Gravitation

- The Phenomenon of attraction b/w any two objects in the Universe is called gravitation.

- Gravity — attractive force which is exerted by earth on any body.

Universal law of Gravitation.

m_1 A, m_2 B, r

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

$F \propto m_1 m_2$

$F \propto \frac{1}{r^2}$

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

G → Universal gravitational constant.

SI unit of G

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

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

$$G = 6.67 \times 10^{-11}\ Nm^2\ Kg^{-2}$$

Universal gravitational Constant

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

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

$$G = \frac{F \times (1m)^2}{1 kg \times 1 kg}$$

$$\boxed{G = F}$$

Universal gravitational constant is numerically equal to the gravitational force of attraction between two bodies each of mass 1kg kept at unit distance from each other.

Why gravitational constant (G) is known as Universal gravitational constant?

→ The value of G doesn't depend on mass of two bodies, distance b/w two bodies, nature, medium, shape / size.

Conditions

(i) when two objects each of 1kg and 1m apart.

1kg, 1kg, 1m

$$F = G \frac{m_1 m_2}{r^2} = 6.67 \times 10^{-11} \frac{1 \times 1}{1} = 6.67 \times 10^{-11} N$$

$$= 0.000 \ldots\ldots 67 N$$

(ii) ball m_1, 1m, m_2 Train

2kg, 5000 kg

$$\text{force of Ball to Train} = G \frac{m_1 m_2}{r^2} = \frac{G\, 2 \times 5000}{(1)^2}$$

$$F = 1000 G N$$

$$\text{Force of Train to Ball} = \frac{G m_2 m_1}{r^2} = \frac{G.\, 5000 \times 2}{(1)^2} = 1000 G N$$

(iii)

earth mass = 6×10^{24} kg.

Radius of earth = 6400 km.

$= 6400 \times 1000$ m.

$= 6.4 \times 10^6$ m

$$F_{AE} = \frac{6.67 \times 10^{-11} \times 1 \times 6 \times 10^{24}}{(6.4 \times 10^6)^2} = \boxed{9.8 N}$$

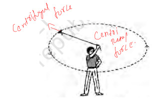
$F_{EA} = 9.8 N$

Newton's 2nd law of motion

$F = ma.$

$$a_{FA} = \frac{F}{m} = \frac{9.8}{1} = 9.8 ms^{-2}$$

$$a_{AE} = \frac{F}{m} = \frac{9.8}{6 \times 10^{24} kg} = \boxed{1.63 \times 10^{-24} ms^{-2}}$$



Earth. moon

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

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. If there were no such force, the moon would pursue a uniform straight line motion.

m_1 3 time, m_2 $\frac{1}{2}$ time, r $\frac{1}{3}$ times

$$F_1 = \frac{G m_1 m_2}{r^2}$$

$$F_2 = \frac{G\, 3m_1 \frac{1}{2} m_2}{(\frac{r}{3})^2} = \frac{G\, 3 \times 9\, m_1 m_1}{2 \times r^2} = \boxed{F_2 = \frac{27}{2} F_1}$$

half / 6

1) Two particles A and B of mass m_1 and m_2 respectively are placed on same distance. If the mass of each of the two particles is doubled, Keeping the distance b/w them unchanged, the gravitational force b/w them will be.

1) m_1, m_2, r

$$F_1 = \frac{G m_1 m_2}{r^2}$$

2) $2m_1$, $2m_2$, r

$$F_2 = \frac{G\, 2m_1 2m_2}{r^2}$$

$$F_2 = \frac{G m_1 m_2}{r^2} 4$$

$$\boxed{F_2 = 4F_1}$$

$$\boxed{F_2 = \frac{F_1}{4}}$$

$$F_2 = \frac{G m_1 m_2}{(\frac{r}{2})^2}$$

$$F_2 = \frac{}{\frac{r^2}{4}}$$

$\frac{1}{3}$

$\frac{r}{3}$

2) mass of sun is 2×10^{30} kg & mass of earth is 6×10^{24} kg. If the avg distance b/w the sun and the earth is 1.5×10^{8} km, calculate the gravitational force b/w them.

$F = \frac{Gm_1m_2}{r^2}$

3) The gravitational force b/w two objects is F. If masses of both objects are halved w/o changing distance b/w them, gravitational force would become.

$F_1 = \frac{Gm_1m_2}{d^2}$

$F_2 = \frac{G\left(\frac{m_1}{2}\right)\left(\frac{m_2}{2}\right)}{d^2} = \frac{Gm_1m_2}{d^2\,4} = \frac{F_1}{4}$

$F_2 = F_1/4$

4) Gravitational force b/w two objects weighing 20g and 15g is 150×10^{-10} N2. Find distance b/w two objects.

