MOTION™
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PHYSICS
CLASS - IX
BOOKLET - 1

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MOTION

FORCE AND LAW OF MOTION

GRAVITATION

ANSWER KEY

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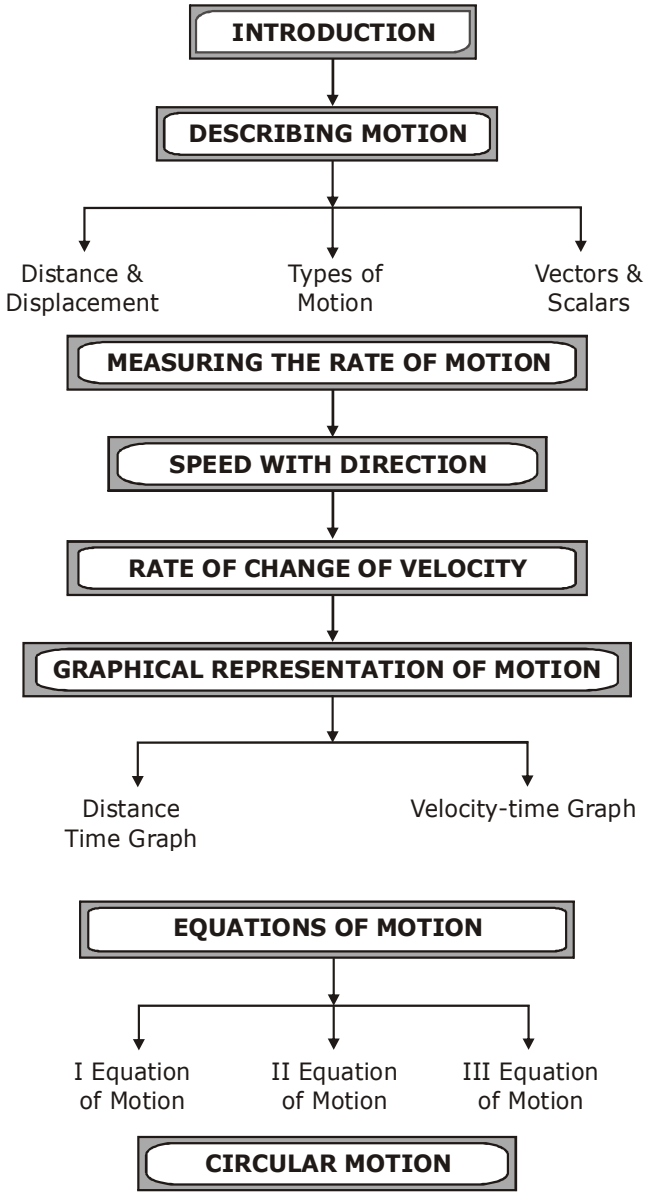
CHAPTER 1

MOTION



INTRODUCTION

Motion is a very preliminary state of action associated with living and non-living beings. The study of the displacement, velocity and acceleration associated with moving bodies can make us understand the motion of bodies. To have an in-depth study of motion, equational representation and graphical analysis of various related quantities in motion with time is also done.

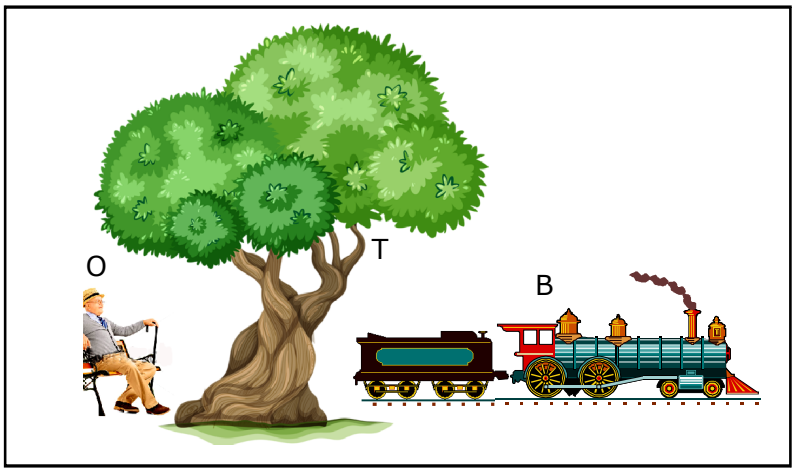
When a body does not change its position with time, we can say that the body is at **rest**. While if a body changes its position with time, it is said to be in **motion**.

