Work and Energy

Work

Work is defined as product of force and displacement in the direction of force.
Work is done when we swim, work is done we lift water from well, etc. Work done is denoted by a letter 'W'.

$$W = F \times s$$

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 1N when displacement is 1m.

- 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.
  $$W = (-F) \times s \text{ or } W = F \times (-s)$$
  Angle between force and displacement is 180^o.
- When either force or displacement is zero, then work done is said to be zero. Also if force and displacement act an angle of 90^o then also work done is zero.

For examples:

1. The man applies force on wall but displacement is zero so no work is done.

2. In below picture force and displacement are perpendicular to each other so here also work done is zero.

Sign of work done by gravity

Let us consider an example where a man throws a ball up in air, then

- When ball is going up its displacement is upwards and gravitational force is
- acting upwards. So, displacement and force are in opposite direction therefore work done is negative.
- And when ball is coming downwards its displacement and gravitational force are both acting downwards. So, displacement and force are in same direction therefore work done is positive.

Work done against Gravity

Whenever an object is lifted against gravity then the amount of work done in lifting the object is called as work done against gravity.

Note – When we lift an object against gravity, we have to apply force equal to weight of object.
For example; when we lift an object from ground and put in a table then

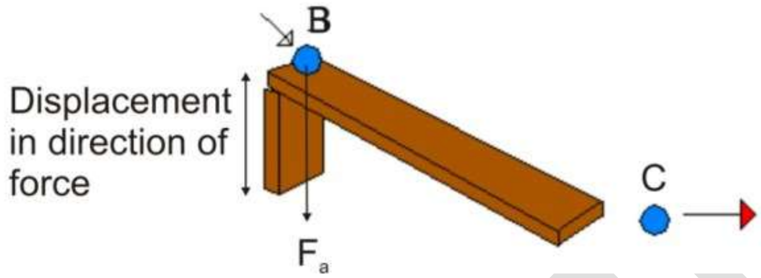
- Work done by gravity will be negative because displacement of object is upwards and gravitational force is acting downwards.

- Work done against gravity is positive because it is the force of our which is acting against gravity in upward direction and also displacement is upwards.

Oblique Displacement (Advance Topic)

- In this case force and displacement make some angle with each other.
- When displacement and force make some angle between them, we use displacement in direction of force for work calculation.
- In this case force and displacement act an angle to each other.

Work done by gravity = Force due to gravity displacement in direction of force



Energy

- Energy is ability to do work.
- Energy possessed by an object is the amount of work it can do.
- If an object can do more work, it has more energy and vice versa.

For example; a raised hammer can do work so it has energy and similarly a bomb can do work so it has also energy, a running bike can do work so it has energy, etc.

SI Unit of Energy:

The SI unit of energy is joule and denoted by 'J'.

- Larger unit of energy is kilo joule and is denoted by kJ.
- 1kJ = 1000J
- Energy required to do 1J of work is 1J of energy.

Different forms of Energy:

Things have different forms of energy due to different reasons.

1. Kinetic Energy
2. Potential Energy
3. Chemical Energy
4. Sound Energy
5. Light Energy
6. Heat Energy
7. Electrical Energy

Here we will discussed mainly two types of energy: Kinetic Energy and Potential Energy.

Kinetic Energy:

- It is the energy possessed by an object due to its motion.
- Anything moving is said to have kinetic energy.

For example; here the car is moving so it has kinetic energy.

Kinetic energy (K.E.) = $1/2mv^2$

Here,

m = Mass of object;

v = Speed of object;

- If two objects have same velocity but different masses then object which have more mass possesses more kinetic energy.
- Similarly more speed means more kinetic energy and vice versa.

Kinetic Energy and Work:

Consider that initially a body is at rest. If a force is applied on it, body starts moving with some velocity (say v).

As we applied a force on body, work is done by us and as velocity is changing from zero to 'v', there is a change in kinetic energy too.

Initial K.E. = 0, Final K.E. = $1/2mv^2$

So we can say that "*if work is done on an object, its kinetic energy changes*".

Work = Final K.E. – Initial K.E.

Derivation of formula of K.E:

Consider a body of mass m moving with velocity v and due to applied force F opposite to direction of velocity, body comes to rest.

Step 1 – As the ball comes to rest it means force must be applied in a direction opposite to the displacement of ball so,

$W = (-F) \times s;$

Step 2 – $W = (-ma) \times s$ ...(1)

Step 3 – $v^2 = u^2 + 2as$

Since the body has come to rest so

$0 = v^2 - 2as;$

$\Rightarrow s = \frac{v^2}{2a}$

Step 4 – From equation (1)

$$W = (-ma) \times \frac{v^2}{2a} = -\frac{1}{2}mv^2$$

Step 5 – W = Final K.E. – Initial K.E.

$-\frac{1}{2}mv^2 = 0 -$ initial K.E.

