

'Work is done on an object when a force causes a displacement of the object'.



## The concept of work

- ▶ Work is not done on an object unless the object is moved with the action of a force.
- ▶ Two important conditions that must be satisfied for work to be done are :
  - ▶ A person exerts a force on the car and displaces it to the left. The work done is done by him on the car.



(i) A force should act on an object

(ii) The object must be displaced.

## Mathematical definition of work

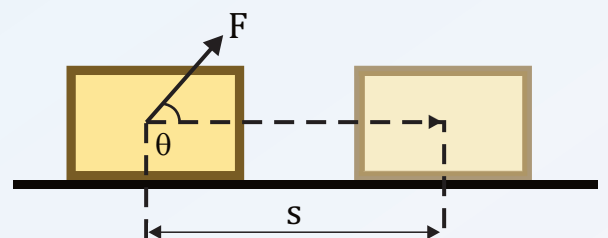
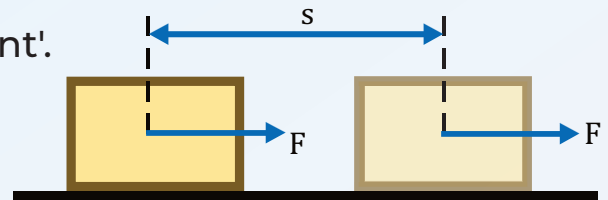
- ▶ 'The product of the force and displacement'.

Work done = Force  $\times$  Displacement

$$W = F \times s$$

- ▶ A constant force is applied at a certain angle with the direction of the displacement of an object.

$$W = F \times s \times \cos\theta$$



- (a) Work done by a constant force acting in the direction of displacement.
- (b) Work done by a constant force acting at an angle with the direction of displacement.

- 'The force multiplied by the displacement multiplied by the cosine of the angle between them'.  
Work is a scalar quantity.

**Unit of work :** S.I. unit : Joule

C.G.S. unit : Erg  $1 \text{ erg} = 1 \text{ Joule} = 10^7 \text{ ergs}$

## Some important points related to work

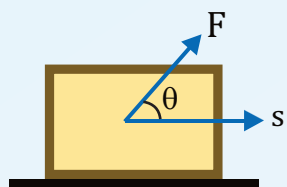
If  $\theta = 0^\circ$ , then  $\cos 0^\circ = 1$  and  $W = F \times s$ .

If  $\theta = 90^\circ$ , then,  $W = 0$  because  $\cos 90^\circ = 0$ .

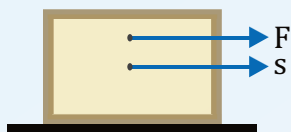
If  $\theta = 180^\circ$ , then  $\cos 180^\circ = -1$  and  $W = -F \times s$ .

## Concept of negative and positive work

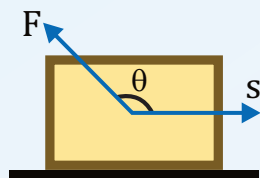
- The work done by a force can be either positive or negative.
- $0^\circ < \theta < 90^\circ$ , the work done is positive.
- Force and displacement are in same direction, the work done is positive.
- $90^\circ < \theta < 180^\circ$ , the work done is negative.
- Force and displacement are in opposite direction, the work done is negative.



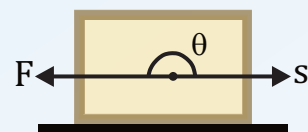
(a)  $\theta$  is acute angle  
Work is positive



(b)  $\theta$  is zero Work  
is positive



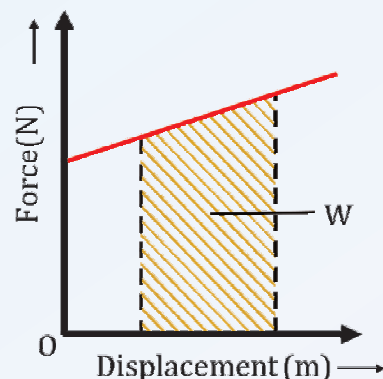
(c)  $\theta$  is obtuse angle  
Work is negative



(d)  $\theta$  is  $180^\circ$  Work  
is negative

## Concept of negative and positive work

- Area under the force (F)-displacement (s) graph gives the work done on an object or a system.
- Work done by the centripetal force is always zero because it is always perpendicular to the displacement.