(i) An object is said to be a **point object** if it changes its position by distances which are much greater than its size.

(ii) A point or some stationary object with respect to which a body continuously changes its position in the state of motion is known as **origin** or **reference point**.

DESCRIBING MOTION

When a tree, is observed by an observer O sitting on a bench, the tree is at rest. This is because position of the tree is not changing with respect to the observer O.



Now, When the same tree T is observed by an observer sitting in a superfast train moving with a velocity v, then the tree is moving with respect to the observer because the position of tree is changing with respect to the observer B.

1. DISTANCE & DISPLACEMENT

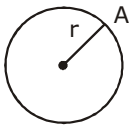
(A) The actual path length between the initial and final positions of the particle gives the **distance** covered by the particle.

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

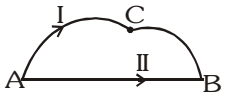
Analysis

(i) 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 zero.



(ii) 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.



Displacement $\leq$ Distance

DIFFERENCES BETWEEN DISTANCE AND DISPLACEMENT		
	Distance	**Displacement**
1	It is defined as the actual path traversed by a body.	It is the shortest distance between two points which the body moves.
2	It is a scalar quantity.	It is a vector quantity.
3	It can never be negative or zero.	It can be negative, zero or positive.
4	Distance can be equal to or greater than displacement.	Displacement can be equal to or less than distance.
5	Distance travelled is not a unique path between two points.	Displacement is a unique path between two points.
6	The distance between two points gives full information of the type of path followed by the body.	Displacement between two points does not give full information of the type of path followed by the body.
7	Distance never decreases with time for a moving body it is never zero.	Displacement can decrease with time for a moving body it can be zero.
8	Distance in SI is measured in metre.	Displacement in SI is measured in metre.

2. TYPES OF MOTION

(A) According to Directions

(i) One dimensional motion A particle moving in a straight line has 1-dimensional motion.

(ii) Two dimensional motion A particle moving along a curved path in a plane has 2-dimensional motion.

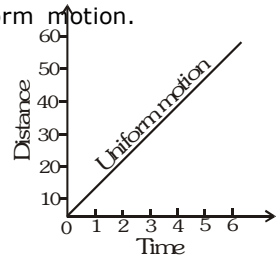
(iii) Three dimensional motion A particle moving in space has 3-dimensional motion.

(B) According to state of motion

A moving body may cover equal distances in equal intervals of time or different distances in equal intervals of time. On the basis of above assumption, the motion of a body can be classified as uniform motion and non-uniform motion.

(i) Uniform motion:

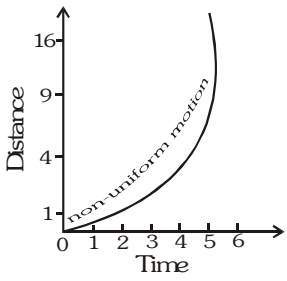
Time (in second)	0	1	2	3	4	5	6
Distance covered (in metre)	0	10	20	30	40	50	60



When a body covers equal distances in equal intervals of time however small may be time intervals, the body is said to describe a uniform motion.

Example of uniform motion –

- An aeroplane flying at a speed of 600 km/h
- A train running at a speed of 120 km/h
- Light energy travelling at a speed of 3×10^8 m/s
- A spaceship moving at a speed of 100 km/s



(ii) Non-uniform motion:

Time (in second)	0	1	2	3	4
Distance (in metre)	0	1	4	9	16

When a body covers unequal distances in equal intervals of time, the body is said to be moving with a non-uniform motion.

