SLO 2: Kinematics

Kinematics is the branch of Mechanics which deals with motion of objects without reference of force.

2.1 Rest and Motion

2.1.1 Define Rest And Motion

- A body is said to be in rest if it does not change its position with respect to its surroundings.
- A body is said to be in motion if it changes its position with respect to its surroundings.

2.2 Types of Motion

2.2.1 Differentiate Among The Different Types Of Motion

All objects in universe are in motion. However the nature of their motion is different, some objects move along circular path, other move in straight line while some objects move back and forth only. There are three types of motion:

Translatory Motion (Linear, Circular And Random)

When all points of a moving body move uniformly along the same straight line, such motion is called translatory motion.

- Linear Motion: Motion of a body along a straight line is called linear motion. For example, motion of a train along a straight track.
- Circular Motion: Motion of a body along a circular path is called circular motion. For example, motion of satellites around Earth.
- Random Motion: Irregular motion of an object is called random motion. For example, motion of flies or insects is random.

Rotatory Motion

The motion of the body around a fixed axes which passes through body itself is called spin or rotatory motion. The motion of a wheel about the axle, the motion of a rider on the Ferris wheel are some examples of rotatory motion.

Vibratory Motion

Back and forth motion of a body about its mean position is called vibratory or oscillatory motion. There are many examples of vibratory or oscillatory motion in daily life. for example, motion of the clock's pendulum, or to-and-fro movement of a spring if it is stretched and then released.

2.3 Terms Associated with Motion

2.3.1 Define The Following Terms:

1. Distance: The total length covered by moving body from any point A to B, without mentioning direction of motion.
2. Displacement: The shortest length covered by moving body from any point A to B, which is always a straight line.
3. Speed: Distance covered by an object in a unit time is called speed.
4. Velocity: Rate of change of displacement with respect to time is called velocity.
5. Acceleration: Rate of change of velocity of an object with respect to time is called acceleration.

2.3.2 Calculate Average Speed, Average Velocity And Acceleration

Average speed is the mean value of speed during complete motion from any point A to B.

$$v_{avg} = \frac{v_1 + v_2 + v_3 + \cdots + v_n}{n}$$

Average velocity is the mean value of velocity during complete motion from any point A to B.

$$\overrightarrow{v_{avg}} = \frac{\overrightarrow{v_1} + \overrightarrow{v_2} + \overrightarrow{v_3} + \cdots + \overrightarrow{v_n}}{n}$$

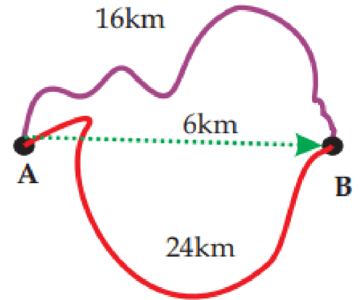
An object accelerates when its velocity changes. Since velocity is a vector quantity so it has both magnitude and direction. Thus, acceleration is produced whenever:

- Velocity of an object changes
- Direction of motion of the object changes
- Speed and direction of motion of the object change.

Rate of change of velocity of an object with respect to time is called acceleration.

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

2.3.3 Differentiate Between:

DISTANCE	DISPLACEMENT
The total length covered by moving body without mentioning direction of motion.	The distance measured in straight line.
It is a scalar quantity.	It is a vector quantity.
	
The distance travelled by the person from A to B is either 16 km or 24km	The displacement of the person is 6 km from A to B due west of A.

