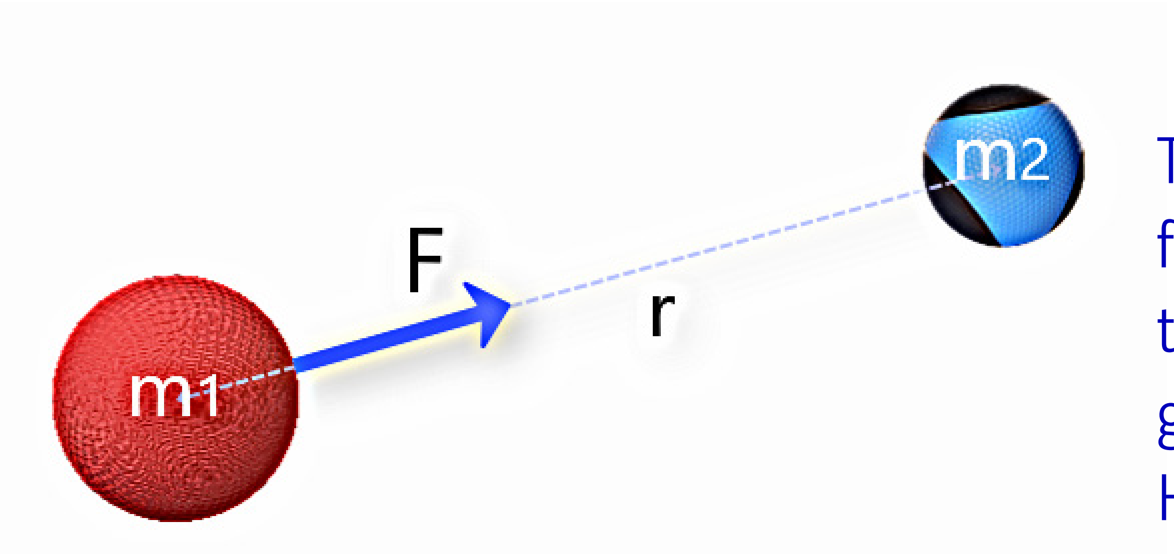
Newton's Law of Universal Gravitation

1. The balance of gravity - Not too much, not too less
2. Newton's Law of Universal Gravitation (scalar form)
3. Newton's Law of Universal Gravitation (vector form)
4. Key characteristics of gravitational force
5. Apple and the Earth - The dynamics of gravitational force
6. Gravitational Force on two people standing 1 m apart
7. Acceleration due to gravity
8. Key formulas and equations
9. Common misconceptions and clarifications

NEWTON'S LAW OF UNIVERSAL GRAVITATION

Scalar Form

$$F = G \times (m_1 \times m_2) / r^2$$



The force F shown is the attractive force on m_1 due to m_2, directed toward m_2. This highlights that gravitational force is a vector. However, the formula on the left gives only the magnitude of the force, not its direction

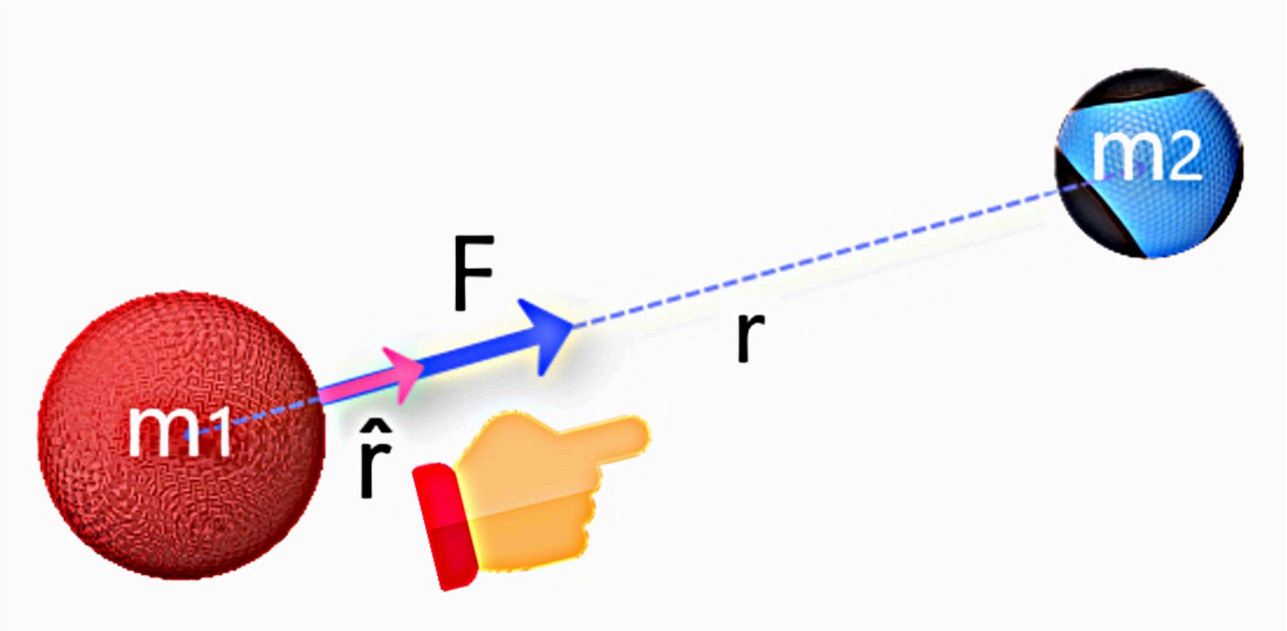
- F: *Gravitational force between two masses (in N)*
- G: *Gravitational constant* = 6.674×10^{-11} N·m²/kg²
- m_1, m_2: *Masses of the two objects (in kg)*
- *r: Distance between the center of masses*

