GRAVITATION

Class IX

Gravitational force of the earth or Gravity

A force is necessary to produce motion in a body.

A body dropped from a height falls towards the earth. It indicates that the earth exerts a force of attraction (called gravity) on the body.

In fact, the earth attracts all the objects towards its centre.

The force with which the earth pulls the objects towards it is called the gravitational force of the earth or gravity.

The gravitational force between the sun and the earth keeps the earth in uniform circular motion around the sun.

The gravitational force of the earth (or gravity) is responsible –

for holding the atmosphere above the earth
for the rain falling to the earth
for flow of water in the rivers
for keeping us firmly on the earth,
for the revolution of moon around the earth, etc.

NEWTON'S UNIVERSAL LAW OF GRAVITATION

Every body in the universe attracts every other body with a force which is directly proportional to the product of their masses and is inversely proportional to the square of the distance between them.

The direction of force is along the line joining the centres of the two bodies.

Let two bodies A and B of masses m_1 and m_2 are placed at a distance of 'r' from each other. Let 'F' be the force of attraction between the bodies.

Then,

(i) the force of attraction is directly proportional the product of their masses

i.e. $F \propto m_1 \times m_2$

(ii) the force of attraction is inversely proportional the square of the distance between them

i.e. $F \propto \frac{1}{r^2}$

$$\therefore \quad F \propto \frac{m_1 \times m_2}{r^2}$$

or $$\boxed{F = G\,\frac{m_1 \times m_2}{r^2}}$$

where G is a constant called as "universal gravitational constant"

Properties of gravitational force

1. Gravitational force is the weakest force in nature.
2. It is an attractive force. (Unlike electrostatic and magnetic force; they are both attractive and repulsive)
3. It is a mutual force. (First body attracts the second body and the second body attracts the first body with equal force)
4. It is a central force. (Acts along the line joining the centres of the bodies)
5. It is mass and distance dependent.
6. It obeys inverse square law.
7. It is a long range force. (It decreases with distance as per inverse square law and becomes zero only at infinite distance – like electrostatic and magnetic force)
8. It does not depend on the medium between the interacting bodies. (There is no gravitational shielding)

Gravitational force is the weakest force of all.

If two bodies of mass 1 kg each are separated by 1 m from each other, then, $F = G = 6.67 \times 10^{-11}$ N

Though the various objects on this earth attract one another constantly, they do not cause any visible motion because the gravitational force of attraction between them is very, very small.

Imagine a situation on the earth if the objects continuously move towards each other due to gravitational force between them !

When both the objects are very big, having very large masses, then the gravitational force of attraction between them becomes extremely large.

The gravitational force due to earth on an object of mass 1 kg placed on the ground is 9.8 N.

The gravitational force between the earth and the moon even at a large distance is very large and is 2×10^{20} N.

Universal Gravitational Constant (G)

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

- The value of Universal Gravitational Constant G is 6.67×10^{-11} N m^2 Kg^{-2}.
- The value of G does not depend on the medium between two bodies.
- The value of G is same throughout the Universe and hence the name.
- Universal Gravitational Constant G is different from acceleration due to gravity g. Therefore correct symbol must be used accordingly.
- SI unit of G is N m^2 Kg^{-2}.
- If two bodies of mass 1 kg each are separated by 1 m from each other, then, G = F.
- Therefore, Universal gravitational constant G is numerically equal to the force of gravitation which exists between two bodies of unit masses kept at a unit distance from each other.

Acceleration due to gravity (g)

Acceleration due to gravity is defined as the uniform acceleration produced in a freely falling body due to the gravitational force of the earth.

Acceleration due to gravity (g) = 9.8 m/s² = 980 cm/s².

Calculation of acceleration due to gravity (g)

Suppose a body of mass 'm' is placed on the earth of mass 'M' and radius 'R'.

According to Newton's universal law of gravitation,

Force exerted by the earth on the body is given by

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

This force exerted by the earth produces an acceleration on the body.

Therefore, $F = mg$ (g - acceleration due to gravity)

From the two equations, we have

$$mg = G\,\frac{M \times m}{R^2} \quad \text{or} \quad \boxed{g = \frac{G\,M}{R^2}}$$

FREE FALL

When a body falls from a height towards the earth only under the influence of the gravitational force (with no other forces acting on it), the body is said to have a free fall.

The body having a free fall is called a 'freely falling body'.

Galileo proved that the acceleration of an object falling freely towards the earth does not depend on the mass of the object.

