



MOTION & REFERENCE POINT

“To describe the motion of an object, we must choose a **REFERENCE POINT** or a **REFERENCE FRAME**.”



An object is said to be in **motion** if its position changes with time with respect to a **reference point**.



WHAT IS MOTION?

An object is in motion if its position changes with time with respect to a **reference point**.



KEY IDEA

Motion is **relative**. It depends on the **reference point** or observer.

EXAMPLE: THE SAME OBJECT, DIFFERENT REFERENCE POINTS

REFERENCE POINT: **TREE**

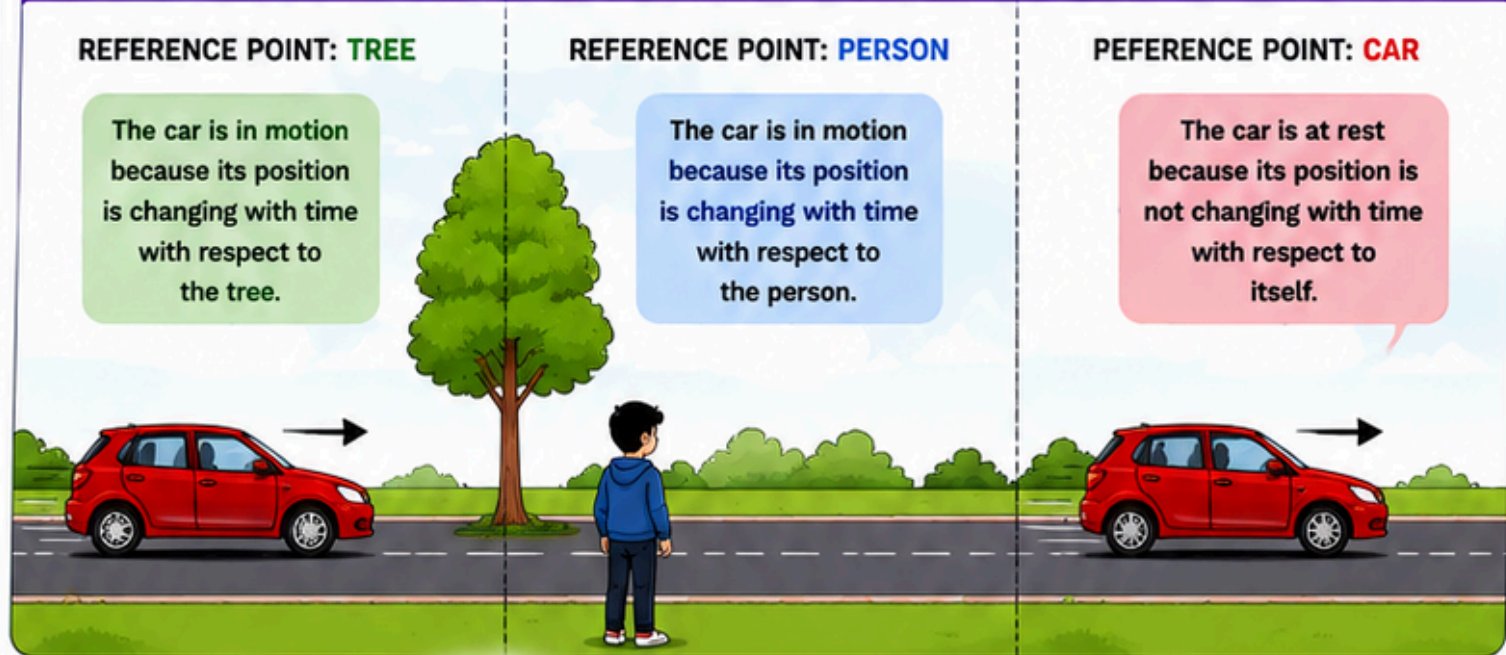
The car is in motion because its position is changing with time with respect to the tree.

REFERENCE POINT: **PERSON**

The car is in motion because its position is changing with time with respect to the person.

REFERENCE POINT: **CAR**

The car is at rest because its position is not changing with time with respect to itself.



MORE EXAMPLES

1. PASSENGER IN A BUS



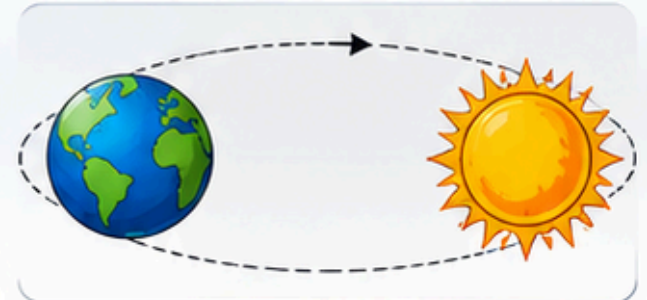
- With respect to the **bus** – He is **at rest**.
- With respect to a **tree on the road** – He is **in motion**.

2. FAN ON THE CEILING



- With respect to the **fan's center** – The blades are **in motion**.
- With respect to a **blade** – The blade is **at rest**.

3. EARTH AND THE SUN



- The **Earth** is **in motion** with respect to the **Sun**.
- The **Sun** is **at rest** with respect to itself.

TYPES OF REFERENCE POINTS



Fixed Reference Point
(e.g., tree, building, pole)



Moving Reference Point
(e.g., person in a vehicle)



Object as Reference Point
(e.g., another moving object)

IMPORTANT POINTS



Motion is not absolute; it is **relative**.



An object can be in **motion** for one observer and **at rest** for another.



To describe motion, we must always specify the **reference point** or **reference frame**.

IN SHORT

Choose a **reference point**.
Observe the position of an object with time. If the position changes, the object is **in motion** with respect to that reference point.



Remember: **Motion** is **relative** and depends on the **reference point** or observer.



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POSITION OF AN OBJECT

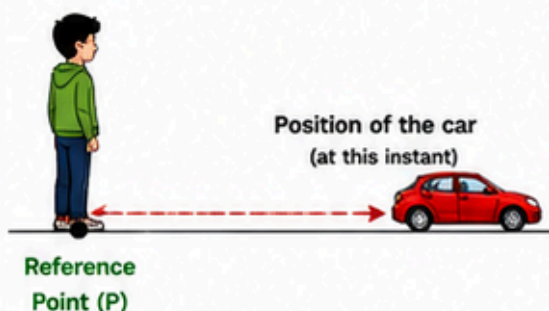
To describe the position of an object, we need a **reference point**, a **direction** and a **distance**.

“Position tells us **where** an object is located with respect to a **reference point**.”



WHAT IS POSITION?

Position of an object is the location of the object with respect to a **reference point** at a given **instant of time**.

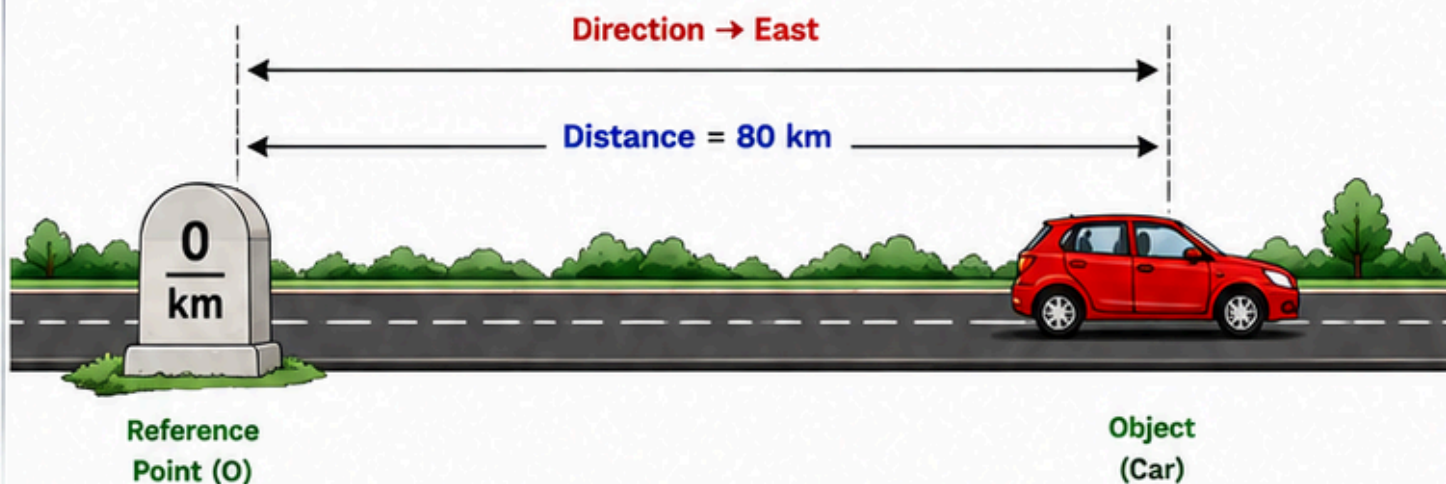


KEY IDEA

- Position is always measured with respect to a **reference point**.
- It has both **magnitude** (distance) and **direction**.
- It changes as the object moves.

HOW TO SPECIFY POSITION?

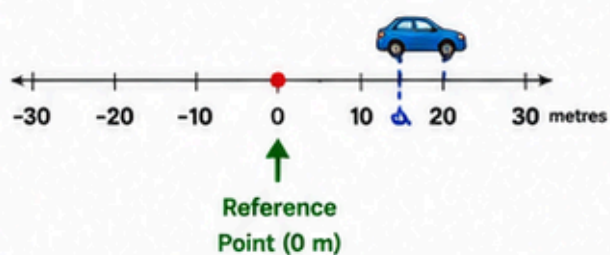
The position of an object can be specified by using a **reference point**, a **direction** and a **distance**.



The position of the car is **80 km** towards **East** with respect to the reference point **O**.

