GRAVITATION

CBSE CLASS 9 SCIENCE • CHAPTER 10 • PREMIUM HIGH-YIELD STUDY MANUAL

1. Introduction to Gravitational Force

Every object in the universe possessing mass exerts an unprompted pulling force on every other massive body. This attractive pull is defined as **gravitation**. It is the silent, pervasive fundamental force responsible for keeping us on the Earth's crust, locking the Moon in orbit, and driving planetary motion around the Sun.

2. The Universal Law of Gravitation

Formulated by Sir Isaac Newton, this universal law states:

> *"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."*

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$$F = G  rac{m_1 m_2}{r^2}$$
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Where: $F = ext{Gravitational Force}$, $G = ext{Universal Gravitational Constant}$, $m_1, m_2 = ext{Masses}$, $r = ext{Center Distance}$

Core Features of Gravitational Interactions:

- It is strictly a **mutual attractive force**; it can never manifest as repulsion.
- It operates uniformly across all scales, binding macroscopic stellar constellations as well as subatomic dust particles.
- It represents the weakest fundamental force of nature but operates across long ranges.

Universal Gravitational Constant (G):

The scalar value of G remains absolute across all space and time parameters, measured first by Henry Cavendish:

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$$G = 6.673 imes 10^{-11} \ ext{N}\cdot ext{m}^2/ ext{kg}^2$$
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3. Natural Phenomena Driven by Gravitation

Planetary & Lunar Orbits:

The gravitational pull provides the continuous centripetal force required to keep planets spinning around the Sun and moons locking around their planets.

The Dynamics of Tides:

Periodic high and low ocean tides on Earth occur due to the moving gravitational pull of the Moon and, to a lesser degree, the Sun acting on the oceans.

4. Free Fall & Acceleration Due to Gravity (g)

When an object drops towards the Earth under the exclusive, single influence of gravitational force alone, the object is said to be in a state of **free fall**.

During free fall, the direction of motion remains uniform, but the object experiences a continuous increase in velocity. This constant acceleration generated inside a freely falling body by the Earth's pull is defined as the **acceleration due to gravity (g)**.

- Standard average value at the Earth's sea-level surface: **$g = 9.8 \ ext{m/s}^2$**.
- Crucially, g is completely **independent of the falling body's mass**. In a complete vacuum lacking air resistance, a heavy iron block and a light bird feather will fall with identical acceleration and hit the ground simultaneously.

Mathematical Derivation & Relationship Mapping Between g and G

Let an object of mass m be dropped near the surface of the Earth. According to Newton's Universal Law of Gravitation, the force of attraction is:

$$F = G rac{M \cdot m}{R^2}$$

Where M is the mass of the Earth and R is the Earth's radius. From Newton's Second Law of Motion, we know that Force is the product of mass and acceleration ($F = m \cdot g$). Equating both expressions:

$$m \cdot g = G rac{M \cdot m}{R^2}$$

By eliminating the object's mass (m) from both sides, we get the fundamental relationship:

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$$g =  rac{G \cdot M}{R^2}$$
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Key Geological Insight: Since the Earth is not a perfect sphere but an oblate spheroid, the equatorial radius is larger than the polar radius. Because acceleration due to gravity is inversely proportional to the square of the radius ($g \propto rac{1}{R^2}$), the value of **g is maximum at the poles and minimum at the equator**.

Equations of Motion under Free Fall Conditions

For uniform gravitational acceleration fields, the regular linear equations of motion are modified by substituting acceleration a with $+g$ (for downwards motion) or $-g$ (for objects thrown upwards):

First Equation: $v = u + gt$

Second Equation: $s = ut + rac{1}{2}gt^2$

Third Equation: $v^2 - u^2 = 2gs$

5. Distinct Scientific Demarcations: Mass vs. Weight

In standard science, mass and weight are fundamentally different physical concepts:

Property	Mass	Weight
Definition	The intrinsic quantification of the amount of matter present inside a body.	The actual net gravitational force with which an object is pulled toward a celestial body.
Quantity Type	**Scalar quantity** (only contains magnitude).	**Vector quantity** (points downwards towards the center of gravity).
Variability	Absolute constant; remains identical anywhere in the universe.	Variable parameter; shifts continuously based on local gravity changes.
Zero Limit	Can never equal zero for any physical object.	Becomes exactly zero in space environments lacking gravity fields.
SI Unit	Kilogram ($ ext{kg}$)	

Property	Mass	Weight
		Newton ($ ext{N}$) • Computed via formula: $W = m \cdot g$

Weight of an Object on the Lunar Surface (The Moon)

The Moon's mass is significantly smaller than the Earth's, making its surface gravitational acceleration approximately $ rac{1}{6} ext{th}$ of the Earth's ($g_{ ext{moon}} pprox rac{g_{ ext{earth}}}{6}$). Consequently, an individual weighing $600 \ ext{N}$ on Earth would register a weight of exactly **$100 \ ext{N}$** on the Moon, despite their mass remaining identical.

