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# 1

## CHAPTER

# Measurement and Units



### Physical Quantities

- Physical quantities are those that can be defined and measured.
- **Examples:** Length, Force, Temperature, etc.
- A physical quantity consists of a **numerical value** and a **unit**.

### Types of Physical Quantities:

- **Fundamental Quantities:** Independent basic quantities; there are 7 types:
  - ✓ Mass, Temperature, Length, Time, Electric Current, Amount of Substance, Luminous Intensity
- **Derived Quantities:** Quantities derived from fundamental quantities.
  - ✓ **Examples:** Momentum, Volume, Force, etc.
- **Supplementary Quantities:** Neither fundamental nor derived.
  - ✓ **Examples:** Plane Angle, Solid Angle

### Classification based on Direction:

- **Scalar Quantities:** Quantities having only magnitude, no direction.
  - ✓ **Examples:** Distance, Energy, Speed, Power, Mass
- **Vector Quantities:** Quantities having both magnitude and direction.
  - ✓ **Examples:** Displacement, Velocity, Force, Weight, Momentum

### System of Units:

- The complete set of fundamental and derived units is called a **system of units**.

Physical Quantity	MKS System	CGS System	FPS System
Length	Metre (m)	Centimetre (cm)	Foot (ft)
Mass	Kilogram (kg)	Gram (g)	Pound (lb)
Time	Second (s)	Second (s)	Second (s)

### SI System:

- The currently accepted international system of measurement is the “**Système International d’Unités**” (**International System of Units**), abbreviated as **SI**.
- This system was developed by the **International Bureau of Weights and Measures (BIPM)** in 1971.

### Measurement:

- Measurement is the process of determining the value of a physical quantity by comparing it with a known standard.
- It involves:
  - ✓ A numerical value
  - ✓ A measurement unit



### Units:

- Units are standardized measures used to express physical quantities.

### Types of Units:

- **Fundamental Units:** Used for fundamental quantities.
  - Examples:** Meter (m), Kilogram (kg), Second (s), Ampere (A)
- **Derived Units:** Expressed as combinations of fundamental units.
- **Supplementary Units:** Used for specific purposes; not part of fundamental or derived units.
  - ✓ **Plane Angle:** Ratio of arc length (ds) to radius (r), measured in **radians (rad)**  
Formula: Plane Angle = Arc / Radius
  - ✓ **Solid Angle:** Ratio of surface area (dA) to square of radius (r<sup>2</sup>), measured in **steradians (sr)**



## Fundamental Units of the SI System

S. No.	Physical Quantity	Symbol	Dimension	SI Unit	Important Practical Units
1	Length	L	[L]	Metre (m)	1 fermi = $10^{-15}$ m 1 Å (angstrom) = $10^{-10}$ m 1 nm = $10^{-9}$ m 1 µm = $10^{-6}$ m 1 mm = $10^{-3}$ m 1 cm = $10^{-2}$ m 1 inch = 2.54 cm 1 foot = 0.3048 m 1 km = $10^3$ m 1 mile = 1.6 km 1 nautical mile = 1852 m 1 AU = $1.5 \times 10^{11}$ m 1 light year $\approx 9.46 \times 10^{15}$ m 1 parsec $\approx 3.083 \times 10^{16}$ m
2	Mass	M	[M]	Kilogram (kg)	1 µg = $10^{-9}$ kg 1 mg = $10^{-6}$ kg 1 g = $10^{-3}$ kg 1 quintal = $10^2$ kg 1 metric ton = $10^3$ kg 1 amu = $1.66 \times 10^{-27}$ kg 1 pound = 0.4537 kg 1 slug = 14.59 kg Chandrasekhar limit $\approx 2.8 \times 10^{30}$ kg
3	Time	T	[T]	Second (s)	1 ps = $10^{-12}$ s 1 ns = $10^{-9}$ s 1 µs = $10^{-6}$ s 1 ms = $10^{-3}$ s 1 min = 60 s 1 hour = 3600 s 1 day = 86400 s 1 week = 7 days 1 month = 28–31 days 1 year = 365.25 days 1 shake = $10^{-8}$ s
4	Electric Current	I	[I]	Ampere (A)	—
5	Temperature	Θ	[Θ]	Kelvin (K)	—
6	Amount of Substance	N	[N]	Mole (mol)	—
7	Luminous Intensity	J	[J]	Candela (cd)	1 nit = 1 cd/m <sup>2</sup>

## Derived Units

S. No.	Physical Quantity	Formula / Derivation	SI Unit	Dimensions	Notes
1	Area	Length × Breadth	m <sup>2</sup>	[M <sup>0</sup> L <sup>2</sup> T <sup>0</sup> ]	1 barn = $10^{-28}$ m <sup>2</sup> 1 hectare = $10^4$ m <sup>2</sup>