NEWTON'S LAW OF UNIVERSAL GRAVITATION

Vector Form

$$\vec{F} = G \times (m_1 \times m_2) / r^2 \times r$$

Its only role is to give direction

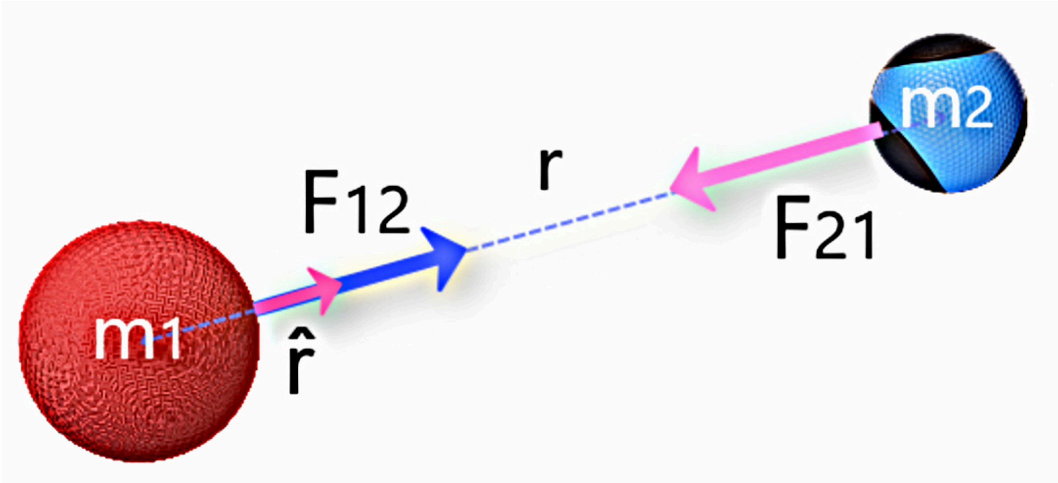


Here unit vector r helps us give vector identity to the force F

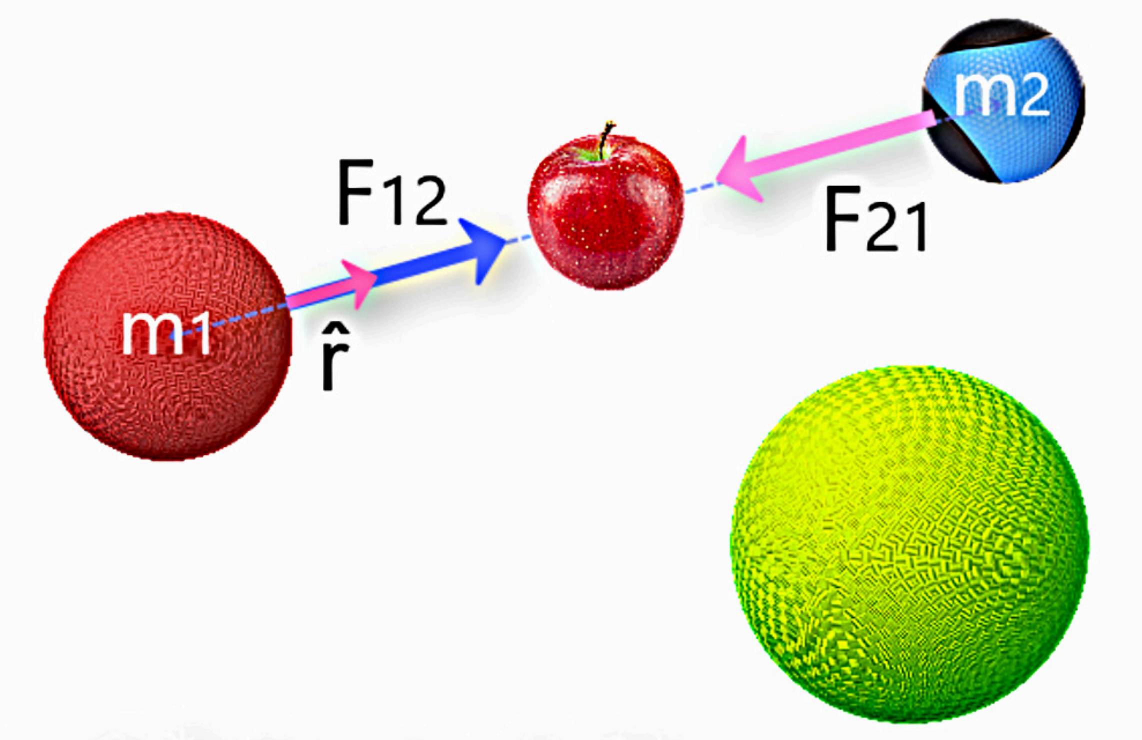
- r: *Unit vector indicating the direction of the force*
- $\vec{F}$ *Vector form of the gravitational force*

KEY CHARACTERISTICS OF GRAVITATIONAL FORCE

1. Mutual Attraction: Both masses exert equal & opposite gravitational forces on each other
2. Dependence on Mass and Distance