SPEED	VELOCITY
distance travelled per unit time.	displacement per unit time.
Scalar (has only magnitude)	Vector (has both magnitude and direction)
No direction is involved	Direction is always specified
Always positive	Can be positive, negative, or zero

AVERAGE SPEED	INSTANTANEOUS SPEED
Total distance travelled divided by total time taken	Speed of an object at a particular moment of time
$\text{Average Speed} = \frac{\text{Total Distance}}{\text{Total Time}}$	No fixed formula; it is the value shown by a speedometer at a given instant
Over a longer time interval	At a specific instant or very short time

UNIFORM VELOCITY	NON-UNIFORM VELOCITY
Velocity remains constant.	Velocity changes with time.
Same direction throughout the motion.	Direction may change during motion.
Speed is constant.	Speed may increase or decrease.
Acceleration is zero.	Acceleration is not zero.
A car moving straight at 60 km/h constantly.	A car turning a corner or speeding up/slowing down.
UNIFORM ACCELERATION	**NON-UNIFORM ACCELERATION**
Acceleration is constant	Acceleration changes with time
Same amount of velocity is added or subtracted in equal time intervals.	Different amounts of velocity are added or subtracted in equal time intervals.
Straight line (sloped)	Curved line
A freely falling object under gravity (ignoring air resistance).	A car speeding up in traffic or braking suddenly.

2.3.4 Describe The Universal Speed Limit Of Any Object In The Universe

- Speed of light is the fastest speed possible in the universe and is considered the universal speed limit.
- The speed of light in a vacuum, denoted by [$c = 3 \times 10^8\ ms^{-1}$] is the maximum speed at which any object, energy, or information can travel in the universe.
- According to Albert Einstein's theory of relativity, nothing can travel faster than the speed of light in a vacuum. $E = mc^2$ shows how energy and mass are related through the speed of light.
- Light travels at this speed in a vacuum (like space), but it can slow down in materials like air, water, or glass. Even if a spaceship goes super fast, it can never reach or cross this speed limit.

2.4 Graphical Analysis of Motion

2.4.1 Interpret

Distance – Time Graph

This graph shows how distance changes with time. It tells us about:

1. Shape of the graph = type of motion
2. Slope of the graph = speed

GRAPH SHAPE	INTERPRETATION	EXPLANATION
Straight line with constant slope	Uniform motion	Object is moving at constant speed.
Curved line (increasing slope)	Accelerated motion	Speed is increasing over time.
Horizontal line (flat)	At rest	Distance doesn't change → object is not moving.

Speed – Time Graph

This graph shows how speed (or velocity) changes with time. It tells us about:

1. Shape of the graph = acceleration
2. Area under the graph = distance travelled

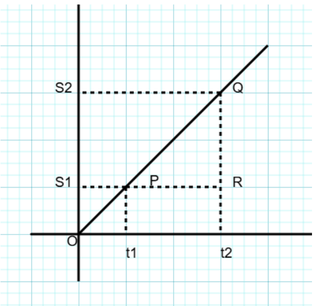
GRAPH SHAPE	INTERPRETATION	EXPLANATION
Horizontal line (constant speed)	Uniform motion	Speed doesn’t change with time.
Upward sloping line	Uniform acceleration	Speed increases at a steady rate.
Downward sloping line	Uniform deceleration	Speed decreases at a steady rate.
Line at speed = 0	At rest	Object is not moving.

2.4.2 Determine The Slope/ Gradient Of

Distance – Time Graph

The gradient is the measure of slope of a line. Gradient of the distance – time graph is equal to the average speed of the body.

Consider a distance – time graph of uniform speed. Take any points t_1 and t_2 on x-axis meeting the graph at points P and Q. From these points draw horizontal lines to meet y-axis at S_1 and S_2. The slope of the gradient of the graph is the measure of tangent theta $tan\theta$ of triangle RPQ.



Distance Covered = $S_2 - S_1$

Time Taken = $t_2 - t_1$

$$Slope = tan\theta = \frac{perpendicular}{base} = \frac{RQ}{PR}$$

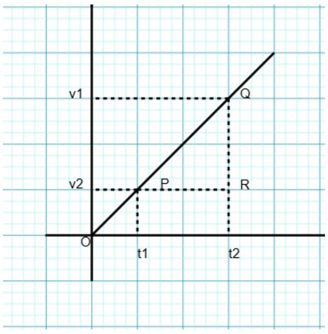
$$\tan\theta = \frac{S_2 - S_1}{t_2 - t_1} = \frac{\Delta S}{\Delta t}$$

But we know that $v_{avg} = \frac{\Delta S}{\Delta t}$ therefore the slop of distance – time graph is average speed of the body.

