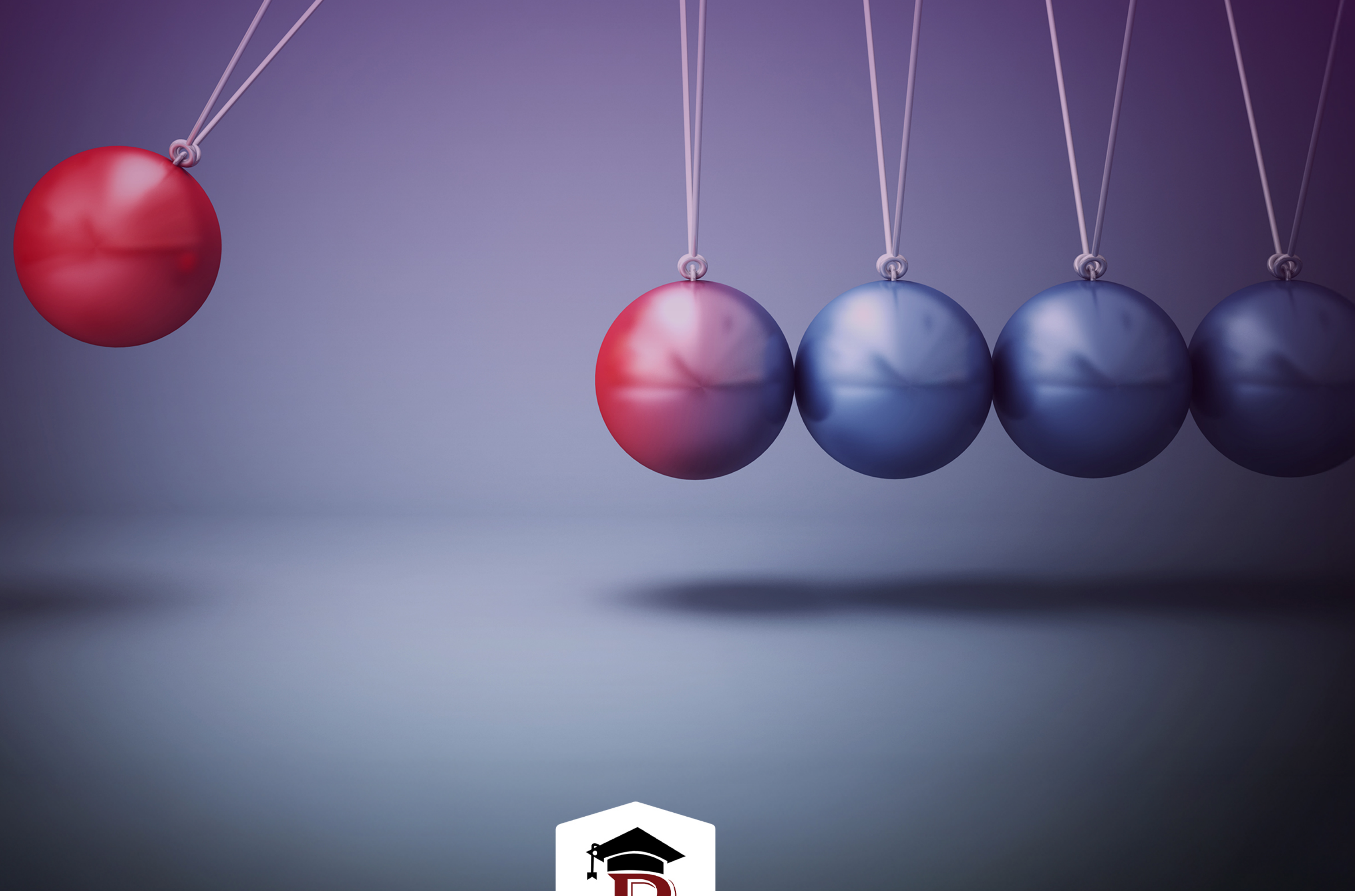
UNIT I

UG TRB

PHYSICS



MECHANICS

Professor Academy

UG TRB

PHYSICS

Mechanics

UNIT – 1

Professor Academy

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Unit – 1
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CHAPTER 1

Mechanics

What is Mechanics?

Mechanics is the branch of physics that studies the motion of objects and the forces that produce or change this motion. In simple terms, mechanics explains why objects move, how they move, and what happens when forces act on them.

Role of Mechanics in Physics

Mechanics is one of the oldest and most fundamental areas of physics. Almost every branch of physical science uses principles of mechanics as a foundation.

Understanding mechanics helps in explaining:

- Motion of vehicles
- Movement of planets and satellites
- Stability of buildings and bridges
- Operation of machines
- Sports movements and human body motion

Many advanced areas of science such as astrophysics, engineering mechanics, and biomechanics are built upon the basic laws of mechanics.

Branches of Mechanics

Mechanics is broadly divided into three main branches based on the type of motion and forces studied.

1. Statics

Statics deals with objects that remain at rest or in equilibrium under the action of forces.

In statics, the forces acting on a body balance each other, and there is no change in motion.

Examples:

- A book resting on a table
- A bridge supporting vehicles
- A ladder leaning against a wall

2. Dynamics

Dynamics studies objects that are in motion under the action of forces. It explains how forces influence the motion of bodies. Dynamics is further divided into two sub-branches.

(a) Kinematics: Kinematics describes motion **without considering the forces causing it**. It focuses on quantities such as Displacement, Velocity, Acceleration and Time Example: Studying how fast a car moves or how far it travels without analysing the engine force.

(b) Kinetics

Kinetics studies motion **by considering the forces responsible for that motion**. It explains the relationship between force, mass, and acceleration and forms the basis of Newton's laws of motion. Example: Analysing how engine force changes the speed of a car.

Exam Insight

Students often confuse **kinematics** and **kinetics**.

Kinematics → Describes motion
Kinetics → Explains causes of motion

Remember:
Kinematics answers *how objects move*.
Kinetics answers *why objects move*.

Scope of Mechanics

The study of mechanics helps in understanding:

- Motion of microscopic particles
- Motion of celestial bodies
- Behaviour of machines
- Energy transfer during motion
- Stability of physical systems

Because of its wide applicability, mechanics forms the foundation for studying advanced areas of physics.

1.2 Physical Quantities and Measurement

Physics describes natural phenomena using measurable quantities. These measurable properties are called **physical quantities**. Examples of physical quantities include length, mass, time, velocity, force, and temperature.

Every physical quantity consists of two parts:

- Numerical value
- Unit

For example, if the length of a table is written as 2 meters, the number 2 represents the magnitude and meter represents the unit.

Fundamental Quantities	Derived Quantities
Basic physical quantities that cannot be expressed in terms of other quantities	Physical quantities obtained by combining fundamental quantities
Form the foundation for all measurements in physics	Used to describe complex physical phenomena
Independent of other physical quantities	Dependent on fundamental quantities
Examples: Length, Mass, Time, Temperature	Examples: Velocity = Displacement / Time, Force = Mass × Acceleration, Density = Mass / Volume

SI system (International System of Units):

The fundamental quantities and their SI units are given below:

Physical Quantity	SI Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Significance of SI System

The SI system is accepted worldwide because it:

- Provides uniformity in scientific communication
- Simplifies calculations
- Avoids confusion in unit conversions
- Supports advanced scientific research

Exam Insight

In numerical problems, wrong unit conversion is one of the most common reasons for incorrect answers.

Always check:

- Unit consistency
- Conversion factors
- Standard SI usage

Dimensions of Physical Quantities

Dimensions indicate the relationship between a physical quantity and the fundamental quantities involved in it. Dimensions help in understanding how a physical quantity depends on basic quantities such as mass, length, and time.

For example:

- Velocity = displacement / time
- Therefore, dimensions of velocity are: Length / Time or $[L\ T^{-1}]$
- Similarly: Force = mass × acceleration; Acceleration = length / $time^2$
- Hence, dimensions of force are: $[M\ L\ T^{-2}]$

Dimensional Formula

The dimensional formula of a physical quantity expresses it in terms of fundamental quantities.