2	Volume	Length × Breadth × Height	m <sup>3</sup>	[M <sup>0</sup> L <sup>3</sup> T <sup>0</sup> ]	1 litre = 10 <sup>-3</sup> m <sup>3</sup> 1 gallon = 4.546 L
3	Velocity	Displacement / Time	m/s	[M <sup>0</sup> LT <sup>-1</sup> ]	—
4	Acceleration	Change in velocity / Time	m/s <sup>2</sup>	[M <sup>0</sup> LT <sup>-2</sup> ]	—
5	Momentum	Mass × Velocity	kg·m/s	[MLT <sup>-1</sup> ]	—
6	Force	Mass × Acceleration	Newton (N)	[MLT <sup>-2</sup> ]	1 N = kg·m/s <sup>2</sup> 1 dyne = 10 <sup>-5</sup> N
7	Impulse	Force × Time	N·s	[MLT <sup>-1</sup> ]	—
8	Work / Energy	Force × Distance	Joule (J)	[ML <sup>2</sup> T <sup>-2</sup> ]	1 J = kg·m <sup>2</sup> /s <sup>2</sup> 1 cal = 4.184 J 1 erg = 10 <sup>-7</sup> J 1 kWh = 3.6 × 10 <sup>6</sup> J 1 eV = 1.6 × 10 <sup>-19</sup> J
9	Power	Work / Time	Watt (W)	[ML <sup>2</sup> T <sup>-3</sup> ]	1 HP = 746 W
10	Pressure	Force / Area	Pascal (Pa)	[ML <sup>-1</sup> T <sup>-2</sup> ]	1 Pa = N/m <sup>2</sup> 1 bar = 10 <sup>5</sup> Pa 1 torr = 133.32 Pa 1 atm = 1.01 × 10 <sup>5</sup> Pa
11	Density	Mass / Volume	kg/m <sup>3</sup>	[ML <sup>-3</sup> T <sup>0</sup> ]	—
12	Frequency	Repetitions per second	Hertz (Hz)	[T <sup>-1</sup> ]	1 Hz = 1/s
13	Electric Charge	Current × Time	Coulomb (C)	[IT]	1 C = A·s
14	Potential Difference	V = kQ/r	Volt (V)	[ML <sup>2</sup> T <sup>-3</sup> I <sup>-1</sup> ]	1 V = kg·m <sup>2</sup> /(A·s <sup>3</sup> )
15	Resistance	Potential Difference / Current	Ohm (Ω)	[ML <sup>2</sup> T <sup>-3</sup> I <sup>-2</sup> ]	1 Ω = kg·m <sup>2</sup> /(A <sup>2</sup> ·s <sup>3</sup> )
16	Capacitance	Charge / Potential Difference	Farad (F)	[M <sup>-1</sup> L <sup>-2</sup> T <sup>4</sup> I <sup>2</sup> ]	1 F = s <sup>4</sup> ·A <sup>2</sup> /(kg·m <sup>2</sup> )
17	Magnetic Flux	Magnetic Field × Area	Weber (Wb)	[ML <sup>2</sup> T <sup>-2</sup> I <sup>-1</sup> ]	1 Wb = kg·m <sup>2</sup> /(s <sup>2</sup> ·A)
18	Inductance	—	Henry (H)	[ML <sup>2</sup> T <sup>-2</sup> I <sup>-2</sup> ]	1 H = kg·m <sup>2</sup> /(s <sup>2</sup> ·A <sup>2</sup> )
19	Focal Length	—	Metre (m)	[M <sup>0</sup> L <sup>1</sup> T <sup>0</sup> ]	—

### Did You Know?

- **Intensity of light:** Lux
- **Intensity of sound:** Decibel
- **Magnetic field intensity:** Oersted
- **Amount of radiation:** Curie

Powers of 10					
Prefix	Symbol	10 की घात	Prefix	Symbol	Powers of 10
Yotta	Y	10 <sup>24</sup>	Yocto	y	10 <sup>-24</sup>
Zetta	Z	10 <sup>21</sup>	Zepto	z	10 <sup>-21</sup>

Exa	E	$10^{18}$	Atto	a	$10^{-18}$
Peta	P	$10^{15}$	Femto	f	$10^{-15}$
Tera	T	$10^{12}$	Pico	p	$10^{-12}$
Giga	G	$10^9$	Nano	n	$10^{-9}$
Mega	M	$10^6$	Micro	$\mu$	$10^{-6}$
Kilo	k	$10^3$	Mili	m	$10^{-3}$
Hecto	h	$10^2$	Centi	c	$10^{-2}$
Deca	da	$10^1$	Deci	d	$10^{-1}$



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# 2

## CHAPTER

# Motion



### Rest:

- If an object **does not change its position** with respect to its surroundings over time, it is said to be at **rest**.
- **Example:** A book kept on a table is considered at rest relative to the table.

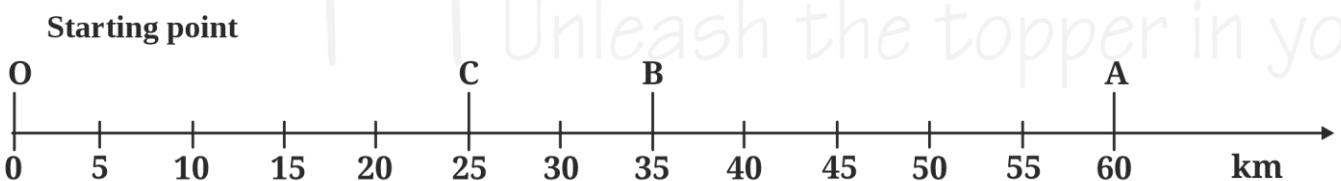
### Motion:

- When an object **continually changes its position** with respect to time, it is said to be in **motion**.
- **Example:** A bird flying in the sky.

### Types of Motion of a Body:

- **Rectilinear Motion:** Motion along a straight line.  
**Example:** A car moving straight on a road; an airplane flying straight in the sky.
- **Curvilinear Motion:** Motion along a curved path.  
**Example:** A roller coaster moving on a track.
- **Rotational Motion:** Motion of a body around a fixed axis or point.

### General Definitions Related to Motion:



Positions of a Moving Object on a Straight Linear Path

### Distance:

- The **actual length** traveled by an object in a given time interval is called **distance**.
- **Unit:** meter (m)
- **Nature:** scalar quantity
- **Instrument:** Odometer is used to measure distance

### Displacement:

- The **shortest distance** between the initial and final position of an object is called **displacement**.

**Example:** A spinning top; a wheel rotating on an axle.

- **Circular Motion:** Motion along a circular path.

**Example:** Earth revolving around the Sun.

- **Oscillatory Motion:** Motion of a body **back and forth around a fixed point**.

