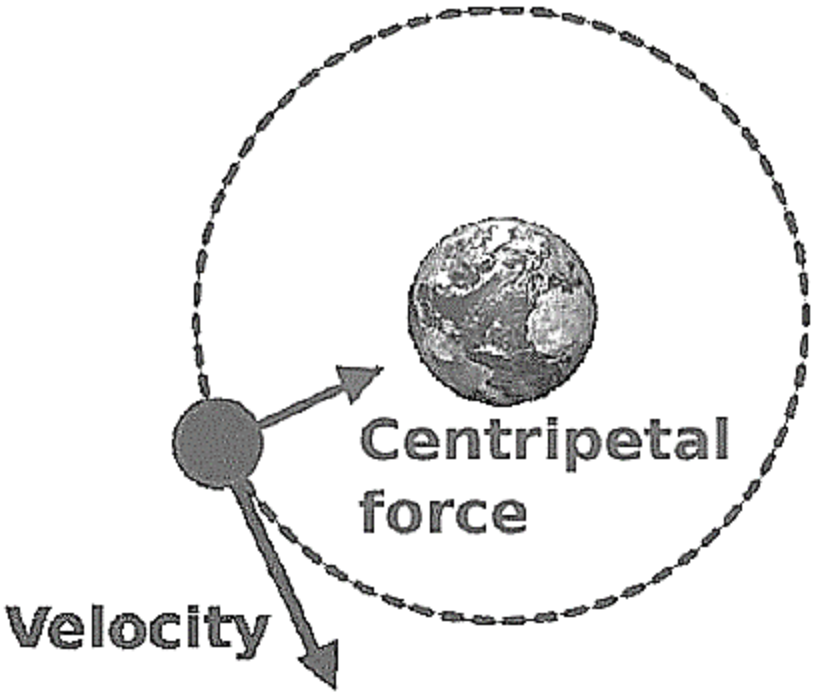
Board – CBSE	Class – 9th	Topic – Gravitation

1. Centripetal Force
   - We know that an object in circular motion keeps on changing its direction.
   - Due to this, the velocity of the object also changes.
   - A force called Centripetal Force acts upon the object that keeps it moving in a circular path.
   - The centripetal force is exerted from the centre of the path.
   - Without the Centripetal Force, objects cannot move in circular paths; they would always travel straight.
   - For Example, The rotation of the Moon around the Earth is possible because of the centripetal force exerted by Earth.



2. Newton's Observations
   - Why does Apple fall on Earth from a tree? - Because the Earth attracts it towards itself.

- Can Apple attract the Earth? - Yes. As per Newton's Third Law (every action has an equal and opposite reaction). But the mass of the Earth is much larger than Apple's mass; thus, the force applied by Apple appears negligible, and Earth never moves towards it.
- Newton thus suggested that all objects in this universe attract each other. This force of attraction is called Gravitational Force

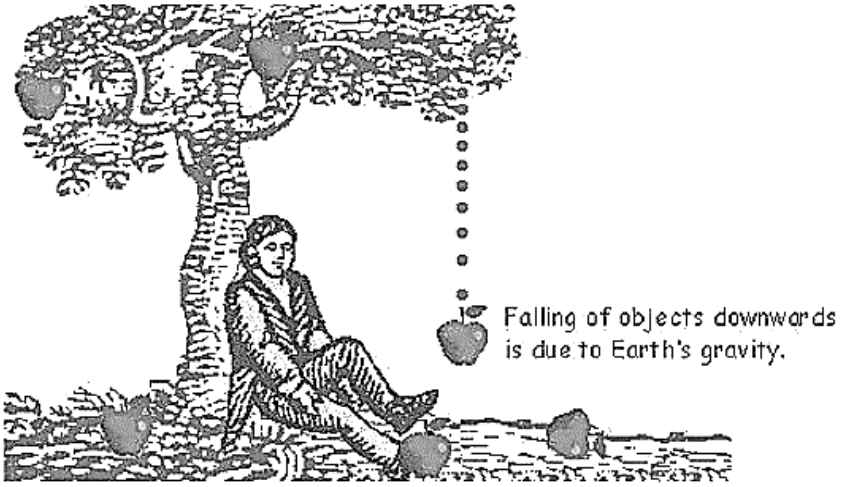
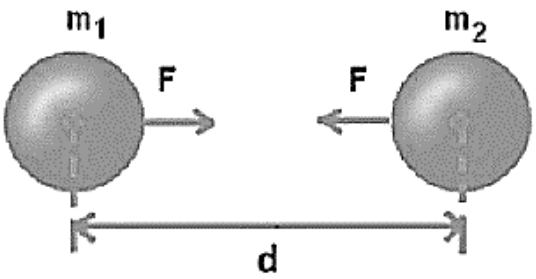


Figure 2 Gravitational Force of Earth

3. Universal Law of Gravitation by Newton

- According to the universal Law of gravitation, every object attracts every other object with force.
- This force is directly proportional to the product of their masses.
- This force is inversely proportional to the square of distances between them.
- Consider the figure given below. It depicts the force of attraction between two objects with masses m_1 and m_2 respectively that are 'd' distance apart.