For example:

- Force → $[M\ L\ T^{-2}]$
- Velocity → $[L\ T^{-1}]$
- Energy → $[M\ L^2\ T^{-2}]$

Uses of Dimensional Analysis

Dimensional analysis is a powerful tool in physics. It helps in several ways.

1. Checking Correctness of Equations

- An equation is physically correct only if dimensions on both sides are the same.
- Example: If distance = velocity × time

- Left side dimension = [L]
  Right side dimension = $[L\,T^{-1} \times T] = [L]$
- Since dimensions match, the equation is correct.

2. Conversion of Units: Dimensional analysis helps in converting one system of units into another.

3. Deriving Relationships Between Physical Quantities: It helps in predicting mathematical relationships between physical variables when exact formula is unknown.

Keep a note: Common Mistake

Dimensional analysis can confirm whether an equation is dimensionally correct, but it **cannot guarantee the equation is completely correct**. Constants such as numerical factors cannot be determined using dimensional analysis.

1.3 Scalars and Vectors

Physical quantities can be classified based on whether direction is required to describe them. These quantities are grouped into **scalars** and **vectors**.

Scalar Quantities

Scalar quantities have magnitude but no direction. Scalar quantities follow ordinary algebraic rules during addition and subtraction.

Examples:

- Mass
- Time
- Temperature
- Distance
- Energy
- Speed

For instance, if the temperature of a room is 30°C, the information is complete without specifying any direction.

Vector Quantities

Vector quantities possess both magnitude and direction. Vectors are usually represented by arrows. The length of the arrow represents magnitude, and the direction of the arrow represents direction.

Examples:

- Displacement
- Velocity
- Acceleration
- Force
- Momentum

For example, stating that a car is moving at 40 km/h is incomplete. The direction of motion must also be specified to fully describe the motion.

Difference Between Scalar and Vector Quantities

Basis of Comparison	Scalar Quantity	Vector Quantity
Definition	Quantity described completely by magnitude only	Quantity described by both magnitude and direction
Need for Direction	Direction is not required	Direction is essential
Representation	Represented by a single numerical value with unit	Represented by an arrow showing magnitude and direction
Addition Rule	Added using ordinary algebra	Added using vector laws (triangle/parallelogram law)
Can Cancel by Direction?	No directional cancellation possible	Opposite vectors can cancel each other
Examples in Mechanics	Mass, time, temperature, energy, speed	Displacement, velocity, acceleration, force, momentum
Effect of Sign	Sign indicates increase/decrease (not direction in space)	Sign indicates direction along chosen axis
Graphical Representation	Cannot be represented meaningfully as arrows	Represented by directed line segments

Exam Insight

Speed and velocity are commonly confused.

Speed → Scalar (only magnitude of motion)
Velocity → Vector (magnitude + direction of motion)

Similarly: Distance → Scalar; Displacement → Vector

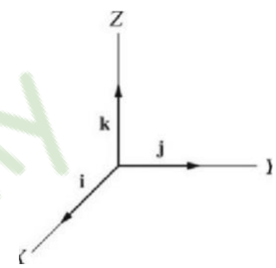
Representation of Vectors

Vectors are commonly represented using directed line segments. If a vector acts from point A to point B, it is written as **AB**. The magnitude of a vector is written using vertical bars. Example: |AB| represents the magnitude of vector AB.

Types of Vectors

Unit Vector

A unit vector is a vector having magnitude equal to one. It indicates only direction.



Unit vectors along coordinate axes are represented as:

- i → along x-axis
- j → along y-axis
- k → along z-axis

$$|\ \hat{\imath}\ |=|\ \hat{\jmath}\ |=|\ \hat{k}\ |=1$$

Unit vectors help in expressing vectors in component form.

The position vector can be expressed as,

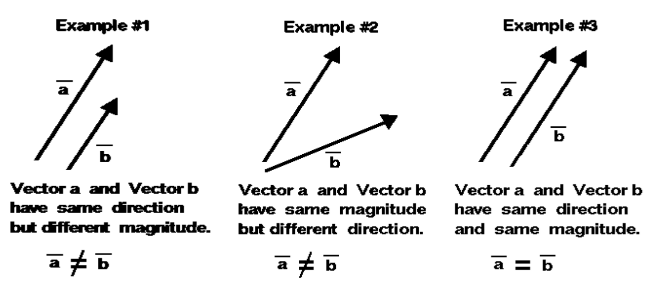
$$r = x\hat{\imath} + y\hat{\jmath} + z\hat{k}$$

Zero Vector

A zero vector has zero magnitude and no definite direction. It represents absence of vector quantity. Example: If displacement of an object is zero, it indicates that the object returns to its starting point.

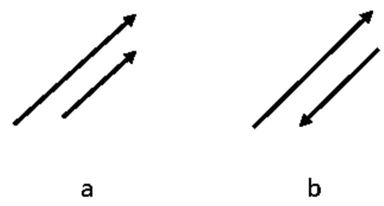
Equal Vectors

Two vectors are said to be equal if they have same magnitude and same direction, regardless of their positions.



Parallel and Anti-Parallel Vectors

- Parallel vectors act in the same direction
- Anti-parallel vectors act in opposite directions



Addition of Vectors

Vector addition is different from scalar addition because direction must be considered.

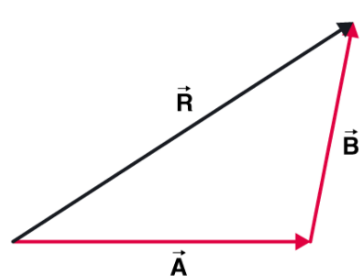
Triangle Law of Vector Addition

According to this law, if two vectors are represented in magnitude and direction by two sides of a triangle taken in order, then their resultant is represented by the third side of the triangle taken in opposite order. This law helps in determining the resultant of two vectors acting at a point.

Explanation:

- Draw vector **A**.
- From the head of **A**, draw vector **B**.
- Join the tail of **A** to the head of **B**.
- This third side represents the **resultant vector R**.

$$\mathbf{R} = \mathbf{A} + \mathbf{B}$$



Triangle law of vector addition

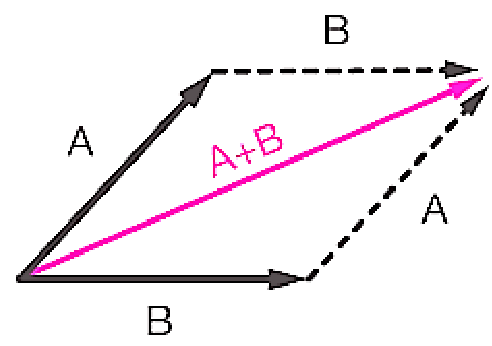
Magnitude:

$$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$$

Where θ is the angle between vectors **A** and **B**.

Parallelogram Law of Vector Addition

If two vectors acting simultaneously on a particle are represented by two adjacent sides of a parallelogram, then the diagonal passing through the common point represents the resultant vector. This method is widely used in force analysis.



1. Link vectors tail-to-tail.
2. Draw the resulting parallelogram.
3. The resultant vector, **A+B**, bisects the parallelogram as shown.

Resolution of Vectors

Resolution of vectors is the process of splitting a vector into components along chosen directions, usually along x-axis and y-axis. If a vector makes an angle θ with the horizontal axis, its components are: Horizontal component = V cos θ; Vertical component = V sin θ

Direction of Resultant

$$\tan\ \alpha = \frac{B\sin\ \theta}{A + B\cos\ \theta}$$

Where α is the angle between resultant **R** and vector **A**.

Resolution of vectors simplifies mathematical calculations in mechanics.

1.4. Position, Distance and Displacement

To describe motion, it is necessary to specify the location of an object at different times. The change in location helps in understanding how an object moves. The position of an object is described relative to a fixed reference point. The concepts of distance and displacement help in measuring motion.

Frame of Reference

A frame of reference is a fixed coordinate system or point with respect to which the position of an object is measured.

For example: When we say a car is 10 meters from a building, the building acts as the reference point.

Without a frame of reference, motion cannot be properly described because position becomes undefined.

Different observers may describe motion differently depending on their frame of reference.

Position of an Object

The position of an object specifies its location relative to a chosen reference point. Position is often represented using a position vector. The position vector gives both magnitude and direction of the object from the origin.

