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UPPSC

Prelims

Uttar Pradesh Public Service Commission

Volume – 8

General Science

SIERRA INNOVATIONS

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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

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^2), measured in **steradians (sr)**

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.

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 = 1.5×10^{11} m 1 light year ≈ 9.46×10^{15} m 1 parsec ≈ 3.083×10^{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 = 1.66×10^{-27} kg 1 pound = 0.4537 kg 1 slug = 14.59 kg Chandrasekhar limit ≈ 2.8×10^{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/m²

Derived Units

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

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

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^{24}	Yocto	y	10^{-24}
Zetta	Z	10^{21}	Zepto	z	10^{-21}

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	µ	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}

2
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^2**

  ✓ **1 Newton (N) = 10^5 dyne**

Types of Force:

Type of Force	What It Is	Simple Example
Contact Force	Force produced due to direct physical contact between two objects.	Pushing or pulling an object
Muscular Force	Force generated by the action of muscles.	Lifting a box, pushing a door
Frictional Force	Force that opposes motion when two surfaces are in contact.	A sliding book coming to rest
Non-Contact Force	Force acting between objects without direct physical contact.	Earth pulling an object
Gravitational Force	Force by which the Earth attracts objects toward itself; a type of attractive force.	Falling of an apple
Electrostatic Force	Force between two charged particles or objects.	A balloon sticking to a wall
Magnetic Force	Force between two magnets or moving electric charges.	Attraction between magnets
Nuclear Force	Force that binds protons and neutrons inside the atomic nucleus.	Binding of proton and neutron in the nucleus
Balanced Force	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
Unbalanced Force	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**.
New momentum $= 2 \times 3000 = 6000$ 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:

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

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, Δt= duration of force

Relation between impulse and momentum:

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

Characteristics of impulse:

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

Examples:

- Stopping a ball slowly increases time → smaller force → no injury to hand.
- Train buffers absorb shocks during shunting → increase collision time → reduce force → 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:

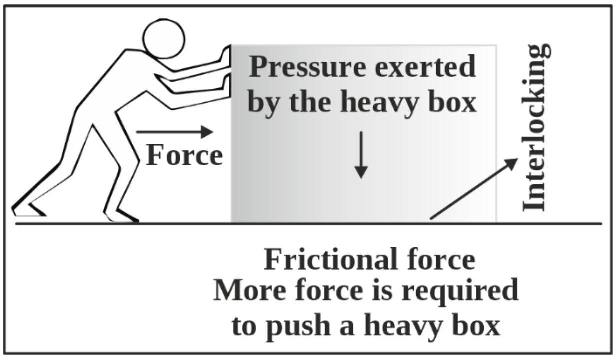
$$v = u + at = 5 + (2.5 \times 5) = 17.5 \text{ m/s}$$

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.

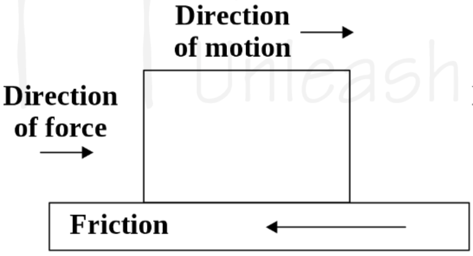


Examples:

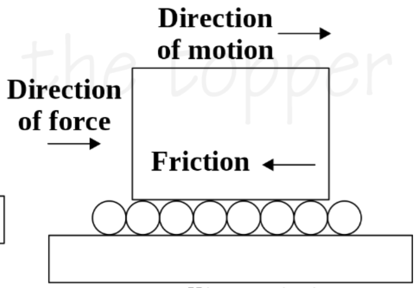
- Walking – friction between shoes and ground helps movement.

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.



Sliding Friction



Rolling Friction

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:

τ= torque, F= applied force, r= lever arm distance, θ= angle between force and lever arm

- **SI unit:** Newton-meter (N·m)
- Maximum torque occurs at $\theta = 90°$.
- **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: τ= 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.