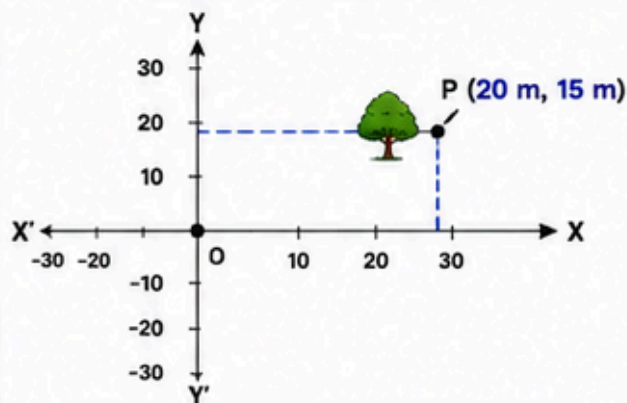
EXAMPLES OF SPECIFYING POSITION

1. ON A STRAIGHT LINE (1-D)



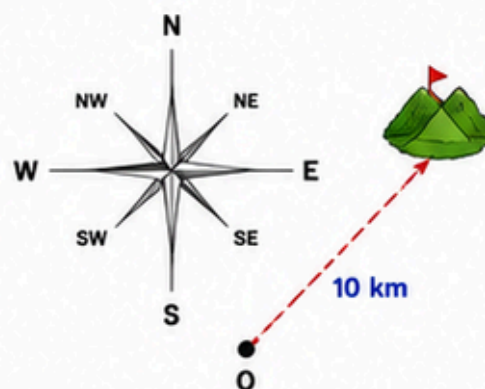
Position of the car = **+10 m**
(10 m to the right of **reference point**)

2. ON A PLANE (2-D)



Position of the tree = **(20 m, 15 m)**
(20 m along **+X** and 15 m along **+Y**)

3. USING DIRECTION (BEARING)



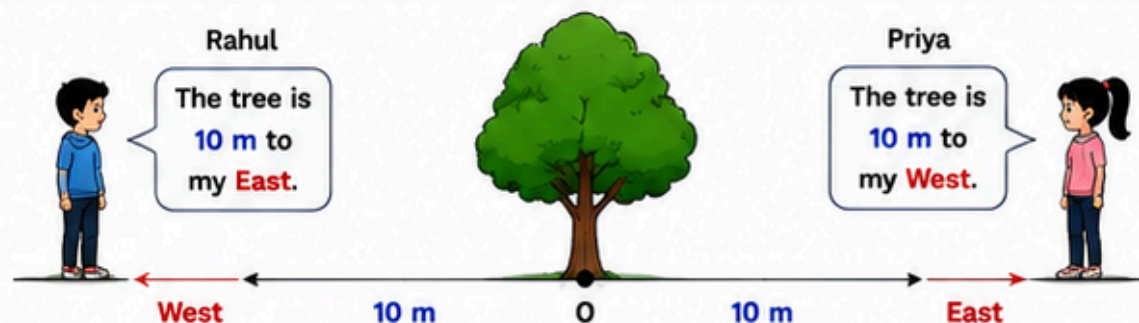
The position of the hill is **10 km** towards **North-East** from the reference point **O**.

IMPORTANT POINTS



- ✓ Position is always **relative**, never absolute.
- ✓ It depends on the chosen **reference point**.
- ✓ Different observers may give different positions for the same object.
- ✓ To completely describe position, we need **distance** and **direction**.

DIFFERENT OBSERVERS, DIFFERENT POSITIONS



REMEMBER

Position = **Reference Point** + **Direction** + **Distance**



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DISTANCE VS DISPLACEMENT

Both describe how far an object moves, but they are NOT the same!

DISTANCE

Distance is the total length of the actual path traveled by an object.

It is a **SCALAR** quantity (magnitude only).

KEY POINTS

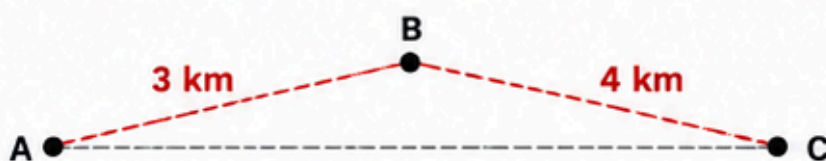
- ✓ It is the total path length.
- ✓ It has only magnitude.
- ✓ It is always positive or zero.
- ✓ It does not depend on direction.
- ✓ Its SI unit is metre (m).

Formula

Distance =
Total path
length

EXAMPLE

Rahul walks from A to B then to C.
Total distance traveled = AB + BC



Total distance = 3 km + 4 km = **7 km**
(Path followed)

DISPLACEMENT

Displacement is the shortest straight line distance from the initial position to the final position in a specified direction.

It is a **VECTOR** quantity (magnitude + direction).

KEY POINTS

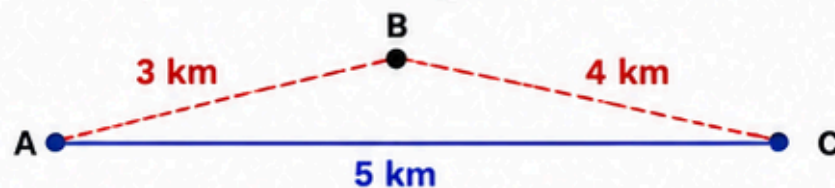
- ✓ It is the shortest distance from initial to final position.
- ✓ It has both magnitude and **direction**.
- ✓ It can be positive, negative or zero.
- ✓ It depends on direction.
- ✓ Its SI unit is metre (m).

Formula

Displacement =
Shortest distance
in a given direction

EXAMPLE

Rahul walks from A to B then to C.
Displacement is the straight line from A to C.



Displacement = 5 km towards C
(Shortest straight line from A to C)

MORE EXAMPLES

1. ROUND TRIP (RETURNS TO START)

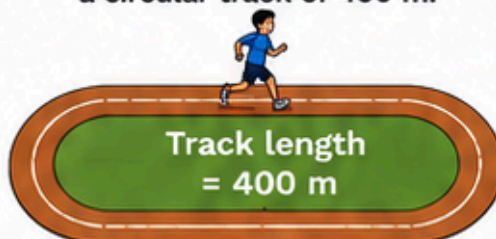
Rahul goes from Home to Park and returns back to Home.



Total distance = 2 km + 2 km = **4 km**
Displacement = **0 m**
(Initial and final positions are same)

2. ONE COMPLETE LAP (CLOSED PATH)

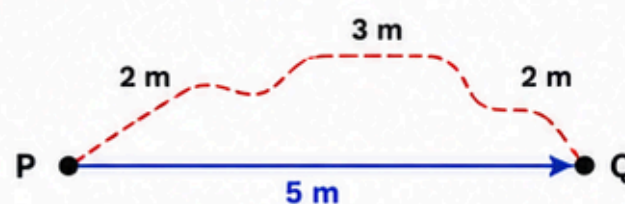
Rahul runs one complete lap around a circular track of 400 m.



Total distance = **400 m**
Displacement = **0 m**
(Initial and final positions are same)

3. IRREGULAR PATH

Rahul moves from P to Q through an irregular path.



Total distance = 2 + 3 + 2 = **7 m**
Displacement = **5 m towards Q**
(Shortest straight line from P to Q)

KEY DIFFERENCES

Feature	Distance	Displacement
Definition	Total length of the actual path traveled	Shortest straight line distance from initial to final position
Type	Scalar (magnitude only)	Vector (magnitude + direction)
Depends on direction?	No	Yes
Can be zero?	Only if no motion	Yes, if initial and final positions are same
Always positive?	Yes	No, can be positive, negative or zero
Example	Length of path, running track	Change in position, straight line from start to end

IMPORTANT NOTES



Distance can never be less than displacement.
(Distance $\geq$ Displacement)



If an object moves in a straight line in one direction, then **Distance = Displacement**.



To completely describe motion, we need magnitude and direction (displacement).



Distance tells how much ground is covered, displacement tells how much position is changed.



DID YOU KNOW?

If you walk 10 km in a square field and return to the starting point, your displacement is **0**, but distance is **10 km**!



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REMEMBER

Distance is about the path you take, Displacement is about the change in position.





DISPLACEMENT - MAGNITUDE & DIRECTION



Displacement is a vector quantity.
It has both **MAGNITUDE** (how much) and **DIRECTION** (towards where).

WHAT IS DISPLACEMENT?

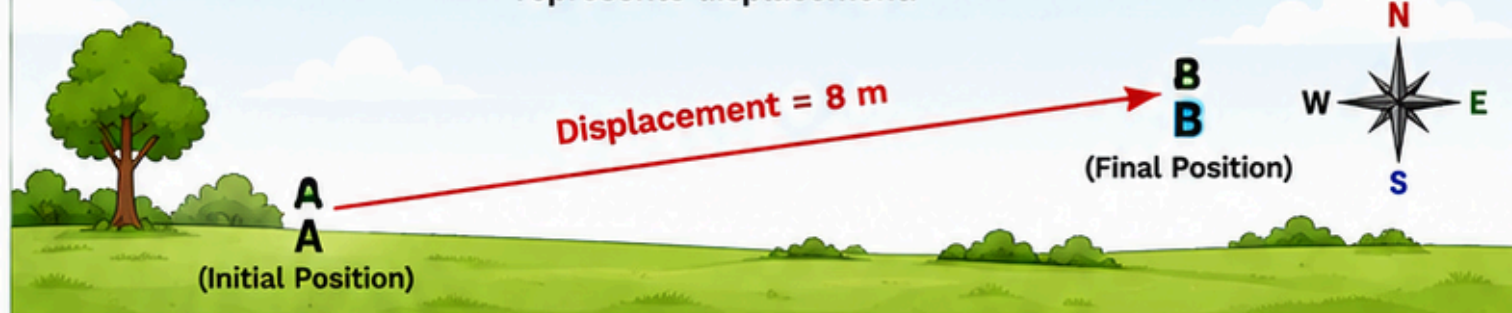
Displacement is the **shortest straight line** distance from the initial position to the final position in a **specific direction**.

➔ Vector Quantity

- ✓ It has magnitude.
- ✓ It has direction.
- ✓ Its SI unit is metre (m).

DISPLACEMENT - MAGNITUDE & DIRECTION

The straight line from initial position (A) to final position (B) represents displacement.



MAGNITUDE

The length of the displacement.
(How much)
In the figure, magnitude = **8 m**.

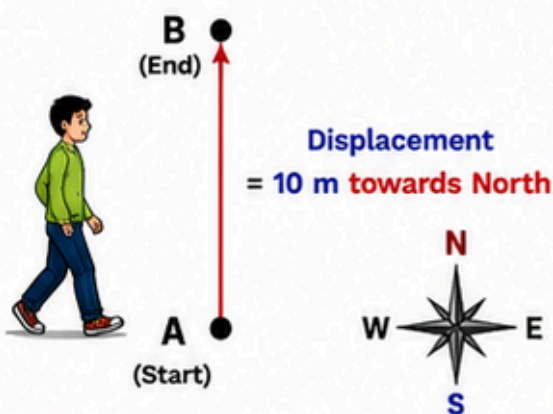
DIRECTION

The direction from initial to final position.
(Towards East)
In the figure, direction = **East**.