**Example:** A swinging pendulum; vibration of a guitar string.

- **Periodic Motion:** Oscillatory motion that **repeats at regular intervals**.

**Example:** Hands of a clock moving in circular motion.

### Classification Based on Number of Directions (Dimensions) in Motion:

1. **One-Dimensional Motion:** Position changes along **only one direction**.
2. **Two-Dimensional Motion:** Position changes along **two directions**.
3. **Three-Dimensional Motion:** Position changes along **three directions**.

- **Unit:** meter (m)
- **Nature:** vector quantity
- Displacement can be **positive, negative, or zero**

### Speed:

- The distance covered by an object per unit time is called **speed**.

$$\text{Speed} = \frac{\text{Total distance}}{\text{Total time}}$$

- **Unit:** meter per second (m/s)
- **Nature:** scalar quantity
- Speed can **never be zero**

**Question:** If a man covers a certain distance at a speed of 5 km/h in 36 minutes, what is the distance he covers?

**Solution:**

**Speed:** 5 km/h

**Time:** 36 minutes = 36/60 = 0.6 hours

**Distance:** Speed  $\times$  Time = 5  $\times$  0.6 = **3 km**

### Velocity:

- Velocity of an object is the displacement done in a unit time in a specific direction.

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

- **Unit:** meter per second (m/s)
- **Nature:** Vector quantity
- Velocity can be positive, negative, or zero

### Types of velocity:

- **Uniform velocity:** Equal displacement in equal time intervals
- **Non-uniform velocity:** Unequal displacement in equal time intervals
- **Average velocity:**

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

- **Instantaneous velocity:** Displacement at a particular instant of time

### Acceleration:

- Rate of change of velocity with time is called acceleration.

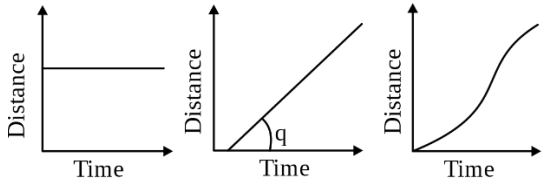
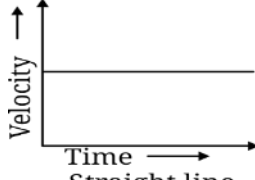
$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time}}$$

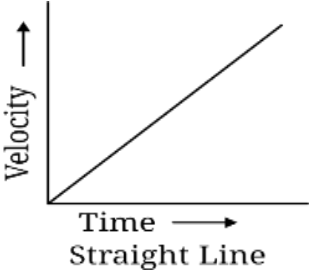
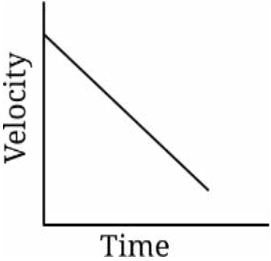
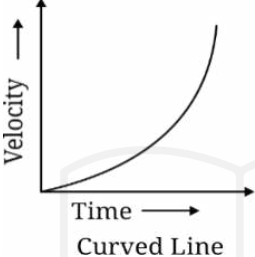
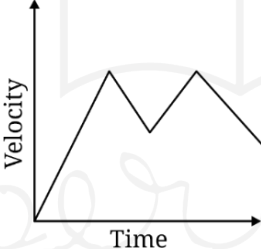

- **Unit:** meter per second squared (m/s<sup>2</sup>)
- **Nature:** Vector quantity
- Value can be zero, positive, or negative
- **Negative acceleration** is called **retardation**, and its direction is opposite to velocity

### Types of acceleration:

- **Uniform acceleration:** Velocity changes by equal amounts in equal intervals of time; acceleration is constant
  - **Non-uniform acceleration:** Velocity changes irregularly (e.g., car in traffic)
  - **Average acceleration:**
- $$\text{Average acceleration} = \frac{\text{Total change in velocity}}{\text{Total time}}$$
- **Instantaneous acceleration:** Acceleration at a specific instant of time.

### Graphical Representation of Motion:

S. No	State of Motion	Type of Graph	Graphical Representation	Main Feature
1	Object at rest	Displacement–Time graph	Straight line parallel to the time axis	Displacement constant; velocity = 0
2	Uniform motion	Displacement–Time graph	Straight line making an angle with the time axis	Constant slope $\Rightarrow$ uniform velocity
3	Non-uniform motion / Acceleration	Displacement–Time graph	Curved line  When the object is at rest    When the object is in uniform motion    When the object is in non-uniform motion	Slope changes continuously
4	Uniform velocity	Velocity–Time graph	Horizontal straight line  Straight line parallel to x-axis	Velocity constant

5	Positive uniform acceleration	Velocity–Time graph	Straight line sloping upward 	Velocity increases uniformly
6	Negative uniform acceleration	Velocity–Time graph	Straight line sloping downward 	Velocity decreases uniformly
7	Non-uniform velocity	Velocity–Time graph	Curved line 	Velocity varies irregularly
8	Non-uniform acceleration	Velocity–Time graph	Zig-zag line  	Acceleration varies irregularly

### Equations of Motion:

- Equations of motion describe the relationship between **displacement, initial velocity, final velocity, acceleration**, and time for an object moving with **uniform acceleration**.

### For uniform acceleration:

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

$$3. \quad 2as = v^2 - u^2$$

Where:  $u$  =initial velocity     $v$  =final velocity  
 $s$  =displacement             $t$  =time  
 $a$  =acceleration

### Under gravity (g) as acceleration:

- $v = u + gt$
- $s = ut + \frac{1}{2}gt^2$
- $2gs = v^2 - u^2$

**Question:** A bus is moving on a straight road at **10 km/h** and increases its speed to **70 km/h** in **2 minutes**. What is the **average acceleration** of the bus?