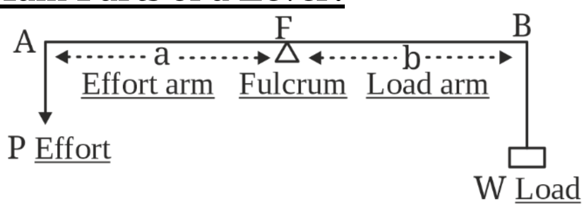
Simple Machines:

- 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:

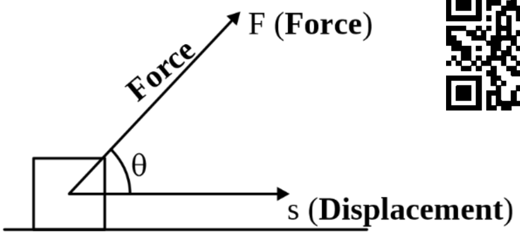
S. No.	Contribution	Description / Importance
1	**Law of Lever**	The force required to lift an object is inversely proportional to its distance from the **fulcrum**. A heavy object can be lifted with a smaller force if the force is applied at a greater distance from the fulcrum.
2	**Pulley and Mechanical Advantage**	Pulley systems make it possible to lift heavy loads with less effort. Explained the concept of **mechanical advantage**.
3	**Foundation of Statics**	Study of forces acting on bodies in **static equilibrium**. Led to the development of **statics** in mechanics.
4	**Overall Contribution to Mechanics**	Archimedes' principles influenced the development of both **theoretical and practical mechanics**.

3 CHAPTER

Work, Energy and Power

Work:

- In physics, **work** is the process in which a force is applied on an object causing it to be displaced in the direction of the force. When a force acts on an object and the object moves some distance in the direction of the force, work is said to be done.



Displacement

Mathematical Expression:

- If a **force F** is applied on an object causing it to move a displacement **s**, then work done: $W = F \times s$
- If the angle between force and displacement is **θ**, then:

$$W = F \times s \times \cos\,\theta$$

- Work is a **scalar quantity**.
- SI unit of work: **Joule (J)**
    - ✓ 1 Joule = work done when 1 Newton force displaces an object by 1 meter in the direction of the force.
    - ✓ 1 J = 1 N × 1 m
- CGS unit: **erg**
    - ✓ 1 erg = 10^{-7} J
- Larger unit: **Kilowatt (kW)**
    - ✓ 1 kW = 1000 W

Special Cases:

- θ = 0° → cosθ = 1 → Work maximum
- θ = 90° → cosθ = 0 → Work = 0
- If displacement s = 0 or force F = 0 → Work = 0

Example: A brick is pushed with a force of 7 N and it moves 5 m.
Sol-

$$W = F \times d = 7 \times 5 = 35\text{ J}$$

Work done = **35 Joules**

Energy:

- The **capacity of an object to do work** is called **energy**.
- Energy is a **scalar quantity**.
- SI unit of energy: **Joule (J)**

Unit	Definition	Conversion
Erg	CGS unit of energy.	1 erg = 10^{-7} joule
Calorie	Amount of energy required to raise the temperature of 1 gram of water by 1°C.	1 calorie ≈ 4.2 joule
Kilowatt-hour (kWh)	Common unit of electrical energy used in households.	1 kWh = 3.6×10^6 joule
Electron Volt (eV)	Energy gained by an electron when it passes through a potential difference of 1 volt.	1 eV = 1.6×10^{-19} joule
Kilojoule (kJ)	Larger unit of energy.	1 kJ = 1000 joule

Kinetic Energy (KE):

- The **kinetic energy** of an object moving with a certain velocity is equal to the work done to bring it to that velocity.

$$E_k = \frac{1}{2}mv^2$$

where **m** is mass and **v** is velocity. KE is always positive.

