Chapter 10: - GRAVITATION

Part-1:

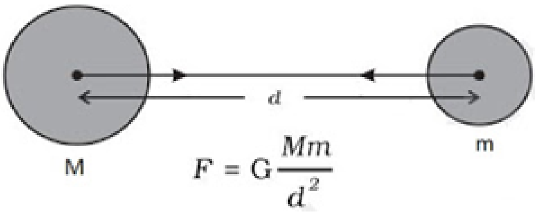
<u>Gravitation</u>

Earth attracts everything towards it by an unseen force of attraction. This force of attraction is known as gravitation or gravitational pull.

Universal Law of Gravitation

Every object in the universe attracts other object by a force of attraction, called gravitation, which is directly proportional to the product of masses of the objects and inversely proportional to the square of distance between them. This is called Law of Gravitation or Universal Law of Gravitation.

Let masses (*M*) and (*m*) of two objects are distance (*d*) apart. Let **F** be the attractional force between two masses.



Here, $F \propto M \times m$

Also, $F \propto \frac{1}{d^2}$

$\Rightarrow \quad F \propto \frac{Mm}{d^2}$

Or $\quad F = \frac{GMm}{d^2}$

Where,

G is a constant and is known as Gravitational constant.

Value of $G = 6.67 \times 10^{-11}\ \text{Nm}^2/\text{kg}^2$

G is called universal gravitational constant.

Importance of The Universal Law of Gravitation

- It binds us to the earth.
- It is responsible for the motion of the moon around the earth.
- It is responsible for the motion of planets around the Sun.
- Gravitational force of moon causes tides in seas on earth.

Free Fall

When an object falls from any height under the influence of gravitational force only, it is known as free fall.

Acceleration Due to Gravity

When an object falls towards the earth there is a change in its acceleration due to the gravitational force of the earth. So this acceleration is called acceleration due to gravity.

The acceleration due to gravity is denoted by g.

The unit of g is same as the unit of acceleration, i.e., ms^{-2}

Mathematical Expression for *g*

From the second law of motion, force is the product of mass and acceleration.

$$F = ma$$

For free fall, acceleration is replaced by acceleration due to gravity.

Therefore, force becomes:

$$F = mg \quad \text{....(i)}$$

But from Universal Law of Gravitation,

$$F = \frac{GMm}{d^2} \quad \text{....(ii)}$$

From equations (i) and (ii), we get:

$$mg = \frac{GMm}{d^2}$$

$$\Rightarrow \quad g = \frac{GM}{d^2}$$

Where M is the mass of the earth and d is the distance between the object and the earth.

For objects near or on the surface of the earth distance d is equal to the radius of the earth R.

Thus, $$g = \frac{GM}{R^2} \quad \text{.....(iii)}$$

Factors Affecting the Value of g

- As the radius of the earth increases from the poles to the equator, the value of *g* becomes greater at the poles than at the equator.
- As we go at large heights, value of *g* decreases.

To Calculate the Value of g

Value of universal gravitational constant, $G = 6.7 \times 10^{-11}$ N m^2/ kg^2,
Mass of the earth, $M = 6 \times 10^{24}$ kg, and
Radius of the earth, $R = 6.4 \times 10^6$ m

Putting all these values in equation (iii), we get:

$$g = \frac{6.7\times10^{-11}\text{Nm}^2/\text{kg}^2\times6\times10^{24}\text{kg}}{\left(6.4\times10^6\text{m}\right)^2} = 9.8\,\text{m/s}^2$$

Thus, the value of acceleration due to gravity of the earth, g = 9.8 m/s^2.

Difference between Gravitation Constant (G) and Gravitational Acceleration (g)

S. No.	Gravitation Constant (G)	Gravitational acceleration (g)
1.	Its value is $6.67\times10^{-11}Nm^2/kg^2$.	Its value is 9.8 m/s^2.
2.	It is a scalar quantity.	It is a vactor quantity.
3.	Its value remains constant always and everywhere.	Its value varies at various places.
4.	Its unit is Nm^2/kg^2.	Its unit is m/s^2.

Motion of Objects Under the Influence of Gravitational Force of the Earth

Let an object is falling towards earth with initial velocity u. Let its velocity, under the effect of gravitational acceleration g, changes to v after covering the height h in time t.
Then the three equations of motion can be represented as:
Velocity (v) after t seconds, $v = u + ght$
Height covered in t seconds, $h = ut + ½gt^2$
Relation between v and u excluding t, $v^2 = u^2 + 2gh$
The value of g is taken as positive in case of the object is moving towards earth and taken as negative in case of the object is thrown in opposite direction of the earth.

Mass & weight

Mass (m)

- The mass of a body is the quantity of matter contained in it.
- Mass is a scalar quantity which has only magnitude but no direction.
- Mass of a body always remains constant and does not change from place to place.
- SI unit of mass is kilogram (kg).
- Mass of a body can never be zero.

Weight (W)

- The force with which an object is attracted towards the centre of the earth, is called the weight of the object.