Imagine that vacuum is created by evacuating the air from the glass jar.

The feather and the coin fall with same acceleration and reach the ground at the same time.

Acceleration due to gravity on the earth is calculated as follows:

Mass of the earth = 6×10^{24} kg

Radius of the earth = 6.4×10^{6} m

Gravitational constant = 6.67×10^{-11} N m^2 kg^{-2}

$$g = \frac{G\,M}{R^2}$$

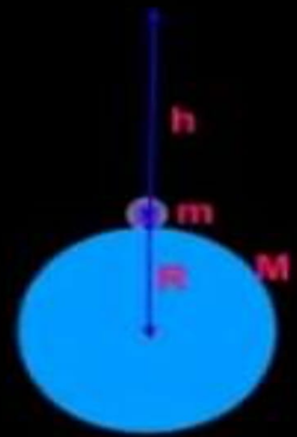
Substituting the values, we get $g = 9.8$ m/s^2

For simplified calculations we can take g as 10 m/s^2

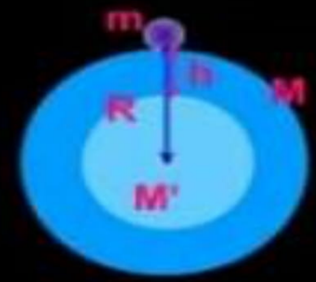
Variation of acceleration due to gravity (g)

1. Acceleration due to gravity decrease with altitude.

$$g = \frac{G\,M}{R^2} \qquad g' = \frac{G\,M}{(R+h)^2}$$



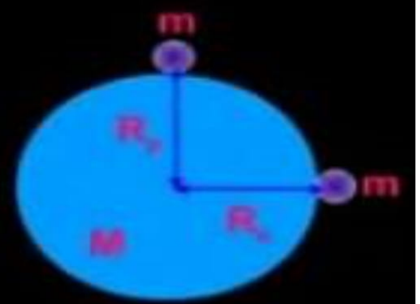
2. Acceleration due to gravity decrease with depth.



$$g = \frac{G\,M}{R^2} \qquad g' = \frac{G\,M'}{(R-h)^2}$$

3. Acceleration due to gravity is greater at the poles and less at the equator.

$$g_p = \frac{G\,M}{R_p^2} \qquad g_e = \frac{G\,M}{R_e^2}$$



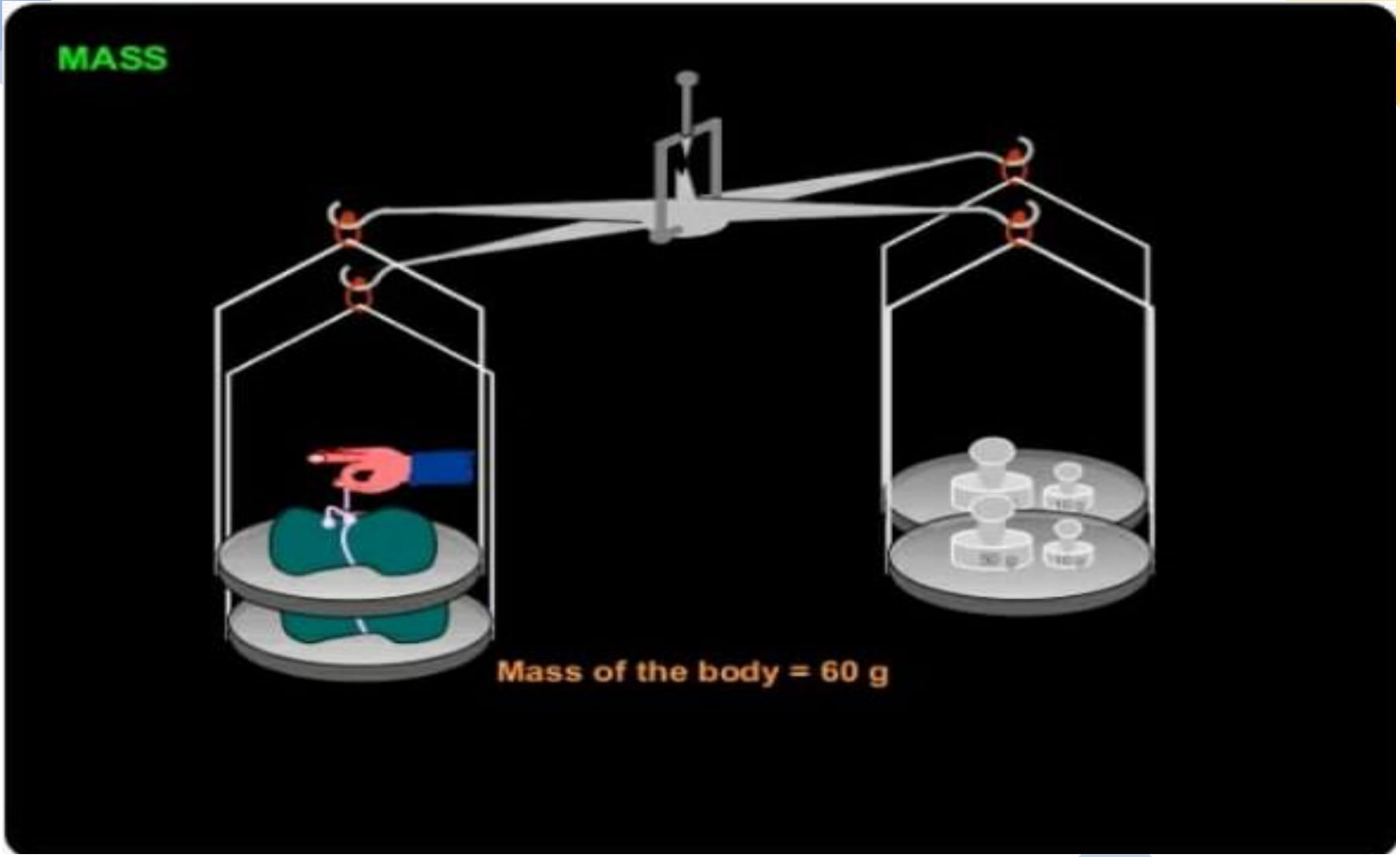
Earth is slightly flattened at the poles and bulging at the equator. The radius of the earth at the poles is 21 km less than that at the equator.

