# CLASS 9
# GRAVITATION

## Topics in the Chapter

- Introduction
- Newton's Universal law of Gravitation

→ Importance of universal law of gravitation

- Free fall of an object and acceleration due to gravity

→ Value of g

→ Relationship between G and g

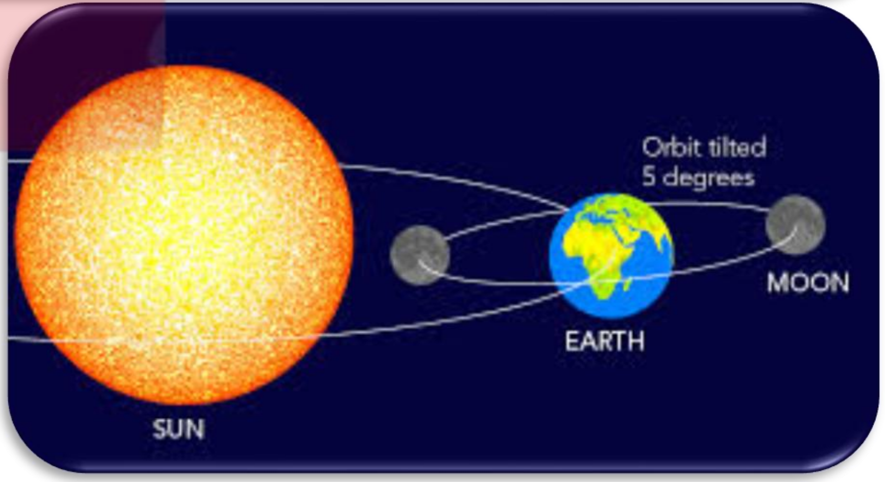
- Mass
- Weight
- Difference between Mass and Weight
- Factors that affect value of g
- Thrust and Pressure
- Buoyancy
- Density
- Archimede's Principle

→ Application of Archimede's Principle

- Solved Numericals

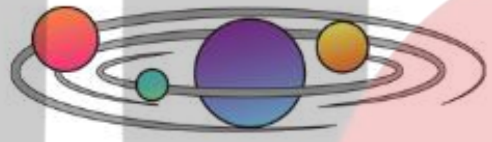
# Introduction

- An object dropped from a height falls towards the earth.
- We know that all the planets go around the Sun.
- The moon goes around the earth.
- There must be some force acting on the objects, the planets and on the moon.
- **Isaac Newton** could grasp that the same force is responsible for all these. This force is called the **gravitational force.**