UNDERSTANDING WITH EXAMPLES

1. STRAIGHT LINE MOTION

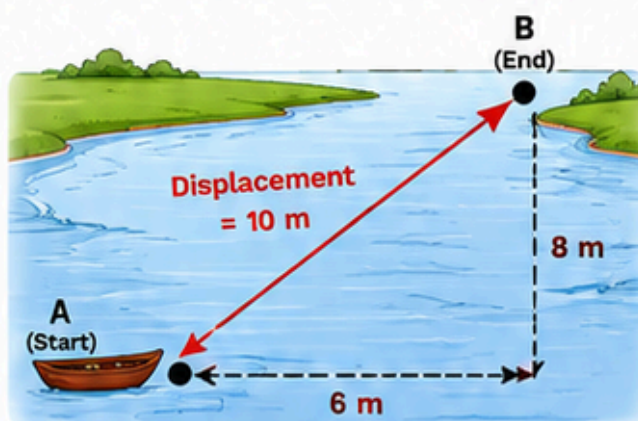
A person walks 10 m towards North.



Magnitude = **10 m**
Direction = **North**

2. OBLIQUE MOTION

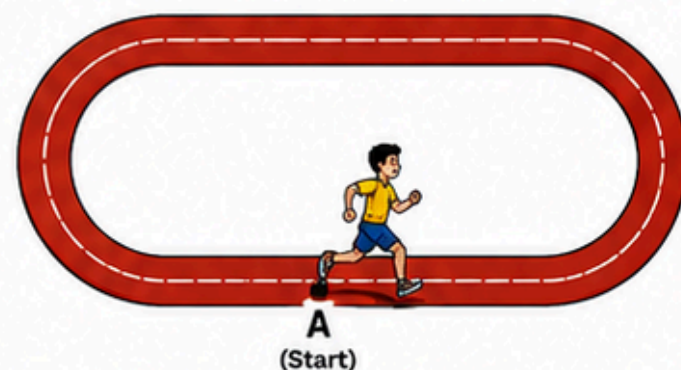
A boat moves from point A to point B.



Magnitude = $\sqrt{6^2 + 8^2} = 10 \text{ m}$
Direction = Towards **North-East**

3. CLOSED PATH

A runner completes one round of a track and comes back to the starting point.



Initial position = Final position
Displacement = **0 m**
(No direction)

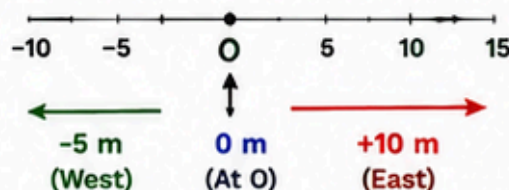
HOW TO FIND DISPLACEMENT

1. Identify the initial position.
2. Identify the final position.
3. Draw a straight line from initial to final position.
4. Measure the length of this line → Magnitude.
5. Note the direction from initial to final position → Direction.



MORE EXAMPLES

A. Displacement can be **positive**, negative or zero.



B. Displacement depends on initial and final positions.

A $\xrightarrow{5 \text{ m}}$ B

Displacement from A to B = **5 m (East)**

B $\xleftarrow{5 \text{ m}}$ A

Displacement from B to A = **5 m (West)**



KEY TAKEAWAYS

- ✓ Displacement is the shortest distance between two points in a given direction.
- ✓ It has both magnitude and direction.
- ✓ It is a vector quantity.
- ✓ The displacement can be positive, negative or zero.



DID YOU KNOW?

If you go 5 m East and then 5 m West, the total distance travelled is 10 m, but your **displacement** is **0 m**!



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LEARN • UNDERSTAND • SUCCEED



SPEED – CONCEPT & FORMULA

Speed tells us how fast an object is moving.
It is a **SCALAR** quantity (magnitude only, no direction).



WHAT IS SPEED?

Speed is the **distance** travelled by an object in a unit **time**.



In simple words,
speed = **how far** in **how much time**

KEY POINTS

- ✓ Speed has only magnitude.
- ✓ Its SI unit is metre per second (m/s).
- ✓ It is always positive or zero.
- ✓ Higher speed means the object covers more distance in less time.

FORMULA

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

v = speed
 d = distance travelled
 t = time taken

SI UNIT

metre per second (m/s)

Other common units:

- kilometre per hour (km/h)
- centimetre per second (cm/s)
- metre per minute (m/min)
- kilometre per minute (km/min)

FORMULA TRIANGLE

Use the triangle to remember the formula.



How to use?

- Cover the quantity you want to find.
- The remaining two will give the formula.

$$\text{Speed } (v) = \frac{\text{Distance } (d)}{\text{Time } (t)}$$

$$\text{Distance } (d) = \text{Speed } (v) \times \text{Time } (t)$$

$$\text{Time } (t) = \frac{\text{Distance } (d)}{\text{Speed } (v)}$$

UNIT CONVERSIONS

- $1 \text{ km/h} = \frac{5}{18} \text{ m/s} (\approx 0.278 \text{ m/s})$
- $1 \text{ m/s} = 3.6 \text{ km/h}$



EXAMPLES

1. FINDING SPEED

A car covers a distance of 240 km in 3 hours.
What is its speed?



$$\begin{aligned} \text{Speed} &= \frac{\text{Distance}}{\text{Time}} \\ &= \frac{240 \text{ km}}{3 \text{ h}} \\ &= 80 \text{ km/h} \end{aligned}$$

The speed of the car is **80 km/h**.

2. FINDING DISTANCE

A train is moving with a speed of 72 km/h for 2.5 hours. Find the distance covered.



$$\begin{aligned} \text{Distance} &= \text{Speed} \times \text{Time} \\ &= 72 \text{ km/h} \times 2.5 \text{ h} \\ &= 180 \text{ km} \end{aligned}$$

The distance covered is **180 km**.

3. FINDING TIME

A cyclist covers a distance of 45 km with a speed of 15 km/h. Find the time taken.



$$\begin{aligned} \text{Time} &= \frac{\text{Distance}}{\text{Speed}} \\ &= \frac{45 \text{ km}}{15 \text{ km/h}} \\ &= 3 \text{ h} \end{aligned}$$

The time taken is **3 hours**.

AVERAGE SPEED

If an object covers different distances in equal intervals of time, its average speed is:

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

Example: A car covers 120 km in the first hour and 180 km in the second hour.

$$\begin{aligned} \text{Average Speed} &= \frac{120 + 180}{2} \\ &= 150 \text{ km/h} \end{aligned}$$



SOME TYPICAL SPEEDS

Object	Typical Speed
Walking person	1 – 1.5 m/s
Running person	3 – 5 m/s
Cyclist	5 – 8 m/s
Car	20 – 30 m/s (72 – 108 km/h)
Train	20 – 30 m/s (72 – 108 km/h)
Aeroplane	250 – 300 m/s (900 – 1080 km/h)

IMPORTANT NOTES

- ✓ Speed is a scalar quantity.
- ✓ It does not tell us in which direction the object is moving.
- ✓ Speed can be zero if the object is at rest.
- ✓ Speed depends on both distance covered and time taken.
- ✓ Always use the same units for distance and time.



DID YOU KNOW?

A cheetah can run up to 30 m/s (about 108 km/h)!



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REMEMBER

More distance in the same time means more speed.
More time for the same distance means less speed.





UNIFORM VS NON-UNIFORM MOTION



Motion tells us that an object is **changing its position with time**.
Objects can move in **different ways**.

UNIFORM MOTION

An object is said to be in uniform motion if it covers **equal distances in equal intervals of time**.

KEY FEATURES

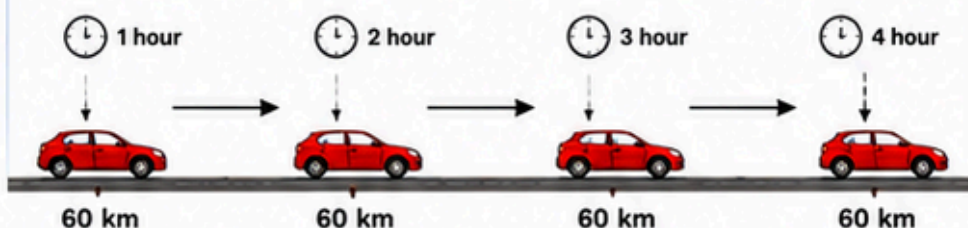
- ✓ Covers equal distances in equal time.
- ✓ Speed (or velocity) remains constant.
- ✓ Acceleration is zero.
- ✓ If it is moving in a straight line, its velocity is constant.

MATHEMATICAL VIEW

Speed = Constant
Velocity = Constant
Acceleration = 0

EXAMPLE – A Car Moving at Constant Speed

A car moves at 60 km/h. It covers 60 km every hour.



Distance covered in equal intervals of time is equal.
Speed is constant.

NON-UNIFORM MOTION

An object is said to be in non-uniform motion if it covers **unequal distances in equal intervals of time**.

KEY FEATURES

- ✓ Covers unequal distances in equal time.
- ✓ Speed (or velocity) changes.
- ✓ Acceleration is not zero.
- ✓ Its velocity is changing (either in magnitude, direction or both).

MATHEMATICAL VIEW

Speed = Not constant
Velocity = Not constant
Acceleration $\neq 0$

EXAMPLE – A Car in City Traffic

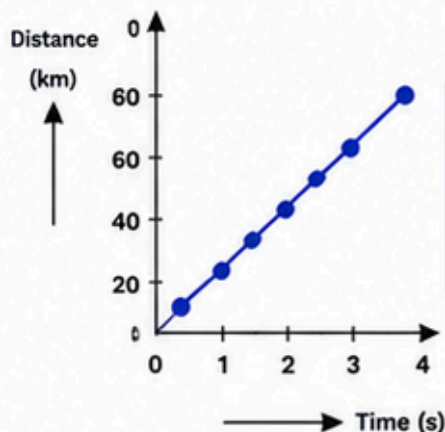
A car moves in city traffic. It covers different distances every hour.



Distance covered in equal intervals of time is not equal.
Speed is changing.

