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. $F \alpha\ m_1 \times m_2$

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

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

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

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)

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

- 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/s^2 = 980 cm/s^2.

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

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

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}

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

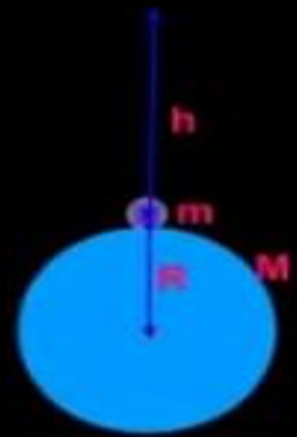
Substituting the values, we get 9 = 9.8 m/s^2

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

Variation of acceleration due to gravity (g)

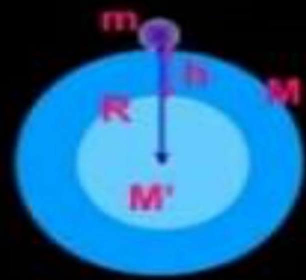
1. Acceleration due to gravity decrease with altitude.

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



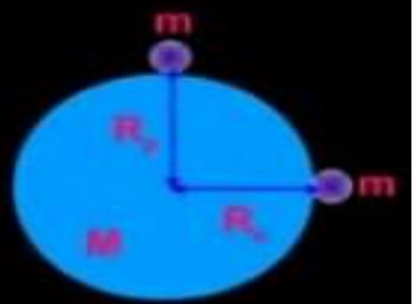
2. Acceleration due to gravity decrease with depth.

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



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

$$g_p = \frac{GM}{R_p^2} \qquad g_e = \frac{GM}{R_e^2}$$



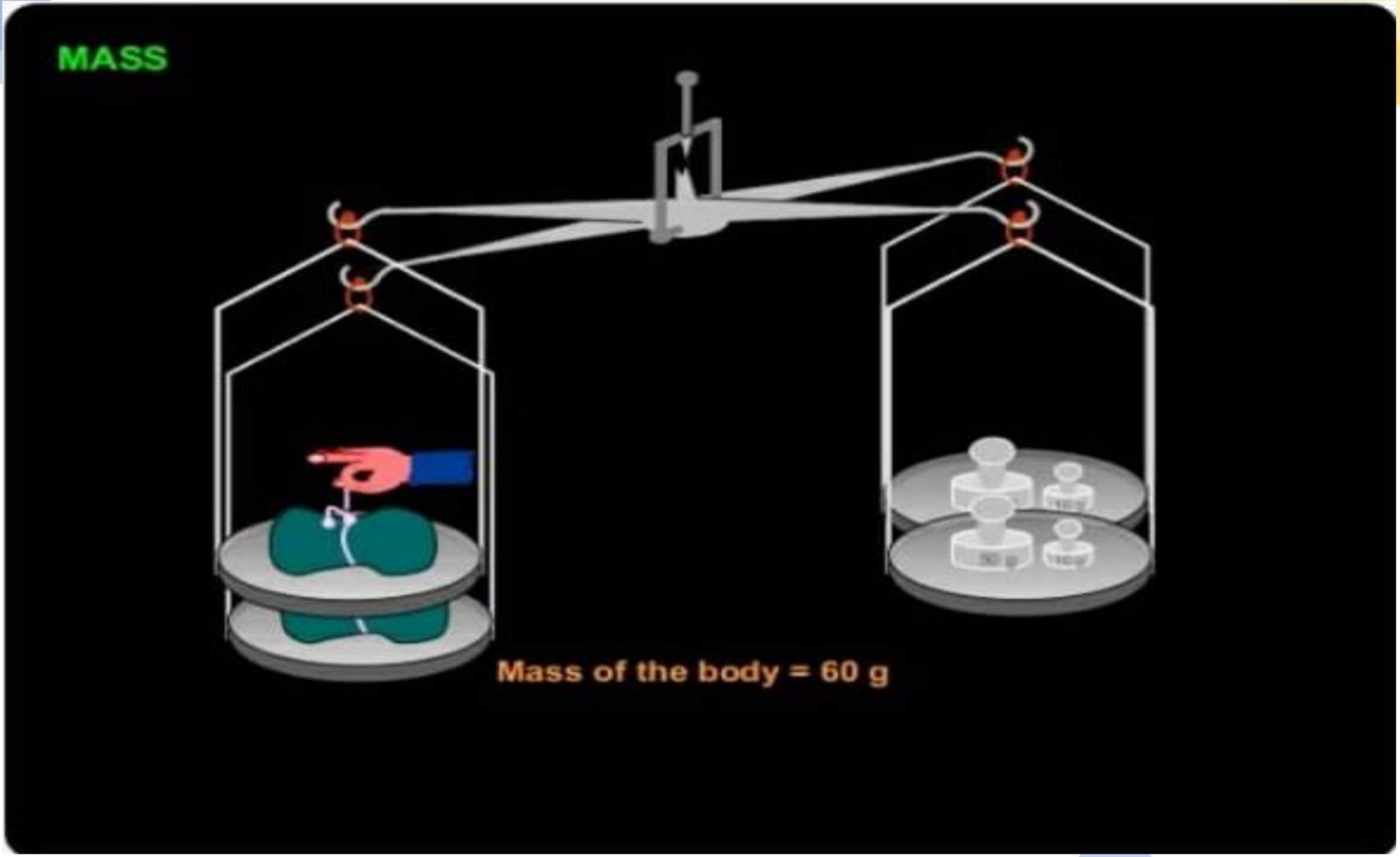
Earth is slightly flattened at the poles and bulging at the equator. The radius of the earth at the poles is 21 km less than that at the equator.