- The figure below describes how the universal Law of gravitation is derived mathematically.

  From the above equation, we can rewrite them as the following:

  If we remove the proportionality, we get proportionality constant G as the following:

  The above equation is the mathematical representation of Newton's Universal Law of gravitation

  Hence, $G = \frac{Fr^2}{m_1 m_2}$

  SI Unit: $Nm^2 kg^{-2}$

  Value of $G = 6.673 \times 10^{-11} Nm^2 kg^{-2}$ (was found out by Henry Cavendish (1731-1810))
- The proportionality constant G is also known as the Universal Gravitational Constant.

4. Why do we study the universal Law of gravitation?

It explains many important phenomena of the universe -

- Earth's gravitational force
- Why the Moon always move in a circular motion around the Earth and the sun.
- Why do all planets revolve around the sun
- How the sun and Moon can cause tides

5. Free Fall

- Acceleration due to Gravity - Whenever an object falls towards the Earth, there is an acceleration associated with the object's movement. This acceleration is called acceleration due to Gravity.
- Denoted by: g
- SI Unit: ms^{-2}
- We know that, $F = ma$
- Therefore, $F = mg$

- The following figure demonstrates the mathematical derivation of.' g

The force (F) of gravitational attraction on a body of mass m due to Earth of mass M and radius R is given by

We know from Newton's Second Law of motion that force is the product of mass and acceleration.

$\therefore F = ma$

But the acceleration due to Gravity is represented by the symbol g. Therefore, we can write

$F = mg$ .....(2)

From the equation (1) and (2), we get

When the body is at a distance ' r ' from the centre of the Earth, then

6. Value of 'g' may vary at different parts of the Earth -

- From the equation $g = GM/r^2$ it is clear that the value of ' g depends upon the distance of the object from the Earth's centre.
- This is because the shape of the Earth is not a perfect sphere. It is rather flattened at poles and bulged out at the equator.
- Hence, the value of g is greater at the poles and lesser at the equator. However, for our convenience, we take a constant value of ' g ' throughout.

We can find the value of acceleration due to Gravity by the following –

7. What is Free Fall?

When an object falls towards the Earth due to Earth's Gravity and no other force is acting upon it, it is said to be in a free-fall state. The air does not even resist Free-falling objects. $g = 9.8\ m/s^2$ is also called the Free-fall Acceleration.

Value of ' g is the same on the Earth, so the equations of motion for an object with uniform motion are valid where acceleration.' a is replaced by ' g^1, as given under:

$v = u + gts = ut + (1/2)gt^2 2gs = v^2 - u^2$

8. Consider the equations of motion given in different scenarios:

When an object at rest falls towards Earth - its initial velocity is zero

$v = gt$

$s = t + (1/2)gt^2$

$2gs = v^2$

When an object with some initial velocity (u) falls towards Earth –

$v = u + gt$

$s = ut + (1/2)gt^2$

$2gs = v^2 - u^2$

When an object is thrown upwards from Earth - the gravitational force acts in the opposite direction. Hence g is negative

$v = u - gt$

$s = ut - (1/2)gt^2$

$2gs = v^2 - u^2$

9. Difference between Universal gravitational Constant and Acceleration due to Gravity

Mass	**Weight**
Mass is defined as the quantity of matter in an object.	The weight of an object is the force by which the gravitational pull of Earth attracts the object.
Mass is a scalar quantity	Weight is a vector quantity
The mass of an object is always constant as it depends upon the inertia of the object	The weight of an object can vary at different locations because of changes in the gravitational force of the Earth
Mass can never be zero	Weight can be zero at a place there is no gravitational force
Denoted as: m	Denoted as W

	F = mg
	Where m = mass of an object
	a = acceleration due to Gravity
	Similarly, W is force, so
	W = mg
SI unit: kg	SI unit: N

10. Weight of an object on the Moon

Just like the Earth, the Moon also exerts a force upon objects. Hence, objects on Moon also have some weight. The weight will not be the same as that on the Earth. So, weight on the Moon can be calculated as -

$$W_M = \frac{GM_M m}{R_M^2}$$

Now,

$$\Rightarrow \frac{W_M}{W_E} = \frac{M_M R_E^2}{M_E R_M^2}$$

Where,

$$M_E = 5.98\times10^{24}\ kg$$

$$M_M = 7.36\times10^{22}\ kg$$

$$R_E = 6.4\times10^{6}\ m$$

$$R_M = 1.74\times10^{6}\ m$$

$$\Rightarrow \frac{W_M}{W_E} = \frac{7.36\times10^{22}\times\left(6.4\times10^{6}\right)^2}{5.98\times10^{24}\times\left(1.74\times10^{6}\right)^2} = 0.165\approx\frac{1}{6}$$

Therefore, the weight of an object on the Moon is $\frac{1}{6}$ of its weight on the Earth.