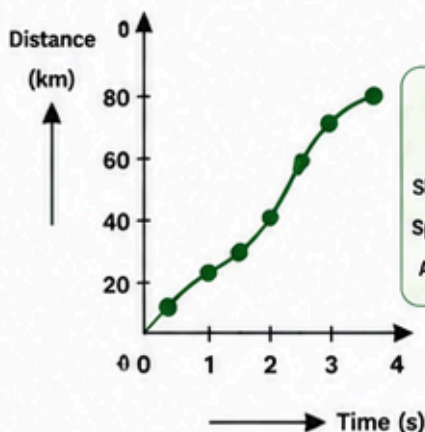
GRAPHICAL REPRESENTATION

1. UNIFORM MOTION (Distance-Time Graph)



The graph is a straight line.
Slope is constant.
Speed is constant.
Acceleration = 0

2. NON-UNIFORM MOTION (Distance-Time Graph)



The graph is a curved line.
Slope is changing.
Speed is changing.
Acceleration $\neq 0$

REAL LIFE EXAMPLES

UNIFORM MOTION

- A train moving on a straight track at constant speed.



- A ceiling fan rotating at constant speed.

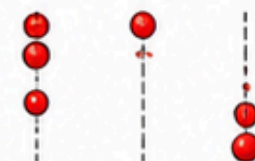


NON-UNIFORM MOTION

- A bus in stop and go traffic.



- A freely falling object.



QUICK COMPARISON

Feature	Uniform Motion	Non-Uniform Motion
Distance in equal time	Equal	Unequal
Speed	Constant	Changing
Velocity	Constant	Changing
Acceleration	Zero	Not zero
Graph (Distance-Time)	Straight line	Curved line

IMPORTANT POINTS

- ✓ Uniform motion means no change in speed.
- ✓ Non-uniform motion means change in speed.
- ✓ All uniform motions are non-accelerated.
- ✓ All non-uniform motions are accelerated. (positive or negative).



DID YOU KNOW?

Even while running, you change your speed many times – so your motion is non-uniform!



REMEMBER

Uniform motion = Constant speed

Non-uniform motion = Changing speed

Motion is all around us!

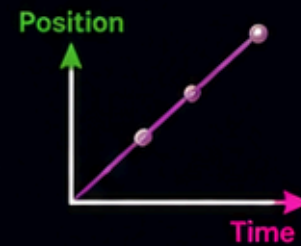


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POSITION-TIME GRAPH



A **position-time** graph shows how the **position** of an object changes with **time**.

WHAT IS IT?

A position-time graph is a graph between the **position** of an object and the **time**.

Axes

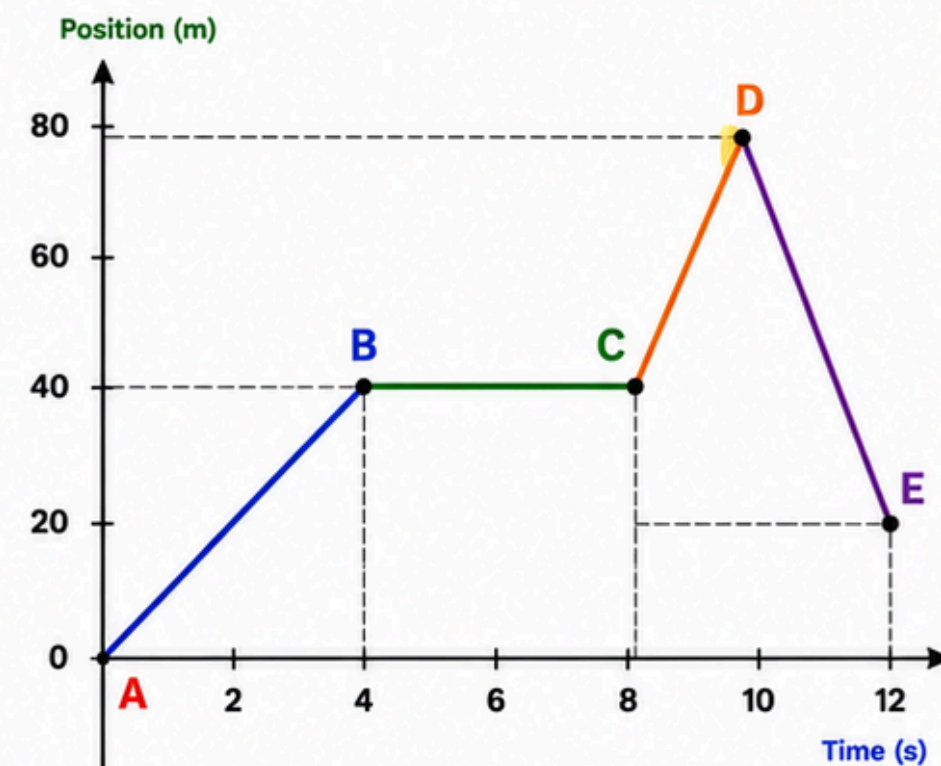
- X-axis (horizontal) : Time (s)
- Y-axis (vertical) : Position (m)

Position can be distance from a **reference point** or **displacement**.

KEY POINTS

- ✓ It helps us understand motion.
- ✓ Slope of the graph gives velocity.
- ✓ Steeper slope means higher velocity.
- ✓ A horizontal line means the object is at **rest**.
- ✓ A straight line means constant velocity.
- ✓ A curved line means changing velocity.

UNDERSTANDING THE GRAPH



At any time, the **position** of the object is given by the **y-value** (vertical value) on the graph.

AB (0-4 s)

Position increases uniformly from 0 m to 40 m.
→ Object moves with constant velocity.

BC (4-8 s)

Position is constant (40 m).
→ Object is at **rest**.

CD (8-10 s)

Position increases uniformly from 40 m to 80 m.
→ Object moves with constant velocity (faster than AB).

DE (10-12 s)

Position decreases uniformly from 80 m to 20 m.
→ Object moves back towards the reference point with constant velocity.

WHAT DOES THE SLOPE TELL US?

Slope of the position-time graph represents **velocity**.

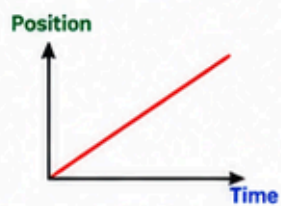
$$\text{Velocity (v)} = \frac{\text{Change in position}}{\text{Change in time}}$$

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}}$$

Slope	Graph	Meaning	Velocity
Positive slope (line rising)		Position increases with time. Object is moving in + direction.	Positive (constant)
Zero slope (horizontal line)		Position is constant. Object is at rest.	Zero
Negative slope (line falling)		Position decreases with time. Object is moving in - direction.	Negative (constant)

EXAMPLES

1. Object moving with constant velocity



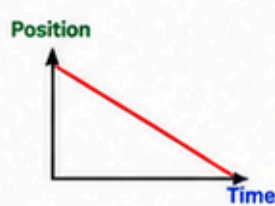
Straight line with positive slope.
Velocity is constant and positive.

2. Object at rest



Horizontal line.
Velocity is zero.

3. Object moving back towards start



Straight line with negative slope.
Velocity is constant and negative.

IMPORTANT NOTES

- ✓ The steeper the line, the greater the speed.
- ✓ A straight line means constant velocity.
- ✓ A curved line means changing velocity.
- ✓ Position can be +, 0 or - depending on the reference point.

REAL LIFE EXAMPLES



A car moving on a straight road at constant speed.



A train waiting at a station.



A cyclist moving back towards the starting point.



DID YOU KNOW?

If the position-time graph is a straight line, the object's velocity is constant (no acceleration).



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REMEMBER

Position-time graph is a powerful tool to describe and understand motion easily!





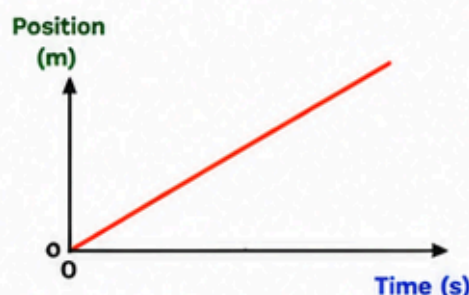
TYPES OF POSITION-TIME GRAPHS



A **position-time** graph shows how the **position** of an object changes with **time**.

1. UNIFORM MOTION (POSITIVE VELOCITY)

Straight line with **positive slope**.

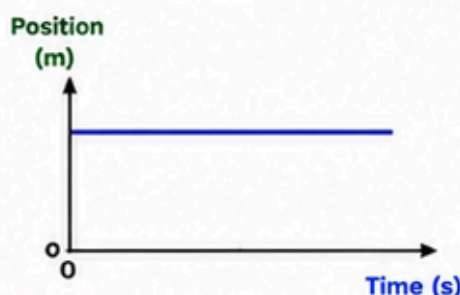


Meaning: Position increases uniformly with time. The object moves in + direction with constant velocity.

Velocity: Constant (+)

2. AT REST (ZERO VELOCITY)

Horizontal straight line (**zero slope**).

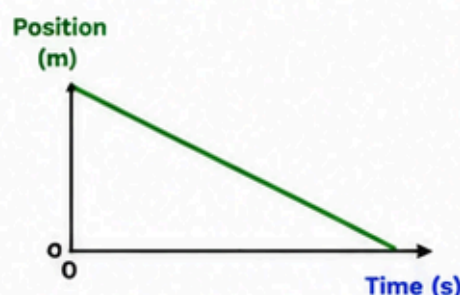


Meaning: Position remains constant with time. The object is at rest.

Velocity: Zero

3. UNIFORM MOTION (NEGATIVE VELOCITY)

Straight line with **negative slope**.

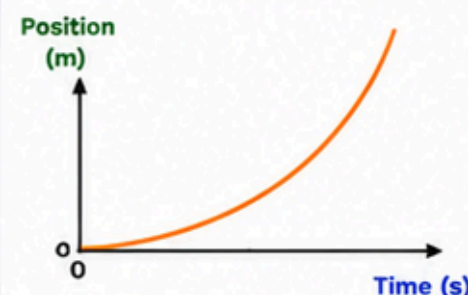


Meaning: Position decreases uniformly with time. The object moves in - direction with constant velocity.

Velocity: Constant (-)

4. NON-UNIFORM MOTION (ACCELERATED, POSITIVE)

Curve with **increasing positive slope**.

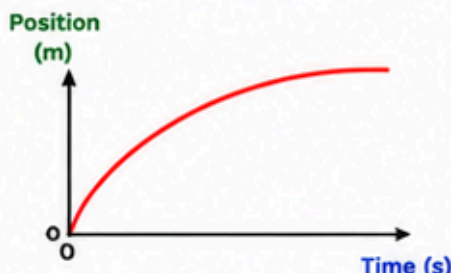


Meaning: Position increases with time but the slope increases. The object is speeding up in + direction.

Velocity: Increasing (+)

5. NON-UNIFORM MOTION (DECELERATED, POSITIVE)

Curve with **decreasing positive slope**.