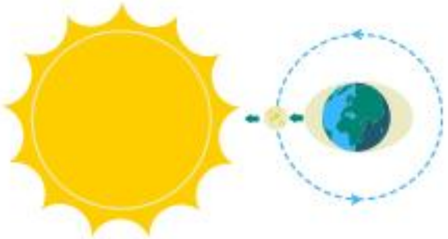


# Examples of Gravitation

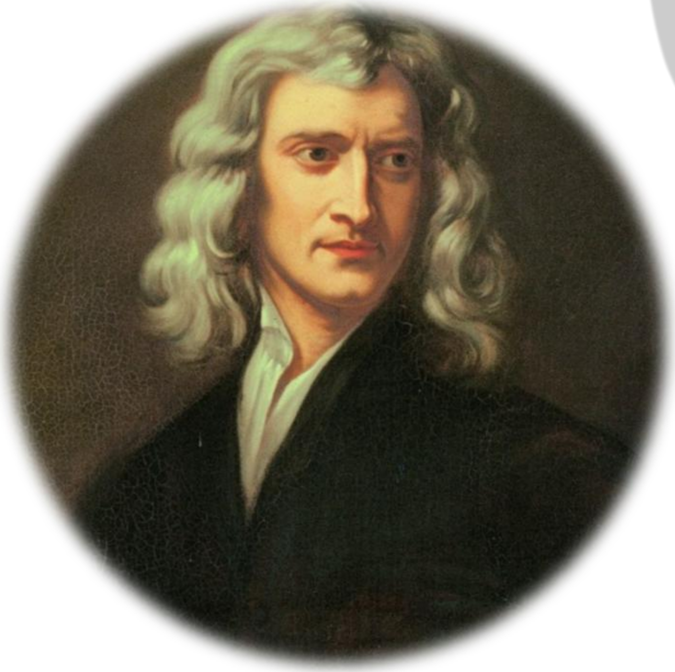
Apple Tree



Orbit Planet



Moon's Tides



Formation of planets

Satellite Orbits

- Before the thread is released, the stone moves in a circular path with a certain speed and changes direction at every point. The change in direction involves change in velocity or acceleration. The force that causes this acceleration and keeps the body moving along the circular path is acting towards the centre. This force is called the centripetal (meaning 'centre-seeking') force. In the absence of this force, the stone flies off along a straight line. This straight line will be a tangent to the circular path.
- The motion of the moon around the earth is due to the centripetal force. The centripetal force is provided by the force of attraction of the earth

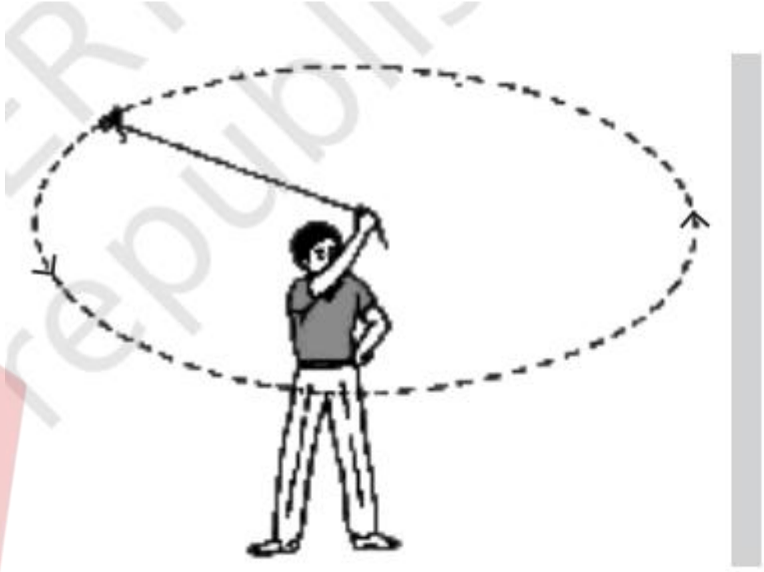


*Fig. 9.1: A stone describing a circular path with a velocity of constant magnitude.*