Example: If a particle is located 5 meters east of a point, its position is completely defined using magnitude and direction.

Distance

Distance is the total length of the path travelled by an object during motion. Distance is a scalar quantity because it depends only on magnitude and not on direction.

Properties of distance:

- Always positive
- Depends on actual path travelled
- Indicates total movement

Example:

If a person walks 3 meters forward and then 2 meters backward, total distance travelled is 5 meters.

Displacement

Displacement is the shortest straight-line distance between the initial and final positions of an object. Displacement is a vector quantity because it includes both magnitude and direction.

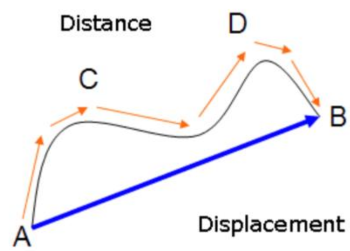
Properties of displacement:

- Can be positive, negative, or zero
- Depends only on initial and final positions
- Independent of path taken

Example: If a person walks 3 meters forward and then 2 meters backward, displacement is 1 meter in the forward direction.

Path Length and Motion

The path followed by an object determines the distance travelled, but displacement depends only on the starting and ending points. Thus, different paths may produce same displacement but different distances.



Exam Insight

If an object moves and returns to its starting point:

Distance → Non-zero
Displacement → Zero

This is a frequently asked conceptual question.

Distance vs Displacement

Basis of Comparison	Distance	Displacement
Definition	Total path travelled	Shortest distance between initial and final position
Nature	Scalar quantity	Vector quantity
Direction	Not required	Direction is required
Value	Always positive	Can be positive, negative or zero
Path Dependence	Depends on actual path	Depends only on initial and final points
Possibility of Zero	Cannot be zero if motion occurs	Can be zero even if motion occurs

Memory Tip:

Distance cares about path.
Displacement cares about start and end.

Common Error corner

Students often assume distance and displacement are always equal.

They are equal only when motion occurs in a straight line without changing direction.

1.5 Speed, Velocity and Acceleration

Motion describes how the position of an object changes with time. To understand motion clearly, three important physical quantities are used:

- Speed
- Velocity
- Acceleration

These quantities help in describing how fast an object moves, in which direction it moves, and how its motion changes with time.

Speed

- Speed is defined as the rate of change of distance with respect to time.
- Speed = Distance travelled / Time taken
- Speed is a scalar quantity because it involves only magnitude and not direction.
- Unit of speed in SI system is metre per second ($m\ s^{-1}$).

Types of Speed

Basis of Comparison	Average Speed	Instantaneous Speed
Definition	Total distance travelled divided by total time taken	Speed of an object at a particular instant of time
Formula	Average Speed = Total Distance / Total Time	Instantaneous Speed = Speed at a specific moment
Nature	Calculated over a time interval	Measured at a single instant
Example	A car travels 100 km in 2 hours → Average speed = 50 km/h	Speedometer reading at a particular moment

Velocity

- Velocity is defined as the rate of change of displacement with respect to time.
- Velocity = Displacement / Time

- Velocity is a vector quantity because it involves both magnitude and direction.
- Unit of velocity is metre per second ($m\ s^{-1}$).

Types of Velocity

Basis of Comparison	Average Velocity	Instantaneous Velocity
Definition	Total displacement divided by total time taken	Velocity of an object at a specific instant of time
Formula	Average Velocity = Total Displacement / Total Time	Instantaneous Velocity = Velocity at a particular moment
Nature	Calculated over a time interval	Measured at a single instant
Example	A car moves 100 m east in 10 s → Average velocity = 10 m/s east	Velocity shown by speedometer with direction at a particular moment

Exam Points

- If motion occurs in a straight line without change in direction: Speed = Magnitude of velocity
- If direction changes during motion: Speed ≥ Magnitude of velocity.

Common Error corner

Students often assume speed and velocity are identical. This is true only when motion is in one direction without reversal.

Acceleration

- Acceleration is defined as the rate of change of velocity with respect to time.
- Acceleration = Change in velocity / Time
- Acceleration is a vector quantity because velocity involves direction.
- Unit of acceleration is metre per second squared ($m\ s^{-2}$).

Types of Acceleration

Uniform Acceleration	Non-Uniform Acceleration	Retardation (Negative Acceleration)
Velocity changes by equal amounts in equal intervals of time	Velocity changes by unequal amounts in equal intervals of time	Acceleration acts opposite to the direction of velocity, causing reduction in speed
Example: Free fall of a body under gravity	Example: Motion of a vehicle in traffic	Example: Braking of a moving vehicle

Comparison Between Speed, Velocity and Acceleration

Basis of Comparison	Speed	Velocity	Acceleration
Definition	Rate of change of distance with time	Rate of change of displacement with time	Rate of change of velocity with time
Physical Meaning	Describes how fast an object moves	Describes how fast and in which direction an object moves	Describes how motion changes with time
Nature of Quantity	Scalar quantity	Vector quantity	Vector quantity
Direction Requirement	Not required	Required	Required
Formula	Speed = Distance / Time	Velocity = Displacement / Time	Acceleration = Change in velocity / Time
SI Unit	metre per second (m s^{-1})	metre per second (m s^{-1})	metre per second squared (m s^{-2})
Possibility of Negative Value	Always positive	Can be positive, negative or zero	Can be positive, negative or zero
Dependence on Path	Depends on actual path travelled	Depends only on initial and final position	Depends on rate of change of velocity
Relation With Each Other	Magnitude of velocity gives speed	Velocity determines acceleration	Acceleration changes velocity
Example	Car moving at 60 km/h	Car moving at 60 km/h towards east	Car increasing speed at 2 m s^{-2}

Exam Insight

If direction of motion changes while speed remains constant, acceleration is still present.

Example:

Uniform circular motion has constant speed but continuously changing velocity, so acceleration exists.

Formula Summary Table

Speed = Distance / Time
Velocity = Displacement / Time
Acceleration = Change in velocity / Time

1.6 Basic Equations of Motion

When an object moves with **uniform acceleration**, there exists a definite mathematical relationship between displacement, velocity, acceleration, and time. These relationships are called **equations of motion**. These equations help in predicting the motion of objects without analysing forces directly.

1.6.1 Conditions for Using Equations of Motion

The equations of motion are valid only when:

- Motion occurs in a straight line
- Acceleration remains constant
- Motion is uniformly accelerated

If acceleration changes continuously, these equations cannot be applied directly.

1.6.2 First Equation of Motion

This equation relates velocity, acceleration, and time.

Statement: Final velocity of a body is equal to the sum of initial velocity and product of acceleration and time.

Equation: $v = u + at$

Where: v = Final velocity, u = Initial velocity, a = Acceleration, t = Time

1.6.3 Second Equation of Motion

This equation relates displacement with velocity, time, and acceleration.

Statement: Displacement of a body is equal to initial velocity multiplied by time plus half of acceleration multiplied by square of time.

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

Where: s = Displacement, u = Initial velocity, a = Acceleration, t = Time

1.6.4 Third Equation of Motion

This equation relates velocity, displacement, and acceleration without involving time.

Statement: Square of final velocity is equal to square of initial velocity plus two times acceleration multiplied by displacement.

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

Quick Selection Trick

Choosing the correct equation depends on the given quantities.

- If **displacement (s)** is not involved → Use
  $v = u + at$
- If **final velocity (v)** is not given → Use
  $s = ut + \frac{1}{2}at^2$
- If **time (t)** is not given → Use
  $v^2 = u^2 + 2as$

1.7 Introduction to Force

Force is an external influence that can change the state of rest or motion of an object. It can also change the shape or size of an object. In everyday life, force is experienced as a push or pull acting on a body.

Meaning of Force

An object continues to remain at rest or move with constant velocity unless acted upon by an external force. Force is therefore responsible for producing or changing motion.

Force can:

- Start motion in a stationary object
- Stop a moving object
- Change the speed of an object
- Change the direction of motion
- Change the shape of an object

Force as a Vector Quantity

- Force is a vector quantity.
- The SI unit of force is **Newton (N)**.
- One Newton is defined as the force required to produce an acceleration of 1 m s^{-2} in a body of mass 1 kg.