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.

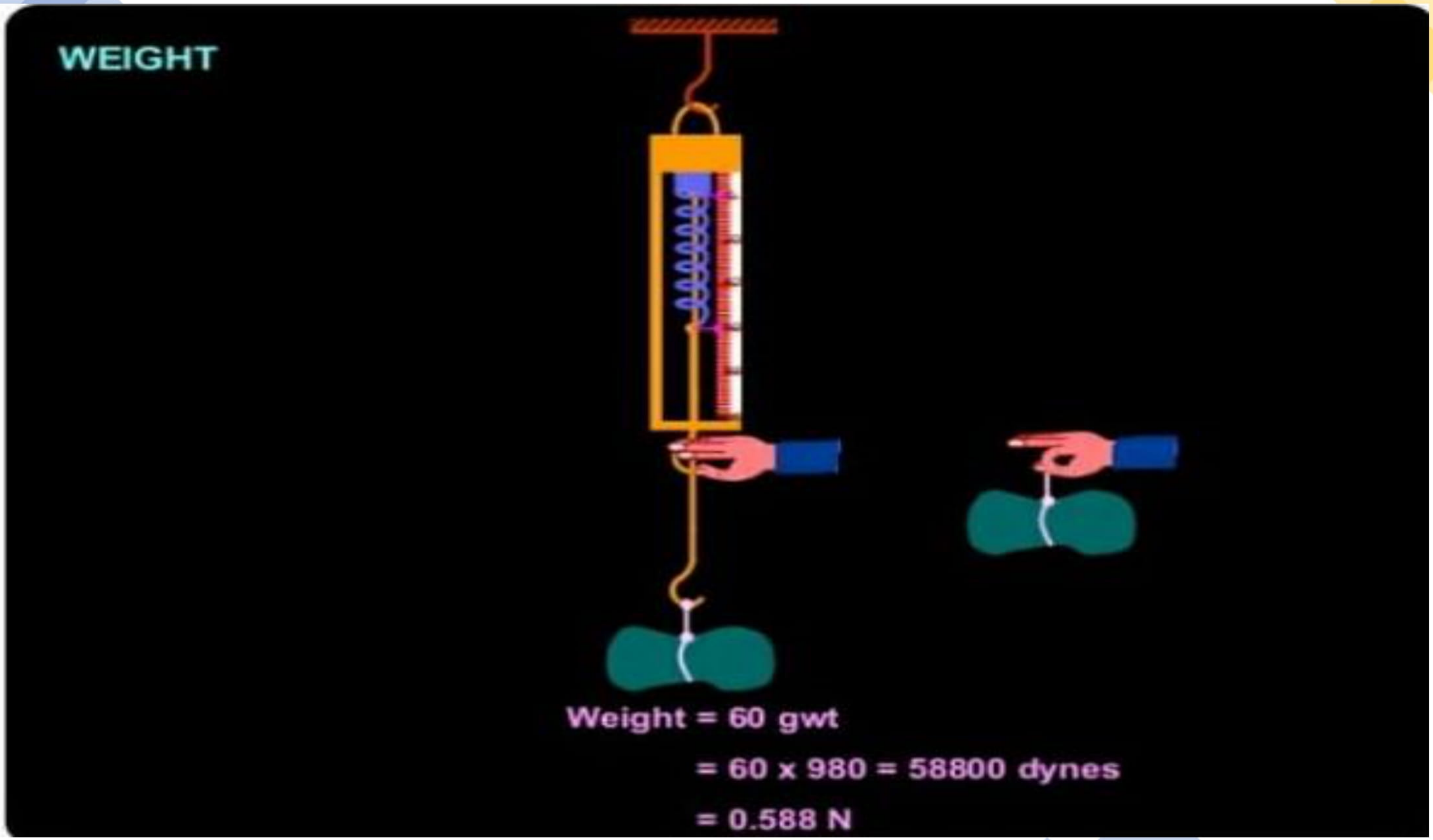
SI unit of mass is kilogramme or kg.