Examples: Running person, falling ball, flowing water, swinging pendulum.

Example Problem:

Question- Two objects A (2 kg) and B (3 kg) are dropped from different heights. A takes 5 s and B takes 3 s to reach the ground. Find the ratio of their kinetic energies upon impact.

Solution: In free fall, final velocity $v = gt \rightarrow KE \propto \frac{1}{2}mv^2 \propto mt^2$

$$KE_A : KE_B = (2 \times 5^2) : (3 \times 3^2) = 50 : 27$$

Potential Energy (PE):

- Energy stored in an object due to its **position** or **configuration**.
- **Gravitational PE:** Depends on height.

$$PE = mgh$$

Examples: Book on a shelf.

- **Elastic PE:** Energy stored in stretched or compressed objects.
  Examples: Bow-arrow, spring toys.
- **Chemical Energy:** Stored in chemical bonds and released during reactions.
  Examples: Battery, food, petrol.
- **Nuclear Energy:** Energy stored in atomic nuclei released via fission or fusion.
  Examples: Nuclear reactor, Sun.

Fact:
- The sum of **kinetic energy** and **potential energy** is called **mechanical energy**.

Example Problem: A 2 kg object is dropped from 10 m. Find PE and KE at 5 m height. $g = 10$ m/s²

Solution:

$$PE_{10m} = mgh = 2 \times 10 \times 10 = 200\,J$$
$$PE_{5m} = 2 \times 10 \times 5 = 100\,J \Rightarrow KE = 100\,J$$
$$PE : KE = 1 : 1$$

Work-Energy Theorem:

- The work done by a force on a particle equals the **change in its kinetic energy**.

Law of Conservation of Energy:

- Energy can transform from one form to another but cannot be created or destroyed. Total energy remains constant. **Example:** Falling book: gravitational PE converts into kinetic energy.

Einstein's Mass-Energy Equivalence:

- According to Einstein, every substance possesses energy due to its mass. This is called **mass energy**, and mass can be converted into energy and energy can be converted into mass.
- If an object of mass is completely converted into energy, then the total energy produced is given by

$$E = mc^2$$

where **c = 3 × 10⁸ m/s** (speed of light in vacuum).

Forms of Energy and Their Conversion:

Form of Energy	Description	Energy Conversion
Thermal Energy	Energy due to temperature of a body.	Steam engine → Mechanical energy Thermal power plant → Electrical energy
Electrical Energy	Energy produced by the movement of electrons.	Bulb → Light energy Heater → Thermal energy
Light Energy	Energy transmitted through waves (e.g., sunlight).	Solar panel → Electrical energy
Sound Energy	Energy produced by vibrations.	Microphone → Electrical energy Speaker → Sound energy
Mechanical Energy	Sum of kinetic and potential energy.	Fan, windmill, generator, etc.
Chemical Energy	Energy stored in chemical reactions.	Battery, engine, candle, etc.

Non-Conventional Energy Sources

Energy Source	Description	Example / Conversion
Wind Energy	Energy from fast-moving air.	Wind turbine → Electrical energy
Hydro Energy	Energy obtained from flowing water.	Hydroelectric plant → Electrical energy
Biomass Energy	Energy obtained from organic waste or dead plants/animals.	Biogas plant → Thermal energy

Solar Energy	Energy obtained from the Sun.	Solar cooker → Thermal energy Solar panel → Electrical energy
Tidal Energy	Energy stored in ocean tides.	Tidal dam → Electrical energy
Wave Energy	Kinetic energy of ocean waves.	Turbine → Electrical energy
Ocean Thermal Energy	Energy from temperature difference between surface and deep sea water.	OTEC plant → Electrical energy
Geothermal Energy	Heat stored inside the Earth.	Hot water sources → Electricity generation
Nuclear Energy	Energy obtained from nuclear fission or fusion.	Nuclear plant → Thermal energy → Electrical energy

Power (P):

- **Power** is the rate of doing work or the rate of energy transfer. It measures how quickly or slowly work is done.

$$P = \frac{W}{t}$$

where **W** = work done, **t** = time taken.