Types of Forces

Forces are broadly classified into two categories:

Contact Forces	Non-Contact Forces
Act only when two objects are in physical contact	Act even when objects are not physically touching
Examples: Frictional force, Normal reaction force, Tension force, Muscular force	Examples: Gravitational force, Magnetic force, Electrostatic force
Depend on nature of surfaces and interaction between bodies	Act through fields and influence objects from a distance

Did you know?

Students sometimes assume forces always require physical contact. Gravitational attraction between Earth and Moon is a clear example showing force acting without contact.

Net Force

In real situations, more than one force can act on an object simultaneously. The combined effect of all forces acting on an object is called the **net force**. **If forces act in the same direction, they add together. If forces act in opposite directions, they subtract from each other.** Net force determines the overall motion of the object.

Keep a Note:

If forces acting on an object balance each other, students often assume no forces are present. This is incorrect. Balanced forces mean net force is zero, but individual forces still exist.

Example:

A book resting on a table experiences gravitational force downward and normal reaction force upward.

Force and Motion

Force and motion are closely related. Motion can change only when a net external force acts on an object. This concept forms the foundation for Newton's laws of motion, which will be studied in the next chapter.

Conversion & Calculation Tricks - Exam Shortcuts

Topic	Shortcut / Rule	Formula / Application
Speed Conversion	Convert km/h to m/s	Multiply by 5/18
	Convert m/s to km/h	Multiply by 18/5
	Example	72 km/h = 72 × (5/18) = 20 m/s
Average Velocity (Constant Acceleration)	For straight line motion with uniform acceleration	Average velocity = (Initial velocity + Final velocity) / 2
Distance in Uniform Motion	When speed is constant	Distance = Speed × Time
Velocity–Time Graph	Area under velocity–time graph	Gives Displacement
	Slope of velocity–time graph	Gives Acceleration
Distance vs Displacement	If object returns to starting point	Displacement = 0
		Distance is always positive

PRACTICE QUESTIONS

1. Which of the following is a derived quantity?

(a) Mass (b) Time
(c) Velocity (d) Temperature

2. A body moves in a circular path with constant speed. Which of the following is correct?

(a) Acceleration is zero
(b) Velocity is constant
(c) Acceleration is present
(d) Displacement is always zero

3. Match Column A with Column B.

Column A
(a) Kinematics
(b) Statics
(c) Kinetics
(d) Mechanics

Column B
(i) Study of bodies at rest
(ii) Motion considering forces
(iii) Motion without considering forces
(iv) Study of motion and forces

(a)–(iii), (b)–(i), (c)–(ii), (d)–(iv)
(a)–(ii), (b)–(iii), (c)–(i), (d)–(iv)
(a)–(iii), (b)–(iv), (c)–(ii), (d)–(i)
(a)–(iv), (b)–(iii), (c)–(ii), (d)–(i)

4. Assertion (A): Displacement can be zero even when distance is not zero. Reason (R): Displacement depends only on initial and final positions.

(a) Both A and R are true, and R is the correct explanation of A
(b) Both A and R are true, but R is not the correct explanation
(c) A is true, but R is false
(d) A is false, but R is true

5. Statement I: Speed is always greater than or equal to the magnitude of velocity. Statement II: Speed depends on total path length.

(a) Both statements are true
(b) Both statements are false
(c) Statement I is true, Statement II is false
(d) Statement I is false, Statement II is true

6. Consider the following statements:

1. **Acceleration is a scalar quantity.**
2. **Velocity can be negative.**
3. **Distance can never be negative.**
4. **If a body returns to starting point, displacement becomes zero.**
5. **Instantaneous speed can be zero even when average speed is non-zero.**
6. **Which of the following combinations is correct?**

(a) 1, 2, 3 (b) 2, 3, 4
(c) 2, 4, 5 (d) 3, 4, 5

7. If a car travels at 72 km/h, its speed in m/s is:

(a) 10 m/s (b) 15 m/s
(c) 20 m/s (d) 25 m/s

8. Which of the following has dimensions of acceleration?

(a) $[L\,T^{-1}]$ (b) $[L\,T^{-2}]$
(c) $[M\,L\,T^{-2}]$ (d) $[M\,T^{-2}]$

9. The slope of a velocity–time graph represents:

(a) Displacement (b) Speed
(c) Acceleration (d) Distance

10. If time is not given in a uniformly accelerated motion problem, which equation is most appropriate?

(a) $v = u + at$ (b) $s = ut + \frac{1}{2} at^2$
(c) $v^2 = u^2 + 2as$ (d) $s = vt$

11. Which of the following is a vector quantity?

(a) Work (b) Energy
(c) Momentum (d) Temperature

12. The SI unit of force is:

(a) Joule (b) Newton
(c) Watt (d) Pascal

13. Match Column A with Column B.

Column A
(a) Unit vector
(b) Zero vector
(c) Parallel vectors
(d) Anti-parallel vectors

Column B
(i) Vectors in opposite directions
(ii) Vector with magnitude equal to one
(iii) Vectors in same direction
(iv) Vector with zero magnitude

(a)–(ii), (b)–(iv), (c)–(iii), (d)–(i)
(a)–(iii), (b)–(ii), (c)–(iv), (d)–(i)
(a)–(ii), (b)–(iii), (c)–(i), (d)–(iv)
(a)–(iv), (b)–(ii), (c)–(iii), (d)–(i)

14. Assertion (A): Acceleration can exist even when speed is constant. Reason (R): Acceleration depends on change in direction of velocity.

(a) Both A and R are true, and R is the correct explanation of A
(b) Both A and R are true, but R is not the correct explanation
(c) A is true, but R is false
(d) A is false, but R is true

15. Statement I: Velocity can be zero even when acceleration is not zero. Statement II: Acceleration depends only on change in speed.

(a) Both statements are true
(b) Both statements are false
(c) Statement I is true, Statement II is false
(d) Statement I is false, Statement II is true

16. Consider the following statements:

1. Displacement is always less than or equal to distance.

2. Speed is always equal to magnitude of velocity.

3. Acceleration is not always in the direction of motion.

4. Distance can be zero even if motion occurs.

5. Velocity can change even if speed remains constant.

6. Which of the following combinations is correct?

(a) 1, 2, 3 (b) 1, 3, 5
(c) 1, 4, 5 (d) 2, 3, 4

17. A body starts from rest and moves with uniform acceleration. The initial velocity of the body is:

(a) Zero (b) Maximum
(c) Equal to final velocity (d) Infinite

18. Which of the following quantities has dimensions $[M L^2 T^{-2}]$?

(a) Force (b) Momentum
(c) Energy (d) Acceleration

19. The area under an acceleration–time graph represents:

(a) Displacement (b) Change in velocity
(c) Speed (d) Distance

20. When forces acting on a body are balanced, the body:

(a) Must be at rest
(b) Must move with increasing velocity
(c) Has zero net force
(d) Cannot move

21. Which of the following quantities is always positive?

(a) Velocity (b) Displacement
(c) Distance (d) Acceleration

22. The dimensional formula for momentum is:

(a) $[M L T^{-1}]$ (b) $[M L T^{-2}]$
(c) $[M L^2 T^{-2}]$ (d) $[L T^{-1}]$

23. Match Column A with Column B.

Column A
(a) Distance
(b) Velocity
(c) Acceleration
(d) Displacement

Column B
(i) Rate of change of velocity
(ii) Shortest distance between two points
(iii) Total path travelled
(iv) Rate of change of displacement

(a)–(iii), (b)–(iv), (c)–(i), (d)–(ii)
(a)–(ii), (b)–(iii), (c)–(iv), (d)–(i)
(a)–(iii), (b)–(i), (c)–(iv), (d)–(ii)
(a)–(iv), (b)–(iii), (c)–(i), (d)–(ii)

24. Assertion (A): A body moving with uniform velocity has zero acceleration. Reason (R): Velocity remains constant in magnitude and direction.

(a) Both A and R are true, and R is the correct explanation of A
(b) Both A and R are true, but R is not the correct explanation
(c) A is true, but R is false
(d) A is false, but R is true

25. Statement I: A vector quantity can be zero even if its components are non-zero. Statement II: Components of a vector depend on chosen coordinate system.