Example of non-uniform motion –

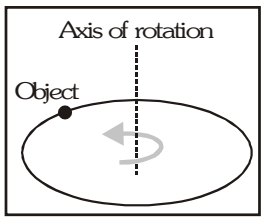
- An aeroplane running on a runway before taking off.
- A freely falling stone under the action of gravity.
- An object thrown vertically upward.
- When the brakes are applied to a moving car.

(C) According to path

(i) Linear motion : A body has linear motion if it moves in a straight line or path.

Ex. (a) Motion of a moving car on a straight road.
(b) Motion of a ball dropped from the roof of a building.

(ii) Circular or rotational motion : A body has circular motion if it moves around a fixed point by maintaining equal distance from that point.



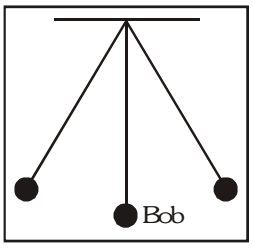
And if a body spins on its axis then it will be rotational motion.

A vertical passing through the fixed point around which the body moves is known as axis of rotation.

Ex. (a) Motion of an electric fan.
(b) Motion of merry-go-round
(c) Motion of a spinning top.

(iii) Vibratory motion :

A body has vibratory motion if it moves to and fro about a fixed point (or mean position).



Ex. (a) Motion of a pendulum of a wall clock.
(b) Motion of a simple pendulum.

3. VECTORS & SCALARS

Vectors : Physical quantities defined with both magnitude and direction are called vector quantities. They should also satisfy the law of vector addition.

Examples: Velocity, acceleration, force, displacement, momentum, weight, torque, electric field, magnetic field, etc.

Scalars : Physical quantities having only magnitude are called scalar quantities.

Examples*:* Mass, time, distance, speed, work, power, energy, electric charge, area, volume, density, pressure, electric potential, temperature, etc.

DIFFERENCE BETWEEN SCALAR & VECTOR QUANTITIES :

	Scalar Quantities	Vector Quantities
1	These are completely specified by their magnitude only.	These are completely specified by their magnitude as well as direction.
2	These change by change of their magnitude only	These change by change of either their magnitude or direction or both
3	These are added or subtracted by laws of ordinary algebra like 4m+5m=9m.	These are added or subtracted by laws of vector addition.

Info Bubble

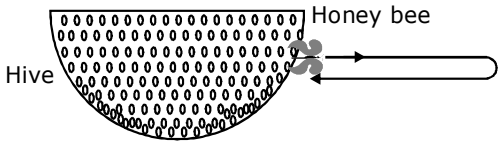
The walls of our classroom are at rest with respect to the ground or earth. But, they are in motion with respect to an object or an observer outside the earth. This is because the earth is moving about its own axis as well as it is revolving around the sun. Thus, the state of rest and motion are not absolute, they are relative terms.

PRACTICE YOUR CONCEPTS

1. What do you understand by displacement of an object?

Ans. Displacement of an object is the shortest distance between initial and final positions of the moving object.

2. A honeybee leaves the hive and travels 2m before returning. Is the displacement for the trip the same as the distance travelled? If not, why not ?



Ans. No, the displacement and the distance are not same. This is because the displacement is the change of position of object in motion while distance is length of path travelled by it.
Here, the distance travelled = 2m
While, the displacement = 0, because the position of honey bee is not changed.
Displacement is least in this activity.

3. Can displacement be negative?

Ans. Yes, displacement can be negative.

MEASURING THE RATE OF MOTION

1. **SPEED :** The distance travelled in one second is called speed. It is a scalar quantity. Its SI unit is m/s. Speed always remains positive.

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} (\text{m/s})$$

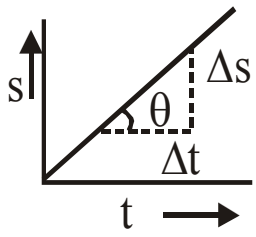
$$\text{Speed} = \frac{s_2 - s_1}{t_2 - t_2} = \frac{\Delta s}{\Delta t}$$

Where Δs = distance in time interval Δt.