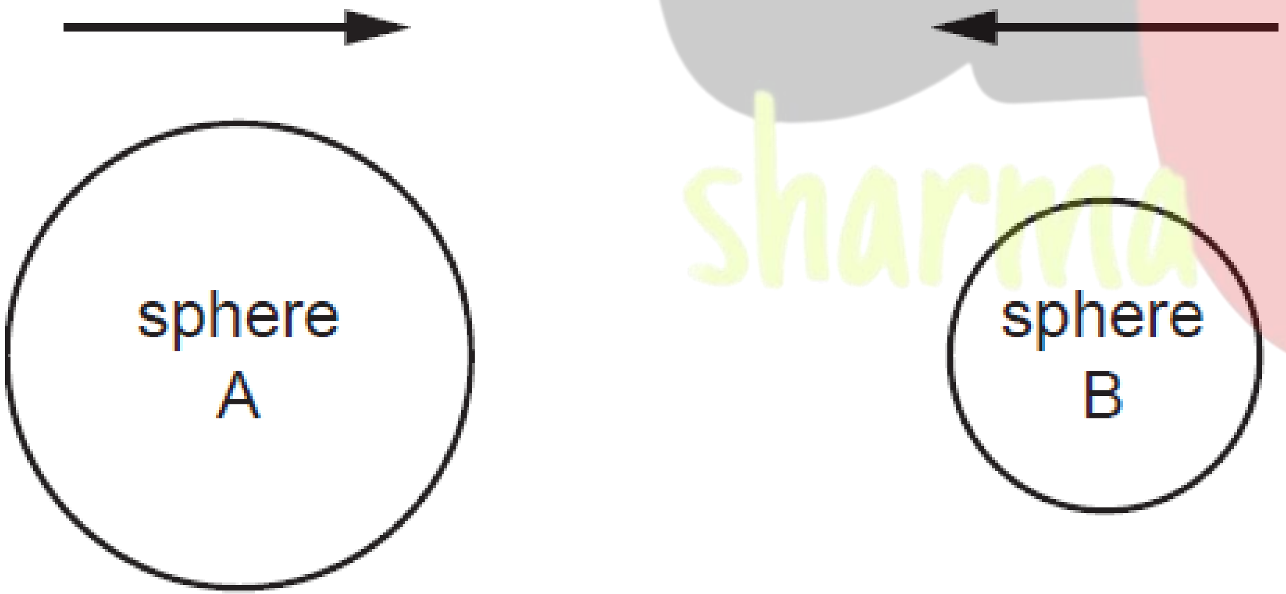
- It is seen that a falling apple is attracted towards the earth. Does the apple attract the earth? If so, we do not see the earth moving towards an apple. Why?
- From the above facts, Newton concluded that not only does the earth attract an apple and the moon, but all objects in the universe attract each other. This force of attraction between objects is called the **gravitational force**.

# Newton's Universal law of Gravitation

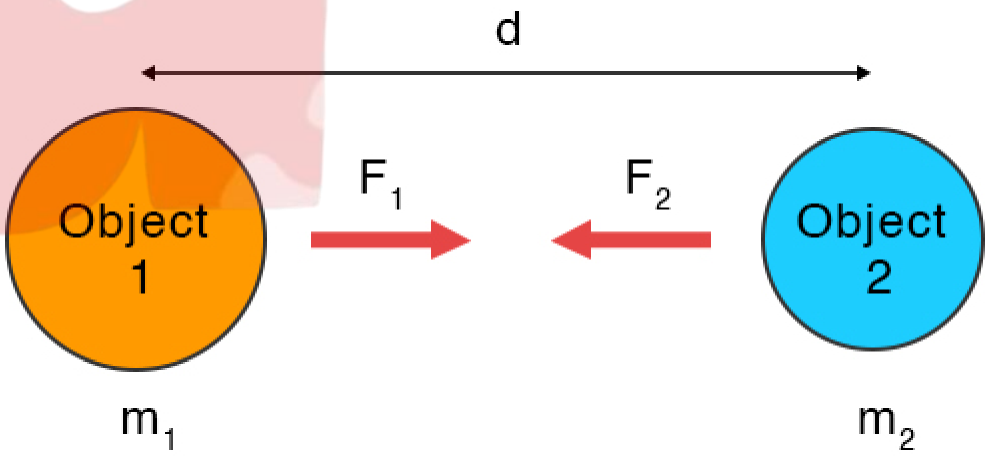
- Sir Isaac Newton in 1687 proposed a law about the force of attraction between the two objects in the universe which is known as Newton’s law of gravitation.

According to universal law of gravitation :-

- Every object in the universe attracts every other object with a force which is proportional to the product of their masses and inversely proportional to the square of the distance between them.
- The force is along the line joining the centres of two objects.