6. Fluid Mechanics Foundations: Thrust & Pressure

- **Thrust:** The net physical force acting completely **perpendicular (normal) to a surface**. Unit: Newton ($ ext{N}$).
- **Pressure (P):** Defined as the magnitude of thrust acting per unit area of a surface.

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$$ ext{Pressure } (P) =  rac{ ext{Thrust}}{ ext{Area}}$$
```

- **SI Unit:** **Pascal ($ ext{Pa}$)**, where $1 \ ext{Pa} = 1 \ ext{N/m}^2$.

The Inverse Relationship with Contact Area ($P \propto rac{1}{ ext{Area}}$):

For a fixed, constant force, reducing the distribution area causes the pressure to rise significantly. Conversely, increasing the contact area spreads out the force, lowering the overall pressure.

- **Sharp Knife:** Features an extremely minute edge area, producing high pressure under small forces to slice materials smoothly.
- **School Bag Straps:** Designed intentionally broad to maximize surface contact with the shoulders, lowering the pressure and reducing strain.

7. Buoyancy & Floating Dynamics

When any solid object is immersed into a liquid or gas, the fluid exerts an unprompted, net **upward force** that opposes gravity. This phenomenon is defined as **buoyancy**, and the upward force is called the **buoyant force**.

The Physics Governing Sinking and Floating:

- An object will **sink** if its downward weight exceeds the maximum upward buoyant force ($ ext{Weight} > F_{ ext{buoyant}}$). This happens when the object's density is greater than the fluid's density.
- An object will **float** stably if the upward buoyant force matches or exceeds its total weight ($ ext{Weight} \le F_{ ext{buoyant}}$), meaning its internal density is lower than the surrounding medium.

8. Archimedes' Principle & Applications

Formulated by the ancient Greek scholar Archimedes, this foundational principle states:

> *"When a body is immersed fully or partially in a fluid, it experiences an upward buoyant force that is exactly equal to the weight of the fluid that the body displaces."*

High-Yield Technical Applications of Archimedes' Principle:

1. **Ship & Submarine Engineering:** Heavy iron ships are designed with large volumes to displace massive weights of water, creating enough buoyant force to float safely.
2. **Hydrometers:** Instruments used to determine the specific gravity and density profiles of varied liquids.
3. **Lactometers:** Specialized instruments used to test the purity and water-dilution levels of milk samples.

9. Density & Relative Density

- **Density ($ ho$):** The mass contained per unit volume of a substance ($ ho = rac{ ext{Mass}}{ ext{Volume}} $). SI Unit: $ ext{kg/m}^3$.
- **Relative Density:** The ratio of a substance's density to the density of pure water at $4^\circ ext{C}$.

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$$ ext{Relative Density} =  rac{ ext{Density of Substance}}{ ext{Density of Water}}$$
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- Since it is a ratio of identical quantities, **Relative Density has no unit**. If a substance's relative density is < 1, it will float on water; if it is > 1, it will sink.

10. Chapter Summary & Core Keywords

Summary: Gravitation is a universal attractive force directly proportional to mass and inversely proportional to the square of center distance ($F = rac{G M m}{r^2}$). Free fall creates a mass-independent acceleration ($g = 9.8 \ ext{m/s}^2$). Mass remains constant everywhere, while weight shifts based on gravity. In fluid mechanics, thrust distributed over an area determines pressure, and Archimedes' Principle states that buoyant force matches the weight of displaced fluid, explaining floating dynamics.

Essential Exam Keywords for High Scoring:

`Universal Law` `Cavendish G-Constant` `Mass-Independent g` `Oblate Spheroid Variance` `Lunar Weight Ratio` `Pascal Pressure Unit` `Displaced Fluid Weight` `Dimensionless Relative Density`