**Solution:**

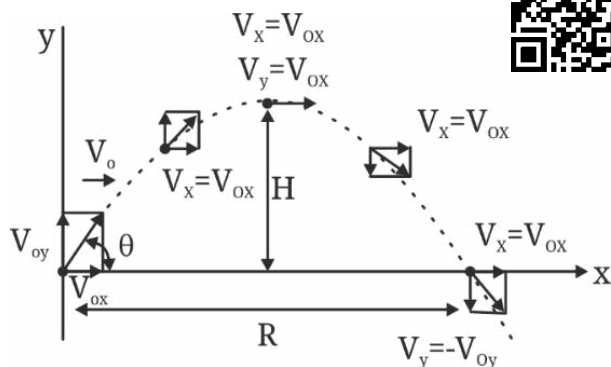
$$\text{Average acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}} = \frac{70 - 10}{2 \text{ min}} = \frac{60}{2} = 30 \text{ km/h per minute}$$

Converting units:

$$30 \text{ km/h per min} = 0.5 \text{ km/min}^2$$

**Answer:** 0.5 km/min<sup>2</sup>

## Projectile Motion:



- When an object is thrown at an angle under the influence of **gravity** and follows a **curved path** in the atmosphere, it is called **projectile motion**.
- **Example:** A stone thrown at an angle follows a curved path before landing.

### Projectile Motion Terminology:

- **Trajectory:** The path followed by the projectile, which is **parabolic**.
- **Angle of projection ( $\theta$ ):** The initial angle formed with the horizontal at which the object is thrown.
- **Time of flight (T):** The time taken by the projectile to return to its initial height.

$$T = \frac{2u \sin \theta}{g}$$

where  $u$  = initial velocity,  $g$  = acceleration due to gravity ( $9.8 \text{ m/s}^2$ )

- **Horizontal range (R):** Maximum horizontal distance covered by the projectile.

$$R = \frac{u^2 \sin 2\theta}{g}$$

- **Maximum height (H):** The highest vertical position reached by the projectile.

$$H = \frac{u^2 \sin^2 \theta}{2g}$$

**Question:** Which of the following equations of motion is correct?

I.  $v = \frac{u}{2} + at$

II.  $s = 2ut + at^2$

- (A) Only I  
 (B) Neither I nor II  
 (C) Only II  
 (D) Both I and II

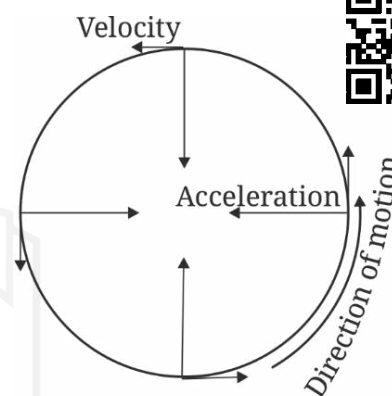
**Answer:** (B) Neither I nor II

**Explanation:** The correct first equation of motion is  $v = u + at$ , not  $v = \frac{u}{2} + at$ , so statement I is incorrect.

The correct displacement equation is  $s = ut + \frac{1}{2}at^2$ , not  $s = 2ut + at^2$ , so statement II is also incorrect.

## Circular Motion:

- When an object moves along the circumference of a circle or a circular path, it is called **circular motion**. The velocity of an object moving along a circular path is called **instantaneous velocity**, as its direction continuously changes.

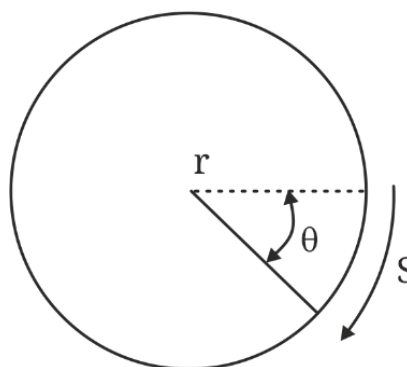


### Types of Circular Motion:

- **Uniform Circular Motion:** The object moves along a circular path with **constant speed**. Although the speed is constant, the direction continuously changes, so the **velocity changes**.
- **Non-Uniform Circular Motion:** The object moves along a circular path with **changing speed**. Both **speed and direction change**, so velocity and acceleration vary.

**Example:** A car turning along a curved road exhibits circular motion with changing direction.

### Key Terms Related to Circular Motion:



S. No.	Physical Quantity	Definition	Formula	SI Unit
1	Time Period (T)	Time taken by a particle to complete one full revolution on a circular path.	—	Second (s)
2	Frequency (n)	Number of revolutions completed per second on a circular path.	$n = 1/T$	Hertz (Hz)
3	Angular Displacement ( $\theta$ )	Angle subtended at the center of a circle by the radius vector.	$\theta = \text{Arc} / \text{Radius}$	Radian (rad)
4	Angular Velocity ( $\omega$ )	Rate of change of angular displacement with time.	$\omega = \theta / t$	rad/s
5	Angular Acceleration ( $\alpha$ )	Rate of change of angular velocity with time.	$\alpha = \omega / t$	rad/s <sup>2</sup>
6	Centripetal Acceleration	Acceleration of a body moving in a circular path directed toward the center.	$a = v^2 / r$	m/s <sup>2</sup>



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# 3

## CHAPTER

# Force and Motion



### Force:

- When an object is **pulled** or **pushed**, causing a change in its **position, shape, or motion**, the action is called a **force**.
- It is the result of an **external influence**, which can move a stationary object or stop a moving object.
- **Conservative force:** The work done by a conservative force does **not depend on the path**, only on the initial and final positions.