(a) Both statements are true
(b) Both statements are false
(c) Statement I is true, Statement II is false
(d) Statement I is false, Statement II is true

26. Consider the following statements:

1. Net force acting on a body can be zero when multiple forces act.

2. Scalar quantities cannot be negative.

3. Velocity and speed always have same numerical value.

4. A body moving with constant speed in a circle has acceleration.

5. Displacement depends only on final position.

6. Which of the following combinations is correct?

(a) 1, 2, 3 (b) 1, 4, 5
(c) 2, 3, 4 (d) 1, 3, 5

27. A body moving with constant velocity must have:

(a) Zero acceleration
(b) Maximum acceleration
(c) Variable displacement
(d) Increasing speed

28. Which of the following equations is dimensionally correct?

(a) $s = ut + at$ (b) $s = ut + \frac{1}{2} at^2$
(c) $s = u + at^2$ (d) $s = ut^2 + at$

29. If a vector makes an angle θ with horizontal, its horizontal component is:

(a) $V \sin\theta$ (b) $V \cos\theta$
(c) $V \tan\theta$ (d) $V \cot\theta$

30. The SI unit of acceleration is:

(a) $m\ s^{-1}$ (b) $m\ s^{-2}$
(c) $kg\ m\ s^{-1}$ (d) N m

31. Which of the following is not a vector quantity?

(a) Force (b) Momentum
(c) Work (d) Acceleration

32. The dimensional formula of force is:

(a) $[M\ L\ T^{-1}]$ (b) $[M\ L\ T^{-2}]$
(c) $[M\ L^2\ T^{-2}]$ (d) $[L\ T^{-2}]$

33. Match Column A with Column B.

Column A
(a) Uniform motion
(b) Uniform acceleration
(c) Retardation
(d) Net force

Column B
(i) Equal distances in equal intervals of time
(ii) Equal change in velocity in equal intervals of time
(iii) Combined effect of all forces
(iv) Acceleration opposite to direction of motion

(a)–(i), (b)–(ii), (c)–(iv), (d)–(iii)
(a)–(ii), (b)–(i), (c)–(iii), (d)–(iv)
(a)–(i), (b)–(iv), (c)–(ii), (d)–(iii)
(a)–(iii), (b)–(ii), (c)–(i), (d)–(iv)

34. Assertion (A): If the net force acting on a body is zero, the body may still be in motion. Reason (R): Balanced forces imply zero acceleration.

(a) Both A and R are true, and R is the correct explanation of A
(b) Both A and R are true, but R is not the correct explanation
(c) A is true, but R is false
(d) A is false, but R is true

35. Statement I: The slope of a displacement–time graph gives velocity. Statement II: The slope of a velocity–time graph gives displacement.

(a) Both statements are true
(b) Both statements are false
(c) Statement I is true, Statement II is false
(d) Statement I is false, Statement II is true

36. Consider the following statements:

1. Force is a vector quantity.

2. Acceleration is always in the direction of velocity.

3. Speed can be zero even when acceleration is non-zero.

4. A body moving with uniform velocity has zero net force.

5. Distance depends only on initial and final positions.

6. Which of the following combinations is correct?

(a) 1, 3, 4 (b) 1, 2, 5
(c) 2, 3, 4 (d) 3, 4, 5

37. If a body starts from rest and moves with uniform acceleration of 2 m s^{-2} for 5 s, its final velocity is:

(a) 5 m/s (b) 7 m/s
(c) 10 m/s (d) 15 m/s

38. Which of the following quantities has dimensions [L T^{-1}]?

(a) Acceleration (b) Momentum
(c) Velocity (d) Force

39. The area under a velocity–time graph represents:

(a) Acceleration (b) Displacement
(c) Speed (d) Force

40. When a body returns to its starting point after motion, which of the following is true?

(a) Distance is zero
(b) Displacement is zero
(c) Velocity is zero throughout motion
(d) Acceleration is zero throughout motion

41. Which of the following quantities represents the rate of change of displacement with respect to time?

(a) Speed (b) Velocity
(c) Acceleration (d) Momentum

42. The dimensional formula of energy is:

(a) [M L T^{-2}] (b) [M L^2 T^{-2}]
(c) [M L T^{-1}] (d) [L T^{-2}]

43. Match Column A with Column B.

Column A
(a) Contact force
(b) Non-contact force
(c) Unit vector
(d) Frame of reference

Column B
(i) Reference point used to describe motion
(ii) Force acting without physical contact
(iii) Vector having magnitude equal to one
(iv) Force acting through physical contact

(a)–(iv), (b)–(ii), (c)–(iii), (d)–(i)
(a)–(ii), (b)–(iv), (c)–(i), (d)–(iii)
(a)–(iv), (b)–(i), (c)–(iii), (d)–(ii)
(a)–(iii), (b)–(ii), (c)–(iv), (d)–(i)

44. Assertion (A): Acceleration can be negative.
Reason (R): Acceleration depends on direction of motion.

(a) Both A and R are true, and R is the correct explanation of A
(b) Both A and R are true, but R is not the correct explanation
(c) A is true, but R is false
(d) A is false, but R is true

45. Statement I: Velocity is zero at the highest point of vertical upward motion. Statement II: Acceleration is zero at the highest point of vertical upward motion.

(a) Both statements are true
(b) Both statements are false
(c) Statement I is true, Statement II is false
(d) Statement I is false, Statement II is true

46. Consider the following statements:

1. Force can change the direction of motion.

2. A body can have acceleration without change in speed.

3. Speed and velocity always have same direction.

4. Net force determines motion of a body.

5. Displacement can never be greater than distance.

6. Which of the following combinations is correct?

(a) 1, 2, 4 (b) 2, 3, 5
(c) 1, 3, 4 (d) 3, 4, 5

47. A body moving with uniform acceleration has initial velocity 5 m/s and acceleration 3 m s^{-2} for 4 s. Its final velocity is:

(a) 12 m/s (b) 15 m/s
(c) 17 m/s (d) 20 m/s

48. Which of the following equations is used when displacement is not involved?

(a) $v = u + at$ (b) $s = ut + ½ at^2$
(c) $v^2 = u^2 + 2as$ (d) $s = vt$

49. If a vector has components V cos θ and V sin θ, the magnitude of the vector is:

(a) V (b) V^2 (c) V/2 (d) √V

50. A body is said to be in equilibrium when:

(a) Velocity is zero
(b) Acceleration is zero
(c) Net force acting on the body is zero
(d) Displacement is zero

Answer Key

1. (c)	11. (c)	21. (c)	31. (c)	41. (b)
2. (c)	12. (b)	22. (a)	32. (b)	42. (b)
3. (a)	13. (a)	23. (a)	33. (a)	43. (a)
4. (a)	14. (a)	24. (a)	34. (a)	44. (a)
5. (a)	15. (c)	25. (d)	35. (c)	45. (c)
6. (b)	16. (b)	26. (b)	36. (a)	46. (a)
7. (c)	17. (a)	27. (a)	37. (c)	47. (c)
8. (b)	18. (c)	28. (b)	38. (c)	48. (a)
9. (c)	19. (b)	29. (b)	39. (b)	49. (a)
10. (c)	20. (c)	30. (b)	40. (b)	50. (c)

❖❖❖

CHAPTER 2

Newton's Laws of Motion

2.1 Concept of Force and Inertia

2.1.1 Introduction

In mechanics, motion of objects does not change on its own. Any change in the state of rest or motion of a body occurs due to the action of forces. Understanding the concept of force is essential because all motion-related phenomena originate from the interaction between bodies.

Before studying Newton's laws formally, it is necessary to understand what force represents, how forces act, and why objects resist changes in motion. The property responsible for resisting changes in motion is called inertia.

2.1.2 Definition of Force

Force is an interaction between two bodies that can change or tend to change the state of rest, state of motion, or shape of a body. In everyday situations, force is experienced as a push or pull acting on a body. However, in physics, force is treated as an interaction between two bodies that can modify motion or deformation.