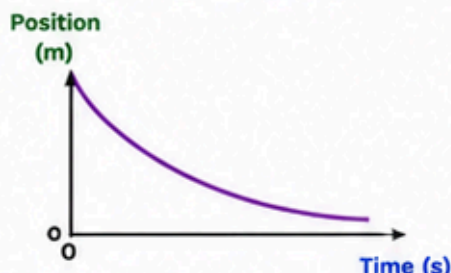


Meaning: Position increases with time but the slope decreases. The object is slowing down in + direction.

Velocity: Decreasing (+)

6. NON-UNIFORM MOTION (ACCELERATED, NEGATIVE)

Curve with **increasing negative slope**.

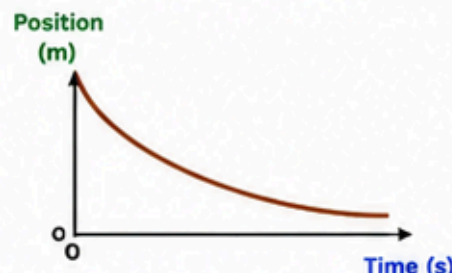


Meaning: Position decreases with time and slope becomes more negative. The object is speeding up in - direction.

Velocity: Increasing (-)

7. NON-UNIFORM MOTION (DECELERATED, NEGATIVE)

Curve with **decreasing negative slope**.

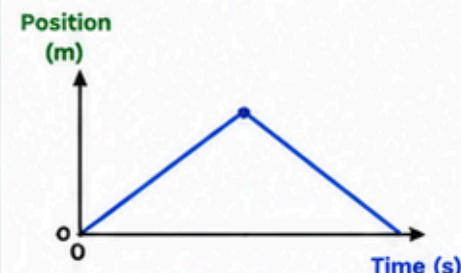


Meaning: Position decreases with time but the slope becomes less negative. The object is slowing down in - direction.

Velocity: Decreasing (-)

8. OBJECT RETURNS TO STARTING POSITION

Line/curve that comes back to the starting position.



Meaning: Object first moves away from the reference point and then returns to the same position.

Velocity: + then - (changes)

HOW TO READ POSITION-TIME GRAPHS

- ✓ The y-axis shows **position (m)**.
- ✓ The x-axis shows **time (s)**.
- ✓ The slope of the line/curve gives velocity.
- ✓ Steeper slope → higher speed.
- ✓ Horizontal line → object is at rest.
- ✓ Curved line → object is in non-uniform motion.



QUICK SUMMARY TABLE

Type of Motion	Graph Shape	Slope	Velocity
Uniform (+)		Positive (Constant)	Constant (+)
At Rest		Zero	Zero
Uniform (-)		Negative (Constant)	Constant (-)
Non-Uniform (+) Accelerated		Positive & Increasing	Increasing (+)
Non-Uniform (+) Decelerated		Positive & Decreasing	Decreasing (+)
Non-Uniform (-) Accelerated		Negative & Increasing (in -)	Increasing (-)
Non-Uniform (-) Decelerated		Negative & Decreasing (in -)	Decreasing (-)
Returns to Start		Changes Sign	Changes Sign

IMPORTANT NOTES

- ★ $\text{Slope} = \frac{\Delta \text{Position}}{\Delta \text{Time}} = \text{Velocity}$
- ★ Positive slope → Motion in + direction.
- ★ Negative slope → Motion in - direction.
- ★ Zero slope → Object is at rest.
- ★ The area under the velocity-time graph gives displacement, not the position-time graph.



DID YOU KNOW?

If the position-time graph is a straight line, the object is moving with constant velocity (no acceleration).



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VELOCITY & VELOCITY-TIME GRAPH

Velocity tells us **how fast** an object is moving and **in what direction**.



1. CONCEPT OF VELOCITY

Velocity is the rate of change of displacement.
It is a **VECTOR** quantity.

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

v = velocity
 s = displacement
 t = time taken

SI UNIT

metre per second (m/s)

Other units

- kilometre per hour (km/h)
- centimetre per second (cm/s)



2. VELOCITY vs SPEED

SPEED (Scalar)

- Tells how fast an object is moving.
- Has magnitude only.
- Unit: m/s, km/h



Example:

A car moving at 60 km/h.

VELOCITY (Vector)

- Tells how fast and in what **direction** an object is moving.
- Has **both** magnitude and **direction**.
- Unit: m/s



Example:

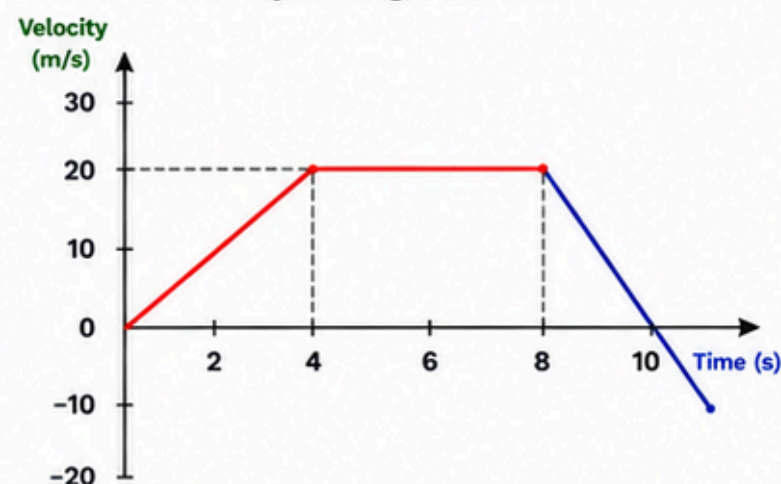
A car moving at 60 km/h towards North.



Two objects can have the same speed but different velocity if their directions are different.

3. VELOCITY-TIME GRAPH (v-t GRAPH)

A velocity-time graph shows how the velocity of an object changes with time.

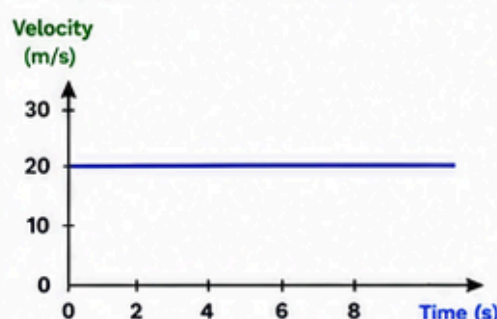


At any time, the velocity of the object is given by the **y-value** (vertical value) on the graph.

4. TYPES OF MOTION ON VELOCITY-TIME GRAPH

(i) UNIFORM MOTION (CONSTANT VELOCITY)

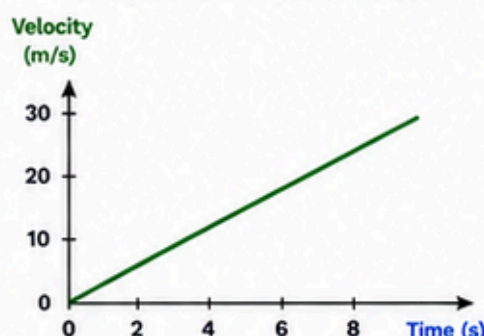
Horizontal line parallel to time axis.



Velocity is constant.
Acceleration = 0

(ii) UNIFORMLY ACCELERATED MOTION

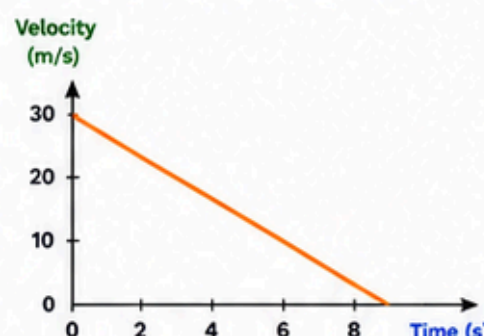
Straight line with positive slope.



Velocity increases uniformly.
Acceleration = **Positive**

(iii) UNIFORMLY DECELERATED MOTION

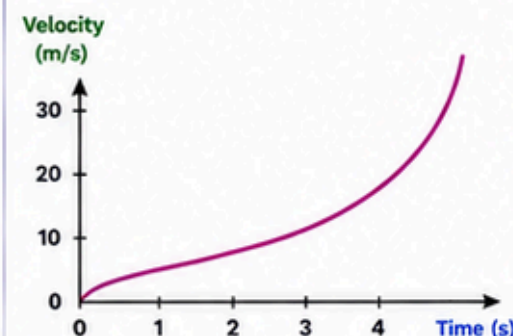
Straight line with negative slope.



Velocity decreases uniformly.
Acceleration = **Negative**

(iv) NON-UNIFORM MOTION

Curved line.

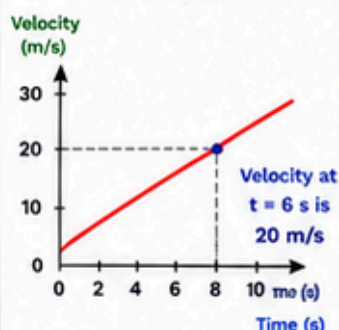


Velocity changes in a non-uniform way.
Acceleration is not constant.

5. FINDING INFORMATION FROM v-t GRAPH

(a) VELOCITY

Velocity at any time = y-value on the graph.



(b) ACCELERATION (a)

Acceleration = Slope of v-t graph

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

Where,

v_1, v_2 = velocities at times t_1, t_2

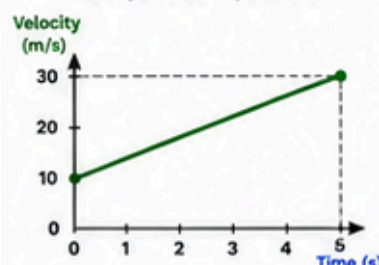
Δv = change in velocity

Δt = change in time

6. EXAMPLES

EXAMPLE 1 (Acceleration)

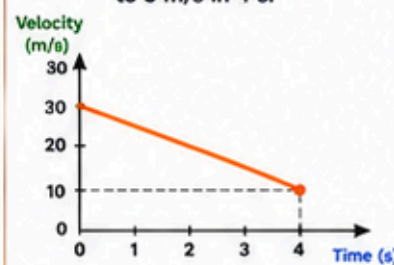
A car's velocity increases from 10 m/s to 30 m/s in 5 s.



$$a = \frac{\Delta v}{\Delta t} = \frac{30 - 10}{5} = \frac{20}{5} = 4 \text{ m/s}^2$$

EXAMPLE 2 (Deceleration)

A car slows down from 25 m/s to 5 m/s in 4 s.



$$a = \frac{\Delta v}{\Delta t} = \frac{5 - 25}{4} = \frac{-20}{4} = -5 \text{ m/s}^2$$

7. KEY TAKEAWAYS

- ✓ Velocity is a vector quantity (magnitude + direction).
- ✓ $v = \text{displacement} / \text{time}$
- ✓ Slope of v-t graph = acceleration.
- ✓ Positive slope → acceleration is positive.
- ✓ Negative slope → acceleration is negative.
- ✓ Horizontal line → acceleration = 0 (constant velocity).
- ✓ Area under v-t graph = displacement.