   a. Directly proportional to the product of the two masses.
   b. Inversely proportional to the square of the distance between their centers.
3. Universality: Gravity acts between all objects with mass, regardless of their size.
4. Non-Shieldable: Unlike electromagnetic forces, gravity cannot be shielded or blocked by other matter.
5. Always Attractive: Gravitational force always pulls objects together; it never pushes them apart.



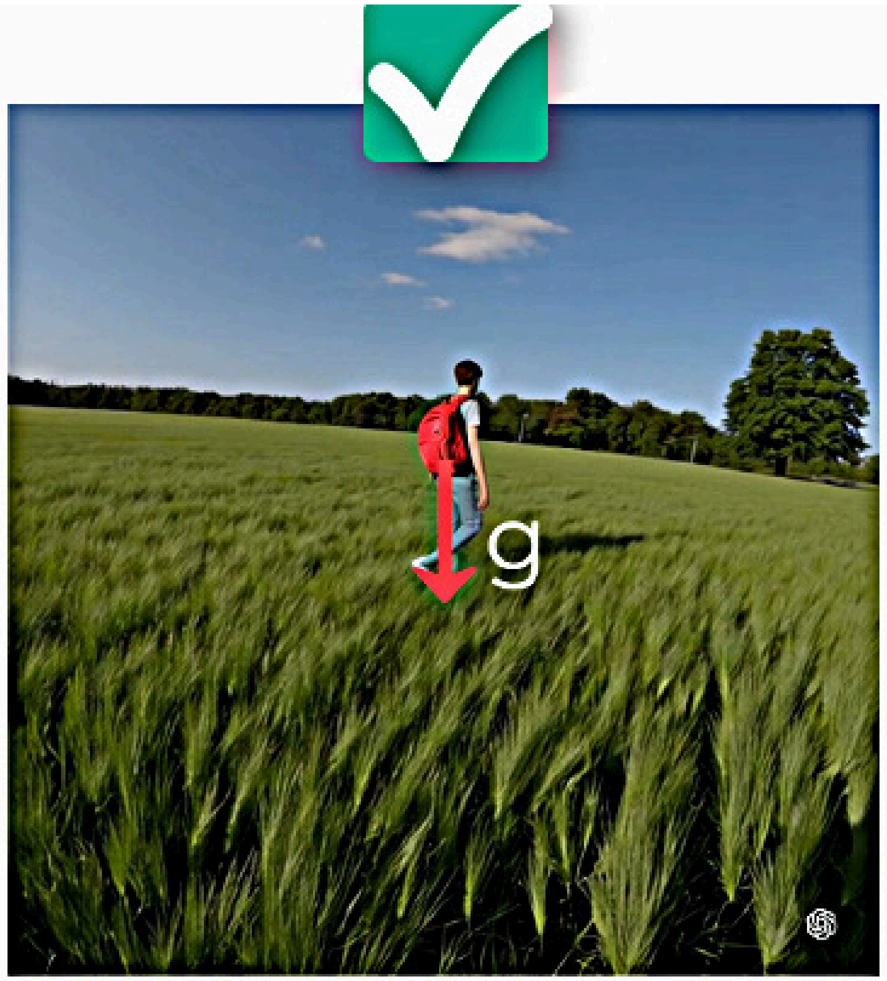
F_{12} and F_{21} are equal in magnitude and opposite in direction ($F_{12} = -F_{21}$)