Now, Force = $m \times a$
But in case of earth, $a = g$
$\therefore F = m \times g$
But the force of attraction of earth on an object is called its weight (W).
$\therefore W = mg$

- As weight always acts vertically downwards, therefore, weight has both magnitude and direction and thus it is a vector quantity.
- The weight of a body changes from place to place, depending on mass of object.
- The SI unit of weight is Newton.
- Weight of the object becomes zero if g is zero.

Weight of an Object on the Surface of Moon

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

$$W = mg$$

Where $W = \frac{GMm}{R^2}$

$\Rightarrow$ Let weight of object on earth be given as:

$$W_e = \frac{GM_e m}{R_e^2}$$

Where, G = Gravitational constant
M_e = Mass of earth
R_e = Radius of earth
And m = Mass of object
And, weight of object on moon be given as:

$$W_m = \frac{GM_m m}{R_m^2}$$

Where, M_m = Mass of earth
R_m = Radius of earth

$$\frac{W_e}{W_m} = \frac{GM_e m}{R_e^2} \times \frac{R_m^2}{GM_m m}$$

$$\Rightarrow \quad \frac{W_e}{W_m} = \frac{M_e}{M_m} \times \left(\frac{R_m}{R_e}\right)^2$$

Now, We know that mass of earth is 100 times the mass of the moon.
$\Rightarrow \quad M_e = 100\ M_m$
And radius of earth is 4 times the radius of moon.
$\Rightarrow \quad R_e = 4R_m$

$$\Rightarrow \quad \frac{W_e}{W_m} = \frac{100M_m}{M_m} \times \left(\frac{R_m}{4R_m}\right)^2$$

$$\Rightarrow \quad \frac{W_e}{W_m} = \frac{100}{16} = 6.25 \approx 6(\text{approx.})$$

$$\Rightarrow \quad W_m = \frac{1}{6} W_e$$

Hence, weight of the object on the moon = (1/6) × its weight on the earth.

Try the following questions:

Q1. State the universal law of gravitation.
Q2. When we move from the poles to the equator, the value of g decreases. Why?
Q3. If two stones of 150 gm and 500 gm are dropped from a height, which stone will reach the surface of the earth first and why ?
Q4. Differentiate between weight and mass.
Q5. Why is the weight of an object on the moon 1/6th its weight on the earth?

Chapter 10: - GRAVITATION

Part-2:

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.

- Pressure = Thrust/Area
- SI unit of pressure is Newton/meter^2 (N/m^2).
- SI unit of pressure is called Pascal (Pa).

Factors affecting Pressure
Pressure depends on two factors:

(i) Force applied
(ii) Area of surface over which force acts

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

Applications of Pressure in daily life

- The base of high buildings is made wider to spread the weight of the whole building over a large surface area due to which less pressure acts on the ground.
- School bags are provided with broad straps so that the weight of school bags fall over a larger area of the shoulder and produce less pressure hence making it easy to carry.
- The blades of knives are made sharp so that on applying force on it, a large pressure is produced on the very small surface area, thus cutting the object easily.

Pressure in Fluids

- Anything that can flow is called Fluid. Example: liquid and gas.
- Molecules of a fluid move randomly and collide with walls of vessel. Thus, fluids apply pressure on walls.
- Fluids exert pressure in all directions.

Buoyancy & Buoyant Force

- Force applied by the fluid on a solid which is partially or fully submerged in liquid, is called the buoyant force and this phenomenon is named as buoyancy.
- Buoyant force acts in upward direction and it depends on the density of the fluid.

Factors affecting the Buoyant Force:
Magnitude of the buoyant force depends on two factors:

- Volume of the object immersed in liquid
- Density of the liquid

Why does an object sink or float over water?
When an object is immersed in water, it exerts pressure over water due to its weight. At the same time water also exerts upward thrust, i.e., buoyant force over the object.

- If the force exerted by the object is greater than the buoyant force of water, the object sinks in water.
- If the force exerted by the object is less than the buoyant force of water, the object floats over water.

Archimedes' Principle

- It states that when a body is immersed fully or partially in a fluid, it experiences an upward force that is equal to the weight of the fluid displaced by it.

Applications of Archimedes' Principle:

- It is used in designing ships and submarines.
- It is used in determining relative density of substances.
- Hydrometers used to determine the density of liquids, work on this principle.
- Lactometers used to determine purity of milk, are also based on this principle.

It is because of this principle that ship made of iron and steel floats in water whereas a small piece of iron like nail, sinks in it.

Density (ρ)

- The mass per unit volume is called density of an object.
- Density (ρ) = Mass(M)/Volume(V)
- SI unit of density = kg/m^3

Relative density

- It is the ratio of the density of a substance to the density of water.

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

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

Applications of density

- If an object has density more than that of the liquid, it will float over that liquid.
- If an object has density lower than that of a liquid, it will sink in that liquid.

- When the relative density of a substance is less than 1, it will float in water otherwise it will sink in water.

Try the following questions:
Q1. What is buoyancy and buoyant force? Upon what factors do they depend?
Q2. Why does iron sink in water but floats on mercury?
Q3. Why does a buffalo float on the river but not the man?
Q4. Why does a mug full of water appear lighter inside the water?
Q5. The density of ice is $918kgm^{-3}$ and that of sea water is $1{,}030kgm^{-3}$. An iceberg floats with a portion 224 litres outside water. Find the volume of iceberg.