- Force has both **magnitude and direction**, so it is a **vector quantity**.
- **SI unit:** Newton (N), **CGS unit:** dyne.
- The force on an object is calculated using **Newton's second law of motion:**  

$$\text{Force} = \text{Mass} \times \text{Acceleration} = ma$$
  - ✓ **1 Newton (N) = 1 kg·m/s<sup>2</sup>**
  - ✓ **1 Newton (N) = 10<sup>5</sup> dyne**

### Types of Force:

Type of Force	What It Is	Simple Example
<b>Contact Force</b>	Force produced due to direct physical contact between two objects.	Pushing or pulling an object
<b>Muscular Force</b>	Force generated by the action of muscles.	Lifting a box, pushing a door
<b>Frictional Force</b>	Force that opposes motion when two surfaces are in contact.	A sliding book coming to rest
<b>Non-Contact Force</b>	Force acting between objects without direct physical contact.	Earth pulling an object
<b>Gravitational Force</b>	Force by which the Earth attracts objects toward itself; a type of attractive force.	Falling of an apple
<b>Electrostatic Force</b>	Force between two charged particles or objects.	A balloon sticking to a wall
<b>Magnetic Force</b>	Force between two magnets or moving electric charges.	Attraction between magnets
<b>Nuclear Force</b>	Force that binds protons and neutrons inside the atomic nucleus.	Binding of proton and neutron in the nucleus
<b>Balanced Force</b>	When equal forces act on an object in opposite directions, resulting in zero net force and no change in motion.	Equal push from both sides
<b>Unbalanced Force</b>	When forces acting on an object are unequal, causing a change in motion.	Kicking a ball

### Inertia:

- The property of an object due to which it **resists changes** in its **state of rest** or **uniform motion** is called **inertia**.



### Types of Inertia:

1. **Inertia of Rest:** The property of an object to **resist changes** in its **state of rest**.
2. **Inertia of Motion:** The property of an object to **resist changes** in its **uniform motion**.

3. **Inertia of Direction:** The property of an object to **resist changes** in the **direction of its motion**.

#### Did you know?

##### Relationship between Inertia and Mass:

- The **inertia** of an object **depends on its mass**.
- Inertia is **directly proportional to mass**, i.e., if the mass increases, the inertia also increases, and vice versa.

## Newton's Laws of Motion:

### Newton's First Law of Motion:

- If an object is at rest, it will remain at rest, and if it is moving with uniform velocity, it will continue to move in the same velocity and direction **unless acted upon by an external force**.
- This is also called the **Law of Inertia** or **Galileo's Law**.
- This law helps in **defining force**.  
**Example:** When a tree is shaken, the branches move, but the fruits remain at rest due to inertia and fall down.

### Momentum:

- The effect of an object's motion depends on its **mass** and **velocity**. This is called **momentum**.

$$p = m \times v$$

Where:  $m$  = mass,  $v$  = velocity

- Momentum is a **vector quantity**, SI unit: **kg·m/s**

### Types of Momentum:

- **Linear Momentum:** For an object moving in a straight line, the product of mass and linear velocity is called linear momentum. The greater the mass and velocity, the higher the momentum.
- **Angular Momentum:** Momentum of an object in rotational or circular motion; depends on mass, velocity, and distance from the **axis**.  
**Example:** Rotating wheel, motion of planets.

### Law of Conservation of Linear Momentum:

- According to this law, if no **external force** acts on a system of two or more objects, the **total linear momentum of the system remains constant**. The change in momentum of one object is **equal and opposite** to the change in another.
- Devices based on this principle: **rocket propulsion, Bunsen burner, fire extinguisher, recoil of a cannon**.

### Collision of Two Bodies:

- When **two bodies collide**, the total momentum before and after the collision is conserved.

- Example: If **two balls with equal momentum** collide head-on, they may come to rest momentarily because the **total momentum before collision equals the total momentum after collision**, which can be zero.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Where:

$m_1, m_2$  = masses of the two bodies

$u_1, u_2$  = initial velocities

$v_1, v_2$  = final velocities

**Question:** A ball has a momentum of 3000 units. If the velocity of the ball is doubled, what will be its new momentum?

**Solution:** With constant mass, doubling the velocity **doubles the momentum**.

$$\text{New momentum} = 2 \times 3000 = 6000 \text{ units}$$

### Newton's Second Law of Motion:

- According to this law, "The rate of change of momentum of an object is directly proportional to the applied force, and the force acts in the direction of the momentum change."

Mathematical form:

$$F \propto \frac{\Delta p}{\Delta t} \Rightarrow F = ma$$

Where:  $F$  = force,  $m$  = mass,  $a$  = acceleration

- Force is calculated using Newton's second law:  $F = m \times a$

Example: Table tennis – When a player hits the ball, it does not hurt the hand because both mass and velocity of the ball are small, resulting in small acceleration and force.

### Impulse:

- If a force acts on an object for a short time, the product of force and time interval is called **impulse** or the change in momentum.

$$I = F\Delta t$$

Where:  $I$  = impulse,  $F$  = applied force,  $\Delta t$  = duration of force

### Relation between impulse and momentum:

$$\text{Impulse} = \text{Change in momentum} \Rightarrow I = \Delta p = m(v - u)$$

## Characteristics of impulse:

- Vector quantity
  - ✓ SI unit: Newton-second (N·s)
  - ✓ For the same force:
    - Shorter time  $\Rightarrow$  smaller impulse
    - Longer time  $\Rightarrow$  larger impulse

Examples:

- Stopping a ball slowly increases time  $\rightarrow$  smaller force  $\rightarrow$  no injury to hand.
- Train buffers absorb shocks during shunting  $\rightarrow$  increase collision time  $\rightarrow$  reduce force  $\rightarrow$  prevent damage.

**Problem:** A 10 kg object is acted upon by a constant force for 2 seconds. Its velocity increases from 5 m/s to 10 m/s. Find the magnitude of the force. If the same force is applied for 5 seconds, what will be the final velocity?