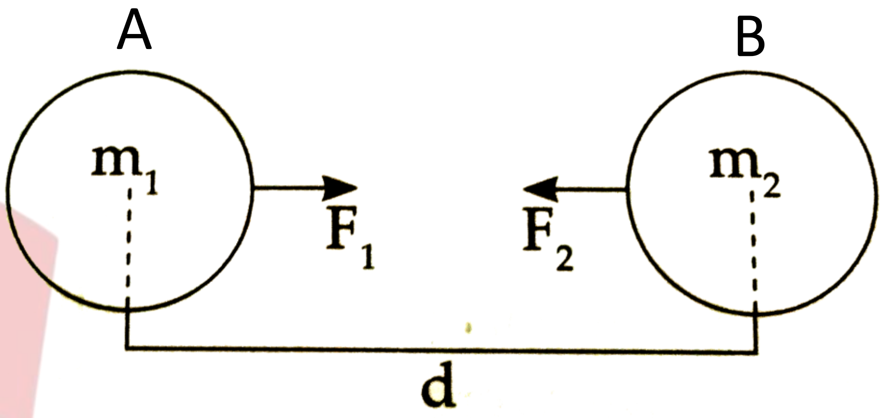



**Gravitational Force**



# Expression for law of gravitation :-

Let two objects A and B of masses $m_1$ and $m_2$ lie at a distance d from each other. Let the force of attraction between two objects be F.




According to the universal law of gravitation,
the force between two objects is directly proportional to the product of their masses.

i.e. $F \propto m_1 \times m_2$ ---------- (i)

And, the force between two objects is inversely proportional to the square of the distance between them,

i.e. $F \propto \frac{1}{d^2}$ ---------- (ii)

On combining Eqs. (i) and (ii), we get

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

Or, $$F = G \frac{m_1 \times m_2}{d^2}$$

where G is the constant of proportionality and is called the universal gravitation constant.

## Unit of G :-

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

$$F \times d^2 = G\, m_1 \times m_2$$

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

$$G = \frac{N \times m^2}{kg \times kg}$$

Thus,

- The SI unit of G is N $m^2$ $kg^{-2}$
- The value of G was found out by **Henry Cavendish** (1731 – 1810) by using a sensitive balance.
- The accepted value of G is **6.673 x $10^{-11}$ N $m^2$ $kg^{-2}$** .

Example 9.1 The mass of the earth is 6 x $10^{24}$ kg and that of the moon is 7.4 × $10^{22}$ kg. If the distance between the earth and the moon is 3.84×$10^5$ km, calculate the force exerted by the earth on the moon. (Take G = 6.7 × $10^{-11}$ N $m^2$ $kg^{-2}$)

Solution:

The mass of the earth, M = 6 × $10^{24}$ kg

The mass of the moon, m = 7.4 × $10^{22}$ kg

The distance between the earth and the moon, d = 3.84 × $10^5$ km

= 3.84 × 105 × 1000 m

= 3.84 × $10^8$ m

G = 6.7 × $10^{11}$ N $m^2$ $kg^{-2}$

The force exerted by the earth on the moon is

$$F = G\frac{M \times m}{d^2}$$

$$= \frac{6.7\times10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 6\times10^{24}\ \text{kg}\times7.4\times10^{22}\ \text{kg}}{(3.84\times10^{8}\ \text{m})^2}$$

$$= 2.02 \times 10^{20}\ \text{N}.$$

Thus, the force exerted by the earth on the moon is 2.02 × $10^{20}$ N.

# Questions

1. *State the universal law of gravitation.*
2. *Write the formula to find the magnitude of the gravitational force between the earth and an object on the surface of the earth.*

## Importance of universal law of gravitation

(i) The force that binds us to the earth.
(ii) The motion of moon around the earth.
(iii) The motion of earth around the sun.
(iv) The tides due to moon and the sun.