Scientists → Arrangement of planets

Ptolemy $\xrightarrow{140\ AD}$ Geocentric theory — Earth is at center & all planets revolve around

Copernicus $\xrightarrow{1543}$ Heliocentric theory — Sun at the center

Tycho brahe $\xrightarrow{1548}$ Tychonic system — Moon is at the center.

Galileo $\xrightarrow{1609}$ Sun is at the center — Heliocentric theory, telescope

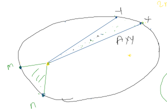
Kepler's law of planetary motion

He stated three laws which govern the motion of planets around the sun. These are known as Kepler's law of planetary motion.

Kepler's 1st law of motion

- Planets move in elliptical orbits around the sun, with the sun at one of two foci of the elliptical orbit.

Kepler's 2nd law of motion



$\uparrow F = \frac{Gm_1m_2}{R^2}\downarrow$

✓ Each planet revolves around the sun in such a way that the line joining the planet to the sun sweeps over equal areas in equal intervals of time.

✓ A planet moves faster when it is closer to the sun & moves slowly when it is farther away from the sun.

Kepler's 3rd law of motion

✓ The cube of the mean distance of a planet from the sun is directly proportional to the square of time, it takes to move around the sun.

$r^3 \propto T^2$

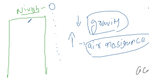
$r^3 = \text{constant}\ T^2$

$r^3/T^2 = \text{constant}$

r = mean distance of planet from the sun.

T = time period of the planet around the sun

Free fall and acceleration due to gravity (g)



The falling of a body (or object) from a height towards the earth under gravitational force of earth (with no other force acting on it), such a body is called freely falling body.

force. acc^n: change in velocity

$\uparrow F = ma\uparrow$

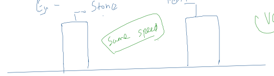
Acc^n due to gravity (g)

→ The uniform acc^n produced in a freely falling body due to gravitational force of the earth is known as acc^n due to gravity.

→ SI unit = ms^{-2}

→ g doesn't depend on the mass of the falling object.

Eg - Stone, Feather — Same speed — no air (vacuum)

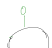


Calculation of acc^n due to gravity

Force exerted by earth on the body

$F = GMm/R^2$ — (i)

→ $F = ma$ — (ii)



This force by earth produces acc^n in the stone due to which stone moves downwards

$GMm/R^2 = m\times a$

$a = \frac{GMm}{m R^2}$

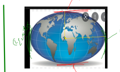
Here, $a = \frac{GM}{R^2}$.

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

$g = \frac{(6.67\times10^{-11}\ Nm^2 Kg^{-2} \times 6\times10^{24}\ kg)}{(6.4\times10^6)^2}$

$\boxed{g = 9.8\ ms^{-2}}$

Variation of acc^n due to gravity (g)



- Earth is not a perfect sphere.
- Geoid shape

✓ poles are flat.

✓ Equators are bulged.

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

Radius pole < Radius of equator

✓ The value of g is not constant at all the places on the surface of earth.

✓ As earth is not a perfect sphere so the value of Radius R is not the same at all the places on its surface.

✓ Radius of earth at the poles is minimum the value of g is maximum.

✓ " " equator is maximum " " " minimum.

✓ But, this formula is not applicable at any point inside the surface of earth.

✓ The value of g decreases as we go down inside the earth.

✓ Value of g becomes zero at the center of earth.

Equation of Motion for freely falling bodies

Equation of motion → for horizontal motion

$v = u + at$

$S = ut + \frac{1}{2}at^2$

$v^2 - u^2 = 2as$

Motion due to gravity

$v = u + gt$

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

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

Horizontal motion

+ve acc^n

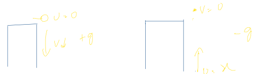
$u = 5 m/s$, $v = 10 m/s$

$a = \frac{v-u}{t} = \frac{10-5}{2} = 2.5 ms^{-2}$

Retardation

$u = 10 m/s$, $v = 5 m/s$

$a = \frac{v-u}{t} = \frac{5-10}{2} = -2.5 ms^{-2}$



✓ $a = \frac{v-u}{t}$ (+ve)

✓ $a = \frac{v-u}{t} = \frac{0-u}{t}$ (−ve)

✓ when a body is falling vertically downwards, it's velocity is increasing. So the acc^n due to gravity is taken as positive

$g = +9.8 ms^{-2}$

✓ " " thrown " upwards, " " negative

decreasing, "

$g = -9.8 ms^{-2}$

18. To estimate the height of the bridge over a river, a stone is dropped freely in the river from the bridge. The stone takes 2 seconds to touch the water surface in the river. Calculate the height of the bridge from water level.

$u = 0$
$t = 2 sec$
$g = 9.8$

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

$h = 0 \times t + \frac{1}{2} \times 9.8 \times 2 \times 2$

$\boxed{h = 19.6 m}$

Example 10.2 A car falls off a ledge and drops to the ground in 0.5 s. Let g = 10 m s⁻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?