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)

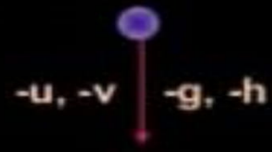
Let a body be thrown vertically downward with initial velocity 'u'. Let the final velocity of the body after time 't' be 'v'. Let 'h' be the height (vertical distance) covered by the body and 'g' be the acceleration due to gravity.

Then the equations of motion are:

$$v = u + gt$$

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

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

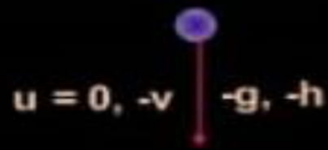


When a body is dropped freely, the equations of motion are:

$$v = gt$$

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

$$v^2 = 2gh$$



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

$$v = u - gt$$

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

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

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.

OBRAHM PRAKASH DAV SCHOOL

CLASS IX

WORK POWER ENERGY

RUNNING NOTES

WORK

In physics, work is said to be done when a force acts on an object and the object shows displacement.

Examples: i) A crane tow a broken car and takes it to a workshop.

Ii) a batman hitting a ball during a cricket match

iii) a person pushing a block from point A to point B

note: when force or displacement is zero the work done is zero. for example, if a person tries to push a heavy rock by applying maximum force but if the rock does not displace from its position the work done is zero.

Two conditions need to be satisfied for work to be done

i) A force should act on an object

ii) The object must be displaced.

Therefore **W = F S**

TYPES OF WORK

i) POSITIVE WORK

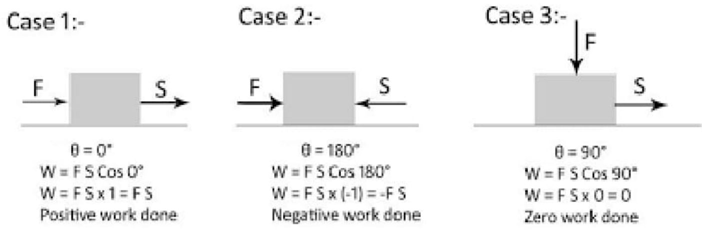
When the direction of force and displacement are the same, the work done is positive

ii) NEGATIVE WORK

When the direction of force and displacement are same, the work done is positive.

iii) ZERO WORK

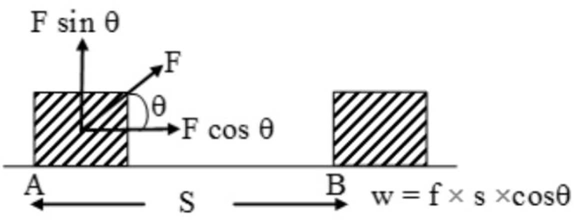
When the direction of force is perpendicular to the direction of displacement, work done is zero



EXAMPLE: i) when a person carrying a weight on his head and walks, the force is applied perpendicular to the direction of displacement

ii)a body moving in a circular path does no work because the force always acts at right angle to the direction of displacement. For this reason, satellites going around do no work.

<u>EXPRESSION FOR WORKDONE WHEN FORCE ACTS WITH SOME DIRECTION:</u>



When force is acting with making some angle to the direction of displacement then the force is is resolved into two components

- F cosθ in the direction of displacement and
- F sinθ perpendicular to the direction of displacement

The force component f cos θ in the direction of displacement. Hence

Work = Force X displacement X cosθ

or **W = FSCosθ** where θ is the angle between the direction of force and direction of displacement

- Work is scalar quantity
- The SI unit of work is Joule (J) or Newton meter (N m).
- I Joule = 1 N.m = 1 kg m^2 / s^2
- 1 joule of work is done when a force of 1N acts on a body such that the body gets displaced by 1m
- The CGS unit of work is dyne cm (or) erg.

CALCULATION OF WORK FROM FOECE-DISPLACEMENT GRAPH:

We know that work is a product of Force and displacement. If a graph is plotted between the force acting on a body and the displacement of the body, then the area under the graph gives the magnitude of work done.