Area under force-displacement graph gives work done

## Work done by applied force against gravity

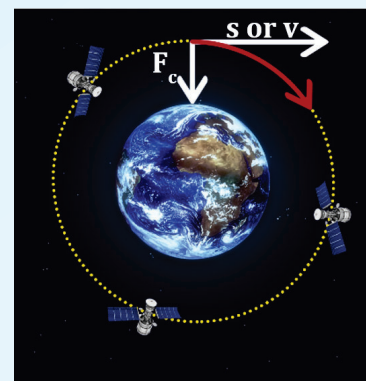
work done is given by,  $W = F \times s = mgh$

Where,

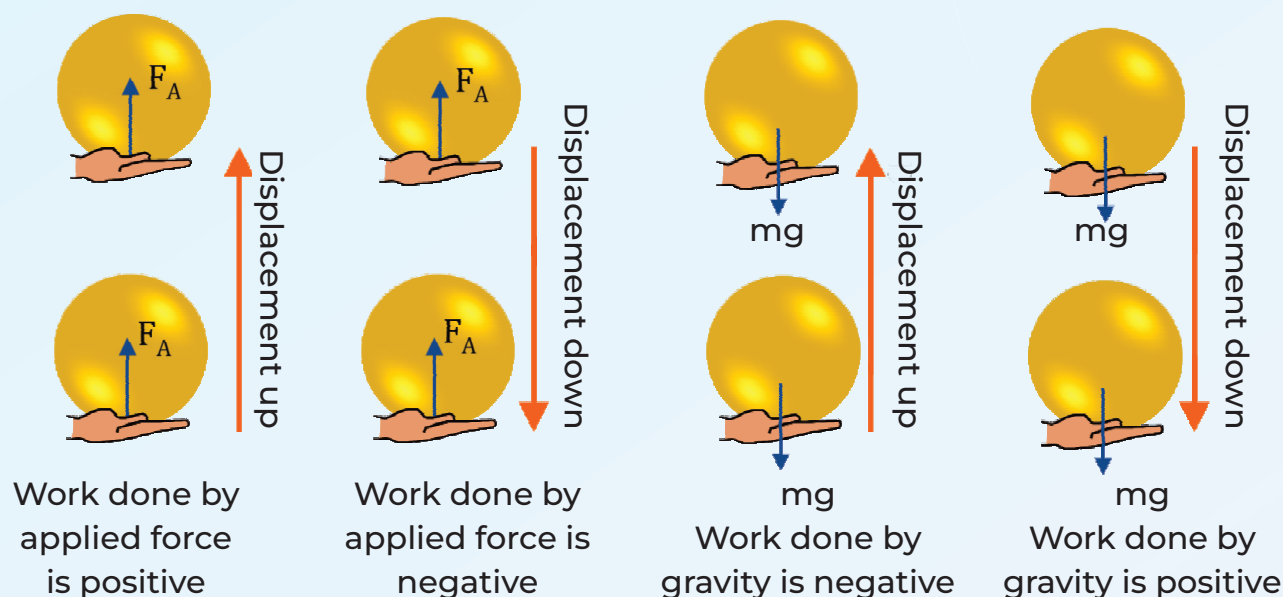
$m$  = mass of object;

$g$  = acceleration due to gravity;

$h$  = height

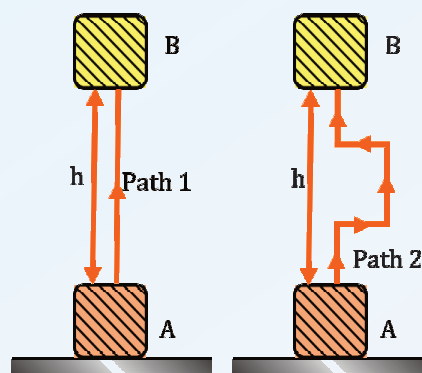


Work done by the centripetal force is zero



### Work done by the applied force and gravity when an object is raised or lowered

- ▶ The work done against gravity depends on the difference in vertical heights of the initial and final positions of the object and not on the path along which the object is moved.
- ▶ This is because force of gravity is a conservative force.



Work done against gravity depends only on initial position and final position.

## Energy

Energy is the capacity to do work.