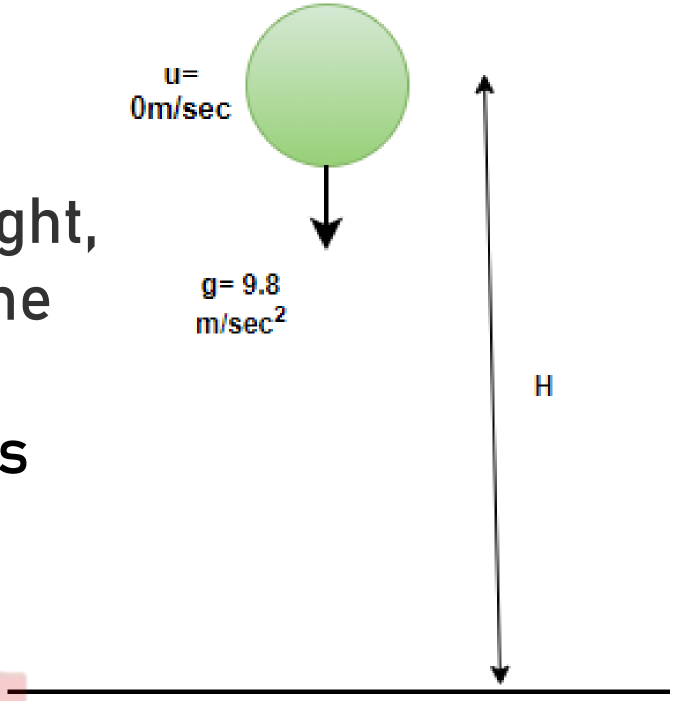
Calculate the force of gravitation between two objects of masses 80 kg and 1200 kg kept at a distance of 10 m from each other.
(Take $G = 6.7 \times 10^{-11}$ N $m^2$ $kg^{-2}$)

**Answer:** The force of gravitation between the two objects is 6.432×10−9 N

How does the gravitational force between two objects change when the distance between them is reduced to half?

**Answer**: When the distance between the two objects is reduced to half, the force of gravitation will increase by a factor of four.

# Free Fall




- When an object is thrown upward, it reaches certain height, then it starts falling down towards earth. It is because the earth's gravitational force exerts on it.
- The fall under the influence of earth gravitational force is called '**free fall of an object**'.
- During this free fall direction do not change but velocity continuously changes which is caused to change in acceleration.
- The acceleration is due gravitational force of earth. So, it is called acc$^{n}$ due to gravitation force or simply acceleration due to gravity.
- It is denoted by 'g'.
- The unit of g is the same as that of acceleration, that is, ms$^{-2}$ .
- It always acts towards the centre of the earth.

# Expression for acceleration due to gravity :-

From the Newton's second law of motion that force is the product of mass and acceleration. $F = m \times a$

Since, acceleration involved in falling objects due to the gravitational force and is denoted by g. $F = m \times g$ ---------- (i)

And, force involve in free fall is gravitational force , it is given as :-

$$F = G\frac{M \times m}{d^2} \quad \text{---------- (ii)}$$

From Eqs. (i) and (ii) we have

$$m \times g = G\frac{M \times m}{d^2} \Rightarrow g = \frac{GM}{d^2}$$

Let an object be on or near the surface of the earth. The distance d will be equal to R, the radius of the earth

$$g = \frac{GM}{R^2}$$

Where, m = mass of object
M = mass of earth
G = Gravitational constant
R = Radius of earth

- The earth is not a perfect sphere. 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.

## To calculate the value of g :-

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.

Put the values of G, M and R in Eq

$$g = \frac{GM}{R^2}$$

$$= \frac{6.7 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 6 \times 10^{24}\ \text{kg}}{(6.4 \times 10^6\ \text{m})^2}$$

$$= 9.8\ \text{m s}^{-2}.$$

Thus, the value of acceleration due to gravity of the earth, $g = 9.8$ m $s^{-2}$.

