Chapter 10: - GRAVITATION

Part-1:

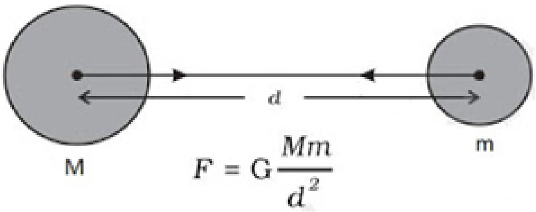
<u>Gravitation</u>

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 $G = 6.67\times10^{-11}\ \mathrm{Nm^2/kg^2}$

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:

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

But from Universal Law of Gravitation,

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

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

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

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

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

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:

$$g = \frac{6.7 \times 10^{-11} \text{Nm}^2/\text{kg}^2 \times 6 \times 10^{24} \text{kg}}{\left(6.4 \times 10^6 \text{m}\right)^2} = 9.8\,\text{m/s}^2$$

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 $6.67 \times 10^{-11} \text{Nm}^2/\text{kg}^2$.	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?