Speed	Velocity
1. Scalar quantity	1. Vector quantity.
2. Rate of distance covered.	2. Rate of displacement.
3. Cannot be zero for a moving body.	3. Can be zero, +ve or –ve.
4. Speed is velocity without direction.	4. Velocity is directed speed.
5. Speed in SI unit is measured in ms^{-1}.	5. Velocity in SI unit is measured in ms^{-1}.

(A) **Unit :** In M.K.S. system = ms^{-1}
In C.G.S. system = Cms^{-1}

(B) If distance time graph is a straight line, then speed can be given by the slope of the line, i.e. $v = \frac{\Delta s}{\Delta t}$



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

(C) The area of velocity time graph gives distance travelled.

(D) Conversion from km/hr to m/sec.

$$\frac{1km}{hr} = \frac{1000}{60 \times 60} m/s = \frac{5}{18} m/s.$$

2. VELOCITY : The displacement in one second is called velocity. It is a vector quantity expressed in m/s. Velocity can be positive, negative or zero.

$$\boxed{\text{Velocity} = \frac{\text{Displacement}}{\text{Time taken}} (ms^{-1})}$$

$$\boxed{\text{Velocity} = \frac{\Delta s}{\Delta t}}$$

Where Δs = displacement travelled in time interval Δt.

3. TYPES OF SPEED

(A) Average and Instantaneous speed

(i) Average speed : The ratio of distance travelled by a body to the total time taken, when the motion can be with varying speeds for various intervals of time.

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

OR

It is obtained by dividing the total distance travelled by the total time interval. i.e.

$$\boxed{\text{Average speed} = \frac{s_2 - s_1}{t_2 - t_1} = \frac{\Delta s}{\Delta t}}$$

- Average speed is a scalar, while average velocity is a vector.
- For a given time interval average velocity is single valued, while average speed can have many values depending on path following.
- If after motion body comes back to its initial position $\vec{v}_{av} = 0$ [as $\Delta \vec{r} = 0$], but $v_{av} > 0$ and finite (as $\Delta s > 0$)
- For a moving body average speed can never be –ve or zero (unless t = 0), while average velocity can be i.e. $v_{av} > 0$ while $\vec{v}_{av} >$ = or < 0
- In general average speed is not equal to magnitude of average velocity (as $\Delta s \neq |\Delta \vec{r}|$). However it can be so if the motion is along a straight line without change in direction (as $\Delta s = |\Delta \vec{r}|$)

- If a particle travels distances L_1, L_2 L_3 at speeds v_1, v_2, v_3 etc respectively, then

$$v_{av} = \frac{\Delta s}{\Delta t} = \frac{L_1 + L_2 + ... + L_n}{\frac{L_1}{v_1} + \frac{L_2}{v_2} + ... + \frac{L_n}{v_n}} = \frac{\sum L_i}{\sum \frac{L_i}{v_i}}$$

- If a particle travels at speeds v_1, v_2 etc for intervals t_1, t_2 etc respectively, then

$$v_{av} = \frac{v_1 t_1 + v_2 t_2 + ...}{t_1 + t_2 + ...} = \frac{\sum v_i t_i}{\sum t_i}$$

- If a particle moves a distance at speed v_1 and comes back with speed v_2, then

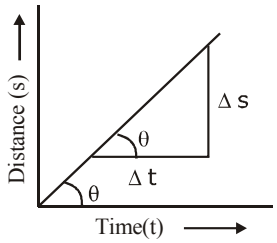
average speed $v_{av} = \frac{2v_1 v_2}{v_1 + v_2}$ ($\vec{v}_{av} = 0$)

- If a particle moves for two equal time intervals

$$v_{av} = \frac{v_1 + v_2}{2}$$

(ii) Instantaneous speed :

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



$$\text{Instantaneous speed} = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$$

(B) Uniform and Non uniform speed

(i) Uniform speed : If the time speed graph of an object is a straight line parallel to time axis then the body is moving with a uniform speed.