DID YOU KNOW?

If an object moves with constant acceleration, its velocity changes by equal amounts in equal intervals of time.



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REMEMBER

Speed tells how fast.
Velocity tells how fast and in what direction!





ACCELERATION – POSITIVE, ZERO & NEGATIVE



Acceleration tells us **HOW** the velocity of an object changes with time.
It is the **rate of change of velocity**.

1. POSITIVE ACCELERATION ($a > 0$)

Velocity **increases** with time
(either in + direction or becomes more +).

Examples

- A car starts from rest and speeds up.
- A bicyclist pedals faster.



Think: **Speeding up**
or **gaining speed**.

2. ZERO ACCELERATION ($a = 0$)

Velocity remains **constant** with time
(no change in speed or direction).

Examples

- A car moving at 60 km/h on a straight road.
- A train moving at constant speed.



Think: Moving **steadily**
without speeding up
or slowing down.

3. NEGATIVE ACCELERATION ($a < 0$)

Velocity **decreases** with time
(either in – direction or becomes less +).

Examples

- A car applying brakes slows down.
- A ball thrown upward slows down due to gravity.

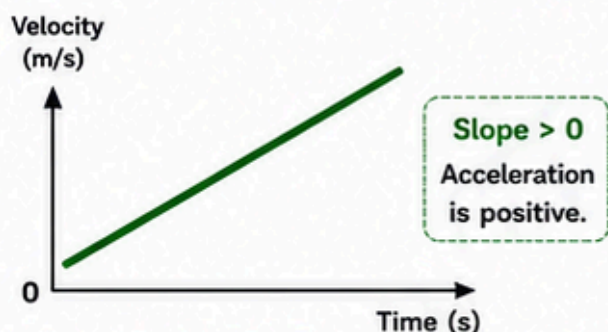


Think: **Slowing down**
or **losing speed**.

VELOCITY–TIME (v–t) GRAPH & ACCELERATION

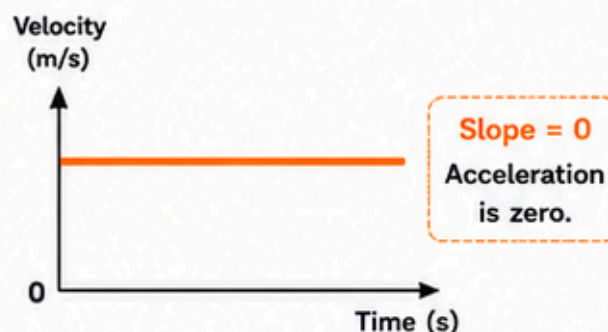
POSITIVE ACCELERATION ($a > 0$)

Velocity–time graph is
a straight line with **positive slope**.



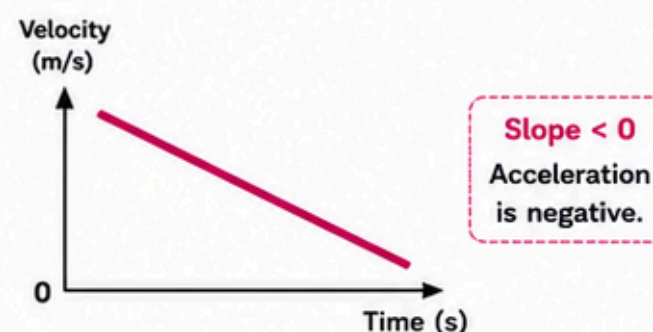
ZERO ACCELERATION ($a = 0$)

Velocity–time graph is
a horizontal line (**zero slope**).



NEGATIVE ACCELERATION ($a < 0$)

Velocity–time graph is
a straight line with **negative slope**.



ACCELERATION FORMULA

$$a = \frac{v_2 - v_1}{t_2 - t_1}$$

Where,

a = acceleration (m/s^2)
 v_1 = initial velocity (m/s)
 v_2 = final velocity (m/s)
 t_1 = initial time (s)
 t_2 = final time (s)

SI Unit of acceleration : m/s^2

QUICK REFERENCE TABLE

Type of Acceleration	Change in Velocity	Sign of Acceleration	v–t Graph (Slope)
Positive ($a > 0$)	Increases	Positive (+)	 Slope > 0
Zero ($a = 0$)	Remains constant	Zero (0)	 Slope = 0
Negative ($a < 0$)	Decreases	Negative (–)	 Slope < 0

REAL-LIFE EXAMPLES



Positive Acceleration
Rocket blasting off
→ speed increases rapidly.



Zero Acceleration
Car moving at constant speed on a highway.
→ speed remains the same.



Negative Acceleration
Car applying brakes
→ speed decreases until it stops.

KEY TAKEAWAYS

- ✓ Positive acceleration → velocity increases.
- ✓ Zero acceleration → velocity remains constant.
- ✓ Negative acceleration → velocity decreases.
- ✓ Acceleration is a vector quantity.
- ✓ Unit of acceleration is m/s^2 .



DID YOU KNOW?

Even when an object slows down, it can have positive acceleration if it is moving in the negative direction and speed is increasing further in that direction!



REMEMBER

- + sign means acceleration in + direction.
- sign means acceleration in – direction.
- Zero acceleration means no change in velocity.



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SLOPE OF VELOCITY-TIME GRAPH → ACCELERATION



The slope (gradient) of a velocity-time graph gives the **acceleration** of the object.

Formula

$$\begin{aligned}\text{Acceleration (a)} &= \frac{\text{Slope of v-t graph}}{\text{}} \\ &= \frac{\Delta v}{\Delta t} \\ &= \frac{v_2 - v_1}{t_2 - t_1}\end{aligned}$$

Unit: m/s^2



Meaning of Slope



Positive slope
→ Positive
acceleration



Zero slope
→ Zero
acceleration



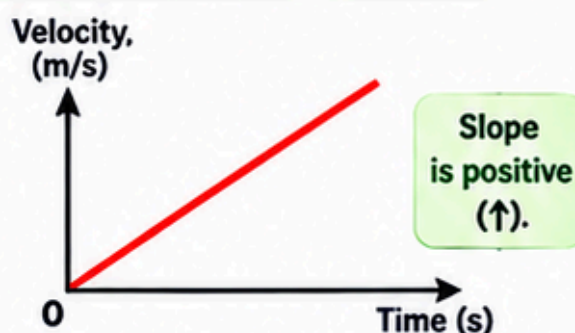
Negative slope
→ Negative
acceleration

Types of Acceleration from v-t Graph

- **Positive acceleration:**
velocity increases with time.
- **Zero acceleration:**
velocity remains constant.
- **Negative acceleration:**
velocity decreases with time.

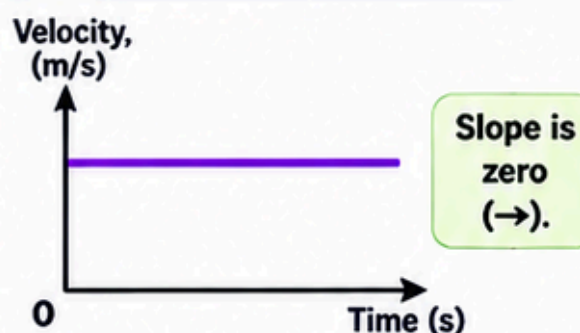
Examples of Velocity-Time Graphs & Acceleration

1. Positive Acceleration (Acceleration > 0)



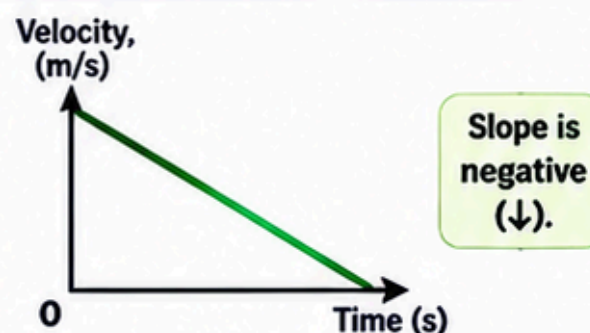
Acceleration is positive.

2. Zero Acceleration (Acceleration = 0)



Acceleration is zero.

3. Negative Acceleration (Acceleration < 0)



Acceleration is negative.

Worked Example

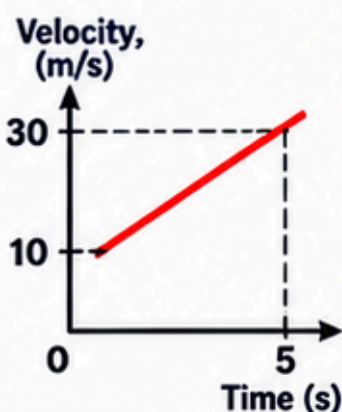
1. A car's velocity increases from 10 m/s to 30 m/s in 5 s. Find the acceleration.

Solution:

$$a = \frac{v_2 - v_1}{t_2 - t_1} = \frac{30 - 10}{5} = \frac{20}{5} = 4 \text{ m/s}^2$$



Since the velocity-time graph would have an upward slope, the acceleration is positive (4 m/s^2).



Quick Reference

Graph Type	Slope	Acceleration	Motion
Rising line (positive slope)	Positive	Positive acceleration	Speeding up
Flat line (zero slope)	Zero	Zero acceleration	Constant speed
Falling line (negative slope)	Negative	Negative acceleration	Slowing down

Key Takeaways:



- ✓ Slope of a velocity-time graph tells the acceleration.
- ✓ Positive slope → **positive** acceleration (**speed increases**).
- ✓ Zero slope → **zero** acceleration (**speed is constant**).
- ✓ Negative slope → **negative** acceleration (**speed decreases**).



Remember:

In a velocity-time graph, "the steeper the slope, the greater the acceleration."