11. Thrust and Pressure

Thrust

- The force that acts in the perpendicular direction is called thrust.
- It is similar to force applied to an object
- It is a vector quantity.

Pressure

- The force that acts per unit area of the object is pressure.
- It is the thrust per unit area.
- Pressure is denoted by.' P'
- P = thrust / area = force / area = F/A
- SI unit: N/m^2 or Pa (Pascal)

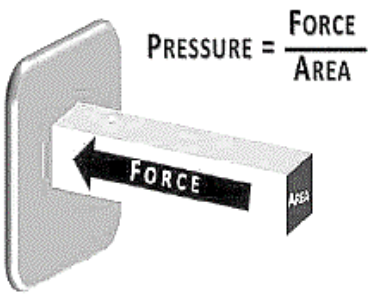


Figure 4 Pressure

12. Why do nails have sharp edges?

We know that pressure is inversely proportional to area. As the area increases, pressure decreases and vice versa. So, nails' sharp edges make it easier for them to get into the wall because more pressure is exerted on the wall from a single point.

- Solids - They exert pressure on the surface because of their weight.
- Fluids (gases and liquids) - They also have weight. Therefore, they exert pressure on the surface and the walls of the container they are put in.

13. Buoyancy

- Whenever an object is immersed in a liquid, the liquid exerts a buoyant force or upthrust in the opposite direction of the gravitational force. This is also called the Force of Buoyancy.

- It depends upon the density of the fluid.
- Therefore, an object can float in water when the gravitational force is less than the buoyant force.
- Similarly, an object sinks into the water when the gravitational force is larger than the buoyant force.

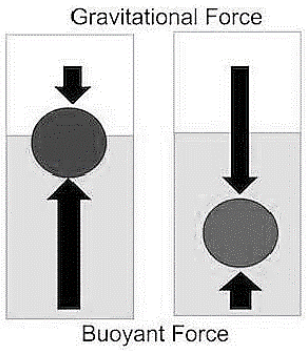


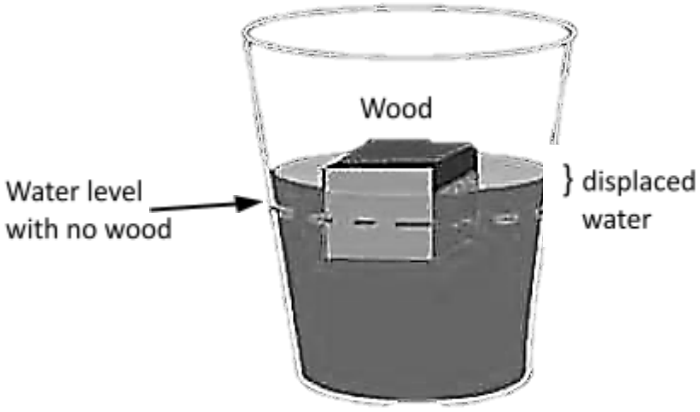
Figure 5 Buoyancy

14. Why does an object sink or float on water?

- An object can sink or float on water based on its density with respect to water. The density is defined as mass per unit volume.
- Objects that have a density less than water float in it. For Example, Cork flows in water because its density is lower than that of water.
- Objects that have a density higher than water sink in it. For Example, Iron nail sinks in water because the density of iron is more than water's density.
- Thus, we can conclude that buoyancy depends upon:
- The density of the liquid
- The volume of the object (as the volume of the object increases, its density decreases and vice-versa)

15. Archimedes Principle

According to the Archimedes principle, whenever an object is immersed in a liquid (fully or partially), the liquid exerts an upward force upon the object. The amount of that force is equivalent to the weight of the liquid displaced by the object.



This means that if the weight of an object is greater than the amount of liquid it displaces, the object will sink into the liquid. However, if the weight of an object is less than the amount of water it displaces, the object will sink.

- Submarines have a tank called Buoyancy Tank. Whenever the submarine needs to be taken inside water, the tank is filled, thus increasing the submarine's weight. Similarly, when the submarine appears above water, the tank is emptied. The weight of the submarine becomes lighter, and it rises above the water.
- Ships are heavier than water, but their unique shape gives them a large volume. Their volume is larger than their weight, and hence the water displaced by a ship provides it with the right upthrust to float on water.

16. Applications of Archimedes Principle

- In evaluating relative density
- In designing ships and submarines
- In making lactometers and hydrometers

17. What is relative density?

When density can be expressed in comparison with water's density, it is called Relative Density. It has no unit because it is a ratio of two similar quantities.

18. Why is water chosen as a reference?

Water is present everywhere on Earth, so it becomes easier to evaluate the density of a substance in relation to water.

How can relative density be used to determine whether an object will sink or float in water?

Relative density of an object	Float / Sink
Greater than 1	Sink in water
Less than 1	Float in water