**Unit of energy :** S.I. unit : Joule (J).  
C.G.S. unit : Erg

## Forms of Energy

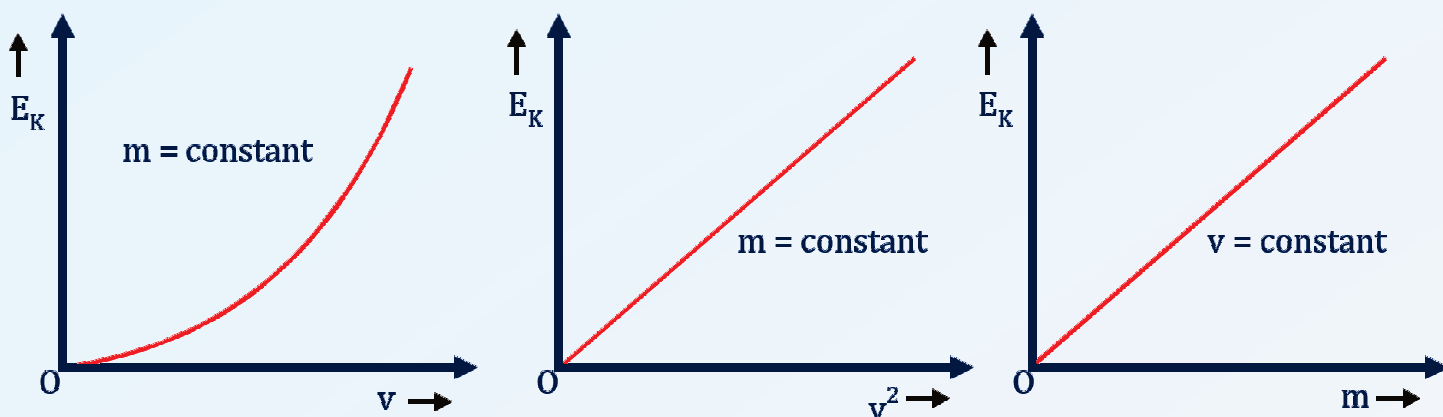
- ▶ The capacity to do mechanical work is called mechanical energy.
- ▶ Mechanical energy can be of two types :
  - (1) Kinetic energy
  - (2) Potential energy
- ▶ The sum of the gravitational potential energy and the kinetic energy is called mechanical energy.

### Kinetic Energy

- ▶ This is the energy a body has due to its movement. To give a body KE, work must be done on the body. The amount of work done will be equal to the increase in KE.
- ▶ Kinetic energy is the energy associated with an object in motion.

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

- ▶ For a given mass, kinetic energy  $E_k \propto v^2$ . That is, more the value of  $v$ , more will be the kinetic energy. Also, if we double the velocity, the kinetic energy becomes four times, if we triple the velocity, the kinetic energy becomes nine times, and so on.
- ▶ For a given velocity,  $E_k \propto m$ . That is, more the mass, more will be the kinetic energy of a body. If a car and a truck are moving with same velocity, the truck possesses more kinetic energy than that of car because the truck has more mass than that of the car.



Graphs relating kinetic energy, velocity and mass

## Relationship between momentum and kinetic energy

$$E_k = \frac{p^2}{2m}$$

Also,  $p = \sqrt{2mE_k}$

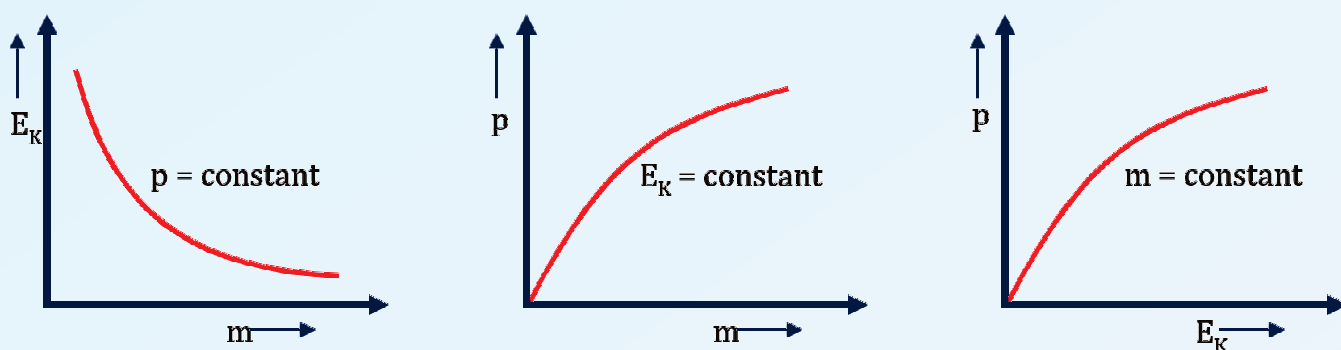
- ▶ For a given momentum, kinetic energy is inversely proportional to mass ( $E_K \propto 1/m$ ).
- ▶ A given kinetic energy, momentum is directly proportional to the square root of mass ( $p \propto \sqrt{m}$ ).

$$p \propto \sqrt{m}$$

- ▶ This means heavier body will have more momentum and vice-versa.
- ▶ For a given mass, momentum is directly proportional to the square root of kinetic energy ( $p \propto \sqrt{E_K}$ ).

$$p \propto \sqrt{E_K}$$

- ▶ This means more the kinetic energy, more will be the momentum and vice-versa.



Graphs related to momentum, kinetic energy and mass.

## Potential energy

- ▶ The energy possessed by an object due to its position or configuration is called 'potential energy'.
- ▶ Potential energy is associated with an object that has the potential to move because of its position or configuration.

### Gravitational potential energy

- ▶ The energy associated with an object due to the object's position relative to a gravitational source is called gravitational potential energy.

