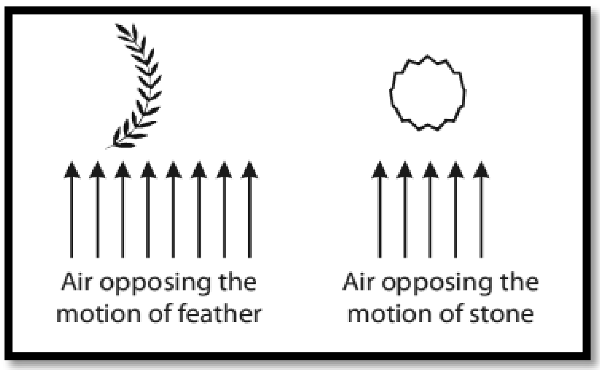
GRAVITATION

CONTRIBUTION OF SCIENTIST AND GRAVITATIONAL ACCELERATION

FREE FALL: -

Any object dropped from some height always falls towards the earth. If a feather and a stone are dropped from the top of a tower, it is observed that feather falls onto the ground much later than the stone. So, it was thought that object of different masses dropped from same height take different times to reach the ground.



However, Galileo dropped three iron balls of different masses simultaneously from the top of the tower of Pisa and found that all the three balls reached the earth's surface at the same time. Galileo explained that the feather suffered much air resistance during fall because of its large surface area. Due to this opposing force, feather takes longer time to reach the ground than the stone. He further explained that if air resistance is eliminated, both feather and the stone will reach the ground simultaneously.

Conclusion

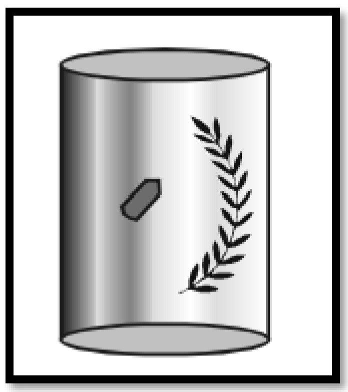
Galileo concluded that the bodies of different masses dropped simultaneously from the same height hit the ground at the same time, if air resistance is neglected.

Definition of Free Fall

The falling body on which only force of gravitation of the earth acts is known as freely falling body and such fall of a body is known as free fall. A freely falling body has acceleration equal to acceleration due to gravity(g).

Experiment verification

This fact was verified experimentally by Robert Boyle just after the death of Galileo. Robert Boyle used his newly invented vacuum pump to evacuate the air from a long jar containing a lead bullet and a feather. Then he inverted the jar and found that both the bullet and the reached the bottom of the jar at the same time.



If the air resistance is neglected or not taken into account, then the only force acting on the falling body is the force of gravitation of the earth. This force of gravitation of the earth is constant and hence produces a constant acceleration in the body. Since this acceleration is produced by the gravitational force of the earth and hence known as acceleration due to gravitational force of earth or acceleration due to gravity.

Acceleration due to gravity

The acceleration with which a body falls towards the earth due to earth's gravitational pull is known as acceleration due to gravity. It is denoted by 'g'. Thus, all bodies irrespective of their masses fall down with constant acceleration.

Determination of value OF g

When a body of mass m is dropped from a certain distance R from the centre of earth of mass M, then the force exerted by the earth on the body is

$$F = G\frac{Mm}{R^2} \qquad \dots \text{(i)}$$

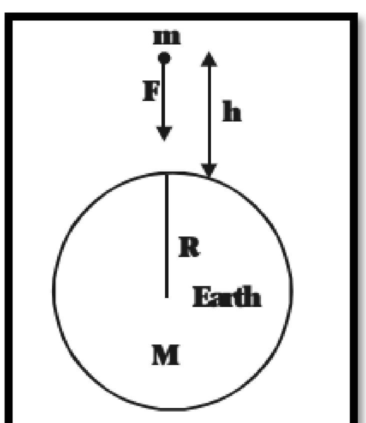
Let this force produces an acceleration a in mass m. h F m R Earth M

$\therefore$ F = ma or F = mg ... (ii)

From (i) and (ii),

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

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



For bodies falling near the surface of earth, this acceleration is called acceleration due to gravity and is represented by g

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

where M is the mass of the earth i.e., 6×10^{24} kg and R, the radius of the earth i.e., 6.4×10^6 m

$$g = \frac{GM}{R^2} = \frac{6.67 \times 10^{-11}\left(6\ \ 10^{24}\right)}{\left(6.4\ \ 10^{6}\right)^2}$$

or g = 9.8 ms^{-2} or nearly 10 ms^{-2}

Value of g on moon

Mass of moon = 7.4×10^{22} kg and its radius = 1,740 km or R = 1,740,000 m = 1.74×10^6 m

$$g = \frac{GM}{R^2} = \frac{6.67 \times 10^{-11}\left(7.4 \times 10^{22}\right)}{\left(1.74 \times 10^{6}\right)^2} = 1.63\, ms^{-2}$$

Mass of the earth We can determine mass of the earth from equation (A)

$$g = \frac{GM}{R^2}\ or\ M = \frac{gR^2}{G}$$

$\therefore$ Mass of the earth $M = \dfrac{9.8\left(6.4\ \ 10^{6}\right)^2}{6.67\ \ 10^{11}}$

or M = 6.018×10^{24} kg

Average density of the earth

It can also be determined from equation (A) above.

$$g = \frac{GM}{R^2} \frac{G\frac{4}{3}R^3 d}{R^2}\ G = \frac{4}{3}Rd \quad volume = \frac{mass}{Density}$$

$$Mass = Volume \times density$$

$$d = \frac{3g}{G4\pi R}$$

Taking the earth to be a sphere of radius R

$$d = \frac{3g}{6.67 \; 10^{11} \; 4 \; \left(6.4 \; 10^{6}\right)}$$

or d = 5.5 × 103 kg m^{-3}

Calculation of acceleration due to gravity on the moon and to prove that it is 1/6th of the acceleration due to gravity on the earth.

Mass of the moon (M) = 7.4 × 10^{22} kg Radius of the moon (R) = 1.74×10^{6} m

Gravitational constant (G) = 6.7 × 10^{-11} Nm^2 /kg^2

$\therefore$ Acceleration due to gravity on the moon, $g = \frac{Gm}{R^2}$

$$g_{moon} = \frac{6.7\times10^{-11} Nm^2 Kg^2 \times 7.4\times10^{22} kg}{\left(1.74\times10^{6} m\right)^2}$$

$$g_{moon} = \frac{6.7\times7.4}{1.74\times1.74}\times\frac{10^{-11+12}}{10^{12}} N / Kg$$

$$g_{moon} = 1.63 \, ms^2$$

$$\frac{g_{moon}}{g_{moon}} = \frac{1.63ms^{-2}}{9.81ms^2}\frac{1}{6} \; approx$$

$$g_{moon} = \frac{1}{6} g \; Earth$$