- **SI unit:** Joule per second (J/s) = **Watt (W)**
  1 W = 1 J/s
- **High power levels:** expressed in kilowatt (kW)
  1 kW = 1000 W

Example Problem: A heater produces 60 kJ of heat in 1 minute 20 seconds. Find the power of the heater.

Solution:

$Q = 60\ \text{kJ} = 60000\ \text{J}, t = 1\ \text{min}\ 20\ \text{s} = 80\ s$

$P = Q/t = 60000/80 = 750\ \text{W}$

Horsepower (HP):

- One horsepower is the power with which a horse can do 33,000 foot-pounds of work in 1 minute. It is a non-SI unit of power for engines and machines.
- **Mechanical HP:** 1 HP ≈ 746 W
- **Metric HP:** 1 HP ≈ 736 W

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 = 6.67×10^{-11} N·m²/kg² (independent of shape, size, or medium).Dimensional Formula -[$M^{-1}L^3T^{-2}$].

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≈9.8 m/s²,"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° latitude and sea level: 9.8 m/s².
- 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 λ: $g' = g - R_e\omega^2\cos^2\lambda$
- Flattened poles → larger radius at equator → smaller $g$at equator.

Example Problem: Two masses, 1 kg and 2 kg, dropped from height $h = 3.2$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: $g = 9.8$ m/s²
- 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.
- **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.

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).

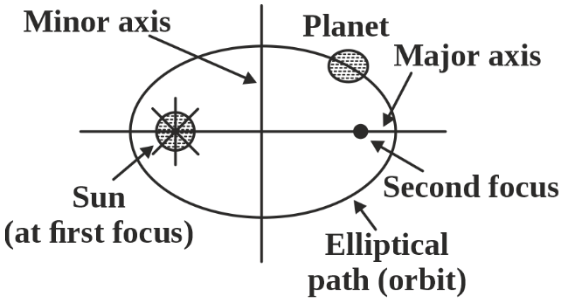
Kepler's Laws of Planetary Motion:

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

- **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 ≈ 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 → 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 √2 times the orbital velocity.

5

CHAPTER

Electricity

- The branch of Electricity in which the study of charges at rest is carried out is called Electrostatics, and the study of charges in motion is called Current Electricity or Dynamic Electricity.

Electric Charge:

- **Electric charge** is a fundamental property of matter due to which it experiences a force in **electric** and **magnetic fields**.
- Its **SI unit** is **Coulomb (C)**, and it is a **scalar quantity**.

Types of Electric Charge

- **Positive Charge:** The deficiency of electrons in a body or particle is called **positive charge**.
- **Negative Charge:** The excess of electrons in a body or particle is called **negative charge**.

Properties of Electric Charge:

- Unlike charges attract each other. Like charges repel each other.
- The total charge of a system is the **algebraic sum** of all individual charges present at different points in the system.
- **Principle of Conservation of Charge:** In an isolated system, the total charge remains constant. Charge can neither be created nor destroyed.
- The total charge acquired by a body is always an **integral multiple** of the charge of an electron.

Total charge of a body:

$$Q = ne$$

Where,

n = number of electrons , e = 1.6×10^{-19} C

Did You Know?

- An **Electroscope** is an instrument used to detect the presence and type (positive or negative) of electric charge on a body.

Coulomb's Law:

In 1785, Charles-Augustin de Coulomb measured the force between electric charges using a torsion balance. The electrostatic force between two point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.

$$F = k\frac{q_1 q_2}{r^2}$$

$$k = 8.99 \times 10^9\ N \cdot m^2/C^2$$

Note:

$$1C = \frac{1}{e} = \frac{1}{1.6 \times 10^{-19}} \approx 6.25 \times 10^{18} \text{ electrons}$$

Electric Field:

The region around an electric charge or a system of charges in which another charge experiences a force of attraction or repulsion is called the **Electric Field** or **Electric Force Field**.