(ii) Non-uniform speed : If the speed of a body is changing with respect to time, then it is said to be moving with a non-uniform speed. Its graph is not a straight line.

4. TYPES OF VELOCITY

(A) Average Velocity:

Total displacement divided by total time is called an average velocity.

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

$$V_{av} = \frac{x_2 - x_1}{t_2 - t_1}$$

OR

The arithmetic mean of initial velocity and final velocity for a given time period, is called average velocity.

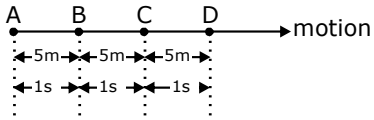
$$\text{Average velocity} = \frac{\text{Initial velocity} + \text{Final velocity}}{2}$$

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

where u = initial velocity, v = final velocity

(B) Uniform & Non uniform Velocity

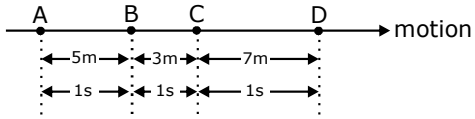
(i) Uniform velocity



Body moving with uniform velocity

When a body covers equal displacement in equal interval of time, the body is said to be moving with a uniform velocity.

(ii) Non-uniform velocity/variable velocity :

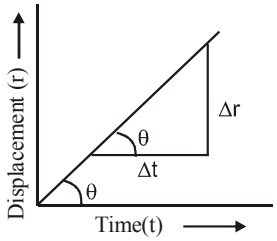


Body moving with non-uniform velocity

When a body covers unequal displacement in equal intervals of time, the body is said to be moving with variable velocity.

(C) Instantaneous velocity :

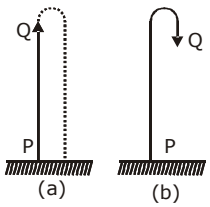
The velocity of a body at a particular instant of time is called its instantaneous velocity.



$$\text{Instantaneous velocity} = \lim_{\Delta t \to 0} \frac{\Delta r}{\Delta t} = \frac{dr}{dt}$$

Info Bubble

A particle is thrown vertically upwards under gravity. What are the signs of displacement and velocity in the given situations (a) & (b) (P to Q):



Explanation

(a) Here, displacement and velocity (average & instantaneous) both are positive.

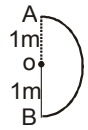
(b)Here, displacement is positive. Instantaneous velocity is negative & average velocity is positive.

PRACTICE YOUR CONCEPTS

4. In 1.0 sec a particle goes from point A to point B moving in a semicircle of radius 1.0 m. The magnitude of average velocity is

(A) 3.14 m/sec (B) 2.0 m/sec (C) 1.0 m/sec (D) zero

Ans. $\text{Average velocity} = \frac{\text{Total displacement}}{\text{Total time}} = \frac{d}{t}$



D = AO + OB

= 1 + 1 = 2m

t = 1 sec (given)

$\Rightarrow$ mg of v of $\frac{2}{1}$ = 2m/sec

5. A particle moves along a semicircular path of radius R in time t with constant speed. For the particle calculate

(i) distance travelled,

(ii) displacement,

(iii) average speed,

(iv) average velocity,

Ans. (i) Distance = length of path of particle = $\overset{\frown}{AB} = \pi R$

(ii) Displacement = minimum distance between initial and final point

= AB = 2R

(iii) Average speed, $v = \frac{\text{total distance}}{\text{time}} = \frac{\pi R}{t}$

(iv) Average velocity = $\frac{2R}{t}$

RATE OF CHANGE OF VELOCITY

The rate at which the velocity changes is called acceleration. It is a vector quantity. Its SI unit is m/s^2 or ms^{-2}.

(i) Rate of change of velocity is called acceleration

(ii) The change in velocity may be in magnitude or in direction or both.

i.e. $\boxed{a = \frac{v-u}{t}}$

(iii) Unit of acceleration = m/s^2 or ms^{-2}

Deceleration or Retardation : If the change in velocity is negative, if velocity of a body decreases, the acceleration is called deceleration or retardation.