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AREA UNDER VELOCITY-TIME GRAPH → DISPLACEMENT

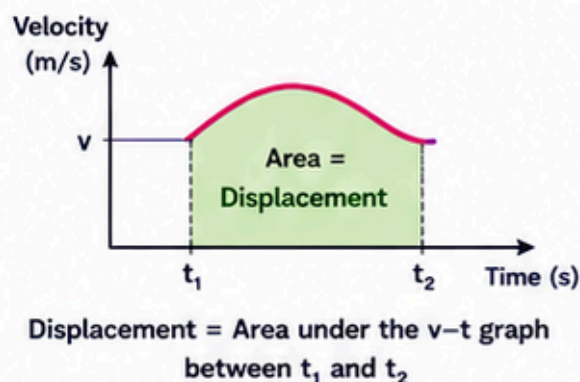


The area under a velocity-time graph between two instants gives the **displacement** of the object during that time interval.



1. CONCEPT

Displacement of an object is equal to the **signed area** under its velocity-time graph between two instants.



2. FORMULA

$$\text{Displacement (s)} = \text{Area under v-t graph}$$

$$= \int_{t_1}^{t_2} v \, dt$$

Unit:

Since velocity (v) is in m/s and time (t) is in s, displacement is in metre (m).



3. MEANING OF AREA (SIGN MATTERS!)

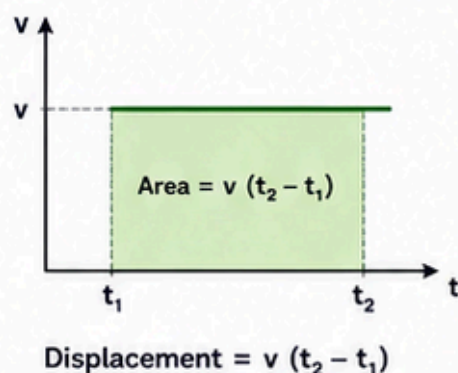
- +** Area above the time axis ($v > 0$) is **positive** → forward displacement.
- Area below the time axis ($v < 0$) is **negative** → backward displacement.
- 0** If velocity is zero, area = 0 → no displacement.



Net Displacement =
(Area above axis) - (Area below axis)

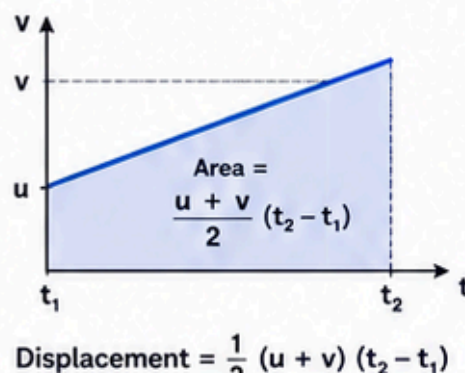
4. TYPES OF VELOCITY-TIME GRAPHS & DISPLACEMENT (AREA)

(i) CONSTANT VELOCITY (Horizontal line)



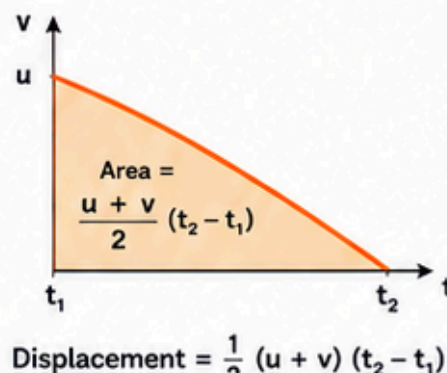
Rectangle
(base × height)

(ii) UNIFORMLY ACCELERATED MOTION (Straight line)



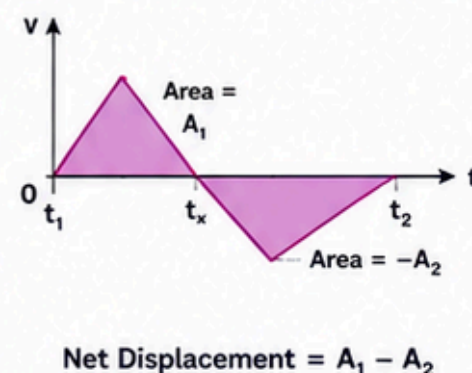
Trapezium
 $\frac{1}{2} \times (\text{sum of parallel sides}) \times \text{height}$

(iii) UNIFORMLY DECELERATED MOTION (Straight line)



Trapezium
 $\frac{1}{2} \times (\text{sum of parallel sides}) \times \text{height}$

(iv) VELOCITY CHANGES SIGN (v-t graph crosses time axis)

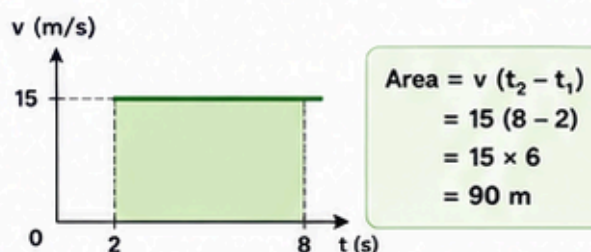


Positive area - Negative area
(Algebraic sum)

5. WORKED EXAMPLES

Example 1: Constant Velocity

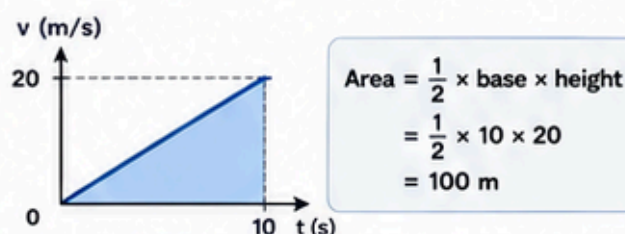
A car moves with a constant velocity of 15 m/s from $t = 2$ s to $t = 8$ s. Find the displacement.



Displacement = 90 m

Example 2: Uniform Acceleration

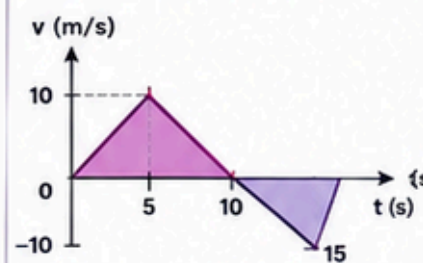
A body starts from rest ($u = 0$) and reaches 20 m/s in 10 s with uniform acceleration. Find the displacement.



Displacement = 100 m

Example 3: Velocity Changes Sign

A body has the v-t graph shown below. Find the net displacement.



Positive area (A_1)
 $= \frac{1}{2} \times 5 \times 10 = 25 \text{ m}$
 Negative area (A_2)
 $= \frac{1}{2} \times 5 \times 10 = 25 \text{ m}$
 Net Displacement
 $= A_1 - A_2 = 25 - 25 = 0 \text{ m}$

Net Displacement = 0 m

6. KEY TAKEAWAYS



- ✓ Area under v-t graph = displacement.
- ✓ Area above axis → positive displacement.
- ✓ Area below axis → negative displacement.
- ✓ Total (net) displacement = (Positive area) - (Negative area).
- ✓ Unit of displacement = metre (m).

7. QUICK NOTES

- ★ If velocity is always positive → displacement is the total area under the curve.
- ★ If velocity is always negative → displacement is negative of the total area.
- ★ Curved v-t graph? Break it into small shapes (rectangles, triangles, trapeziums) and find the total area!



REMEMBER

"The area shows how much ground is covered (with direction) over that time interval."



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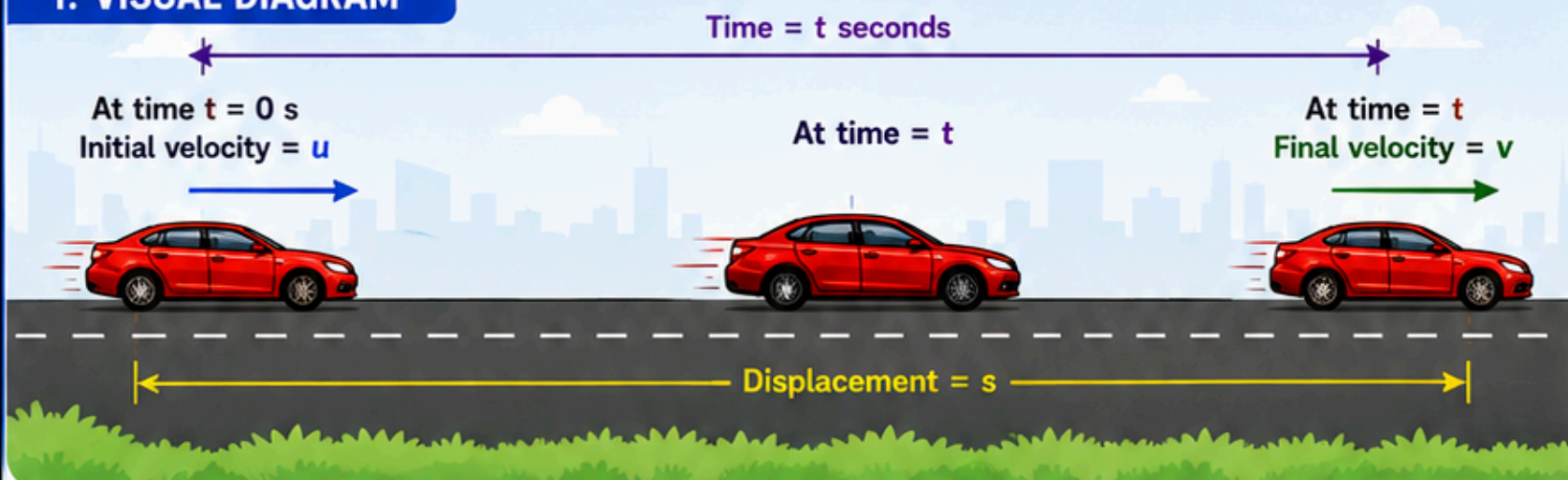
EQUATIONS OF MOTION

For Uniformly Accelerated Linear Motion (Constant Acceleration)

These equations relate Displacement (**s**), Initial Velocity (**u**), Final Velocity (**v**), Acceleration (**a**) and Time (**t**).



1. VISUAL DIAGRAM



Where,

u = Initial velocity (m/s)

v = Final velocity (m/s)

a = Acceleration (m/s²)

t = Time (s)

s = Displacement (m)

2. THE EQUATIONS OF MOTION

1

$$v = u + at$$

Final velocity is equal to initial velocity plus acceleration $\times$ time.

Use when:

🎯 You need to find final velocity (v).

2

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

Displacement is equal to initial velocity $\times$ time plus half $\times$ acceleration $\times$ time².

Use when:

🎯 You need to find displacement (s) (without v).