Force can produce several observable effects:

- It can set a stationary object into motion
- It can stop a moving object
- It can change the speed of a moving object
- It can change the direction of motion
- It can change the shape or size of an object

Thus, force is fundamentally responsible for producing and modifying motion.

2.1.3 Force as a Vector Quantity

Force is a vector quantity because it possesses both magnitude and direction. When forces act on a body, both the strength of the force and the direction in which it acts must be considered. For example, two forces of equal magnitude acting in opposite directions may cancel each other, resulting in no change in motion. Therefore, force cannot be treated as a scalar quantity.

Note:

1. **Line of Action of Force -** Every force acts along a specific straight line called the **line of action** of the force. The effect of a force on a body depends on its magnitude, direction, and line of action. The concept of line of action becomes important while studying rotational motion and torque.

2. **Point of Application of Force -** The point of application of a force is the exact point on a body where the force acts. The effect produced by a force may vary depending on the point at which it is applied. The position of force application becomes important when analysing motion of rigid bodies and rotational effects.

2.1.4 SI Unit of Force

The SI unit of force is the **Newton (N).**

One Newton is defined as the force required to produce an acceleration of 1 m s^{-2} in a body of mass 1 kg.

Force is a derived physical quantity obtained from the product of mass and acceleration.

Mathematically,

$F = ma$; If, $m = 1$ kg; $a = 1$ m s^{-2},

Then, $F = 1$ Newton; The dimensional formula of force is: $[M\,L\,T^{-2}]$

Did You Know?

Besides Newton (SI unit), force is sometimes expressed in other unit systems:

- **Dyne** – CGS system
  1 dyne = 10^{-5} N
- **Kilogram-force (kgf)**
  1 kgf ≈ 9.8 N
- **Pound-force (lbf)** – British system
  1 lbf ≈ 4.45 N

2.1.5 Forces as Interactions Between Bodies

Force always arises due to interaction between two bodies. A single isolated body cannot exert force on itself.

Examples of interaction forces include:

- Gravitational attraction between Earth and objects
- Contact force between surfaces
- Magnetic force between magnets
- Tension force in a stretched string

Understanding force as interaction becomes important while studying Newton's Third Law later.

2.1.6 Classification of Forces

Forces acting on bodies can be classified based on their origin and mode of interaction.

Types of Forces Based on Origin

Type	Description
Internal Forces	Forces acting between parts of the same system. They do not change overall motion of the system.
External Forces	Forces applied on a system by external objects. They can change the position and motion of the system.

Types of Forces Based on Interaction

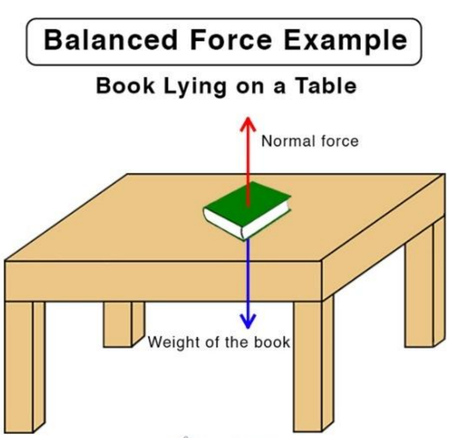
Type	Description	Examples
Contact Forces	Require physical contact between bodies	Friction, Normal reaction, Tension, Muscular force
Non-Contact Forces	Act without physical contact	Gravitational, Magnetic, Electrostatic forces

Classification Based on Result or Effect

Balanced Forces

When multiple forces act on a body and their vector sum is zero, the forces are said to be balanced.

When balanced forces act:



- A body at rest remains at rest
- A moving body continues to move with constant velocity

Balanced forces can change the shape or size of a body, but they cannot change its state of motion.

Example:
A book resting on a table experiences two forces:

- Gravitational force downward
- Normal reaction force upward

These forces balance each other.

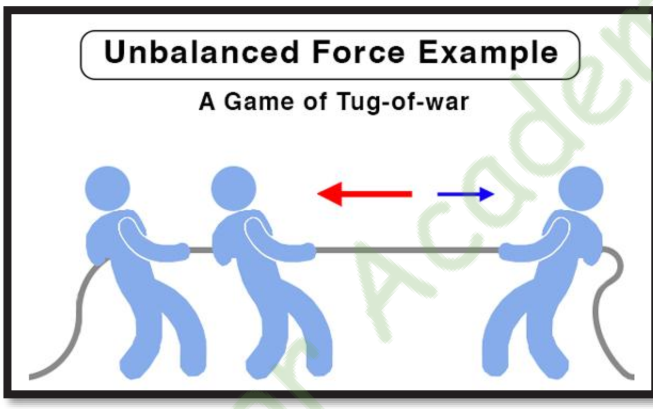
Unbalanced Forces

When forces acting on a body do not cancel each other, the net force becomes ***non-zero***. Such forces are called unbalanced forces.

Effects of unbalanced forces:

- Initiate motion
- Change speed
- Change direction
- Produce acceleration

Example: For example, in tug of war, if one team pulls harder, the rope moves toward the stronger team.



What is a Non-Zero Value?

A **non-zero value** is any number that is **not equal to zero**. It simply means that a measurable quantity is present and has some effect.

Zero (0) indicates absence or perfect cancellation of a quantity.

Non-zero indicates that the quantity exists and can influence motion or physical behavior.

Examples in Physics:

- **Non-zero force** → Can change the motion of an object
- **Non-zero velocity** → Object is moving
- **Non-zero displacement** → Object has changed its position

Important Note:

A quantity may be present but still have zero net value if multiple effects cancel each other. A non-zero value always indicates that a measurable effect remains.

2.1.7 Net Force or Resultant Force

When several forces act simultaneously on a body, their combined effect is called the net force or resultant force. The net force is obtained by vector addition of individual forces. If all forces acting on a body are balanced, net force becomes zero. If forces are unbalanced, net force produces acceleration. The concept of net force is essential for applying Newton's laws quantitatively.

Practice Problem 1

Two forces act on a box in opposite directions. One force is 12 N to the right and the other is 8 N to the left. Find the net force and state whether the forces are balanced or unbalanced.

Solution

- Net force = 12 N − 8 N = 4 N to the right, in the direction of greater force
- Since net force is not zero, the forces are **unbalanced**.
- The box will accelerate toward the right.

Practice Problem 2

Three horizontal forces act on a box. Two forces of 10 N and 6 N act toward the right, while a force of 8 N acts toward the left.

Find the net force acting on the box and state its direction.

Solution

Step 1: Identify forces acting in each direction
Forces toward right = 10 N + 6 N = 16 N
Force toward left = 8 N

Step 2: Calculate net force
Net force = 16 N − 8 N
Net force = 8 N toward the right
Since net force is non-zero, forces are unbalanced and the box will accelerate toward the right.

2.1.8 Inertia

Inertia is the property of matter that causes a body to resist any change in its state of rest or motion. Every object naturally tends to maintain its existing state unless an external force acts upon it.

Inertia explains why:

- Stationary objects do not start moving without external force
- Moving objects do not stop instantly without external influence

Inertia is a fundamental property of matter and is independent of location or environment.

Understanding Inertia Through Everyday Examples

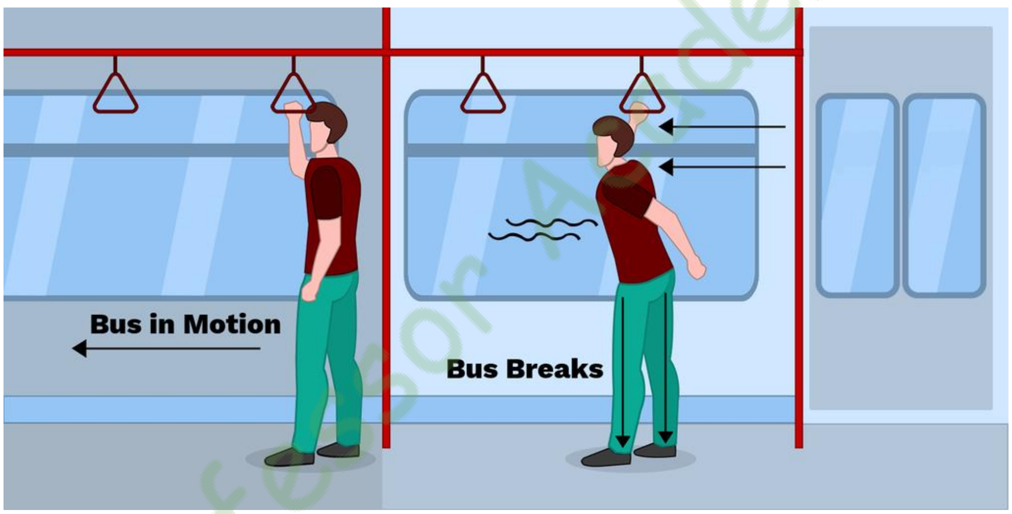
Inertia is the natural tendency of objects to resist any change in their state of rest or motion. This property can be easily observed in daily life.

