v_i^2 = 980$$

Taking square root on both sides

$$\sqrt{v_i^2} = \sqrt{980}$$

$$v_i = 31.3 \text{ m/s}$$

### ASSIGNMENTS

**Assignment 2.1:**

**In 2009, a Jamaican sprinter Usain Bolt created a world record in Berlin by running 100m in just 9.58s. What is his average speed?**

**Data:** Distance covered =  $S = 100$  m

Time taken =  $t = 9.58$  s

**Find:**

Average speed =  $\langle v \rangle = ?$

**Solution:**

As, we know that

$$\langle v \rangle = \frac{S}{t}$$

By putting values

$$\langle v \rangle = \frac{100}{9.58}$$

$$\langle v \rangle = 10.43 \text{ m/s}$$

### Assignment 2.2:

A runner makes one lap around a 270m circular track in 30s. What is his (a) average speed (b) average velocity.

#### Data:

Distance covered =  $S = 270\text{m}$

Time taken =  $t = 30\text{s}$

#### Find:

(a) Average speed =  $\langle v \rangle = ?$

(b) Average velocity =  $\langle \vec{v} \rangle = ?$

#### Solution:

(a) For finding average speed  $\langle v \rangle$ , we know that

$$\langle v \rangle = \frac{S}{t}$$

By putting values

$$\langle v \rangle = \frac{270}{30}$$

$$\langle v \rangle = 9\text{m/s}$$

(b) Now, for finding average velocity, we know that

$$\langle \vec{v} \rangle = \frac{\text{Total displacement}}{\text{Total time}}$$

$$\langle \vec{v} \rangle = \frac{\vec{S}}{t}$$

As we know that displacement in a circular track is zero. i.e,  $\vec{S} = 0$ , So,

$$\langle \vec{v} \rangle = \frac{0}{30}$$

$$\langle \vec{v} \rangle = 0 \text{ m/s}$$

### Assignment 2.3:

If in the same experiment you take the readings of the speedometer of the car as 20km/h in the 4<sup>th</sup> second and 32 km/h in the 9<sup>th</sup> second. What is the acceleration of your car in this interval?

#### Data:

Initial velocity =  $v_i = 20\text{km/h}$

$$= v_i = \frac{20 \times 1000}{3600}$$

$$= v_i = \frac{200}{36} \Rightarrow 5.5 \text{ m/s}$$

Final velocity =  $v_f = 32\text{km/h}$

$$v_f = \frac{32 \times 1000}{3600}$$

$$v_f = 8.8 \text{ m/s}$$

Initial time =  $t_i = 4\text{s}$

Final time =  $t_f = 9\text{s}$

**Find:**

Acceleration = a = ?

**Solution:**

As we know that

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$

Or

$$a = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

By putting values

$$\vec{a} = \frac{8.8 - 5.5}{9 - 4}$$

$$\vec{a} = \frac{3.3}{5}$$

$$\vec{a} = 0.66 \text{ m/s}^2$$

**Assignment 2.4:**

A cyclist increases his speed from zero to  $8 \text{ ms}^{-1}$  in 10s. Then he moves with uniform speed for the next 20 seconds and then its speed decreases uniformly to zero in the next 20 seconds. The graph is plotted for the journey, use this graph to calculate the total distance covered.

(Graph on page no.48)

**Data:**

$$\begin{aligned} \text{Length of 1}^{\text{st}} \text{ parallel side} &= 30 - 10 \\ &= 20 \text{m} \end{aligned}$$

$$\begin{aligned} \text{Length of 2}^{\text{nd}} \text{ parallel side} &= 50 - 0 \\ &= 50 \text{m} \end{aligned}$$

$$\begin{aligned} \text{Height of trapezium} &= 8 \text{m} \end{aligned}$$

**Find:**

Total Distance covered = S = ?