**Solution:**

Acceleration:

$$a = \frac{v - u}{t} = \frac{10 - 5}{2} = 2.5 \text{ m/s}^2$$

Force using Newton's second law:

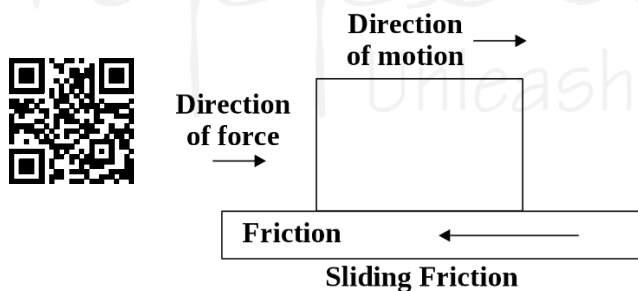
$$F = ma = 10 \times 2.5 = 25 \text{ N}$$

Final velocity if applied for 5 s:

$$v = u + at = 5 + (2.5 \times 5) = 17.5 \text{ m/s}$$

## Newton's Third Law of Motion:

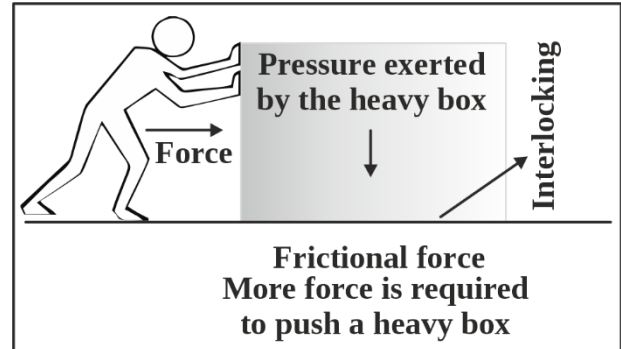
- "For every action, there is an equal and opposite reaction."
- Also called *action-reaction law*.



- Example: A rocket moves forward due to the reaction of fast exhaust gases.

## **Friction:**

- Friction is the force that resists relative motion when an object slides, rolls, or attempts to move over another surface. The direction of friction is always opposite to the relative motion.

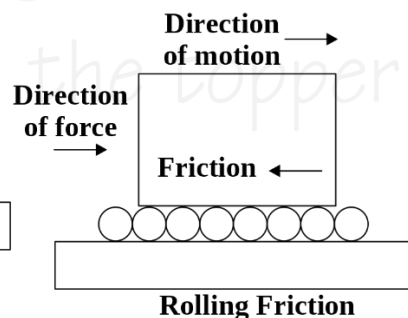


## **Examples:**

- Walking – friction between shoes and ground helps movement.

## **Types of Friction:**

1. **Static friction:** Acts when two surfaces are in contact but not moving relative to each other. Increases until motion starts. Also called self-adjusting force.
2. **Limiting friction:** Maximum value of static friction, just before motion starts; depends on surface nature, not contact area.
3. **Kinetic friction:** When an object slides over a surface.
  - a. **Sliding friction:** Object slides.
  - b. **Rolling friction:** Object rolls.



4. **Fluid friction:** Occurs when an object moves through a fluid like water or air. Depends on fluid density.
  - **Ways to reduce friction:** Polishing surfaces, Using lubricants, Employing ball bearings, Using friction-reducing materials

## **Fluid Friction:**

- Fluid friction occurs when an object moves through a fluid like water or air, and it depends on the fluid's density.

- **Ways to reduce friction:** Polishing, using lubricants, employing ball bearings, and using friction-reducing materials.

## Centripetal and Centrifugal Force

### Centripetal Force:

- When a particle moves along the circumference of a circle, its speed remains constant but its direction changes continuously. This requires a force directed toward the center of the circle, called **centripetal force**.

- **Note:** This force always acts toward the center of the circle.
- **Examples:**
  - ✓ Swinging a stone tied to a rope – the rope provides the centripetal force.
  - ✓ Planets orbiting the Sun – gravitational force pulls planets toward the Sun.



### Centrifugal Force:

- Sometimes it appears as if an object in circular motion experiences an outward force. In reality, no actual force acts outward. This apparent force is called **centrifugal force**. It is a fictitious force acting radially outward from the center.
- **Applications:** Centrifuge, centrifugal clutch, pump, dryer/washing machine, cream separator, fan, and gold separator – all use centrifugal force to separate substances or push them outward.

### Torque:

- “Torque about an axis is the product of the force magnitude and the perpendicular distance from the axis to the line of action of the force.”

$$\tau = F \times r \times \sin \theta$$

Where:

$\tau$  = torque,  $F$  = applied force,  $r$  = lever arm distance,  $\theta$  = angle between force and lever arm

- **SI unit:** Newton-meter (N·m)
- Maximum torque occurs at  $\theta = 90^\circ$ .
- **Examples:**
  - ✓ Pushing a door – torque rotates the door.
  - ✓ Using a wrench to loosen a bolt – torque is applied.

### Couple:

- Two equal and opposite parallel forces whose lines of action do not coincide form a **couple**. The perpendicular distance between the forces is the **arm of the couple**.

$$\tau = F \times d$$

Where:  $\tau$  = torque,  $F$  = magnitude of each force,  $d$  = perpendicular distance between the forces

- **Characteristics:** Produces rotation only, does not translate the center, Torque depends

only on force and distance, giving pure rotational effect.

- **Examples:** Steering wheel of a car, turning a key in a lock, operating a hand pump or tubewell, tightening a nut with a screwdriver.

### Moment of Inertia:

- When an object rotates about a fixed axis, it resists rotational motion due to **moment of inertia**.

$$I = \sum mr^2$$

- Depends on the object's shape, size, and mass distribution.
- **Applications:** Rolling a nut on a rope, rotating machines, Earth's rotation.