Starting a Bus Suddenly

When a bus suddenly starts moving, passengers tend to fall backward. The lower part of the body moves with the bus, but the upper part tries to remain at rest. This happens due to inertia of rest.

Stopping a Moving Bus

When a moving bus stops suddenly, passengers tend to move forward. The body was in motion and tries to continue moving. This demonstrates inertia of motion.



2.1.9 Types of Inertia

Type of Inertia	Description	Everyday Examples
Inertia of Rest	Tendency of a body at rest to remain at rest unless acted upon by an external force	• Passengers fall backward when a stationary bus starts suddenly • Dust falls when a carpet is beaten • Fruits fall when tree branches are shaken • A coin remains at rest when a card placed below it is quickly pulled
Inertia of Motion	Tendency of a moving body to continue moving with constant velocity unless acted upon by an external force	• Passengers move forward when a moving bus stops suddenly • A rolling ball continues to move on a smooth surface • A person jumping from a moving vehicle falls forward • Luggage slides forward when a vehicle brakes suddenly
Inertia of Direction	Tendency of a moving body to continue moving in the same direction unless acted upon by an external force	• Passengers lean sideways when a vehicle takes a sharp turn • A stone tied to a string moves outward when the string is rotated • Water spills sideways when a bucket is rotated quickly • A cyclist tilts while turning to maintain direction balance

Note: All three types are explained by **Newton's First Law of Motion** (Law of Inertia), given by Isaac Newton.

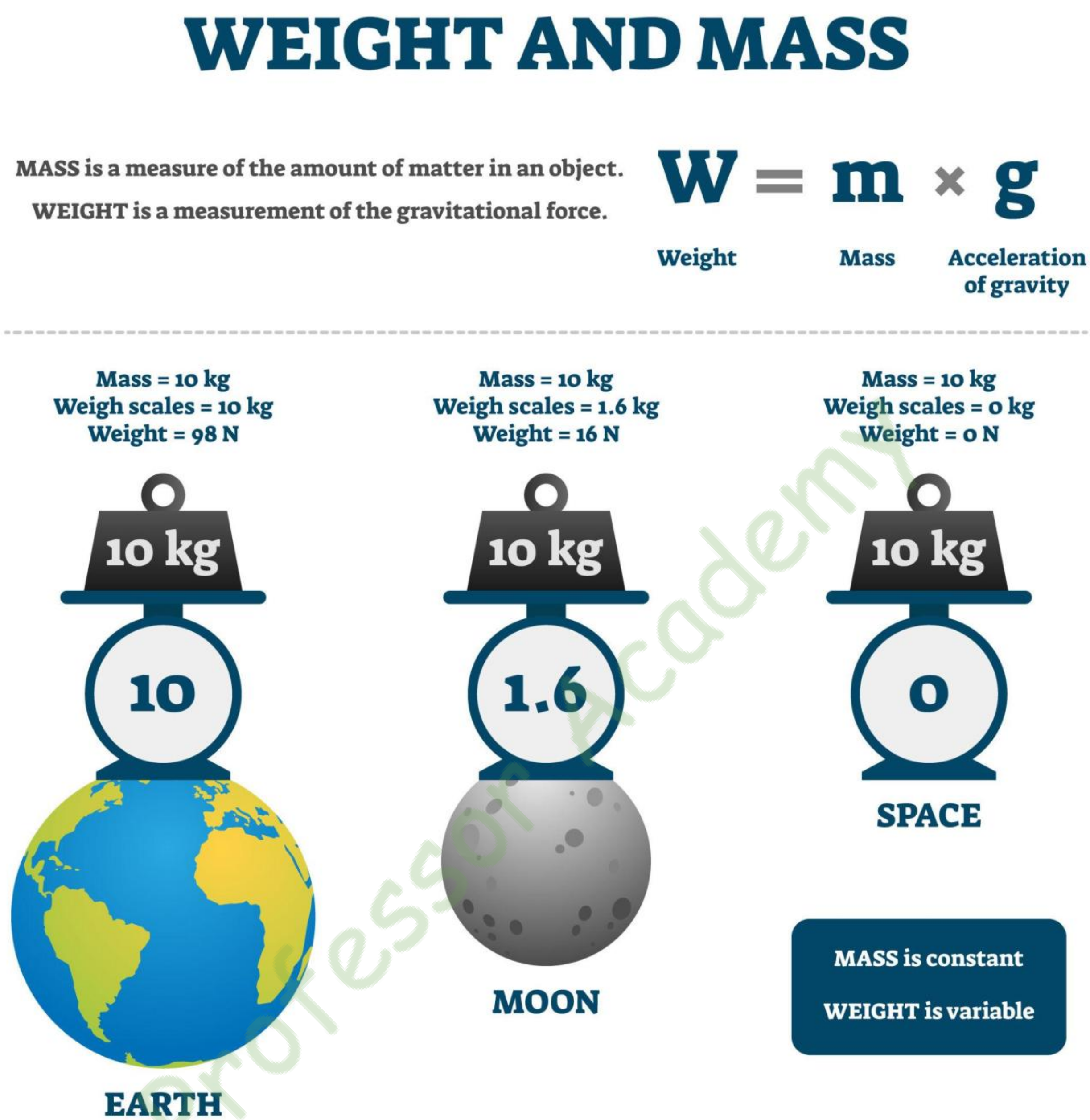
2.1.10 Mass as a Measure of Inertia

Mass of a body represents the amount of matter present in it and also serves as a measure of its inertia. Objects with greater mass offer greater resistance to change in motion. Hence, they possess greater inertia. For example: It is easier to push an empty cart than a loaded cart because the loaded cart has greater mass and therefore greater inertia.

2.1.11 Difference Between Mass and Weight

Mass and weight are often confused, but they represent different physical quantities.

Basis of Comparison	Mass	Weight
Definition	Measure of the amount of matter present in a body	The gravitational force acting on a body.
Nature	Scalar quantity (has magnitude only).	Vector quantity (has both magnitude and direction – towards the centre of Earth).
Physical Meaning	Indicates the inertia of the body (resistance to change in motion).	Indicates how strongly gravity pulls the body.
Formula	No specific formula; represented as m.	$W = mg$, where m = mass, g = acceleration due to gravity.
Dependence on Gravity	Independent of gravity	Depends on gravity (g)
Variation with Location	Remains constant everywhere (Earth, Moon, space).	Changes from place to place (less on Moon, more on Jupiter).
SI Unit	Kilogram (kg)	Newton (N)
CGS Unit	Gram (g)	Dyne
Measuring Instrument	Beam balance	Spring balance
Zero Possibility	Can never be zero (except if no matter).	Can be zero in space where gravity is absent.
Example (Moon Case)	A person of mass 60 kg remains 60 kg on Moon.	The same person weighs about 1/6th of Earth's weight on Moon.



2.1.12 Role of Force in Overcoming Inertia

Force is required to overcome inertia and produce motion or change motion.

Without external force:

- A body at rest remains at rest
- A moving body continues with uniform velocity

The relationship between force, inertia, and motion is formally described through Newton's Laws of Motion.

2.2 Newton's First Law of Motion

2.2.1 Historical Background

Before Newton, most scientists believed that continuous force was necessary to maintain motion. This idea was strongly influenced by Aristotle, who proposed that an object moves only when a force is continuously applied to it. Later, Galileo Galilei challenged this belief through experiments and logical reasoning. He observed that objects continue moving unless friction or resistance stops them. Galileo's work laid the foundation for Newton's laws of motion.

