Chapter 9: Gravitation

Introduction to Gravitation

Falling Objects

We observe that an object dropped from a height falls towards the earth. All planets go around the Sun, and the moon goes around the earth. Isaac Newton grasped that the same force is responsible for all these: the gravitational force.

Newton's Insight

Newton famously thought: if the earth can attract an apple, can it not attract the moon? He conjectured that the same type of force is responsible in both cases.

Centripetal Force

Circular Motion

The moon moves in a circular path around the earth. At every point, it changes direction, which involves a change in velocity or acceleration.

Centre-Seeking Force

The force that causes this acceleration and keeps the body moving along the circular path is acting towards the centre. This force is called the centripetal (meaning 'centre-seeking') force.

Absence of Force

In the absence of this force, the moon would fly off along a straight line tangential to the circular path.

Universal Law of Gravitation

The Law

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.

Formula

$F = G * (M * m) / d^2$, where G is the universal gravitation constant, M and m are masses, and d is the distance.

Direction

The force is along the line joining the centres of two objects.

Free Fall

Falling Under Gravity

Whenever objects fall towards the earth under the gravitational force alone, we say that the objects are in free fall.

Acceleration

While falling, there is no change in the direction of motion, but the magnitude of velocity changes. This change involves acceleration.

Acceleration due to Gravity

Definition

The acceleration during free fall is due to the earth's gravitational force. It is denoted by 'g'. The unit is m/s^2.

Value of g

The value of g on the surface of the earth is approximately 9.8 m/s^2.

Independence of Mass

The acceleration experienced by an object during free fall is independent of its mass. This means all objects, hollow or solid, big or small, fall at the same rate (in vacuum).

Motion under Gravity Equations

Equations

Since g is constant near the earth, the equations of motion apply with 'a' replaced by 'g'. 1) $v = u + gt$, 2) $s = ut + \frac{1}{2}gt^2$, 3) $v^2 = u^2 + 2gs$.

Sign Convention

Acceleration 'a' is taken as positive when it is in the direction of velocity (downward motion) and negative when it opposes motion (upward motion).

Mass vs Weight

Mass

The mass of an object is the measure of its inertia. It remains the same everywhere, whether on earth, moon, or outer space. It is a constant quantity.

Weight

The weight of an object is the force with which it is attracted towards the earth. $W = m * g$. Weight has both magnitude and direction (downwards).

Variation

Weight depends on the value of g, so it changes from place to place. Mass does not change.

Weight on the Moon

Lesser Attraction

The mass of the moon is less than that of the earth. Due to this, the moon exerts lesser force of attraction on objects.

Comparison

The weight of an object on the moon is about one-sixth (1/6th) of its weight on the earth.

Thrust and Pressure

Thrust

The force acting on an object perpendicular to the surface is called thrust.

Pressure

The thrust on unit area is called pressure. Pressure = Thrust / Area. The SI unit is pascal (Pa).

Effect of Area

The same force acting on a smaller area exerts a larger pressure, and a smaller pressure on a larger area.

Pressure Examples

Everyday Applications

Why does a nail have a pointed tip? The small area of the tip results in high pressure, allowing it to penetrate wood easily.

Other Examples

Knives have sharp edges to cut easily (small area, high pressure). Buildings have wide foundations to distribute weight over a large area (low pressure).

Buoyancy

Upward Force

When an object is immersed in a fluid (liquid or gas), it experiences an upward force exerted by the fluid. This is called the buoyant force or upthrust.

Magnitude

The magnitude of the buoyant force depends on the density of the fluid.

Why Objects Float or Sink

Density Comparison

An iron nail sinks while a cork floats. This happens because of the difference in their densities relative to water.

Rule

Objects of density less than that of a liquid float on the liquid. Objects of density greater than that of a liquid sink in the liquid.

Archimedes' Principle

The Principle

When a body is immersed fully or partially in a fluid, it experiences an upward force that is equal to the weight of the fluid displaced by it.

Eureka!

Archimedes discovered this principle while taking a bath, noticing the water level rise.

Applications of Archimedes' Principle

Ships and Submarines

It is used in designing ships and submarines to ensure they float and can control their depth.

Instruments

Lactometers (used to determine purity of milk) and hydrometers (used for determining density of liquids) are based on this principle.

Summary of Gravitation

Key Points

The Law of Gravitation explains the force between any two objects. Weight varies with location; mass is constant. Objects float if less dense than the fluid.