i.e. $R_p < R_e$

Therefore, from the above equations, G and M being same and g is inversely proportional to the square of the radius,

$g_p > g_e$

$g_p = 9.823\ m/s^2$, $g_e = 9.789\ m/s^2$ and average value of $g = 9.8\ m/s^2$


MASS
Mass of the body = 60 g

The mass of a body is the quantity of matter contained in it.

Mass of a body is a measure of inertia of the body and hence called inertial mass.

Mass is a scalar quantity.

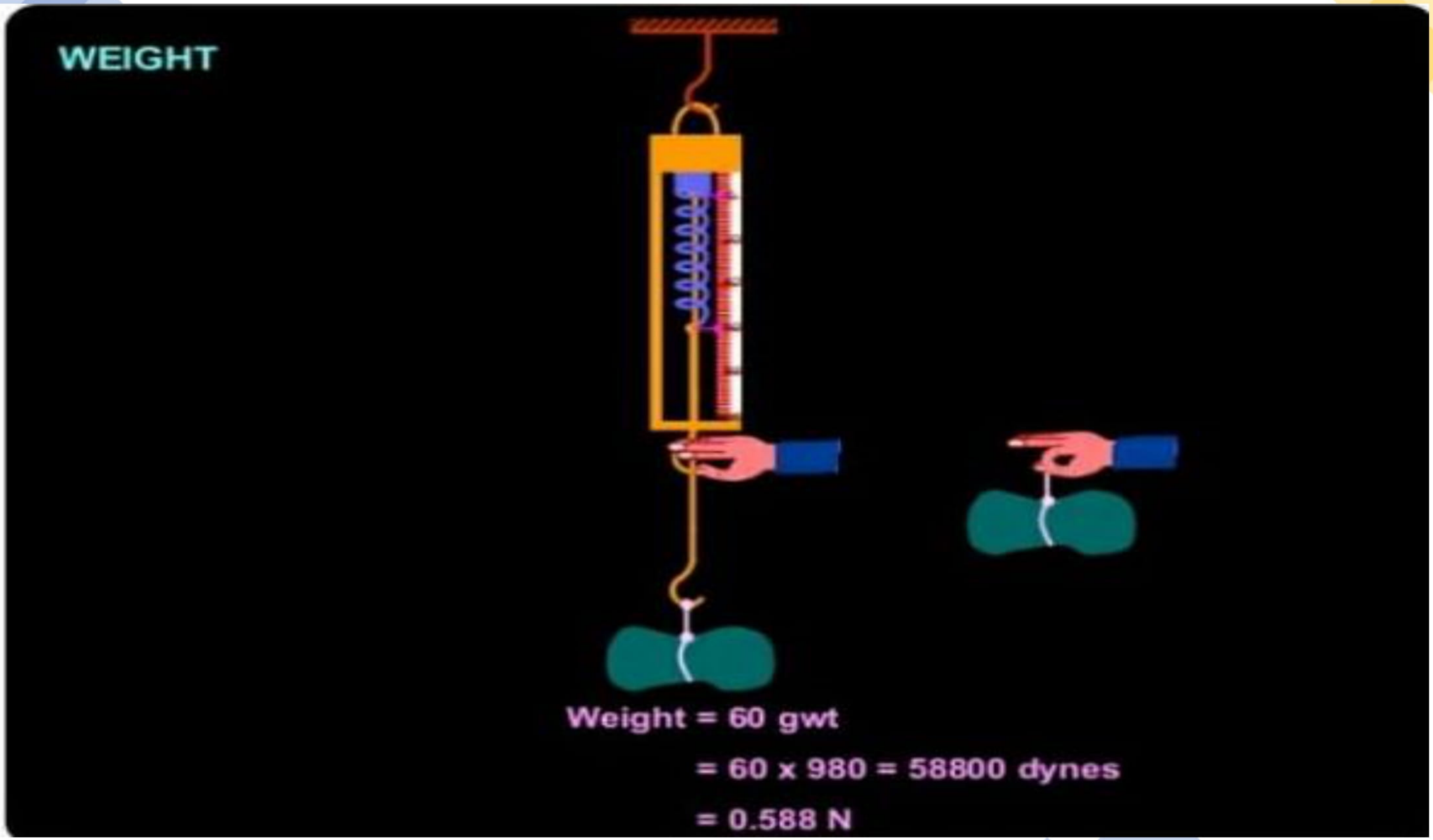
SI unit of mass is kilogramme or kg.

