Gravitation

Introduction

Gravitation is the force of attraction between any two objects having mass. It is one of the fundamental forces of nature and is responsible for the motion of planets around the Sun, the Moon around the Earth, and objects falling towards the Earth. This chapter explains **Newton's law of gravitation, acceleration due to gravity, variation of g, gravitational potential energy, escape velocity, and motion of satellites**.

Universal Law of Gravitation

Newton's Law

Newton's Universal Law of Gravitation states that **every two objects in the universe attract each other with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres**.

Formula:

$$\mathbf{F = Gm_1m_2 / r^2}$$

where:

- **F** = Gravitational force
- $\mathbf{m_1}$, $\mathbf{m_2}$ = Masses of the two objects
- **r** = Distance between their centres
- **G** = Universal gravitational constant

The value of $\mathbf{G = 6.67 \times 10^{-11}\ N\ m^2/kg^2}$.

Acceleration Due to Gravity

Definition

The acceleration produced in a freely falling object due to the gravitational attraction of the Earth is called **acceleration due to gravity (g)**.

Near the Earth's surface:

$$\mathbf{g \approx 9.8\ m/s^2}$$

For an object of mass **m** on the Earth's surface:

$$\mathbf{mg = GMm/R^2}$$

Therefore:

$$\mathbf{g = GM/R^2}$$

where:

- **M** = Mass of Earth
- **R** = Radius of Earth

Variation of g

With Height

The value of **g decreases as height above the Earth's surface increases**.

For height **h**:

$$\mathbf{g_h = g\ (R\ /\ R + h)^2}$$

For small heights:

$$\mathbf{g_h \approx g(1 - 2h/R)}$$

With Depth

The value of **g decreases as we move below the Earth's surface**.

At the centre of the Earth:

$$\mathbf{g = 0}$$

Mass and Weight

Mass

Mass is the amount of matter contained in an object.

- It is constant everywhere.
- SI Unit: **kilogram (kg)**.
- It is a scalar quantity.

Weight

Weight is the gravitational force acting on an object.

W = mg

- Weight changes with the value of **g**.
- SI Unit: **Newton (N)**.
- It is a vector quantity.

Gravitational Potential Energy

Definition

Gravitational Potential Energy is the energy possessed by an object due to its position in a gravitational field.

Near Earth's surface:

U = mgh

For a body at a distance **r** from the centre of Earth:

U = −GMm/r

The negative sign indicates that gravitational force is attractive and the reference point of zero potential energy is taken at infinity.

Escape Velocity

Definition

Escape velocity is the minimum velocity with which an object must be projected from the Earth's surface so that it can escape Earth's gravitational field without further propulsion.

Formula:

ve = $\sqrt{}$(2GM/R)

For Earth:

ve ≈ 11.2 km/s

Escape velocity does not depend on the mass of the object.

Satellites

Definition

A **satellite** is a body that revolves around a planet or another celestial body under the influence of gravity.

The speed of a satellite in a circular orbit is:

$v = \sqrt{(GM/r)}$

where **r** is the distance from the centre of the planet.

Geostationary Satellite

Definition

A **geostationary satellite** appears stationary relative to a point on Earth.

Conditions:

- It moves in a circular orbit.
- It revolves from west to east.
- Its orbital period is **24 hours**.
- It moves in the equatorial plane.

Uses

Geostationary satellites are used for:

- Communication
- Television broadcasting
- Weather monitoring
- Navigation

Orbital Velocity

Definition

The **orbital velocity** is the velocity required by a satellite to remain in a stable orbit around a planet.

For a circular orbit:

$v_o = \sqrt{(GM/r)}$

It depends on the mass of the planet and the orbital radius.

Weightlessness

Meaning

Weightlessness is the condition in which the apparent weight of an object becomes zero.

Astronauts inside an orbiting spacecraft experience weightlessness because both the spacecraft and astronauts are in continuous **free fall** towards Earth.

Kepler's Laws of Planetary Motion

First Law

Planets move in **elliptical orbits** with the Sun at one focus.

Second Law

The line joining the Sun and a planet sweeps out **equal areas in equal intervals of time**.

Third Law

The square of the time period of revolution is proportional to the cube of the semi-major axis of the orbit.

$T^2 \propto a^3$

Applications of Gravitation

Importance

Gravitation explains:

- Falling of objects
- Motion of planets
- Motion of the Moon
- Ocean tides
- Artificial satellites
- Space missions
- Orbits of celestial bodies

Key Points

- Every mass attracts every other mass through gravitational force.
- Gravitational force follows the inverse-square law.
- The value of **g near Earth's surface is approximately 9.8 m/s^2**.
- Mass remains constant, but weight depends on **g**.

- Escape velocity from Earth is approximately **11.2 km/s**.
- Satellites remain in orbit due to gravitational force.
- Geostationary satellites have a period of 24 hours.
- Astronauts experience apparent weightlessness due to free fall.
- Kepler's laws explain planetary motion.

Chapter Summary

This chapter explains gravitation and its role in the motion of objects and celestial bodies. It covers Newton's universal law of gravitation, acceleration due to gravity, variation of **g**, mass and weight, gravitational potential energy, escape velocity, orbital velocity, satellites, weightlessness, and Kepler's laws. Gravitation is essential for understanding the motion of planets, satellites, moons, and other objects in the universe.