Newton's Law Gravitation

Universal Law Explanation

Newton's universal law of gravitation states that every object in the universe attracts every other object 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 Expression

The gravitational force F between two masses m_1 and m_2 separated by a distance r is given by:

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

where G is the universal gravitational constant with a value of $6.67 \times 10^{-11}\,\mathrm{Nm^2/kg^2}$.

Applications

- The gravitational pull between the Earth and the Moon causes tides.
- The attraction between the Sun and planets keeps the planets in orbit.

Solved Examples

Example 1: Calculate the gravitational force between two objects of masses 5 kg and 10 kg placed 2 meters apart.

Solution:

Given: $m_1 = 5\,\text{kg}, m_2 = 10\,\text{kg}, r = 2\,\text{m}, G = 6.67 \times 10^{-11}\,\text{Nm}^2/\text{kg}^2$

Using the formula:

$$F = G\frac{m_1 m_2}{r^2} = 6.67 \times 10^{-11} \times \frac{5 \times 10}{2^2} = 6.67 \times 10^{-11} \times \frac{50}{4} = 6.67 \times 10^{-11} \times 12.5 = 8.34 \times 10^{-10}\,\text{N}$$

Therefore, the gravitational force is $8.34 \times 10^{-10}\,\text{N}$.

Practice Set

- **Level 1:** What does the universal gravitational constant represent?
- **Level 2:** Explain why the gravitational force decreases as the distance between two objects increases.
- **Level 3:** Calculate the gravitational force between two 1 kg masses placed 1 meter apart.

Answer Key

- **Level 1:** It is the force of attraction between two bodies of unit mass each placed at a unit distance apart.
- **Level 2:** Because the force is inversely proportional to the square of the distance between the objects, increasing the distance reduces the force rapidly.
- **Level 3:** Using $F = G\frac{m_1 m_2}{r^2} = 6.67 \times 10^{-11} \times \frac{1 \times 1}{1^2} = 6.67 \times 10^{-11}\,\text{N}$.

Gravity

Definition and Explanation

Gravity is the force of attraction between the Earth and any object lying on or near its surface. It causes objects to fall towards the Earth.

Acceleration Due to Gravity

The acceleration with which a body falls towards the Earth's center is called acceleration due to gravity, denoted by g. Its value on the Earth's surface is approximately $9.8\ \mathrm{m/s^2}$.

Variation of Gravity

- **Altitude:** Gravity decreases with increasing height above the Earth's surface.
- **Depth:** Gravity decreases as we move below the Earth's surface.
- **Latitude:** Gravity is slightly greater at the poles and less at the equator due to Earth's rotation and shape.

Examples of Gravity

- Gravity keeps the atmosphere bound to Earth.
- It causes objects to fall when dropped.

Solved Examples

Example 1: Calculate the weight of a 10 kg object on Earth.

Solution:

Weight $W = m \times g = 10 \times 9.8 = 98\ \mathrm{N}$.

Therefore, the weight is 98 newtons.

Practice Set

- **Level 1:** What is the value of acceleration due to gravity on Earth's surface?
- **Level 2:** How does gravity vary with altitude?
- **Level 3:** Calculate the weight of a 5 kg object at a place where $g = 9.6\ \mathrm{m/s^2}$.

Answer Key

- **Level 1:** 9.8 m/s²
- **Level 2:** Gravity decreases as altitude increases.
- **Level 3:** Weight = mass × gravity = 5 × 9.6 = 48 N.

Free Fall

Definition

Free fall is the motion of a body under the influence of gravity alone, without any resistance.

Examples

- An object dropped from a height in a vacuum.
- Astronauts in orbiting spacecraft experience microgravity and appear to float because both they and the spacecraft are in free fall.

Characteristics

In free fall, all objects accelerate downwards at the same rate g, regardless of their masses.

Solved Examples

Example 1: Calculate the velocity of an object after falling freely for 3 seconds.

Solution:

Using $v = gt = 9.8 \times 3 = 29.4\ \text{m/s}$.

The velocity after 3 seconds is 29.4 m/s downward.

Practice Set

- **Level 1:** What is free fall?
- **Level 2:** Why do astronauts appear weightless in orbit?
- **Level 3:** Calculate the distance fallen by an object in free fall after 4 seconds.

Answer Key

- **Level 1:** Motion under gravity alone without resistance.
- **Level 2:** Because both astronauts and spacecraft are in free fall, creating a sensation of weightlessness.
- **Level 3:** Distance $s = \frac{1}{2}gt^2 = 0.5 \times 9.8 \times 16 = 78.4\ \text{m}$.

Mass and Weight

Mass

Mass is the quantity of matter contained in a body. It is constant and does not change with location.

Weight

Weight is the force with which the Earth attracts a body. It depends on the mass of the body and the acceleration due to gravity.

Weight is given by:

$$W = m \times g$$

Variation of Weight

Weight changes with location because g varies. For example, weight on the Moon is one-sixth of that on Earth due to weaker gravity.

Solved Examples

Example 1: Find the weight of a 20 kg object on the Moon where gravity is $1.63\ \mathrm{m/s^2}$.

Solution:

$$W = m \times g = 20 \times 1.63 = 32.6\ \mathrm{N}.$$

The weight on the Moon is 32.6 newtons.

Practice Set

- **Level 1:** Define mass.
- **Level 2:** Why does weight vary from place to place?
- **Level 3:** Calculate the weight of a 15 kg object on Earth.

Answer Key

- **Level 1:** Quantity of matter in a body.
- **Level 2:** Because acceleration due to gravity varies with location.
- **Level 3:** Weight = 15 × 9.8 = 147 N.

Quick Reference Table

Newton's Law of Gravitation: $F = G\frac{m_1 m_2}{r^2}$, $G = 6.67 \times 10^{-11}\ \mathrm{Nm^2/kg^2}$

Acceleration due to gravity: $g = 9.8\ \mathrm{m/s^2}$ on Earth

Weight formula: $W = m \times g$

Variation of gravity: Decreases with altitude and depth; greater at poles than equator

Common Mistakes and Misconceptions

- Confusing mass and weight: Mass is constant; weight depends on gravity.
- Believing heavier objects fall faster: In free fall, all objects accelerate equally.
- Assuming gravity is the same everywhere on Earth: Gravity varies with location.

Glossary

- **Gravity:** Force of attraction between Earth and objects near its surface.
- **Gravitation:** Force of attraction between any two bodies in the universe.
- **Universal Gravitational Constant (G):** Constant used in gravitation formula, value $6.67 \times 10^{-11}\,\mathrm{Nm^2/kg^2}$.
- **Acceleration due to gravity (g):** Rate at which objects fall towards Earth, $9.8\ \mathrm{m/s^2}$.
- **Free Fall:** Motion under gravity alone without resistance.
- **Mass:** Quantity of matter in a body.
- **Weight:** Force exerted by gravity on a mass.
- **Weightlessness:** Condition of apparent zero weight during free fall.