5:29

$u = 0$
$t = 0.5 s$
$g = 10 ms^{-2}$

(i) $v = u + gt$
$= 0 + 0.5 \times 10$
$= 5 ms^{-1}$

(ii) Avg = $\frac{\text{Initial velocity} + \text{Final velocity}}{2} = \frac{0+5}{2} = 2.5 ms^{-1}$

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

$h = 0 \times t + \frac{1}{2} \times 10 \times (0.5)^2$

$= \frac{1}{2} \times 10 \times \frac{5}{10} \times \frac{5}{10} = 1.25 m$

Example 10.3 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.

$s = 10 m$
$v = 0 ms^{-1}$
$g = -9.8 ms^{-2}$ (upward motion)

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

$(0)^2 - (u)^2 = 2 \times -9.8 \times 10$

$u^2 = 196$
$u = 14$

(ii) $v = u + gt$
$0 = 14 - 9.8 \times t$
$t = \frac{14}{9.8} = \frac{140}{98} = 1.4 s$

Q A stone is dropped from a height of 20m.
a) How long will it take to reach the ground.
b) what will be its speed when it hits the ground. (g = 10)

→ $h = ut + \frac{1}{2}gt^2$
$20 = 0 + \frac{1}{2} \times 10 \times t^2$
$t^2 = \frac{20}{5}$, $t = 2 sec$

b) $v = u + gt$
$= 0 + 10 \times 2 = 20 m/s$

Q) A stone is thrown vertically upwards with a speed of 20 ms⁻¹. How high it go before it begins the fall ?

Mass and Weight

✓ Mass of the body is the quantity of matter (or material) contained in it.

✓ Scalar quantity (only magnitude and no direction).
✓ SI unit is Kg.
✓ Mass of a body is constant, doesn't change from place to place.
✓ Mass of body can't be zero.

Weight

→ weight of a body is the force with which it is attracted towards the center of the earth.

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

→ By Newton's 2nd law of motion
$F = ma$
$\boxed{W = m \times g}$

→ SI unit of weight is Newton.
→ It is a vector quantity.
→ weight of a body acts in vertically downward direction.

→ weight depends on g therefore, weight of a body is not constant.

→ Wt in poles ↑ & wt in equator ↓

Q. In weighing m/c weight or mass ?

↳ load sensor — measures the Force which your body is applying because of the gravitational pull of earth.

$F = W = m \times g$

chip $\frac{W}{g} = m$ in Kg

Weight of an object on the moon.

✓ weight of an object on the moon is the force with which the moon attracts that object.

✓ Value of g differs on earth and on moon.

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

Celestial body	Mass (kg)	Radius (m)
Earth	5.98×10^{24}	6.37×10^{6}
Moon	7.36×10^{22}	1.74×10^{6}

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

$\frac{W_m}{W_e} = \frac{GM_m m}{R_m^2} \times \frac{R_e^2}{GM_e m} = \frac{7.36 \times 10^{22}}{(1.74 \times 10^6)^2} \times \frac{(6.37 \times 10^6)^2}{5.98 \times 10^{24}}$

$\frac{2.431 \times 10^{10}}{1.474 \times 10^{11}}$

$= 0.165 \simeq \frac{1}{6}$

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

✓ Weight of an object on the moon will be about one-sixth of what is on earth.

✓ Gravitation Force of the moon is about one-sixth that of the earth.

1Q Mass of an object is 10 kg. What is weight on the earth?

→ $W = m \times g$
$10 \times 9.8 = 98\,N$

2Q **Example 10.5** 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?

wt of obj on the moon $= \left(\frac{1}{6}\right) \times$ wt of the obj on the earth

$= \frac{1}{6} \times 10 = \frac{10}{6} = 1.67\,N$

3) What is the mass of an object whose weight is 49 N?

→ $W = m \times g$

$m = \frac{49}{98}0 = 5\,kg$

$g\,(10\,m/s^2)$

4) A man weighs 600 N on the earth. What is his mass? If he were taken to the moon, his weight would be 100 N. What is his mass on the moon? What is the accn due to gravity on the moon?

$W = mg$ ← moon ← earth
$\frac{600}{10} = m$
$60\,kg$

$W = mg$
$100 = 60 \times g$
$g = \frac{10}{6}$
$= 1.67\,m/s^2$

5) How much would a 70 kg man weigh on the moon? What would be his mass on the earth and the moon? (accn due to gravity on moon $= 1.63\,m/s^2$)

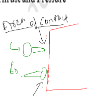
weight will vary

mass constant

$W = m \times g$
$= 70 \times 1.63$
$= 114.1\,N$

10.5 Thrust and Pressure

Area of contact



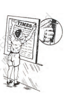


Fig. 10.3: To fix a poster, drawing pins are pressed with the thumb perpendicular to the board.