CGS unit of mass is gramme or g.

Mass of a body is constant and does not change from place to place.

Mass is measured by a beam or common balance.

Mass of a body can not be zero.


WEIGHT
Weight = 60 gwt
= 60 x 980 = 58800 dynes
= 0.588 N

The weight of a body on the earth is the force with which it is attracted towards the centre of the earth.

Weight = mass x acceleration due to gravity

$$W = m \times g$$

SI unit of weight is 'newton' or N

Weight of 1 kg mass is 9.8 newton.

Weight is a vector quantity since it has both magnitude and direction.

Weight changes from place to place.

Weight is measured by a spring balance.

Weight of a body can be zero. When a body is taken to the centre of the earth, acceleration due to gravity at the centre is zero and hence weight is zero.

On the moon, acceleration due to gravity is nearly $1/6^{th}$ of that on the earth and hence the weight of a body on the moon is $1/6^{th}$ of its weight on the earth.

EQUATIONS OF VERTICAL MOTION (Under the influence of g)

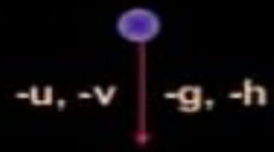
Let a body be thrown vertically downward with initial velocity 'u'. Let the final velocity of the body after time 't' be 'v'. Let 'h' be the height (vertical distance) covered by the body and 'g' be the acceleration due to gravity.

Then the equations of motion are:

$$v = u + gt$$

$$h = ut + \frac{1}{2} gt^2$$

$$v^2 = u^2 + 2gh$$

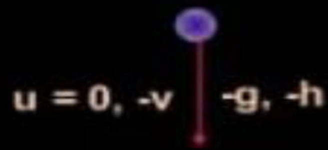


When a body is dropped freely, the equations of motion are:

$$v = gt$$

$$h = \frac{1}{2} gt^2$$

$$v^2 = 2gh$$



When a body is thrown vertically upwards, the equations of motion are:

$$v = u - gt$$

$$h = ut - \frac{1}{2} gt^2$$

$$v^2 = u^2 - 2gh$$

Cartesian Sign Conventions for Vertical Motion

1. The physical quantities having vertically upward motion are assigned positive values.
2. On the other hand, the physical quantities having vertically downward motion are assigned negative values.
3. Acceleration due to gravity (g) always acts in the downward direction and hence taken negative.

TIPS TO SOLVE THE NUMERICAL PROBLEMS

1. g is always taken negative.
2. When a body is dropped freely its initial velocity $u = 0$.
3. When a body is thrown vertically upwards, its final velocity becomes zero at the maximum height.
4. The time taken by a body to rise to the highest point is equal to the time it takes to fall from the same height.