CHAPTER: 2
KINEMATICS

Kinematics:-

The branch of physics in which we study about motion of bodies without discussing the cause of motion.

Rest:-

A body is said to be at rest if it does not change its position with respect to some observer.

Motion:-

A body is said to be in motion if it change its position with respect to some observer.

Types of Motion:-

There are three types of motion.

i. Translator Motion
ii. Rotatory Motion
iii. Vibratory Motion

1. Translatory Motion:-

In tranlatory motion a body moves along a line without any rotation. The line may be straight or curved.

Trnaslatory motion has further three types.

i. Linear Motion
ii. Circular Motion
iii. Random Motion

i. Linear Motion:-

If a body moves along a straight line then its motion is called linear motion.

Example:- Motion of free falling body is linear motion.

ii. Circular Motion:-

The motion of a body in a circular path is called circular motion.

Example:- The motion of earth around the sun is circular motion.

iii. Random Motion:-

The irregular motion of a body is called random motion.

Example:- The motion of gas molecules is random motion.

2. Rotatory Motion:-

The spinning motion of a body about its axis is called rotatory motion.

Example:- The motion of a wheel about its axis and the motion of ceiling electric fan are examples of rotatory motion.

3. Vibratory Motion:-

To and fro motion of a body about its mean position is known as vibratory motion.

Example:- The motion of pendulum of a clock is vibratory motion.

Vectors:-

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

Example:- Velocity, Acceleration, Force, Weight, Momentum and Torque are vector quantities.

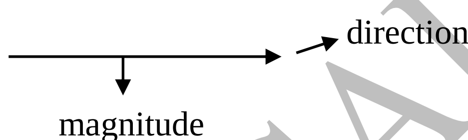
Scalars:-

Those physical quantities which can be completely described by their magnitude only are called scalar quantities.

Example:- Time, Mass, Density, Volume, Temperature and Speed are scalar quantities.

Representation of vector's:-

A vector is represented by a straight line with an arrow head at one end. The length of the line gives its magnitude while arrow head indicated its direction.



Distance:-

Length of the path between two points is called distance of those points.

The unit of distance is metre (m).

Displacement:-

The shortest distance between two points is called displacement.

Displacement is a vector quantity. Its unit is metre.

Speed:-

The distance covered by a body in unit time is called speed.

OR

The rate of distance of a body is called speed.

Formula:-

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

$$V = \frac{S}{t}$$

Unit:-

The unit of speed is metre per second (m/s or ms^{-1})

Quantity:- Speed is a scalar quantity.

Types of speed:-

There are three types of speed.

i. Uniform speed
ii. Non uniform speed or variable speed
iii. Average speed

i. Uniform Speed:-

If a body cover's equal distance in equal interval of a time then its speed is called uniform speed.

ii. Non Uniform Speed:-

If a body does not equal distance in equal interval of a time then its speed is called non uniform speed or variable speed.

iii. Average Speed:-

The total distance divided by total time taken is called speed.

$$\text{Average speed} = \frac{\text{Total distance}}{\text{Total time}}$$

$$V_{av} = \frac{s}{t}$$

Velocity:-

The rate of displacement of a body is called velocity.

OR

The distance covered by a body in unit time and in a particular direction is called velocity.

Formula:-

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

$$\vec{V} = \frac{d}{t}$$

Unit:-

The unit of velocity is metre per second (m/sec or ms^{-1})

Quantity:- velocity is a vector quantity.

Types of Velocity:-

There are three types of velocity.

i. Uniform velocity
ii. Non uniform velocity or variable velocity
iii. Average velocity

i. Uniform Velocity:-

If a body cover's equal displacement in equal interval of a time then its velocity is called uniform speed.

ii. Non Uniform Velocity or variable velocity:-

If a body does not equal displacement in equal interval of a time then its velocity is called non uniform or variable velocity.

iii. Average Velocity:-

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

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

$$V_{av} = \frac{d}{t}$$

Acceleration:-

The rate of change of velocity of a body is called acceleration.

Formula:-

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

$$a = \frac{\triangle v}{t}$$

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

Unit:-

The unit of acceleration is metre per second per second (m/sec^2)

Quantity:- Acceleatration is a vector quantity.

Uniform Acceleration:-

If equal velocity of a body changes after equal interval of time then its acceleration is called uniform acceleration.

Non Uniform Acceleration:-

If a body does not changes its equal velocity in equal interval of time then its acceleration is called non-uniform acceleration.

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Initial velocity = $v_i = o$ (Rest)

Final velocity = $v_f = 20$ m/sec

Time = $t = 8$ sec

Acceleration = $a = ?$

Solution:-

We know

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

$$a = \frac{\triangle v}{t}$$

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

$$a = \frac{20 - 0}{8}$$

$$a = \frac{20}{8} \qquad a = 2.5\ \text{m/sec}^2$$

Example No. 2.4

Initial velocity = $v_i = 30$ m / sec

Final velocity = $v_f = 15$ m/sec

Time = $t = 5$ sec

Retardation = ?

Solution:-

We know

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

$$a = \frac{\triangle v}{t}$$

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

$$a = \frac{15 - 30}{5}$$

$$a = -\frac{20}{5} \qquad a = -3\text{m/sec}^2$$

We know that when acceleration is negative then it is called retardation.

So

Retardation = 3 m/sec^2

Graphical Analysis of Motion:-

The pictorial representation of the relation between two variables is called graph. The motion of a moving body can be represented with the help of graph. This process is called graphical analysis of motion.