Uniform & Non-uniform accelerated motion : When the change in velocity is same in equal time intervals, the motion is called uniform accelerated motion, otherwise, it is non-uniformly accelerated motion.

1. TYPES OF ACCELERATION

(A) Uniform & Non uniform acceleration

(i) 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.

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

(B) Average & Instantaneous acceleration

(i) Average acceleration :

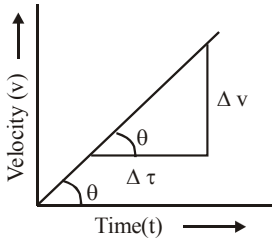
$$\boxed{a_{av} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}}$$

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

If a body travels with a uniform acceleration a_1 for a time interval t_1 and with uniform acceleration a_2 for a time interval t_2 then

$$\boxed{a_{av} = \frac{(a_1 t_1 + a_2 t_2)}{(t_1 + t_2)}}$$

(ii) Instantaneous acceleration : The acceleration of a body at any instant is called its instantaneous acceleration.



e.g. $a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$

If the velocity of a body decreases, then it will experience a negative acceleration which is called deceleration or retardation.

Acceleration is determined by the slope of time-velocity graph.

$$\boxed{\tan\theta = \frac{dv}{dt}}$$

(i) If the time velocity graph is a straight line, acceleration remains constant.

(ii) If the slope of the straight line is positive, positive acceleration occurs.

(iii) If the slope of the straight line is negative, negative acceleration or retardation occurs.

(iv) Larger the slope (tan θ) longer will be the straight line.

(v) If the time velocity graph is a curve, then the acceleration changes continuously.

PRACTICE YOUR CONCEPTS

6. A car is travelling along a straight road and is decelerating. Does the car's acceleration necessarily have a negative value?

Ans. We begin with the meaning of the term "decelerating," which has nothing to do with whether the acceleration 'a' is positive or negative. The term means only that the acceleration is opposite to the velocity and indicates that the moving object is slowing down.

(i) One possibility is that the velocity of the car points to the right (the positive direction) and acceleration points opposite i.e. to the left (the negative direction).

(ii) Another possibility is that the velocity of the car points to the left (the negative direction) and acceleration points opposite i.e. to the right (the positive direction).

7. If initial & Final velocities are same find acceleration?

Ans. Zero, As there is no change in velocities.

GRAPHICAL REPRESENTATION OF MOTION

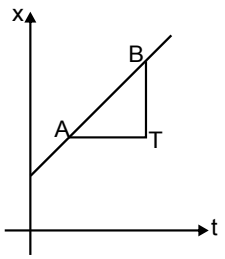
Graphs are the best tools to represent the motion of a body or an object. It provides a convenient method to present basic information about a variety of events.

For example, in the telecast of a one day cricket match, vertical bar graphs show the run rate of a team in each over. In mathematics, a straight line graph helps in solving a linear equation having two variables.

In order to describe the motion of AB object, we can use line graphs. In this case, line graphs show dependence of one physical quantity, such as distance or velocity, on another quantity, such as time.

1. DISPLACEMENT- TIME GRAPH

⇒ The slope of displacement time (x – t) graph gives the velocity of motion. One can find the velocity of motion, finding the slope of x - t graph. To find the slope,



(A) Select any two points on the graph A and B.

(B) Draw a right triangle below the graph (ABT)

(C) Find the length of BT and AT from the axis

(D) Take the ratio of BT to AT

⇒ The ratio has the units of velocity.

$$\text{Slope} = \frac{BT}{AT} = \frac{\text{Displacement}}{\text{Time taken}} = \text{Velocity}$$

If x-t graph is a straight line, then there may be

(A) State of rest – parallel to time axis

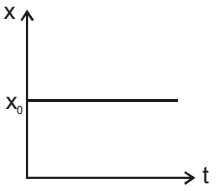
(B) uniform motion – inclined to time axis.

The slope of the straight line is a measure of velocity of motion.

