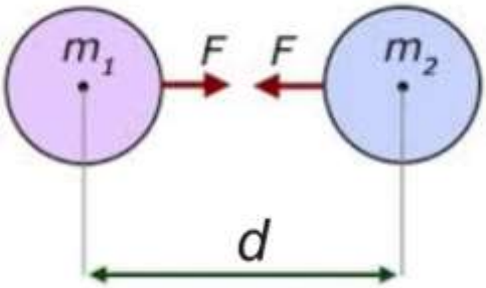
Gravitation

Universal Law of Gravitation

The **Universal law of Gravitation** states that any two bodies having mass attract each other with force directly proportional to the product of their mass and inversely proportional to the square of distance between them. The force acts along the line joining the centres of the objects.



=> $$F \propto \frac{m_1 m_2}{d^2}$$

=> $$F = \frac{G m_1 m_2}{d^2}$$

Here, G is Universal gravitational constant = 6.673×10^{-11} Nm^2kg^{-2}. The value of G was found out by Henry Cavendish.

Note:
- If mass of object is large, force will be more. If mass of object is small, force will be less.
- If distance between two object is more, force exerted will be less and vice versa.

Importance of Gravitational Force

- It binds us to Earth.
- Moon revolves around Earth due to gravitational force. Planets revolve around Sun due to gravitational force.
- Tides in seas are caused due to gravitational force of moon on earth.

Free Fall

The earth attracts objects towards it due to gravitational force. When an object moves such that only gravitational force of earth acts on it, it is said to do "Free Fall".

Attraction of Earth on Objects close to its Surface

When an object is near the surface of earth, the distance between object and centre of the earth will be equal to the radius of earth (i.e.) because the distance of object is negligible in comparison of the radius of earth. Therefore,

$$F = \frac{G m_E m_2}{R_E^2}$$

$$F = m\left(\frac{G m_E}{R_E^2}\right)$$

⇨ $$F = mg \quad \ldots(i)$$

Where,

$$g = \left(\frac{G m_E}{R_E^2}\right)$$

g = acceleration due to gravity. Value of g = 9.8 m/s^2.

Velocity and Acceleration

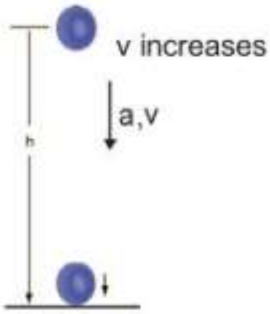
- When an object moves with constant velocity, such motion is called **uniform motion**.
- When an object moves with increasing velocity, motion is called **accelerated motion**.
- When an object moves with decreasing velocity, motion is called **retarded motion**.

Direction of velocity is the direction in which body is moving.

Falling Bodies

Case 1: When an object is released from top, it falls down due to gravitational force of earth. As force acts downwards, acceleration 'a' would be in downward direction.

As object is moving downwards and acceleration is also in downward direction, velocity increases. So when an object is released from top, it does **accelerated motion (increasing velocity)**.



Calculation of acceleration 'a':

According to Newton's 2nd Law

$F = ma$

=> $a = F/m$

From equation (i)

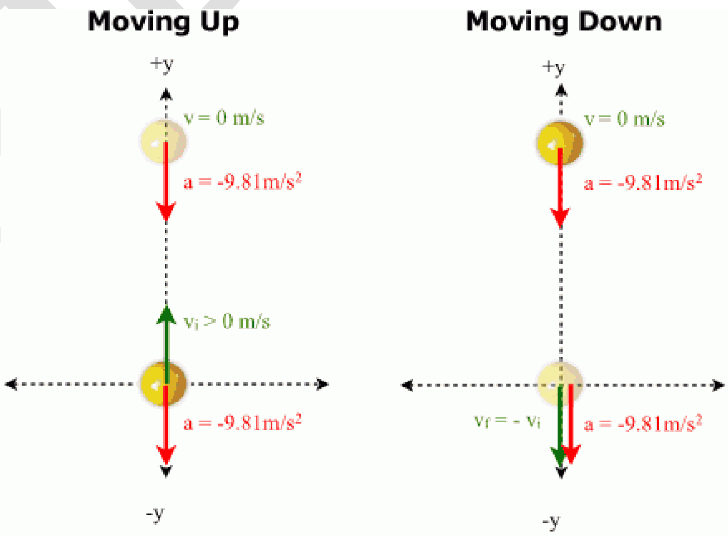
=> $a = mg/m$

=> $a = g = 9.8\ m/s^2$

Thus acceleration acted on a falling object is equal to 'g' (acceleration due to gravity).

Case 2: If we throw a ball upward in the air, a gravitational force acts downwards on it. As force acts downwards, acceleration is in downwards direction. It means velocity will decrease with time and at one point, it becomes zero.

Due to the gravitational force, the ball takes U-turn and reaches to ground with same speed with which it was thrown up. As object is moving downwards and acceleration is also in downward direction, velocity increases.



Note: We have studied three equations of motion.