Distance – Time Graph:-

The graph ploted between different values of time and corresponding values of distance is called distance time graph. In distance time graph time is taken along x-axis while distance is taken along y-axis. There are three different case of distance time graph.

CASE - I

When a body is at rest:-

When a body is at rest then it means this body is not covering any distance. In this case distance time graph is horizontal straight line parallel to time axis.

CASE - II

When an Object move with constant speed:-

If an object covers equal distance in equal interval of time then its speed is called constant speed or uniform speed. In this case the distance – time graph is a straight line between x-axis and y-axis.

CASE - III:

When an object moves with variable Speed:-

If an object does not covers equal distance in equal interval of time then its speed is called non uniform or variable speed.

In this case distance time graph is not straight line. It is actually curved between x-axis and y-axis.

Speed Time Graph

The graph ploted between different values of time and corresponding value of speed is called speed – time graph.

In speed time graph time is taken along x-axis while speed is taken along y-axis.

CASE - I

If an object is moving with Constant Speed:-

If an object covers equal distance in equal interval of a time then its speed is called uniform speed or constant speed. In this case the speed time graph is a horizontal straight line parallel to x-axis (time axis)

CASE - II

If an object is moving with Non-uniform or variable speed (uniform acceleration):-

If an object does not covers equal distance in equal interval of time then its speed is called non uniform or variable speed. In this case speed time graph is a straight line in between x-axis and y-axis.

Slope of this line will give magnitude of acceleration.

This case is also called uniform acceleration case.

Distance Travelled by a moving object:-

The area under speed time graph represents the distance travelled by the object. If the motion of the body is uniform then area can be calculated by using a formula.

EQUATION OF MOTIONS

First Equation of Motion:-

Prove that $V_f = v_i + at$

Consider a body is moving with initial velocity "v_i" in a straight line with uniform acceleration 'a'. Its velocity becomes 'v_f' after some time 't'. The motion of this body is described by speed time graph as shown in figure below.

The slope of line AB is equal to acceleration.

$$\text{Slope of line AB} = \text{acceleration} = a = \frac{\text{Perpendicular}}{\text{Base}}$$

$$a = \frac{BC}{AC} \longrightarrow (1)$$

Here

$BC = BD - CD$

And

$AC = OD$

Putting values in equation (1)

$$a = \frac{BD - CD}{OD} \longrightarrow (2)$$

Now

$OD = \text{time} = t$

$CD = OA = vi$

$BD = OE = vf$

Putting values in equation (2)

$$a = \frac{BD - CD}{OD}$$

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

$$at = v_f - v_i$$

$$at + v_i = v_f$$

$v_f = v_i + at$

$v_f = v_i + at$ Proved

Second Equation of Motion:-

Consider a body is moving with initial velocity 'v_i' in a straight line with uniform acceleration 'a'. Its velocity becomes 'v_f' after some time 't'. The motion of this body is described in figure below.

In this case the total distance covered by a body is equal to the area OABD under the graph.

Now

Total area OABD = Area of triangle ABC + Area of rectangle OACD → (1)

We know

Area of triangle ABC = $\frac{1}{2}$ (Base) (Height)

$= \frac{1}{2}$ (AC) (BC) → (2)

Here

AC = OD = t

And

BC = BD – CD

BC = $v_f - v_i$

From first equation of motion

$v_f = v_i + at$

$v_f - v_i = at$

So

BC = vf – vi

Putting value of 'vf' – vi

BC = at

Now putting values of 'AC' and BC in eq (2)

Area of triangle ABC = $\frac{1}{2}$ (AC) (BC)

$= \frac{1}{2}$ (t) (at)

= 2

$= \frac{1}{2} at^2$

Now

Area of rectangle OACD = (Length) (Width)

Area of rectangle OACD = (OA) (OD)

Area of rectangle OACD = (v_i) (t)

Now putting values in eq (1)

Total area OABD = Area of triangle ABC + Area of rectangle OACD

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

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

$$\boldsymbol{S = v_i t + \frac{1}{2} at^2} \quad \textbf{Proved}$$

Third Equation of Motion

Consider a body moving with initial velocity 'v_i' in a straight line with uniform acceleration. Its velocity becomes 'v_f' after some time 't'. The motion of this body is described by speed time graph gs shows in figure below.

The total distance covered by the body is equal to total area OABD under the graph

Now

Total area OABD = $\frac{1}{2}$ (sum of parallel sides) × base

Total area OABD = $\frac{1}{2}$ [OA + BD] × OD (1)

Here

OA = CD = v_i

OE = BD = v_f

OD = AC = t

Total area OABD = Distance = S

Putting value in equation (1)

Total area OABD $= \frac{1}{2}$ [OA + BD] x OD

$$S = \frac{1}{2a} [v_i + v_f] \times t \qquad (2)$$

Now we will find 't' by using first equation of motion

$$v_f = v_i + at$$

$$v_f - v_i = at$$

$$\frac{v_f - v_i}{a} = t \quad \text{Put in equation (2)}$$

$$s = \frac{1}{2}[v_i + v_f] \times t$$

$$s = \frac{1}{2}[v_i + v_f] \times \left[\frac{v_f - v_i}{a}\right]$$

$$s = \frac{1}{2a}[v_i + v_f] \times [v_f - v_i]$$

$$2as = (v_i + v_f)(v_f - v_i)$$

$$2as = (v_f + v_i)(v_f - v_i)$$

$$2as = (v_f)^2 - (v_i)^2$$

$$2as = v_f^2 - v_i^2$$

$2as = v_f^2 - v_i^2$ **Proved**