Speed – Time Graph

The gradient is the measure of slope of a line. Gradient of the speed – time graph is equal to the average acceleration of the body.

Consider a speed – time graph of uniform speed. Take any points t_1 and t_2 on x-axis meeting the graph at points P and Q. From these points draw horizontal lines to meet y-axis at v_1 and v_2. The slope of the gradient of the graph is the measure of tangent theta $tan\theta$ of triangle RPQ.



Change in Speed = $v_2 - v_1$

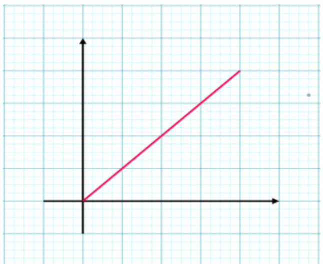
Time Taken = $t_2 - t_1$

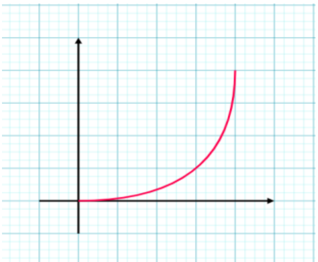
$$Slope = tan\theta = \frac{perpendicular}{base} = \frac{RQ}{PR}$$

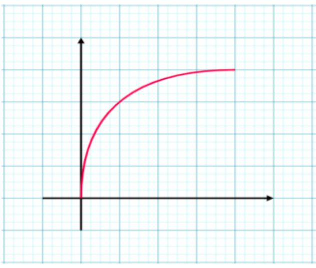
$$\tan\theta = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

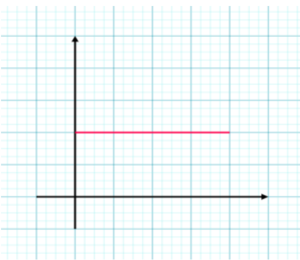
But we know that $a_{avg} = \frac{\Delta v}{\Delta t}$ therefore the slop of speed – time graph is average acceleration of the body.

2.4.3 Infer The Following States Of A Body Based On The Given Graph:


uniform speed


acceleration


deceleration

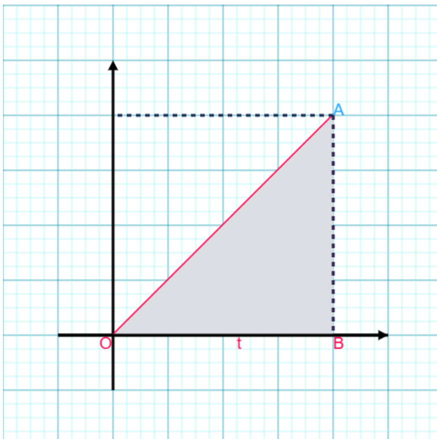

at rest

2.4.4 Area Under The Speed-Time Graph Of Uniformly Accelerated Objects

An object is moving with constant speed v. For a time-interval t, the distance covered by the object is

$$S = v \times t$$

This distance can also be found by calculating the area under the speed-time graph.



$$Area = \frac{1}{2}(base \times height)$$

$$Area = \frac{1}{2}(m\overline{OB} \times m\overline{AB})$$

Where $m\overline{AB}$ is the speed of object and $m\overline{OB}$ is the time taken.

Thus, area under speed – time graph is numerically equal to the distance covered by the object in time t.

2.5 Motion due to Gravity

2.5.1 Define Acceleration Due To Gravity

Acceleration due to gravity is the rate at which an object speeds up when it is falling freely towards the Earth due to the force of gravity. It is the acceleration produced in a body when it falls under the influence of Earth's gravity only, with no air resistance. It is represented by the letter g. Its S.I unit is m/s^2 or ms^{-2}. Standard value of acceleration due to gravity on Earth is $9.8ms^{-2}$.

2.5.2 Solve Word Problems Related To Free-Falling Bodies Using The Relation $g = \frac{\Delta v}{\Delta t}$

Practice questions yourself.