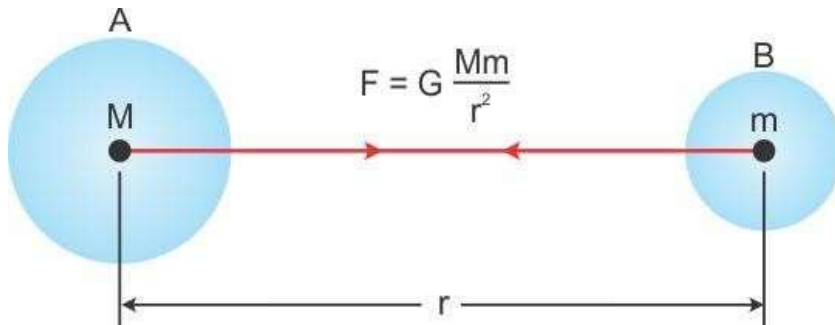# Gravitation

- According to Newton, every object in this Universe attracts every other object with a certain force. This force with which two objects attract each other is called **gravitational force**.
- If the masses of two bodies are small, then the gravitational force between them is very small.
- The gravitational force holds the Solar System together.

Universal Law of Gravitation

- This law was given by **Sir Isaac Newton**.

> Every object in the Universe attracts every other object with a force which is proportional to the product of their masses and inversely proportional to the square of the distance between them.

- Consider two objects A and B of mass 'M' and 'm' separated by a distance 'r'.

According to Newton's law of gravitation, the force of attraction (F) between the two objects is given as

$$F = \frac{GMm}{r^2}$$

where **G** is the proportionality constant known as the **universal gravitation constant.**
- Universal gravitation constant 'G' is numerically equal to the gravitational force of attraction between the two bodies, each of unit mass kept at unit distance from each other.
- The value of G is 6.67×10^{-11} Nm^2/kg^2.
- The universal law of gravitation successfully explained several phenomena such as the motion of the Moon around the Earth, the motion of the planets around the Sun and the force which binds us to the Earth.

Kepler's Laws of Planetary Motion

Kepler's First Law	• The planets move around the Sun in elliptical orbits, with the Sun at one of the two foci of the elliptical orbit.
Kepler's Second Law	• In an elliptical orbit of the planet, the line joining the centre of the planet to the centre of the Sun sweeps out equal areas in equal intervals of time.
Kepler's Third Law	• The cube of the mean distance 'r' of a planet from the Sun is directly proportional to the square of its orbital period 'T'. • i.e. $r^3 \alpha \ T^2$

Free Fall

- Whenever objects fall towards the Earth under the influence of gravitational force alone, the objects are said to be in a state of free fall.
- The uniform acceleration produced in a freely falling body because of the gravitational force of the Earth is known as **acceleration due to gravity**. It is denoted by **g**, and its value on the surface of the Earth is 9.8 m/s^2.
- During free fall, there is no change in the direction of motion of the object, but the magnitude of the velocity of the falling object changes.
- The relation connecting the acceleration due to gravity **g** and universal gravitational constant **G** is

  $$g = \frac{GM}{R^2}$$

  where M is the mass of the Earth and R is the radius of the Earth.
- The value of 'g' is maximum at the **poles** (where R is minimum) and minimum at the **equator** (where R is maximum).
- The value of 'g' is maximum on the surface of the Earth; it decreases as we move above or go beneath the surface of the Earth.

Motion of Objects under the Influence of Gravitational Force of the Earth

- The equations of motion for freely falling bodies are

$$v = u + gt$$

$$h = ut + (1/2)\, gt^2$$

$$v^2 - u^2 = 2gh$$

where '**u**' is the **initial velocity**, '**v**' is the **final velocity** after 't' sec and '**h**' is the **height** covered in 't' sec.

- Here, g should be positive if the acceleration due to gravity is in the direction of motion, and it should be negative if it is in the direction opposite to the motion.

Mass and Weight

- Mass of an object is the measure of its inertia.
- The force with which an object is attracted towards the Earth is the **weight** (W) of the object. It is equal to the product of mass (m) and acceleration due to gravity (g).
  W = mg
- SI unit of weight is Newton, same as that of force.
- The weight of an object on the Moon is one-sixth its weight on the Earth.

Differences between Mass and Weight

Mass	Weight
1. Mass of a body is the quantity of matter contained in it.	1. Weight of a body is the force with which the body is attracted towards the centre of the Earth.
2. Mass of a body is a constant quantity.	2. Weight of a body varies from place to place.
3. It is a scalar quantity.	3. It is a vector quantity.
4. SI unit of mass is kilogram (kg).	4. SI unit of weight is newton (N).

Thrust and Pressure

- Thrust is the force acting perpendicularly on an object.
- Pressure is the force acting perpendicularly on a unit area of the object.

$$\text{Pressure} = \frac{\text{Thrust}}{\text{Area}}$$

- SI unit of thrust is newton (N) and that of pressure is pascal (Pa), where
  1 Pa = 1 N/m^2

Density

- Density (d) of a substance is defined as mass (M) per unit volume (V).

$$d = \frac{M}{V}$$

- The **relative density** of a substance is the ratio of its density to the density of water at 4°C.

$$\text{Relative density} = \frac{\text{Density of a substance}}{\text{Density of water at } 4^{\circ}\text{C}}$$

- Relative density has no units as it is the ratio of similar quantities.

Pressure in Fluids

- A fluid exerts pressure in all directions, even upwards.
- According to **Pascal's law**, pressure exerted in any confined mass of fluid is transmitted uniformly in all directions.

Buoyancy

- When an object is partially or wholly immersed in a fluid, an upward force acts on it, which is called upthrust or **buoyant force**.
- The magnitude of buoyant force depends on
  - The volume of the object immersed in the liquid.
  - The density of the liquid.
- Let W be the weight of a body and F_B be the buoyant force acting on it.
  - If $W > F_B$, then the body sinks.
  - If $W < F_B$, then the body floats.
- An object with density less than the liquid floats on the liquid. If the object is denser than the liquid, then it sinks in the liquid.

Archimedes' Principle

When an object is immersed wholly or partially in a fluid, it experiences an upward force which is equal to the weight of the fluid displaced by it.

- The buoyant force acting on an object = Weight of fluid displaced by that object

Applications of Archimedes' Principle
- In designing ships and submarines
- In determining the purity of milk with a lactometer
- In determining the density of liquids with a hydrometer