No matter what you place between or around two masses, the gravitational force they exert on each other remains unchanged

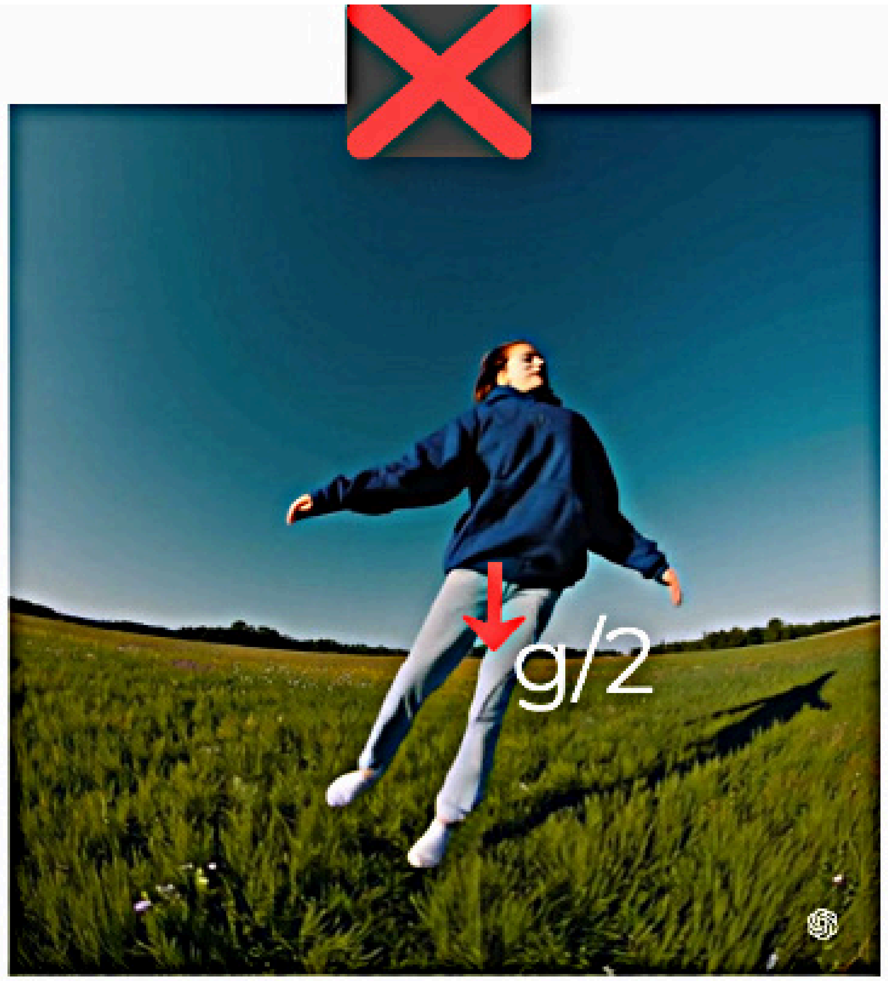
THE BALANCE OF GRAVITY

Gravity's Role on Earth: *Earth's gravity pulls everything toward it. For us humans, it's just right — strong enough to keep us grounded, but not so strong that we can't move around comfortably.*



Gravity = g. Conditions are ideal — you can walk, run, and jump naturally. Perfect for daily life on Earth.

Gravity = 2g. Gravity is twice as strong — every step feels heavy, and moving becomes exhausting. (Visual is exaggerated for effect



Gravity = g/2. Gravity is only half as strong — you might feel super light and bouncy. Jumping is easy, but staying grounded and stable could be tough!