**Solution:**

For finding "S", using formula

Distance covered = Area under the graph

So, S = Area of Trapezium OABC .....(i)

As we know that

$$\text{Area of Trapezium OABC} = \frac{\text{sum of two parallel sides} \times \text{height}}{2}$$

So, eq (i) becomes

$$S = \frac{\text{Sum of two parallel sides} \times \text{height}}{2}$$

By putting values

$$S = \frac{(20 + 50) \times 8}{2}$$

$$S = \frac{(70) \times 8}{2}$$

$$S = \frac{560}{2}$$

$$S = 280\text{m}$$

**Assignment 2.5:**

A cyclist is moving with uniform acceleration of  $1.2\text{m/s}^2$ . How much time will it require to change his velocity from  $6\text{m/s}$  to  $12\text{m/s}$ .

**Data:**

Initial velocity =  $v_i = 6\text{m/s}$

Final velocity =  $v_f = 12\text{m/s}$

Acceleration =  $a = 1.2\text{m/s}^2$

**Find:**

Time  $t = ?$

**Solution:**

By using 1<sup>st</sup> equation of motion

$$v_f = v_i + at$$

Or

$$t = \frac{v_f - v_i}{a}$$

By putting values

$$t = \frac{12 - 6}{1.2}$$

$$t = \frac{06}{1.2}$$

$$t = 5\text{s}$$

**Assignment 2.6:**

On Motorway  $M_1$ , a car is moving at speed limit of  $120\text{km/h}$ . By applying brakes the car comes to rest after covering a distance of  $30\text{m}$ . What is the deceleration of the car?

**Date:**

Initial velocity =  $v_i = 120\text{km/h}$

$$v_i = \frac{120 \times 1000}{3600}$$

$$v_i = 33.33\text{m/s}$$

Final velocity =  $v_f = 0\text{m/s}$

Distance covered =  $S = 30\text{m}$

**Find:**

Deceleration of car =  $a = ?$

**Solution:**

Using 3<sup>rd</sup> equation of motion

$$2aS = v_f^2 - v_i^2$$

Or

$$a = \frac{v_f^2 - v_i^2}{2S}$$

By putting values

$$a = \frac{(0)^2 - (33.33)^2}{2 \times 30}$$

$$a = \frac{0 - 1110.8}{60}$$

$$a = \frac{-1110.8}{60}$$

$$a = -18.5 \text{ m/s}^2$$

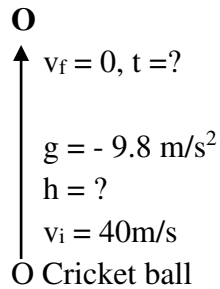
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**Assignment 2.7:**

In a cricket ball go straight up with a velocity of 40m/s. Calculate

(a) Maximum height ball will reach.

(b) Time to reach that height.

**Data:**

Initial velocity =  $v_i = 40 \text{ m/s}$

Final velocity =  $v_f = 0 \text{ m/s}$

Acceleration due to gravity =  $g = -9.8 \text{ m/s}^2$  (For upward motion, value of  $g$  is negative)

**Find:**

(a) Maximum height =  $h = ?$

(b) Time =  $t = ?$

**Solution:**

For finding “h” we use 3<sup>rd</sup> equation of motion

$$2gh = v_f^2 - v_i^2$$

Or

$$h = \frac{v_f^2 - v_i^2}{2g}$$

By putting values

$$h = \frac{(0)^2 - (40)^2}{2 \times -9.8}$$

$$h = \frac{0 - 1600}{-19.6}$$

$$h = \frac{-1600}{-19.6}$$

$$h = 81.6 \text{ m}$$

(b) Now for finding “t”, we use 1<sup>st</sup> equation of motion.

$$v_f = v_i - gt$$

Or

$$t = \frac{v_f - v_i}{g}$$

By putting values

$$t = \frac{0 - 40}{-9.8}$$

$$t = \frac{-40}{-9.8}$$

$$t = 4.08 \text{ s}$$

---

or

$$t = 4s$$

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