

{Final Project}

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Campus Name : Piston College

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Introduction

Gravitation is one of the fundamental forces of nature that governs the motion of objects in the universe. It is the force by which every mass attracts every other mass. From the falling of an apple to the motion of planets around the Sun, gravitational force plays a vital role in maintaining the structure of the universe.

Sir Isaac Newton's Law of Universal Gravitation and Johannes Kepler's Laws of Planetary Motion are cornerstones of classical physics. Newton provided the physical explanation of gravitation, while Kepler described the mathematical relationship governing planetary motion. Together, these laws help scientists understand celestial mechanics, satellite motion, and space exploration.

Universal Law of Gravitation

Statement of the Law

According to Newton's Universal Law of Gravitation, every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers.

Mathematical Formula

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

Explanation of Variables

- F = Gravitational force between two masses

- \mathbf{G} = Universal gravitational constant
- $\mathbf{m}_1, \mathbf{m}_2$ = Masses of the two objects
- \mathbf{r} = Distance between the centers of the two masses

Units and Dimensions

- Unit of force (F): Newton (N)
- Unit of mass (m): kilogram (kg)
- Unit of distance (r): meter (m)
- Value of gravitational constant:
$$G = 6.67 \times 10^{-11} N m^2 kg^{-2}$$

Dimensional Formula of G:

$$[M^{-1} L^3 T^{-2}]$$

Real-Life Applications

- Motion of planets around the Sun
- Artificial satellites orbiting the Earth
- Calculation of weight of objects

- Prediction of tides due to Moon's gravity

Kepler's Third Law

Statement of the Law

Kepler's Third Law states that *the square of the time period of revolution of a planet is directly proportional to the cube of the radius of its orbit.*

Mathematical Expression

$$T^2 \propto r^3$$

or

$$\frac{T^2}{r^3} = \text{constant}$$

Fractional Exponents and Square Roots

From the law:

$$T = \sqrt{r^3}$$

This shows the use of square roots and fractional powers, indicating that as the orbital radius increases, the time period increases at a slower rate.

Relationship Between Orbital Period and Radius

- Larger orbital radius → Longer time period

- Smaller orbital radius → Shorter time period

This relationship explains why distant planets take more time to complete one revolution around the Sun.

Importance in Astronomy

- Helps calculate planetary distances
- Determines mass of celestial bodies
- Used in satellite orbit calculations
- Essential for space mission planning

Derivation of Kepler's Third Law

Consider a planet of mass **m** revolving around the Sun of mass **M** in a circular orbit of radius **r**.

According to Newton's Law of Gravitation:

$$F = G \frac{Mm}{r^2}$$

The centripetal force required for circular motion is:

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

Equating both forces:

$$G \frac{Mm}{r^2} = \frac{mv^2}{r}$$

Cancel \mathbf{m} from both sides:

$$G \frac{M}{r^2} = \frac{v^2}{r}$$

Multiply both sides by \mathbf{r} :

$$v^2 = G \frac{M}{r}$$

Orbital velocity is given by:

$$v = \frac{2\pi r}{T}$$

Squaring both sides:

$$v^2 = \frac{4\pi^2 r^2}{T^2}$$

Substitute in the earlier equation:

$$\frac{4\pi^2 r^2}{T^2} = G \frac{M}{r}$$

Rearranging:

$$T^2 = \frac{4\pi^2}{GM}$$

This proves that:

$$T^2 \propto r^3$$

Hence, **Kepler's Third Law is derived from Newton's Law of Gravitation.**

Applications

Planetary Motion

Kepler's Third Law explains the motion of planets and their varying orbital periods around the Sun.

Artificial Satellites

The law helps determine the height and time period of communication and weather satellites.

Space Missions

Used in planning satellite launches, interplanetary missions, and calculating escape velocities.

Conclusion

Newton's Universal Law of Gravitation and Kepler's Third Law together form the foundation of celestial mechanics. Newton explained the cause of gravitational attraction, while Kepler described the motion of planets mathematically. These laws are essential for understanding planetary motion, satellite technology, and modern space science. Their scientific significance continues to guide astronomical discoveries and space exploration.