EARTH AND AN APPLE

Given

- *Mass of apple (m1)* = 0.1 kg
- *Mass of Earth (m2)* = 5.97×10^{24} kg
- *Distance (r)* = 6.371×10^{6} m

Calculation:

$$F = G \times (m_1 \times m_2) / r^2$$

$$= G \times (0.1 \times 5.97 \times 10^{24}) / (6.371 \times 10^{6})^2 \approx 0.98\ N$$

Interpretation: The apple experiences a gravitational force of approximately 0.98 N towards Earth, and Earth experiences an equal force toward the apple.

The mass of Earth is about 5.97×10^{24} kg — that's an enormous number! Using the formula a = F/m, this huge mass in the denominator makes Earth's acceleration toward the apple almost zero. That's why, even though the apple pulls on Earth with the same force (0.98 N), we don't see the Earth move — only the apple appears to fall

WHEN AN APPLE FALLS - THE EARTH MOVES, VERY SLOWLY

Formula: $a = F / m$

Application

- For the apple: $a = 0.98\ N / 0.1\ kg = 9.8\ m/s^2$
- For Earth: $a = 0.98\ N / (5.97 \times 10^{24}\ kg)$

$\approx 1.64 \times 10^{-25}\ m/s^2$

Interpretation: While both the apple and Earth exert equal forces on each other, Earth's massive mass results in an almost negligible acceleration, making its movement imperceptible.

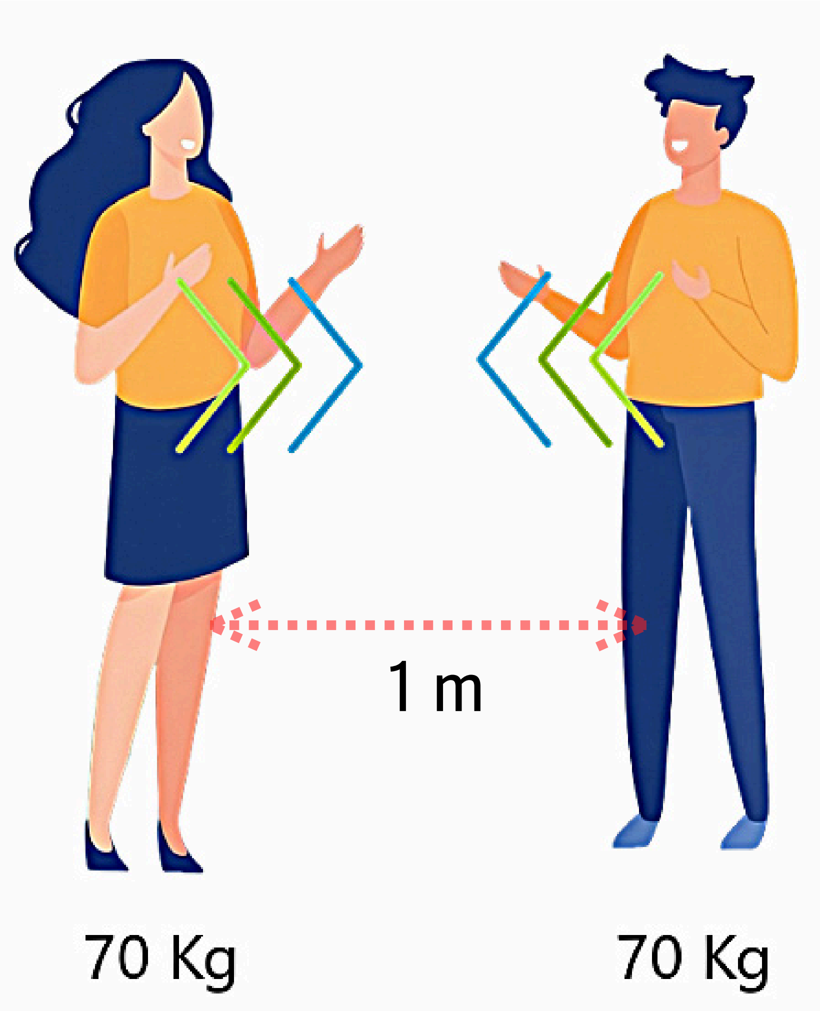
When an apple falls toward Earth, Earth also feels a tiny pull toward the apple. But the Earth is so massive, its acceleration is unbelievably small — about $1.64 \times 10^{-25}\ m/s^2$. So small that even after 13.8 billion years — the age of the universe — Earth would have moved less than a millimeter! That's why we never notice Earth moving when things fall

THE SCIENCE CUBE

TWO PEOPLE STANDING 1 METER APART

Given

- *Mass of each person* = 70 kg
- *Distance (r)* = 1 m



Calculation

$F = G \times (70 \times 70) / 1^2 \approx 3.4 \times 10^{-7}\ N$

Interpretation: The gravitational force between the two individuals is minuscule— comparable with the weight of a human eyelash—and thus imperceptible.