### Galileo and Inertia:

- Galileo used an inclined plane to reduce friction and observed that the object's speed changes slowly on a gentle slope. In an ideal frictionless scenario, the object moves at constant speed.
- **Key conclusion:** Motion changes only when an external force is applied. Without force, a stationary object remains stationary, and a moving object continues at uniform speed.
- **Relation to Newton's First Law:** Galileo's observations laid the foundation for the concept of inertia, later formalized as Newton's first law.

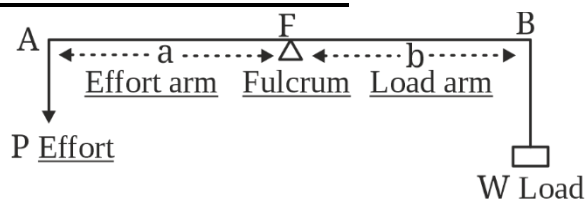
### Simple Machines:

- A **simple machine** is a device that allows a smaller force to move or lift a heavier load efficiently. It includes levers, gears, screw wheels, axles, and pulleys.

### Lever:

- A **lever** is a rigid rod that rotates around a fixed point (fulcrum) to lift a load with less effort.

### Main Parts of a Lever:



1. **Fulcrum:** The fixed point around which the lever rotates.

2. **Effort:** The applied force.
3. **Load:** The object to be lifted.

**Principle of Lever:**

- In equilibrium, **moment of effort = moment of load.**

**Types of Lever:**

- **First-Class Lever:** Fulcrum is in the middle.  
Examples: Seesaw, scissors.
- **Second-Class Lever:** Load is in the middle.  
Example: Lemon squeezer.
- **Third-Class Lever:** Effort is in the middle.  
Examples: Tweezers, human arm.

**Archimedes' Principle:**

- Archimedes was a great Greek mathematician, physicist, engineer, inventor, and astronomer, considered one of the founders of classical mechanics.

**Major Contributions of Archimedes:**

S. No.	Contribution	Description / Importance
1	Law of Lever	The force required to lift an object is

		inversely proportional to its distance from the <b>fulcrum</b> . A heavy object can be lifted with a smaller force if the force is applied at a greater distance from the fulcrum.
2	<b>Pulley and Mechanical Advantage</b>	Pulley systems make it possible to lift heavy loads with less effort. Explained the concept of <b>mechanical advantage</b> .
3	<b>Foundation of Statics</b>	Study of forces acting on bodies in <b>static equilibrium</b> . Led to the development of <b>statics</b> in mechanics.
4	<b>Overall Contribution to Mechanics</b>	Archimedes' principles influenced the development of both <b>theoretical and practical mechanics</b> .

# 4

## CHAPTER

# Gravitation



### Gravity:

- **Gravitational Force:** The attractive force acting between any two objects in the universe.
- Discovered by Sir Isaac Newton.

### Properties of Gravitational Force:

- Always attractive, pulls objects toward each other. Responsible for phenomena like tides.
- Acts without physical contact.
- Can act over long distances.
- Does not require a medium.
- Nearly constant on Earth.
- Weakest of the fundamental forces.
- Acts along the line joining the centers of two objects.

### Universal Law of Gravitation

#### (Newton):

- The force between two masses is directly proportional to the product of their masses and inversely proportional to the square of the distance between them:

$$F \propto \frac{m_1 m_2}{r^2} \text{ or } F = \frac{G m_1 m_2}{r^2}$$

Where **G** is the universal gravitational constant =  $6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$  (independent of shape, size, or medium). Dimensional Formula  $[\text{M}^{-1} \text{L}^3 \text{T}^{-2}]$ .

**Henry Cavendish:** British scientist who measured **G** in 1798.

### Gravity:

- **Center of Gravity:** The point where the entire weight of an object acts; the torque about this point is zero.
- **Gravitational Acceleration (g):** Acceleration of a freely falling object due to gravity.  $g \approx 9.8 \text{ m/s}^2$ , "vector directed toward Earth's center".

### Relationship between G and g:

From the **Universal Law of Gravitation:**

$$F = \frac{G \cdot M \cdot m}{R^2}$$

From **Newton's Second Law:**

$$F = m \cdot g$$

Equating the two expressions and canceling **m**:

$$g = \frac{G \cdot M}{R^2}$$

### **Implications:**

- Gravitational acceleration **g** depends on the universal gravitational constant **G**, Earth's mass **M**, and Earth's radius **R**.

### Variation of g:

- **g** decreases below Earth's surface and increases above it.
- Maximum at the poles, minimum at the equator.
- Zero at Earth's center; weight becomes zero at the center but mass remains constant.
- Two objects of equal mass dropped from the same height experience the same acceleration.
- Standard value of **g** at  $45^\circ$  latitude and sea level:  $9.8 \text{ m/s}^2$ .
- If Earth stops rotating, **g** increases everywhere except at the poles.
- Faster Earth rotation reduces **g**; if rotation increases 17 times, weight at equator becomes zero.

### **Variation formulas:**

- At height **h** above surface:  $g' = g(1 - 2h/R_e)$
- At depth **d** below surface:  $g' = g(1 - d/R_e)$
- At latitude  $\lambda$ :  $g' = g - R_e \omega^2 \cos^2 \lambda$
- Flattened poles → larger radius at equator → smaller **g** at equator.

**Example Problem:** Two masses, 1 kg and 2 kg, dropped from height  $h = 3.2 \text{ m}$ . Final velocity before hitting the ground:

$$v = \sqrt{2gh} = \sqrt{2 \cdot 10 \cdot 3.2} = \sqrt{64} = 8 \text{ m/s}$$

**Observation:** Both masses reach the ground with the same velocity.

**Historical Contribution (Galileo, 1602):**  
Regular pendulum motion explained as a combined effect of **gravity** and acquired momentum.