Newton combined these ideas and formally stated the First Law of Motion, which became one of the fundamental principles of classical mechanics.

2.2.2 Statement of Newton's First Law

Newton's First Law states:

Everybody continues to remain at rest or in uniform motion in a straight line unless acted upon by an external unbalanced force.

2.2.3 Explanation of the First Law

This law describes the natural behaviour of objects. It tells us that motion does not require force to continue. Instead, force is required only to change motion.

The law includes two important conditions:

Condition 1 – State of Rest

If an object is at rest, it will remain at rest unless an **external unbalanced force** acts on it.

Example: A book placed on a table remains stationary until someone applies a force to move it.

Condition 2 – State of Uniform Motion

If an object is moving, it will continue moving with constant velocity in a straight line unless an external unbalanced force acts on it.

Example: A hockey puck continues to slide on ice for a long distance because friction is very small.

2.2.4 Meaning of Uniform Motion

Uniform motion means motion with Constant speed and Constant direction If either speed or direction changes, motion is no longer uniform. Thus, circular motion is not uniform motion because direction continuously changes.

2.2.5 External Unbalanced Force

The First Law specifically mentions external unbalanced force because:

- Internal forces act within a system and cancel each other.
- External forces originate outside the system and can change motion.

Unbalanced force means that the vector sum of all forces acting on a body is not zero.

Note:

- If net force is zero: Motion remains unchanged.
- If net force is non-zero: Motion changes.

Exam insight:

- Newton's First Law is also called the **Law of Inertia** because it explains the property of inertia.
- The First Law states that inertia keeps objects in their existing state unless force acts on them.
- Thus, inertia provides the physical explanation for the First Law.

2.2.6 Inertial Frames of Reference

Newton's First Law is valid only in inertial frames of reference.

An inertial frame is a reference frame in which:

- A body at rest remains at rest
- A body in uniform motion continues to move uniformly
- Net force is required to change motion

Examples:

- Earth is approximately an inertial frame for most practical situations.
- A stationary laboratory is considered an inertial frame.

Frames that accelerate or rotate are called non-inertial frames.

2.2.7 Practical Examples of Newton's First Law

- **Seat Belt Mechanism -** When a car stops suddenly, passengers tend to move forward due to inertia of motion. Seat belts apply external force to stop passengers safely.
- **Pulling a Table Cloth -** When a table cloth is pulled quickly, objects placed on it remain nearly at rest due to inertia of rest.

- **Sliding Object on Smooth Surface -** An object slides longer on a smooth surface because friction is reduced.
- **Shaking Fruits from Tree -** When branches are shaken, fruits detach due to inertia of rest.

2.2.8 Mathematical Interpretation of the First Law

If no external unbalanced force acts on a body:

Net force = 0

According to motion principles:

Acceleration = 0
Velocity remains constant

Thus, Newton's First Law represents a special case where acceleration is zero.

2.2.9 Importance of the First Law

The First Law establishes several fundamental principles:

- Defines natural state of motion
- Introduces concept of force
- Explains inertia
- Provides foundation for Second Law
- Introduces inertial frames

It is the conceptual starting point of dynamics.

Newton's First Law states that objects resist changes in motion due to inertia. External unbalanced forces are required to produce acceleration. The law explains why objects remain at rest or continue uniform motion and introduces inertial reference frames.

Check Your Understanding
Newton's First Law

1. Newton's First Law states that a body will continue in its state of rest or uniform motion unless acted upon by:

(a) Internal force
(b) External unbalanced force
(c) Friction only
(d) Gravitational force only

2. A hockey puck slides on smooth ice for a long distance mainly because:

(a) It has large mass
(b) Friction acting on it is very small
(c) Gravity pulls it forward
(d) Air resistance increases motion

3. A body moving with constant velocity:

(a) Has constant acceleration
(b) Has zero net force acting on it
(c) Must be acted upon by continuous force
(d) Must be moving in circular path

4. Which of the following motions requires force?

(a) Maintaining uniform motion in a straight line
(b) Starting motion of a stationary object
(c) Moving with constant velocity
(d) Maintaining constant speed without changing direction

5. When a car suddenly stops, passengers move forward due to:

(a) Friction (b) Inertia of direction
(c) Inertia of motion (d) Centripetal force

6. If the net external force acting on a body is zero, the body:

(a) Must remain at rest
(b) Must move with increasing speed
(c) May remain at rest or move with constant velocity
(d) Must move in circular path

7. Newton's First Law is also known as:

(a) Law of Momentum
(b) Law of Gravitation
(c) Law of Inertia
(d) Law of Acceleration

8. Assertion (A): Force is required to maintain uniform motion of a body. Reason (R): Friction present in everyday life opposes motion.

(a) Both A and R are true, and R explains A
(b) Both A and R are true, but R does not explain A
(c) A is false, but R is true
(d) Both A and R are false

Answer Key – Newton's First Law

Q1 – Answer: (b) External unbalanced force

• Newton's First Law states that motion changes only when external unbalanced force acts
• Internal forces cancel each other
• Friction and gravity are specific forces, not general conditions
• External unbalanced force produces change in motion

Q2 – Answer: (b) Friction acting on it is very small

• Friction is an external force that opposes motion
• On smooth ice, friction is very low
• Therefore, puck continues moving for longer distance
• This demonstrates Newton's First Law

Q3 – Answer: (b) Has zero net force acting on it

• Constant velocity means speed and direction are constant
• No change in velocity means acceleration = 0
• According to motion principles, zero acceleration implies zero net force
• Continuous force is not required to maintain uniform motion

Q4 – Answer: (b) Starting motion of a stationary object

• Force is required to change state of motion
• Maintaining uniform motion does not require force
• Starting motion changes velocity from zero to non-zero
• Therefore, external force is required

Q5 – Answer: (c) Inertia of motion

• Passengers were moving with car before stopping
• When car stops suddenly, body tends to continue motion
• This tendency is inertia of motion
• Seat belts apply force to stop passengers safely

Q6 – Answer: (c) May remain at rest or move with constant velocity

• Net force zero means acceleration zero
• Object may remain stationary
• Object may also move with constant velocity
• This is direct consequence of Newton's First Law

Q7 – Answer: (c) Law of Inertia

• First Law explains resistance to change in motion
• This resistance property is called inertia
• Therefore, First Law is also known as Law of Inertia

Q8 – Answer: (c) A is false, but R is true

Assertion Analysis:
• Force is NOT required to maintain uniform motion
• Therefore assertion is incorrect

Reason Analysis:
• Friction opposes motion in everyday situations
• Friction creates illusion that continuous force is needed
• Therefore reason is correct

2.3 Newton's Second Law of Motion

2.3.1 Need for the Second Law

Newton's First Law tells us that motion changes only when an external unbalanced force acts on a body. However, it does not explain:

- How much motion changes
- How force affects acceleration
- Why heavier bodies accelerate differently from lighter ones

To answer these questions quantitatively, Newton proposed his Second Law of Motion.

2.3.2 Statement of Newton's Second Law

Newton's Second Law states:

The rate of change of momentum of a body is directly proportional to the external force applied and takes place in the direction of the force.

2.3.3 Concept of Momentum

Before understanding the Second Law fully, we must define momentum.

- Momentum is the quantity of motion possessed by a body and is defined as:
- Momentum (p) = Mass × Velocity; $p = mv$
- Where: m = mass of the body and v = velocity of the body
- Momentum is a vector quantity because velocity has direction.
- The SI unit of momentum is **kilogram metre per second ($kg\ m\ s^{-1}$)**.

2.3.4 Understanding "Rate of Change of Momentum"

The rate of change of momentum means how quickly momentum changes with respect to time.

- If momentum changes from p_1 to p_2 in time t,
- Rate of change of momentum = $(p_2 - p_1) / t$
- According to Newton's Second Law: Force ∝ Rate of change of momentum

2.3.5 Mathematical Derivation for Constant Mass

Let mass of the body (m) be constant.

Initial velocity = u, Final velocity = v, Time taken = t, Initial momentum = mu, Final momentum = mv