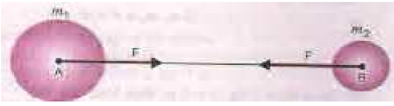
GRAVITATION

NEWTON'S LAW OF GRAVITATION

Everybody in this universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.

The direction of the force is along the line joining the centres of the bodies and is always a vector.



<---------------d-------------->

Consider two bodies A and B of masses m_1 and m_2 respectively, such that d is the distance between their centres.

Let F be the force by which these bodies mutually attract each other.

Then according to Newton,

$F \alpha\ m_1 m_2$ ----------------(1)

$F \alpha\ 1/d^2$ -------------------(2)

Combining equation (1) and (2) we get

$F \alpha\ (m_1 m_2) / d^2$

$F = G\ m_1 m_2 / d^2$

Where G – Constant of proportionality called Gravitational constant. $G = 6.67 \times 10^{-11}\ Nm^2kg^{-2}$.

Importance of the universal law of gravitation

1. The gravitational force of attraction of the earth is responsible for binding all terrestrial objects on the earth.
2. The gravitational force of earth is responsible for holding the atmosphere around the earth.
3. The gravitational force of the earth is also responsible for the rainfall and snowfall on the earth.
4. The tides formed by the rising and falling of water level in the ocean are due to the gravitational force of attraction , which the sun and the moon exert on sea water.

Gravity

It is the force of attraction between the earth and any object lying on or near its surface. A body thrown up falls back on the surface of the earth due to earth's force of gravity.

Relationship between the acceleration due to gravity and the force of attraction.

Let m – mass of the body

M – mass of the earth

R – radius of the earth

g - acceleration due to gravity

F – Force acting on the body

By the Newton's second law of motion

$F = mg$ ------------(1)

From Newton's law of gravitation

$F = GmM / R^2$ ------(2)

Comparing equation (1) and (2)

$mg = GmM / R^2$

$g = GM / R^2$

$g = 6.67 \times 10^{-11} \times 6 \times 10^{24} / (6.4 \times 10^6)^2$

$g = 9.8\ ms^{-2}$.

Note

1. $g_{moon} = (1/6)\ g_{earth}$

2. As the polar radius of the earth is smaller than the equatorial radius, therefore , the acceleration due to gravity on poles is more than that at the equator.

3. To move to higher altitudes or go deep inside the earth, its value always decreases. It becomes zero at the centre of the earth.

Mass

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

Unit (In SI system) - kg.

Inertial Mass

When we apply force on a body , it moves with a certain acceleration. The ratio between the applied force and acceleration produced is called inertial mass.

$F/a = m_i$ Where $\mathbf{m_i}$ – inertial mass , **F** – force applied on a body, **a** - acceleration.

Gravitational mass

When a body falls towards the earth with acceleration due to gravity, it experiences a gravitational force.

The ratio between the gravitational force on the earth on a given body to the acceleration due to gravity is called the gravitational mass.

$m_G = F/g$ where **F** – Force of gravitation due to earth on a given body, **g** - acceleration due to gravity, $\mathbf{m_G}$ – gravitational mass.

It is useful to note that the magnitude of the gravitational mass and the inertial mass at a given place is the same.

To show that if to bodies are attracted by the earth with the same force, then they have equal masses.

Consider two bodies A and B , such that their masses are m_1 and m_2 . Let both the bodies be attracted by the earth with the same force F.

M – mass of earth

R – radius of earth

For body A , $F = Gm_1M / R^2$ -------------- (1)

For body B , $F = Gm_2M / R^2$ -------------- (2)

Comparing equation (1) and (2)

$Gm_1M / R^2 = Gm_2M / R^2$

$m_1 = m_2$

Thus , when two bodies are attracted with the same force at a given place, they have equal masses.

Weight

The force with which a body falls towards the surface of earth, is called its weight.

(OR)

The pull exerted on a body by the earth is called its weight.

F = mg where, F – force with which the body is pulled towards the earth, **m** – mass of the body , **g** – acceleration due to gravity.

Weight of a substance is the product of its mass and acceleration due to gravity.

SI unit – newton

Gravitational unit – 1 kg-wt = 1 kg x 9.8 m/s^2 = 9.8 N

Difference between mass and weight

S.No	Mass	Weight
1	Mass is the quantity of matter contained in a body and is measure of its inertia.	Weight of the body is the force with which the earth attracts the body.
2	It is a scalar quantity	It is a vector quantity
3	Its value remains constant at all places,. i.e. does not change from place to place.	It is a variable quantity and changes with the change in acceleration due to gravity of a place.
4	Mass of a body can never be zero	Weight of a body can be zero during free fall
5	It is measured by using a physical balance.	It is measured by using a spring balance.
6	Its SI unit is kg.	Its SI unit is newton.

Weightlessness

Weightlessness is a situation in which the effective weight of the body becomes zero.

The body can be in a weightlessness state in the following circumstances.

(i) When the body is taken at the centre of the earth.

(ii) When the body is taken at null points (i.e. those points where the gravitational force due to different masses cancel out)

(iii) When a body is lying in a freely falling lift.

(iv) When the body is inside a space craft or satellite which is orbiting around the earth.

Motion equations for freely falling bodies and numerical problems

All freely falling bodies develop uniform acceleration due to gravity

S.No.	General equations of motion	Motion equations for the freely falling bodies
1	$v = u + at$	$v = u + gt$
2	$s = ut + ½ at^2$	$h = ut + ½ gt^2$
3	$v^2 – u^2 =2as$	$v^2 – u^2 =2gh$

Following points must be kept in mind while solving numerical problems on freely falling bodies

1. Acceleration due to gravity **'g' is positive** and its value is **9.8 ms^{-2}**, when a body falls **downwards**.

2. Acceleration due to gravity **'g' is negative** and its value is **-9.8 ms^{-2}**, when a body falls **upwards**.

3. When a body is **dropped** from a certain height, its **initial velocity** is **zero**.

4. When a body is projected **vertically upward**, its **final velocity** is **zero** (at highest point).