**Difference between Mass and Weight:**

- **Mass:** Amount of matter, scalar, constant, SI unit: kg.
- **Weight:** Force due to gravity, vector, depends on  $g$ , SI unit: N.
- Mass cannot be zero; weight can be zero where  $g = 0$  (e.g., in space).
- Mass relates to inertia; weight depends on local gravitational acceleration.

**Free Fall:**

When an object falls solely under the influence of Earth's gravitational force, its motion is called **free fall**.

- Gravitational acceleration:  $g = 9.8 \text{ m/s}^2$
- Free fall follows the laws of uniform acceleration.



**Weightlessness:**

- **Definition:** A condition in which an object or person does not feel their weight because no resistive force acts on them.

**Apparent Weight in a Lift:**

Situation	Apparent Weight (R) Compared to Real Weight (W)	Result
Case 1: Lift moving upward with acceleration = $a$	$R > W$	Apparent weight increases
Case 2: Lift moving downward with acceleration = $a$	$R < W$	Apparent weight decreases
Case 3: Lift at rest (or moving with constant velocity)	$R = W$	Apparent weight equals real weight
Case 4: Lift in free fall	$R = 0$	Complete weightlessness

**Apparent Weight:**

- Apparent weight is the weight of an object as perceived under the influence of real gravitational force along with other forces (like acceleration or deceleration).

**Kepler's Laws of Planetary Motion:**

Based on Tycho Brahe's astronomical observations, Johannes Kepler formulated three laws describing planetary motion:

- **Causes of complete weightlessness:**
  - ✓ In free fall, objects and persons fall with the same acceleration.
  - ✓ In space, where gravity is nearly zero,  $g \approx 0$ .
  - ✓ In orbit, astronauts are in continuous free fall, creating the sensation of weightlessness.

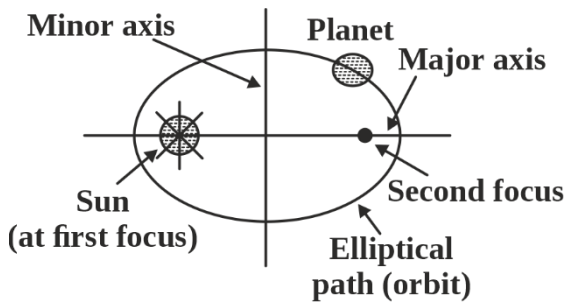
**Did you know?**

- The Moon has its own gravity; gravitational acceleration on the Moon is 1/6 of Earth's, so weight is  $g/6$ .
- On the Sun, gravitational acceleration is 27 times that of Earth.
- A 1 kg mass weighs 9.8 N on Earth.
- At Earth's center, weight is zero because the net gravitational force is zero in all directions, though mass remains constant.
- Earth's rotation can reduce weight at the equator; extremely fast rotation could cause weightlessness at the equator.
- Weightlessness is also experienced in a falling elevator or in a satellite during free fall.

- **First Law (Law of Ellipses):** Each planet moves around the Sun in an elliptical orbit, with the Sun at one focus of the ellipse.
- **Second Law (Law of Areas):** The line joining a planet and the Sun (radius vector) sweeps out equal areas in equal intervals of time. This means the areal velocity of the planet is constant.
- **Third Law (Law of Periods):** The square of the orbital period  $T$  of a planet is proportional to the cube of the semi-major axis  $a$  of its elliptical orbit:

$$T^2 \propto a^3 \text{ or } T = Ka^{3/2}$$

Where  $K$  is the Kepler constant.



### Satellite:

- A satellite is a celestial body that orbits around a planet.
- Examples: Moon (natural satellite of Earth), Aryabhata and INSAT-B (artificial satellites of Earth).

### Orbital Velocity of a Satellite:

- The minimum velocity required for a satellite to remain in orbit under the gravitational influence of a planet:

$$v = \sqrt{\frac{GM}{R}}$$

Where  $G$  is the universal gravitational constant,  $M$  is the mass of the planet, and  $R$  is the distance from the planet's center to the satellite.

- Near Earth's surface, orbital velocity  $\approx 7.92$  km/s.
- The orbital velocity is independent of the satellite's mass.

### Orbital Motion Scenarios:

- If  $v < v_0$ , the satellite follows a spiral path and eventually falls to Earth.
- If  $v = v_0$ , the satellite moves in a circular orbit.
- If  $v > v_0$ , the satellite follows an elliptical orbit around Earth.

### Orbital Period of a Satellite:

- The time for one complete revolution, dependent on orbital radius  $R$ :

$$T = 2\pi \sqrt{\frac{R^3}{GM}}$$

- Higher altitude  $\rightarrow$  longer orbital period (reflecting balance between kinetic and potential energies).

### Geostationary Orbit:

- A satellite orbits directly above the Earth's equator and appears stationary relative to Earth.

### Total Mechanical Energy of a Satellite:

- Sum of kinetic energy (KE) and gravitational potential energy (PE):

$$E = -\frac{GMm}{2R}$$

### Binding Energy:

- Energy required to remove a satellite from Earth's gravitational field (magnitude of total energy, positive value):

$$E_{\text{binding}} = \frac{GMm}{2R}$$

### Escape Velocity:

- Minimum velocity needed for an object to leave Earth's gravitational field without returning:

$$v_e = \sqrt{2gR}$$

Where  $g$  is gravitational acceleration and  $R$  is Earth's radius.

- Earth's surface:  $v_e \approx 11.2$  km/s
- Moon's surface:  $v_e \approx 2.38$  km/s
- Escape velocity is  $\sqrt{2}$  times the orbital velocity.