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

These equations can be used to calculate the value of velocity, distance, etc by replacing 'a' by 'g'.
The value of 'g' is taken as positive in the case of object moving towards earth and taken as negative in the case of object is thrown in opposite direction of earth.

Air Resistance

Theoretically, all objects of different shape, size and mass should take same time to fall through same distance. But practically it is observed that two objects of different mass hit the ground at different times due to different air resistance on them.

Factors affecting Air resistance:

1. More the mass, lesser the effect of air resistance.
2. More the surface area of object, more the effect of air resistance.

Variation in the value of 'g'

- As we go at large heights, g decreases.
- Since, earth is not a perfect sphere rather it has oblique shape. Therefore, radius at the equator is greater than at the poles. Since, value of 'g' is reciprocal of the square of radius of earth, thus, the value of 'g' will be greater at the poles and less at the equator.
- Geography of earth is different at different locations such as mountains, plains, oceans. This causes variation in value of g.

Mass & Weight

Mass

Mass is the quantity of matter present. The mass of a body is always constant and does not change from place to place. Mass has no direction and thus it is scalar quanitity. The SI unit of mass is kg. Mass can be measured using beam balanced.

Weight

Weight of an object is the gravitational force applied by the earth on that object.

$$W = m \times g$$

The weight of a body changes from place to place, depending on mass of object.
Since weight always acts vertically downwards, therefore, weight has both magnitude and direction and thus it is a vector quantity. The SI unit of weight is Newton. Weight can be measured using spring balance.

Weight of an Object on the Surface of Moon

Mass of an object is same on earth as well as moon. But weight is different.

$$\frac{\text{Wt. of body on Earth}}{\text{Wt. of body on Moon}} = \frac{\dfrac{GM_E m}{R_E^2}}{\dfrac{GM_E m}{R_E^2}} = \frac{M_E R_M^2}{R_E^2 M_M}$$

$$= \frac{\left(6\times10^{24}\,Kg\right)}{\left(6.37\times10^{6}\,m\right)^2}\frac{\left(1.74\times10^{6}\,m\right)^2}{\left(7.36\times10^{22}\,Kg\right)}$$

=> $$\frac{\text{Wt. of body on Earth}}{\text{Wt. of body on Moon}} \simeq 6$$

=> Wt. of body on Earth = 6 (Wt. of body on Moon)

Or Wt. of body on Moon = $\frac{1}{6}$ (Wt. of body on Earth)

Circular Motion & Gravitational Force

In circular motion, a force must act on body as its direction of velocity changes. This force is called Centripetal force.

- When moon revolves around earth in circular path, gravitational force of earth provides the centripetal force to moon for circular motion.
- When planets revolve around Sun, gravitational force of Sun provides the centripetal force to planets.

Thrust and Pressure

Thrust: Force exerted by an object perpendicular to the surface is called thrust.

Pressure: Pressure is defined as thrust or force per unit area on a surface.

$$\text{Pressure} = \frac{\text{Thurst}}{\text{Area}}$$

$$\text{SI unit of pressure} = \frac{N}{m^2} = Nm^{-2} = \text{Pascal (Pa)}$$

Since, pressure is indirectly proportional to the surface area of the object, so, pressure increases with decrease in surface area and decreases with increase in surface area.

Pressure in Fluids

Anything that can flow is called **Fluid** like liquid and gases.

Molecules of fluid move around and collide with walls of vessel. Thus fluids apply pressure on walls. Fluids exert pressure in all directions.

Buoyancy & Buoyant Force: Fluid applies an upward force on a solid which is partially or fully submerged in liquid. This phenomenon is called buoyancy (Upthrust) and applied upward force is called buoyant force.

Experiment – 1:

Take a empty bottle and float it on water. If we push it down in the water partially or fully and then release, bottle suddenly jumps upward. This is because the water applies an upward force on bottle.

Experiment – 2:

Hang a rubber string. Attach a stone to the rubber string. String will elongate. Submerge the stone in water – filled bucket. The elongation in string decreases.
This happens due to upward buoyant force of water.

Archimedes Principle

When an object is fully or partially submerged in a liquid, buoyant force acts on it in upward direction. Its value is equal to weight of liquid displaced.

For example, suppose an object is partially submerged in a liquid and the mass of displaced liquid is 1.5 kg. Then

Buoyant force applied on the object (F) = Weight of liquid displaced = mg
= (1.5)(9.8) = 14.7 N

Archimedes principle has many uses. It is used in designing ships, submarines, air balloons etc.

Density

The density of a substance is the mass of a unit volume of the substance.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Every material has its own density. The SI unit of density is kilogram per metre cube (kg m^{-3}).

Material	Density (kg / m³)
Aluminum	2,700
Blood	1,600
Brass	8,600
Copper	8,900
Gold	19,300
Iron	7,800
Lead	11,300
Mercury	13,600
Platinum	21,400
Silver	10,500
Steel	7,800
Water	1,000

Relative Density

The relative density of a substance is the ratio of the density of a substance to the density of water.

$$\text{Relative Density} = \frac{\text{Density of a substance}}{\text{Density of water}}$$

Since relative density is a ratio of similar quantities, it has no unit.