## Relationship and difference between ‘G’ and ‘g’

G = Gravitational constant
g = Acceleration due to gravity

$$g = \frac{GM}{R^2}$$

Difference between G (Gravitational constant) and g (Acceleration due to gravity)

| Gravitation Constant (G) | Gravitational acceleration (g) |
|---|---|
| Its value is $6.67\times10^{-11}$ $Nm^2/kg^2$. | Its value is 9.8 $m/s^2$. |
| Its value remains constant always and everywhere. | Its value varies at various places. |
| Its unit is $Nm^2/kg^2$. | Its unit is $m/s^2$. |
| It is a scalar quantity. | It is a vector quantity. |

## Equation of motion when an object is falling freely towards earth or thrown vertically upwards

**Case 1: When an object is falling towards earth with initial velocity (u)**

Velocity (v) after t seconds, $v = u + gt$

Height covered in t seconds, $h = ut + \frac{1}{2}gt^2$

Relation between v and u when t is not given: $v^2 = u^2 + 2gh$

**Case 2: When object is falling from rest position means initial velocity u=0**

Velocity (v) after t seconds, $v = gt$

Height covered in t seconds, $h = \frac{1}{2}gt^2$

Relation between v and u when t is not given: $v^2 = 2gh$

**Case 3: When an object is thrown vertically upwards with initial velocity u, the gravitational acceleration will be negative (-g)**

Velocity (v) after t seconds, $v = u - gt$

Height covered in t seconds, $h = ut - \frac{1}{2}gt^2$

Relation between v and u when t is given: $v^2 = u^2 - 2gh$

**Example 9.2** A car falls off a ledge and drops to the ground in 0.5 s. Let g = 10 $ms^{-2}$ (for simplifying the calculations).

(i) What is its speed on striking the ground?

(ii) What is its average speed during the 0.5 s?

(iii) How high is the ledge from the ground?

**Example 9.3** An object is thrown vertically upwards and rises to a height of 10 m. Calculate

(i) the velocity with which the object was thrown upwards and

(ii) the time taken by the object to reach the highest point.

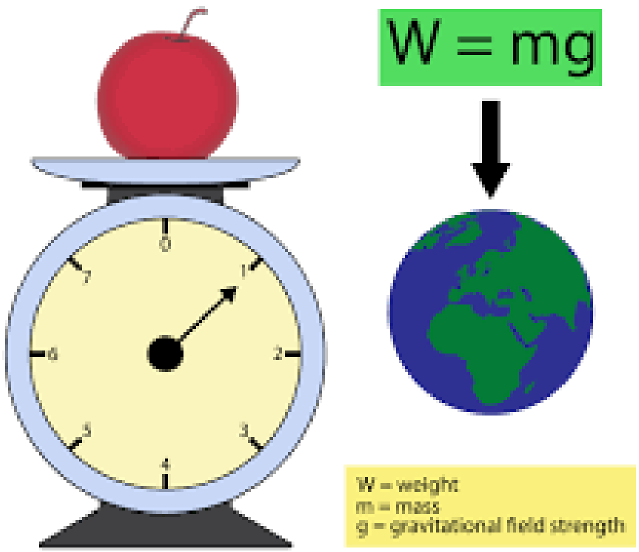
# Mass

→ 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.

→ SI unit of mass is kilogram which is written in short form as kg.

- Mass of a body is constant and does not change from place to place.
- Mass of a body is usually denoted by the small 'm'.
- Mass of a body cannot be zero.