3

$$v^2 = u^2 + 2as$$

Square of final velocity is equal to square of initial velocity plus $2 \times$ acceleration $\times$ displacement.

Use when:

🎯 You need to find final velocity (v) or acceleration (a) (without t).

4

$$s = \frac{(u + v)}{2} \times t$$

Displacement is equal to average velocity $(u + v)/2$ multiplied by time.

Use when:

🎯 You know both u and v and need to find displacement (s).

5

$$s = vt - \frac{1}{2}at^2$$

Displacement is equal to final velocity $\times$ time minus half $\times$ acceleration $\times$ time².

Use when:

🎯 You know v , a , t and need to find displacement (s).

3. VARIABLE GUIDE

u = Initial velocity (m/s)

v = Final velocity (m/s)

a = Acceleration (m/s²)

t = Time (s)

s = Displacement (m)



4. UNITS

- Velocity (u , v) $\rightarrow$ m/s
- Acceleration (a) $\rightarrow$ m/s²
- Time (t) $\rightarrow$ s
- Displacement (s) $\rightarrow$ m

Always use SI Units for consistency.

5. IMPORTANT NOTES

- ★ These equations are valid only for **uniform (constant) acceleration**.
- ★ All equations are interrelated. You can derive one from another.
- ★ Check the given data and choose the most suitable equation.
- ★ Signs of v , a and s depend on the direction you choose as positive.

6. QUICK REFERENCE TABLE

Equation	Used to Find	Known Quantities
1 $v = u + at$	v	u , a , t
2 $s = ut + \frac{1}{2}at^2$	s	u , a , t
3 $v^2 = u^2 + 2as$	v or a	u , a , s or u , v , s
4 $s = \frac{(u + v)}{2} \times t$	s	u , v , t
5 $s = vt - \frac{1}{2}at^2$	s	v , a , t

7. REAL-LIFE EXAMPLES



Rocket launch:

A rocket accelerates uniformly upwards from rest.



Braking car:

A car slows down with constant deceleration.



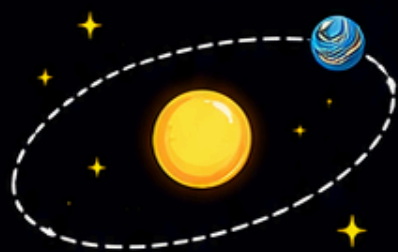
Free fall (near Earth):

Objects fall with constant acceleration due to gravity.



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UNIFORM CIRCULAR MOTION

An object moves in a circle with **CONSTANT SPEED** but continuously changing **DIRECTION**.

In uniform circular motion, the **magnitude of velocity is constant**, but its **direction changes** at every point.

1. WHAT IS UNIFORM CIRCULAR MOTION?

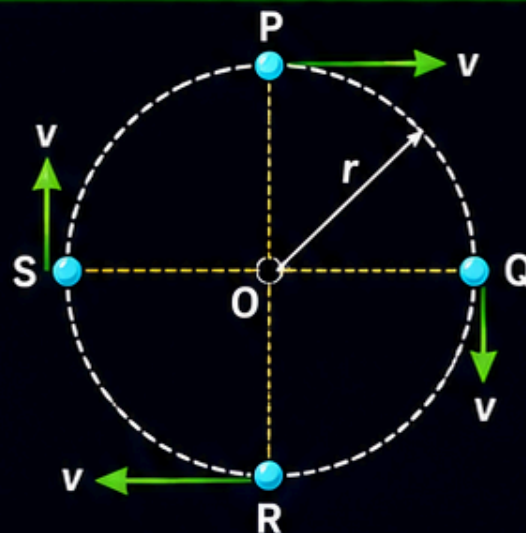
When an object moves along a circular path with **constant speed**, it is said to be in uniform circular motion.

Examples

- A car moving on a circular track
- A stone whirled on a string
- Blades of a ceiling fan
- A planet revolving around the Sun
- A satellite orbiting the Earth



2. DIAGRAM & KEY QUANTITIES



O = Centre of the circle
r = Radius of the circle
v = Constant speed (magnitude of velocity)

3. IMPORTANT POINTS

- ★ Speed (v) is constant, but velocity changes direction.
- ★ The object has acceleration even though speed is constant.
- ★ Acceleration is directed towards the centre of the circle. It is called **centripetal acceleration**.
- ★ The net displacement in one complete circle is zero, but the total distance covered is $2\pi r$.
- ★ Time period (T): time taken to complete one revolution.
- ★ Frequency (f): number of revolutions per second. $f = \frac{1}{T}$

4. IMPORTANT FORMULAS

(i) CENTRIPETAL ACCELERATION (a_c)

Acceleration towards the centre.

$$a_c = \frac{v^2}{r}$$

Unit: m/s^2



(ii) CENTRIPETAL FORCE (F_c)

Force towards the centre.

$$F_c = \frac{mv^2}{r}$$

Unit: newton (N)



(iii) TIME PERIOD (T)

Time taken to complete one revolution.

$$T = \frac{2\pi r}{v}$$

Unit: second (s)



(iv) FREQUENCY (f)

Number of revolutions per second.

$$f = \frac{1}{T} = \frac{v}{2\pi r}$$

Unit: hertz (Hz)



(v) ANGULAR VELOCITY (ω)

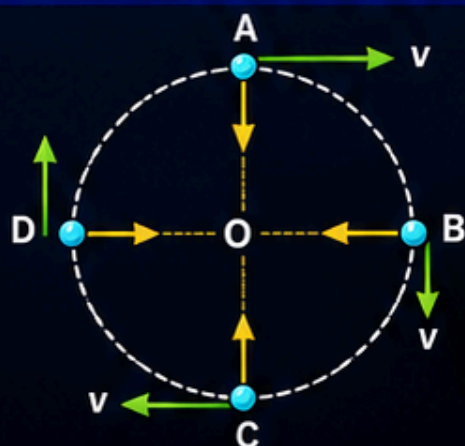
Rate of change of angular displacement.

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

Unit: rad/s



5. DIRECTION OF VELOCITY & ACCELERATION



$\rightarrow v$
Velocity (v) is always tangential to the circle.

$\rightarrow a_c$
Acceleration (a_c) is always towards the centre.

Velocity changes direction at every point, but speed remains constant.

6. CENTRIPETAL FORCE - REAL LIFE EXAMPLES

1. Car on a curved road



Friction provides the centripetal force that keeps the car moving in a circular path.

3. Satellite in orbit



Gravitational force provides the centripetal force.

2. Stone on a string



Tension in the string acts as the centripetal force.

4. Ceiling fan



The motor provides the centripetal force to rotate the blades.

7. KEY TAKEAWAYS

- ✓ Speed is constant, velocity is not constant.
- ✓ Acceleration is always towards the centre.
- ✓ Centripetal force is always towards the centre.
- ✓ All the formulas connect speed, radius, time period and acceleration.



8. DIMENSIONS

Quantity	Dimensions
Centripetal acceleration (a_c)	$[LT^{-2}]$
Centripetal force (F_c)	$[MLT^{-2}]$
Time period (T)	$[T]$
Frequency (f)	$[T^{-1}]$

9. REMEMBER



- ★ Uniform circular motion = constant speed but changing direction.
- ★ Acceleration and force are not zero.
- ★ They are directed towards the centre (centripetal).
- ★ Without centripetal force, the object moves in a straight line (by inertia).



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COMPLETE MOTION GRAPHS QUICK COMPARISON

Three Graphs. One Motion. **Complete Understanding.**



TYPE OF MOTION	POSITION-TIME GRAPH s-t Graph	VELOCITY-TIME GRAPH v-t Graph	ACCELERATION-TIME GRAPH a-t Graph	KEY FEATURES
1. OBJECT AT REST 	 Horizontal line ($s = \text{constant}$)	 On time axis ($v = 0$)	 On time axis ($a = 0$)	- Position is constant - Velocity = 0 - Acceleration = 0
2. UNIFORM MOTION (Constant Velocity) 	 Straight line with positive slope ($s \propto t$)	 Horizontal line above time axis ($v = \text{constant}$)	 On time axis ($a = 0$)	- Velocity is constant - Acceleration = 0 - Equal distances in equal time intervals
3. UNIFORMLY ACCELERATED MOTION ($a > 0$) 	 Parabola (concave up) Slope increases with time	 Straight line with positive slope (Slope = $+a$)	 Horizontal line above time axis ($a = + \text{constant}$)	- Velocity increases uniformly - Acceleration is positive and constant - Unequal distances in equal time intervals (increasing)
4. UNIFORMLY DECELERATED MOTION ($a < 0$) 	 Parabola (concave down) Slope decreases with time	 Straight line with negative slope (Slope = $-a$)	 Horizontal line below time axis ($a = - \text{constant}$)	- Velocity increases uniformly - Acceleration is negative and constant - Unequal distances in equal time intervals (decreasing)
5. NON-UNIFORM ACCELERATION (Changing a) 	 Curve (shape depends on acceleration)	 Curve (slope changes) Slope = instantaneous a	 Curve (not constant) May be $+$, $-$ or changing	- Acceleration is changing - Velocity changes at a non-uniform rate - Graphs are curves

HOW TO READ THE GRAPHS (QUICK GUIDE)

POSITION-TIME (s-t) GRAPH	VELOCITY-TIME (v-t) GRAPH	ACCELERATION-TIME (a-t) GRAPH
Slope = Velocity (v) Positive slope $\rightarrow +v$ Zero slope $\rightarrow v = 0$ Negative slope $\rightarrow -v$ Steeper slope = greater speed	Slope = Acceleration (a) Positive slope $\rightarrow +a$ Speeding up Zero slope $\rightarrow a = 0$ Constant speed Negative slope $\rightarrow -a$ Slowing down Area under v-t graph = Displacement (s)	Value of a = Acceleration Above axis $\rightarrow +a$ On axis $\rightarrow a = 0$ Below axis $\rightarrow -a$ Area under a-t graph = Change in velocity (Δv)

QUICK RELATIONSHIPS

Slope of s-t = v

Slope of v-t = a

Area under v-t = s (displacement)

Area under a-t = Δv (change in velocity)

EXAMPLE AT A GLANCE

	s-t Graph	v-t Graph	a-t Graph	
Car cruising on highway				Uniform motion
Car speeding up				Accelerated motion ($a > 0$)
Car slowing down				Decelerated motion ($a < 0$)
Car stopped				At rest

REMEMBER

- Three graphs describe one motion.
- Shape tells the story.
- Slope gives the rate.
- Area gives the total effect.
- Understand the graphs, master the motion!



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