Chapter 11: - Work and Energy

Work (W)

Work is defined as a force acting upon an object to cause a displacement

It is expressed as the product of force and displacement in the direction of force.

$$W = F \times s$$

Here, W= work done on an object
F **=** Force on the object
s **=** Displacement of the object

The unit of Work is Newton metre (Nm) or joule (J).
1 Joule is defined as the amount of work done by force of 1 N when displacement is 1 m.

Sign Conventions for Work Done

- when both the force and the displacement are in the same direction, positive work is done.
  $$W = F \times s$$
- when force acts in a direction opposite to the direction of displacement, the work done is negative.
  $$W = -F \times s$$

Angle between force and displacement is 180°.

- If force and displacement are inclined at an angle less than 180°, then work done is given as:
  $W = Fs\cos\theta$
- If force and displacement act at an angle of 90° then work done is zero.

Necessary Conditions for Work to be done
Two conditions need to be satisfied for work to be done:

- Force should act on the object.
- Object must be displaced.

Energy

The capacity of a body to do work is called the energy of the body.
Unit of energy = Joules

1KJ = 1000 J

Forms of Energy

The various forms of energy are potential energy, kinetic energy, heat energy, chemical energy, electrical energy and light energy.

Kinetic Energy

- It is the energy possessed by a body due to its motion. Kinetic energy of an object increases with its speed.
- Kinetic energy of body moving with a certain velocity = work done on it to make it acquire that velocity

Derivation: -

Let an object of mass *m*, starts from rest and attains a uniform velocity *v*, after a force *F* is applied on it. Let during this period the object be be displaced by distance s.

Thus, Work done on object, $W = F \times s$ ....(i)

Let the acceleration produced after applying force on object be a.

So, using third equation of motion, we have:

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

$$\Rightarrow \quad s = \frac{v^2 - u^2}{2a} \quad \text{....(ii)}$$

Also, Force is given as, $F = ma$ ....(iii)

Substituting F and s frome quations (ii) and (iii) in equation (i), we get:

$$W = F \times s$$

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

$$\Rightarrow \quad W = \frac{1}{2} mv^2 \left[\text{As, initial velocity, } u = 0\right]$$

But, work done on object = Change in kinetic energy of object

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

Potential Energy

The energy possessed by a body due to its position or shape is called its potential energy.
For Example:

- Water stored in a dam has large amount of potential energy due to its height above the ground.
- A stretched rubber band possesses potential energy due to its distorted shape.

Types of Potential Energy

On the basis of position and change in shape of object, potential energy is of two type:

1. Gravitational Potential Energy:
It is the energy possessed by a body due to its position above the ground.

2. Elastic Potential Energy:
It is the energy possessed by a body due to its change in shape.

Expression for Potential Energy

The potential energy (E_p) is equal to the work done over an object of mass '*m*' to raise it by a height '*h*'.
Thus, $E_p = mgh$, where g = acceleration due to gravity.

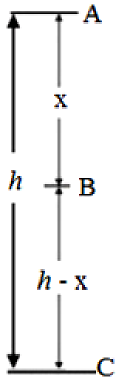
Law of Conservation of Energy

It states that energy can neither be created nor destroyed, but it can be transformed from one form to another.

The total energy before and after the transformation remains the same.

Proof of Law of Conservation of Energy

Let a body of mass *m* falls from a point A, which is at a height *h* from the ground as shown in the following figure:



At point A,
Kinetic energy $E_k = 0$
Potential energy $E_p = mgh$
Total energy, $E_A = E_p + E_k$
$\Rightarrow \quad E_A = mgh + 0$
$\Rightarrow \quad E_A = mgh$

During the fall, after moving a distance x from A, the body has reached at B.

At point B,
Let the velocity at this point be v.

We know, $v^2 = u^2 + 2as$
$\Rightarrow \quad v^2 = 0 + 2ax = 2ax$ [As, velocity at A, $u = 0$]
Also, Kinetic energy, $E_k = 1/2\, mv^2$
$\Rightarrow \quad E_k = 1/2\, m \times 2gx$
$\Rightarrow \quad E_k = mgx$
Potential energy, $E_p = mg(h - x)$
So, total energy, $E_B = E_p + E_k$
$\Rightarrow \quad E_B = mg\,(h - x) + mgx$
$\Rightarrow \quad E_B = mgh - mgx + mgx$
$\Rightarrow \quad E_B = mgh$
At the end the body reaches the position C on ground.

At point C,
Potential energy, $E_p = 0$
Velocity of the body is zero here.

So, $v^2 = u^2 + 2as$
$\Rightarrow \quad v^2 = 0 + 2gh = 2gh$
Kinetic energy, $E_k = 1/2\, mv^2$
$\Rightarrow \quad E_k = 1/2 \times m \times 2gh = mgh$
Total energy at C

$E_C = E_p + E_k$
$E_C = 0 + mgh$
$E_C = mgh$
Hence, energy at all points remains same.

Power

The time rate of doing work is defined as power (P).

Power= work/time

Unit of power

- sI unit of Power is Joule per second or Js1.
- 1 watt is the power when 1J of work is done in 1s.
- The bigger unit of power is Kilowatt and represented by kW.
  1kW = 1000W
- Some another units to measure power are:
  1 Megawatt = 10^6 watt
  1 horse power = 746 watt

Commercial unit of energy

- Commercial unit of energy is kilo watt hour (kWh)
- The unit kilowatt-hour means one kilowatt of power supplied for one hour.

1 kWh = 1 kW x 1 h

= 1000 W x 60 x 60 s

= 1000 Js^{-1} x 3600 s

= 3.6 x 10^6 J

1 unit = 1 kilowatt hour = 3.6x10^6 J.

Try the following questions:

1. Does work have a direction?
2. A body of mass 25 g has a momentum of 0.40 kgm/s. Find its kinetic energy.
3. A body of mass 3.0kg and a body B of mass 10 kg are dropped simultaneously from a height of 9m. Calculate their Momenta, their Potential energies and kinetic energies when they are 10m above the ground.
4. A light and heavy body have equal momenta. Which one has greater kinetic energy?
5. Why does a person standing for a long time get tired when he does not appear to do any work?