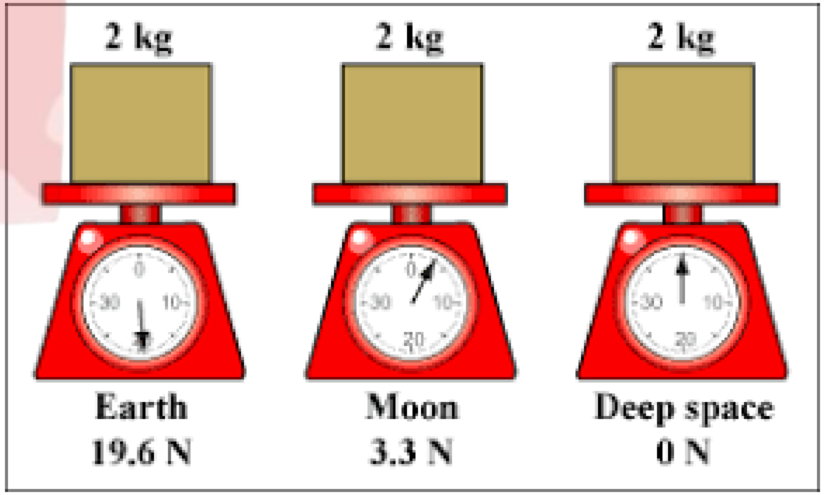
# Weight




→ The force with which an object is attracted towards the centre of the earth, is called the weight of the object.
Or, Weight is defined as product of mass and acceleration due to gravity.

Force = m × a
In case of earth, a = g
∴ F = m× g
But the force of attraction of earth on an object is called its weight (W).
∴ W = m × g

→ Weight is the force and its SI unit is Newton (N).
→ It depends on 'g' and is a vector quantity.



Calculate the weight of an object with a mass of 25 kg on Earth.

- **Question:** An object weighs 98 N on the surface of the Earth. What is its mass?

# Distinguish between Mass and Weight

| Sl. No. | Mass | Weight |
|---|---|---|
| 1. | The mass is a scalar quantity. | The weight is a vector quantity. |
| 2. | Mass of a rigid body is regular everywhere in the universe. | The weight of a rigid body alters from place to place and inclines zero at the center of the earth. |
| 3. | Mass can be resulted by a traditional balance. | Weight can be defined as spring balance |
| 4. | The unit of mass is kg or g. | The unit of weight is Newton. |
| 5. | Mass can never be zero. | Weight can be zero based on the gravity acting upon it. |
| 6. | Mass does not change based on location. | Weight changes based on location, depending on the gravity it experiences. |
| 7. | Mass is measured using an ordinary weighing scale. | Weight is measured using spring balance. |

# WEIGHT OF AN OBJECT ON THE MOON

**Table 9.1**

| Celestial body | Mass (kg) | Radius (m) |
|---|---|---|
| Earth | $5.98 \times 10^{24}$ | $6.37 \times 10^{6}$ |
| Moon | $7.36 \times 10^{22}$ | $1.74 \times 10^{6}$ |

$$W_e = G\frac{M \times m}{R^2}$$

$$W_e = 1.474 \times 10^{11} G \times m$$

$$W_m = G\frac{M_m \times m}{R_m^2}$$

$$W_m = G\frac{7.36 \times 10^{22} \text{kg} \times m}{(1.74 \times 10^6 \text{m})^2}$$

$$W_m = 2.431 \times 10^{10} G \times m$$

$$\frac{W_m}{W_e} = \frac{2.431 \times 10^{10}}{1.474 \times 10^{11}}$$

or $$\frac{W_m}{W_e} = 0.165 \approx \frac{1}{6}$$

$$\frac{\text{Weight of the object on the moon}}{\text{Weight of the object on the earth}} = \frac{1}{6}$$

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

**Example 9.4** Mass of an object is 10 kg. What is its weight on the earth?

**Solution:**

Mass, $m$ = 10 kg
Acceleration due to gravity, $g = 9.8 \text{ m s}^{-2}$

$W = m \times g$

$W = 10 \text{ kg} \times 9.8 \text{ m s}^{-2} = 98 \text{ N}$

Thus, the weight of the object is 98 N.

**Example 9.5** An object weighs 10 N when measured on the surface of the earth. What would be its weight when measured on the surface of the moon?

**Solution:**

We know,
Weight of object on the moon
= (1/6) × its weight on the earth.
That is,

$$W_m = \frac{W_e}{6} = \frac{10}{6} \text{ N.}$$

$$= 1.67 \text{ N.}$$

Thus, the weight of object on the surface of the moon would be 1.67 N.

## Questions

1. *What are the differences between the mass of an object and its weight?*
2. *Why is the weight of an object on the moon $\frac{1}{6}^{th}$ its weight on the earth?*

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