

GRAVITATION

"Gravitation is a force of attraction that acts between all objects in the universe.

THE NEWTONIAN GRAVITATION

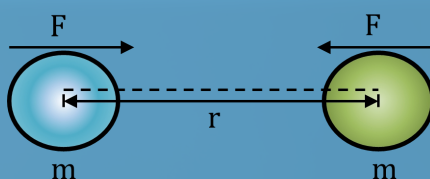
According to Sir Isaac Newton, Newton was sitting under an apple tree, when an apple landed on his head.

He looked up at the sky, noticed the Moon, and reasoned that the same force that made the apple fall to the ground also kept the Moon in its orbit about the Earth.

Gravity from the Earth acted through space and exerted a force on the Moon'.

Newton's universal law of gravitation

'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. The force is along the line joining the centers of the two objects'.



$$F = \frac{Gm_1m_2}{r^2}$$

G = Universal gravitational constant

Characteristics of gravitational force

- It is a universal force of attraction.
- It acts along the line joining the center of each mass.
- It acts equally on each mass, i.e., it obeys Newton's third law. $F_{12} = -F_{21}$
- It is weaker if the masses are further apart. Gravitation acts in an inverse square manner, i.e.,

$$F \propto \frac{1}{r^2}$$
 where r is the distance between the centers of the masses.
- It depends directly on the mass of each body involved, i.e. $F \propto m_1$ and $F \propto m_2$.
- It is a long range force i.e., its influence extends to very large distances.

Importance of Newton's universal law of gravitation

- The force that binds us to the Earth.
- The motion of the Moon around the Earth.
- The motion of planets around the Sun.
- The tides due to the Moon and the Sun.

Why Moon does not fall on Earth directly?

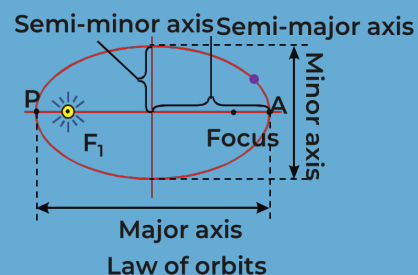
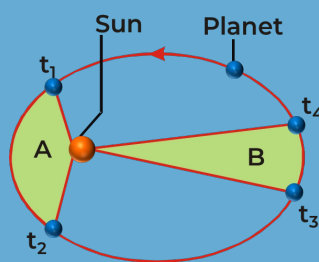
It is the tangential velocity and the gravitational force that are perpendicular to each other, and cause the Moon to fall around the Earth without actually falling onto it.



Kepler's laws of planetary motion

1. Each planet in the Solar system moves in an elliptical orbit with the Sun at one focus.
2. The line joining the planet and the Sun sweeps out equal areas in equal intervals of time.
3. The square of the orbital period of a planet is proportional to the cube of the semimajor axis of the elliptical orbit'.

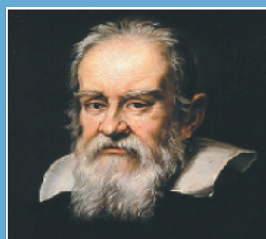
$$\frac{T^2}{R^3} = \text{constant}$$



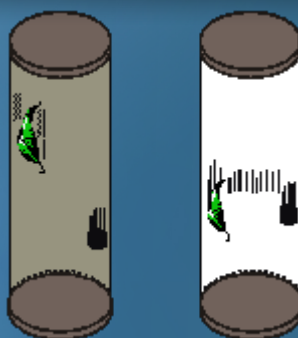
$$\text{or } \frac{T^2}{R^3} = \frac{R_1^3}{R_2^3} \quad \text{or } \left(\frac{T_1}{T_2} \right)^2 = \left(\frac{R_1}{R_2} \right)^3$$

Free fall (motion under gravity)

It is the motion of an object subject only to the influence of gravity. An object is in free fall as soon as it is dropped from rest, thrown downward or thrown upward.



Galileo Galilei (1564–1642), Italian physicist and astronomer, formulated the laws that govern the motion of objects in free-fall.



Air filled tube Evacuated tube In the absence of air, all objects fall with same acceleration (g).

Equations of motion of freely falling body

There are two main assumptions in free fall :

1. Acceleration due to gravity (g) is constant throughout the motion and it acts vertically downwards.

2. Air resistance is negligible.

Case 1 : An object thrown vertically upward and it returns after some time.

$$h = ut - \frac{1}{2}gt^2$$

(a) Time taken to reach maximum height

$$t = \frac{u}{g}$$

(b) Total time of journey

$$T = \frac{2u}{g}$$

(c) Maximum height achieved by the object

$$H = \frac{u^2}{2g}$$

Case 2 : An object is thrown vertically downward from a certain height H .

$$v^2 = 2gy$$

Mass

The amount of matter contained in a body is called its mass.

Mass of a body is constant at all places in the universe.

It is measured by physical balance.

It is a scalar quantity

it is always taken positive.

Unit of mass

SI unit : Kilogram (kg) ; CGS unit :
Gram (g)

Weight

The gravitational force exerted by the Earth on an object is called its weight.

This force is directed towards the center of the Earth.

It is denoted by letter W.

It is measured by a weighing machine or spring balance.

Weight, $W = mg$

Unit of mass Weight

Variation of weight of an object :

SI unit : Newton (N) ; CGS unit : Dyne

Mass and weight are two different quantities. Mass of a body remains constant at all places, while weight of a body may change from place to place. Weight of a freely falling body is zero. At the centre of Earth, weight of a body is zero.

Weightlessness :

If a man is standing in a lift and the lift cable breaks, then the lift and the man will fall towards Earth with an acceleration g . The man is now in free fall, his apparent weight is zero and he will experience weightlessness.

Weight of an object on Moon :

A man weighing 100 N on Earth will weigh only $100/6 = 16.67$ N on Moon. But his mass remains the same on the Moon and the Earth.

$$\frac{W_M}{W_E} = \frac{1}{6}$$

i.e., weight of the object on the Moon = $(1/6) \times$ its weight on the Earth

Now, $W_m = mg_m$ and $W_e = mg_e$, where g_m and g_e are accelerations due to gravity of Moon and Earth respectively.

$$\therefore \frac{W_M}{W_E} = \frac{mg_m}{mg_e} = \frac{1}{6}$$

$$\text{or } \frac{g_m}{g_e} = \frac{1}{6}$$