I)

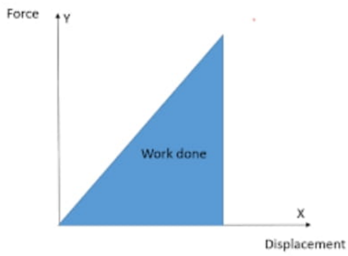
Work done = area under the graph

W = l x b

= OC x BC or

= OA x AB

II)



Work done = area under ΔAOB

= ½ x b x h = ½ x OB x AB

ENERGY

Let us consider some examples to understand the term ENERGY in terms of physics

i) When a raised hammer hits the nail placed on a piece of wood, the nail penetrates into the wood.

ii) When the striker hits the stationery carrom coins, the coin gets displaced

iii) When wind the spring of a toy car and place it on the floor the car gets displaced

In the above examples the objects acquire the capabilities to do work by different means such as, height, change in position and motion.

DEFINITION OF ENERGY

The ability of a body to do work is known as Energy. The body acquires energy because of its height, motion, change in shape.

- SI unit of energy is joule (J)

KINETIC ENERGY

The energy possessed by a body due to its motion is known as kinetic energy.

Examples : i) flowing water

ii)flying aero plane

iii)moving bus

MATHEMTICAL EXPRESSION FOR KINETIC ENERGY

Consider a body of mass ‘m’ kg is moving with velocity ‘v’ m/s then the work done to stop the body equls to the kinetic energy of the body

$$W = F \times s$$

$$= ma \times \frac{v^2 - u^2}{2a}$$

$$W = \frac{1}{2} m (v^2 - u^2)$$

If u = 0, (object starts at rest)

$$W = \frac{1}{2} mv^2$$

Work done = Change in kinetic energy

$$\therefore \quad E_k = \frac{1}{2} mv^2.$$

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POTENTIAL ENERGY

The energy possessed by a body due to its position (height) or change in its shape is known as potential energy.

- If the energy possessed by the body is due to its height, it is known as gravitational potential energy.
- If the energy possessed by the body is due to its shape, it is known as elastic potential energy.

Example: i) Consider a brick lying at the ground level of a building, in this situation brick has no energy. If we carry the brick to the top of the building, we do some work against the gravity. The amount of work done in carrying it will be stored in it, in the form of gravitational potential energy

ii) Consider a bow and arrow. Place the arrow on the string of a bow but don't pull it. In this situation the system of bow and arrow has no energy. Now pull the string along with arrow in backward direction by applying some force. In doing so, you change the shape of bow. The energy spent by you in changing the shape of the bow will be stored inn the bow as static potential energy.

- Potential energy is always dormant (latent)

MATHEMATICAL EXPRESSION FOR POTENTIAL ENERGY

Consider an Object of mass m that is kept on ground. Let the object be raised vertically upwards to a height h against the force of gravity. in order to lift the store we need to apply force equal to the way of the stone

The object is lifted to a height = h

Let:
Force applied on the object = F
The mass of the object = m
The acceleration due to gravity = g

$$PE = W$$
$$W = F \times s$$
Here, $s = h$
$$\Rightarrow PE = F \times h \quad \ldots (1)$$
$$F = m \times g$$
Substituting $F = mg$ in (1):
$$PE = m \times g \times h$$
$$\boxed{PE = mgh}$$

LAW OF CONSERVATION OF ENERGY

The energy in a system is created nor destroyed it may be transformed from one form to another. but the total energy of the system remains constant.

consider a body of mass M at height h held by a person

- Case 1

body is at height H from the ground level but not really, as a body is stationary at a particular height its velocity = 0

KE = ½ mv2

Here v = 0

Therefor KE = 0

PE = mgh

Total energy = PE + KE = 0 + mgh = mgh -----------(i)

- Case 2

when the body just reaches ground, let us calculate the final velocity of freely falling body on the ground level

V2 - u2 = 2gs here u = 0, as the body is dropped

V2 = 2gh ---------(ii)

The kinetic energy I was just by the body

KE = 1/2mv2

KE = 1 /2 * m* 2gh = mgh ---------(iii)

The potential energy possessed by the body at ground level

PE= mgh here h=0

PE = 0 --------- (iv)

From equation (iii) and (iv)

Total energy = PE + KE = 0 + mgh = mgh -------(v)

Total energy on reaching the ground is equals to the the total energy possessed by the body on height h.

hence energy is conserved .

POWER

Rate of doing work or the rate of transfer if energy is known as Power.

If an object does a work W in time t , then

Power = work / time

$P = W / t$

- SI unit of power is Watt
- 1W = 1J/s = 1N - m / s = 1kg m^2 / s^3
- The energy used in one hour at the rate of 1kw is called 1kWh
- 1kWh = 3.6 * 10^6 J
- 1000 watt = 1 kW (Kilo Watt)
- 1KWH = 1 unit,

  which is an International Trade unit whereon we pay Electric Charges to the Electricity Supply Utility . 1 KWH is an unit of Energy not Power.