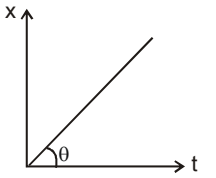
⇒ If the x – t graph is not a straight line, the motion will be a non-uniform motion – accelerated motion.

For example, a body dropped from a height undergoes free fall satisfying the relation $y = \frac{1}{2}gt^2$.

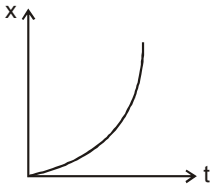
Displacement- time graph (examples)

(1) 

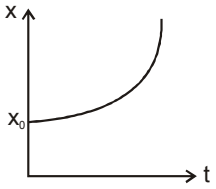
Body is at rest at x_0.

(2) 

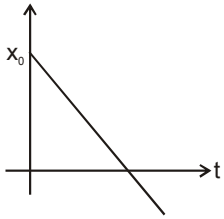
Body starts from origin and is moving with speed = tan θ away from origin.

(3) 

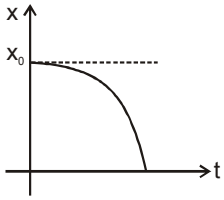
Body starts from rest at origin and moves away from origin with increasing speed and positive acceleration.

(4) 

Body starts from rest from $x = x_0$ and moves away from origin with increasing velocity or +ve acceleration.

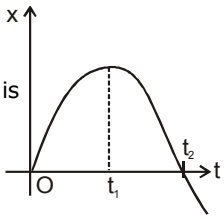
(5) 

Body starts from $x = x_0$ and is moving toward the origin with constant velocity passes throw origin after same time and continues to move away from origin.

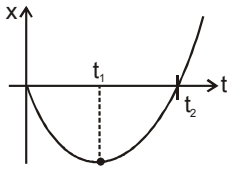
(6) 

Body starts from rest at $x = x_0$ and then moves with increasing speed towards origin

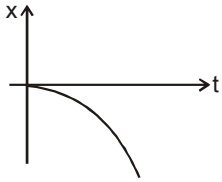
$\therefore$ acceleration is –ve

(7) 

Body starts moving away from origin with some initial speed. Speed of body decreasing till t_1 and it becomes 0 momentarily of $t = t_1$ and at this instant. It reverses its direction and move towards the origin with increasing speed.

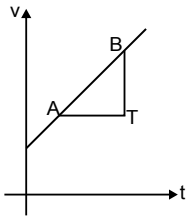
(8) 

Body starts from origin moves away from origin in the –ve x-axis at $t = t_1$ with decreasing speed and at $t= t_1$ it comes at rest momentarily, reverses its direction moves towards the origin with increasing speed, crosses the origin at $t = t_2$.

(9) 

Body starts from origin from rest and moves away from origin with increasing speed.

2. VELOCITY - TIME GRAPH



⇒ The slope of velocity-time (v – t) graph gives the acceleration of motion.

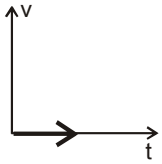
Slope of v – t graph is, $\frac{BT}{AT} = \frac{\text{Change in velocity}}{\text{Time taken}}$

⇒ If v – t graph is a straight line, then there may be

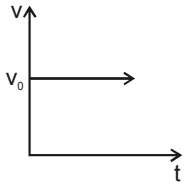
(A) uniform motion –parallel to time axis

(B) non-uniform motion – inclined to time axis.

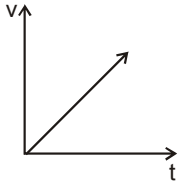
Velocity-time graph (examples)

(1) 

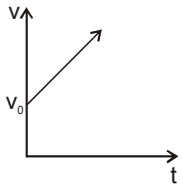
Body is always at rest.

(2) 

Body is moving with constant velocity v_0

(3) 

Body is at rest initially then it starts moving with its velocity increasing at a constant rate i.e. body is moving with constant acceleration.

(4) 

Body starts its motion with initial velocity v_0 and continues to move with its velocity increasing at a constant rate i.e. acceleration of the body is constant.