So, K.E. = $-\frac{1}{2}mv^2$ proved.

Potential Energy:

It is the energy possessed by an object due to its position or change in its shape.

For example:

- In bow the stretched band can do work as when the stretched band is released the arrow starts moving so we can say that stretched band has energy. In this case, energy possessed by the stretched band is due to change in shape.
- The block on ground can't do work. The block at high position can do work so it has energy. In this case, energy possessed by the block is due to its position.

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.

- If an object is at greater height, it has more potential energy.

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

Potential Energy (P.E.) = mgh

Here,

m = mass of body

g= 9.8 m/s^2

h= height of object from ground

Mechanical Energy:

It is defined as the sum of kinetic and potential energy. For example; bird flying in the air has both kinetic and potential energy.

Mechanical Energy (M.E.) = K.E. + P.E.

$$= \frac{1}{2} mv^2 + mgh$$

Transformation of Energy

Energy can transform from one form to another. For example; when a body falls from a height to ground potential energy transforms to kinetic energy.

Energy transformation in gadgets:

- In fan, electrical energy is transformed into kinetic energy.
- In bulb, electrical energy is transformed into heat energy then finally into light energy.
- In riding a bicycle, chemical energy is transformed into muscular then into kinetic energy etc.

Energy transformation in Nature:

- During photosynthesis, light energy is transformed into chemical energy;
- During rain, potential energy is transformed into kinetic energy;
- During striking of clouds, kinetic energy is transformed into light and sound energy etc.

Law of Conservation of Energy

Law of conservation of energy says that

" *Energy can neither be created nor destroyed, but can be converted from one form into another. When energy changes from one form to another, total amount of energy remains constant or conserved* ".

For example:

In an iron the electrical energy required to run it is 100J (say), then this energy is converted into heat energy and the energy still remains 100J only its form gets converted not its amount.

Energy conservation for a falling body:

- Let's suppose a ball of mass 1 kg is kept at a distance 4m from ground.

  Potential energy of ball = mgh

  = (1)(10)(4) = 40 J

- As ball moves down, potential energy decreases. But by conservation of energy, total energy should be constant. It means kinetic energy would increase.

- Kinetic energy (K.E.) = $\frac{1}{2}mv^2$

  Initally velocity is zero, so

  K.E. = 0

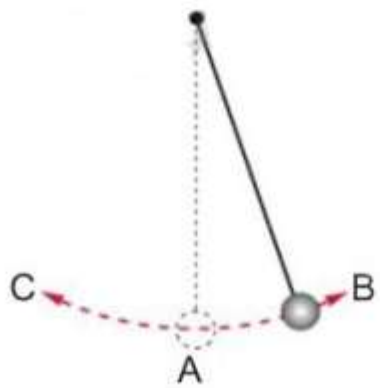
  But as ball moves down, velocity is increasing and thus kinetic energy would increase.

- Thus we can say potential energy is transforming to kinetic energy and total mechanical energy is constant.

  P.E. + K.E. = Mechanical energy = constant
- When the ball finally hits the ground, it comes to rest and its P.E. and K.E. both are zero.
- 40 J kinetic energy is converted to sound and heat energy.
- Sound is produced on hitting and ground gets a bit heated.

Energy Conservation in Pendulum:

We know as pendulum oscillates, its height changes.



- At point A, ball has kinetic energy and no potential energy.
- When pendulum slowly rise, K.E. decreases and P.E. increases. At point B, ball has potential energy and no kinetic energy.
- While going from B to A, P.E changes to K.E. At point A, K.E. becomes maximum and P.E energy becomes zero.
- While going from A to C, K.E changes to P.E. At point C, ball has potential energy and no kinetic energy.
- While going from C to A, P.E changes to K.E.

When pendulum stops, both P.E. and K.E. becomes zero and entire energy is converted into sound and heat energy.

Thus an oscillating pendulum also verifies law of conservation of energy.

Power

Power is defined as the rate of doing work. It tells how fast or slow a work is done.

For example; an aero-plane covers more distance in less time than a car consequently so we say that aero-plane is more powerful than car.

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

=> $P = W / t$

- SI unit of Power is Joule per second or Js^{-1}.
- 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 = 1000 W

Note – If power is more, work is done fast and vice versa.

Power can also be defined as the rate of transfer of energy.

Commercial Unit of Energy

- Since Joule is very small thus, large quantity of energy is expressed in kilo watt hour and is written as kWh. KWh is the commercial unit of energy.
- Electric consumption in house is measured in kWh. Therefore, kWh is called commercial unit of energy.

  1 unit = 1 kwh
- 1 kWh is the energy consumed by a device of power 1kW in 1 hour.

  1 kWh = (1 kW)(1 hr)

  = (1000 W)(60 60s)

  = (1000 J/t) (60 60s) = 3600,000 J

=> 1 kWh = $3.6\ 10^6$ J