Electric Field Intensity:

The force acting on a unit positive test charge placed at a point in an electric field is called the Electric Field Intensity at that point.

$$E = \frac{F}{q_0}$$

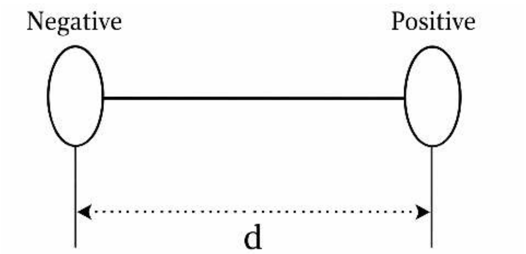
It is a vector quantity. Its SI unit is Volt/meter (V/m) or Newton/Coulomb (N/C).

Electric Field Lines:

- An electric field line is an imaginary smooth curve drawn in an electric field along which a free and isolated unit positive charge would move if free to do so.
- Electric field lines originate from a positive charge and terminate on a negative charge. In the case of a single charge, they extend to infinity.
- The tangent at any point on a field line gives the direction of the electric field at that point.

- Field lines never intersect each other.
- When field lines come closer (contract longitudinally), opposite charges attract; when they spread apart laterally, like charges repel.

Electric Dipole:



A pair of equal and opposite charges (+q and –q) separated by a fixed distance d is called an Electric Dipole.

Electric Dipole Moment: $P = q \cdot d$

Electric Flux:

- The total number of electric field lines passing normally through a surface placed in an electric field is equal to the **electric flux** linked with that surface.
- For an element of area ΔS in an electric field E, the electric flux Δϕ is defined as:

$$\Delta\phi = E \cdot \Delta S$$
$$\Delta\phi = E\Delta S\cos\ \theta$$

Where,
E = electric field intensity
ΔS = area vector

- Electric flux is a scalar quantity. Its unit is Volt–meter (V·m) or Newton–meter²/Coulomb (N·m²/C).

Gauss's Law:

- According to this law, the total electric flux passing through a closed surface is equal to $\frac{1}{\varepsilon_0}$times the total charge enclosed within the surface.

$$\phi_E = \sum E \cdot dS = \frac{1}{\varepsilon_0}\sum q$$

Where,
Σq = total charge enclosed within the surface

Equipotential Surface:

- A surface on which the electric potential is the same at every point is called an **Equipotential Surface**.
- The electric field is always perpendicular to the equipotential surface.

Capacitance:

Capacitance is the ability of a system to store electric charge.

$$C = \frac{Q}{V}$$

Where,
C = capacitance, Q = stored charge, V = potential difference
SI unit: **Coulomb/Volt = Farad (F)**

Capacitor:

- A Capacitor is a device that can store a large amount of electric charge without a change in its size (dimensions).
- **Applications:**
  Energy storage, frequency tuning, sensor technology, memory storage.

Electric Current:

- The rate of flow of electric charge is called **Electric Current**.
- Electric current is defined as the amount of charge flowing through a given area per unit time.

$$i = \frac{Q}{t}$$

(Current = Charge / Time)

- SI unit: **Ampere (A)**
- 1 Ampere = 1 Coulomb/second
  In a current of 1 Ampere, the number of electrons flowing per second is: $\frac{1}{1.602\times10^{-19}} \approx 6.25 \times 10^{18}$ electrons per second

- **Direction of Current:** Conventionally, the direction of current is taken as the direction of flow of positive charge, whereas in reality electrons flow in the opposite direction.

Types of Electric Current:

Feature	Alternating Current (AC)	Direct Current (DC)
Definition	Current whose direction changes periodically with time.	Current that flows in a constant direction.