Pressure is the force acting on a unit area of the object.

Pressure $\propto \frac{\text{force}}{\text{area}}$

Situation 2: You stand on loose sand. Your feet go deep into the sand. Now, lie down on the sand. You will find that your body will not go that deep in the sand. In both cases the force exerted on the sand is the weight of your body.

→ The effect of a force depends on the area of the object on which it acts.

→ Same force can produce different pressures depending on the area over which it acts.

→ When a force acts over large contact area of an object, it produces a small pressure.

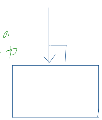
→ " " small "
large

→ SI unit of pressure; $P = \frac{F}{A} = \frac{N}{m^2} = N\,m^{-2}$ = Pascal (Pa)

→ $1\,Pa = 1\,N\,m^{-2}$

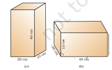
Thrust

The force acting on a body perpendicular to its surface.



Q A force of 100 N is applied to an object of area $2\,m^2$. Calculate the pressure.

Example 10.6 A block of wood is kept on a tabletop. The mass of wooden block is 5 kg and its dimensions are 40 cm × 20 cm × 10 cm. Find the pressure exerted by the wooden block on the table top if it is made to lie on the table top with its sides of dimensions (a) 20 cm × 10 cm and (b) 40 cm × 20 cm.



$P = \frac{F}{A}$

$m = 5\,kg$
Dimensions = 40 cm × 20 cm × 10 cm

$F = W = m \times g = 5 \times 9.8 = 49\,N$

(a) Area of side $= l \times b = 20 \times 40 = 800\,cm^2$

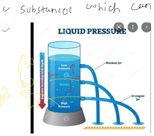
$P = \frac{49}{0.08\,m^2} =$

(b) $\frac{49}{0.02} =$

PRESSURE IN FLUIDS

✓ Substances which can flow easily → Fluids

✓ All liquids and gases exert pressure

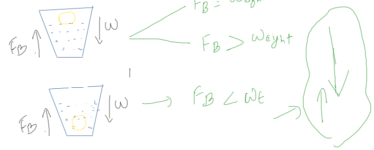


E.g. $W = mg$

Buoyancy

$F = W = mg$

$F_B = $ Weight
$F_B >$ Weight
$F_B < W_t$



The upward force acting on an object immersed in a liquid is called buoyant force. (also known as upthrust).

✓ Due to the upward buoyant force exerted by a liquid, the weight of an object appears to be less in the liquid than it's actual weight in the air.

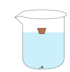
✓

→ weight of an object is due to gravitation attraction of the object.

→ when the ball is immersed the upward force exerted by the water on the ball is greater than its weight, Therefore, it rises up.

→ " " " smaller " "
∴ sinks.

Density



The nail sinks. The force due to the gravitational attraction of the earth on the iron nail pulls it downwards. There is an upthrust of water on the nail, which pushes it upwards. But the downward force acting on the nail is greater than the upthrust of water on the nail. So it sinks (Fig. 10.5).

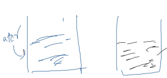
Density $= \frac{\text{Mass}}{\text{Volume}}$

✓ Density of cork < Density of water → upthrust of water on the cork is greater than the weight of the cork, ∴ it is floated

✓ Density of pin > Density of water → upthrust of water on the pin is lesser than the weight of the pin. ∴ it sinked.

Density of object < Density of liquid = object will float.
" > " = object will sink.

Water



Glycerine

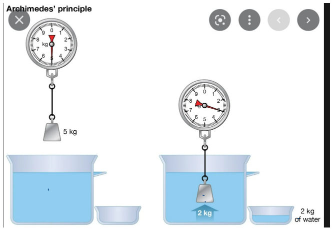
✓ Density of glycerine > Density of water

Buoyant force glycerine > Buoyant force water

Archimedes Principle

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.

on an object partially or completely immersed.

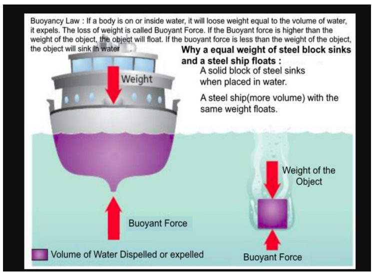


$Wt = 5\,kg$

$F_B = 2\,kg$

$F_B < Wt$

Sink



$F_B > Wt$ ↑ float

Relative Density

Ratio of density of a substance to the density of water.

$$\boxed{\frac{\text{Density substance}}{\text{Density water}}}$$

$$= \frac{m_s}{V_s} \div \frac{m_w}{V_w} = \frac{m_s \times V_w}{V_s \times m_w}$$