KEY FORMULAS & EQUATIONS

Equation	When to Use	Notes
$F = G \times (m_1 \times m_2) / r^2$	Calculating gravitational force between two masses	Scalar form; use when direction is not a concern
$\vec{F} = G \times (m_1 \times m_2) / r^2 \times r$	Calculating gravitational force with direction	Vector form; includes . Use when direction matters – especially in problems involving multiple forces or net force calculationsdirection of the force
$g = G \times M / r^2$	Calculating gravitational field strength at any point	'g' is the acceleration due to gravity at distance 'r' from mass 'M'

COMMON MISTAKES AND MISCONCEPTIONS

Misconception 1: Heavier objects fall faster than lighter ones

Clarification: The gravitational force on an object near Earth is given by $F = G \times (m \times M) / r^2$, where m is the object's mass, M is Earth's mass, and r is the radius of Earth.

When we use $F = m \times a$ to find the object's acceleration, the object's mass m cancels out ($G \times (m \times M) / r^2 = m a$), leaving $a = G \times M / r^2$, which is constant near Earth's surface ($\approx 9.8\ m/s^2$). This means all objects, regardless of mass, fall with the same acceleration in the absence of air resistance. The difference we observe in real life is due to air drag, not gravity.

COMMON MISTAKES AND MISCONCEPTIONS

Misconception 2: Gravity Doesn't Exist in Space

Clarification: Gravity exists everywhere in the universe, it never becomes zero, only weaker with distance. According to Newton's Universal Law of Gravitation, $F = G \times (m_1 \times m_2) / r^2$, the gravitational force decreases with the square of the distance (r) between two masses. Even in orbit, astronauts are still under the influence of Earth's gravity.

Misconception 3: Gravitational Force Can Be Shielded

Clarification: Unlike electromagnetic forces, gravity cannot be blocked or shielded by any material; it acts through all matter.

COMMON MISTAKES AND MISCONCEPTIONS

Misconception 4: The Equal and Opposite Reaction to Gravity Is the Normal Force

Clarification: The normal force is not the third-law reaction to gravity. When Earth pulls an object downward (gravity), the object pulls Earth upward with an equal gravitational force. These two form the true third-law pair.

The normal force comes from the surface pushing up on the object to support it. Its reaction pair is the object pushing down on the surface, not gravity.

In short:

- Gravity pair: Earth on object ↓, object on Earth ↑
- Normal pair: Surface on object ↑, object on surface ↓

Misconception 5: Gravity Only Affects Objects on Earth

Clarification: Gravity is a universal force that acts between any two masses, regardless of their location in the universe. Even in the vast emptiness of space, gravitational forces are at play. For instance, the Moon remains in orbit around Earth due to Earth's gravitational pull, and planets orbit the Sun for the same reason.

The misconception that gravity doesn't exist in space likely arises from the sensation of weightlessness experienced by astronauts. However, this weightlessness is due to being in a continuous state of free fall around Earth, not the absence of gravity.

COMMON MISTAKES AND MISCONCEPTIONS

Misconception 6: The Gravitational Force Depends on Size, Not Mass

Clarification: Gravitational force depends on the masses of the objects and the distance between their centers, not their sizes. Two objects with the same mass but different sizes will exert the same gravitational force on each other if the distance between their centers is the same. This misconception may stem from associating larger size with greater mass, which isn't always the case.

Misconception 7: Objects in Orbit Are Not Under the Influence of Gravity

Clarification: Objects in orbit, such as satellites and the International Space Station, are very much under the influence of Earth's gravity. In fact, gravity is what keeps them in orbit. These objects are in a constant state of free fall towards Earth, but because they have a tangential velocity, they keep missing Earth, resulting in an orbit. The sensation of weightlessness experienced by astronauts is due to this continuous free-fall state, not the absence of gravity.