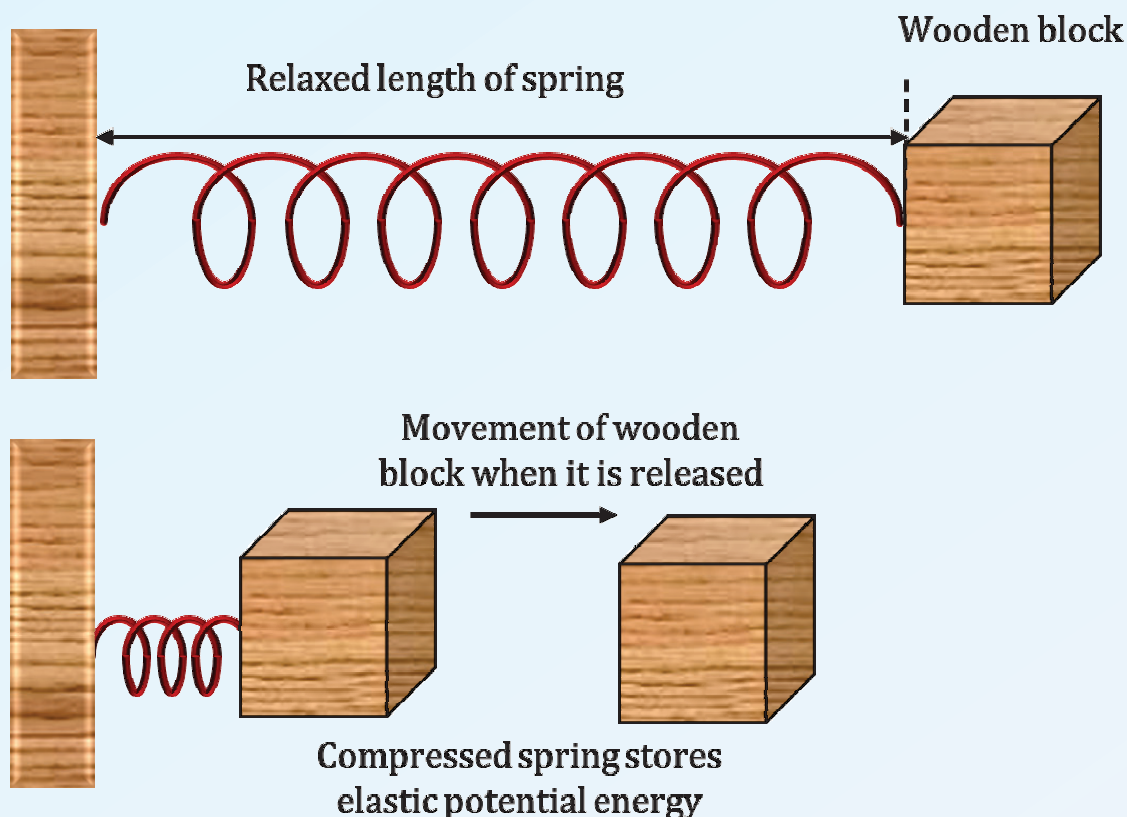
$$E_p = W = mgh$$

### Elastic potential energy

- ▶ The block slides across the tabletop. The kinetic energy of the block came from the stored energy in the compressed spring (see figure). This potential energy is called elastic potential energy.
- ▶ The length of a spring when no external forces are acting on it is called the relaxed length of the spring.

$$E_p = \frac{1}{2} Kx^2$$

Where,  $K$  = Spring constant or force constant,  
 $x$  = Distance compressed or stretched  
 from the relaxed position of a spring.



## Some important points relate to work and energy

- Net work done on a particle or a system of particles is given by,

$$W_{\text{net}} = W_c + W_{\text{nc}} + W_{\text{ext}}$$

Where,  $W_c$  = work done by conservative forces;  $W_{\text{nc}}$  = work done by the non-conservative forces;

$W_{\text{ext}}$  = work done by external or applied forces.

- Work done by conservative forces like elastic forces, gravitational forces is given by,

$$W_c = - \text{change in potential energy} = - \Delta PE = - (U_f - U_i) = U_i - U_f$$

Where,  $U_f$  = final potential energy;  $U_i$  = Initial potential energy

Work done by non-conservative forces like frictional forces, air resistance, etc. is negative as they are opposite to displacement.

- ▶ Net work done by all the forces i.e., the work done by the unbalanced force is always equal to change in kinetic energy.

$$W_{\text{net}} = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

- ▶ This is called work-energy theorem.

$$\text{or } W_c + W_{nc} + W_{\text{ext}} = K_f - K_i$$

- ▶ If a body is lifted with certain acceleration to reach height  $h$ , then work done by the external force is given by,

$$\text{or } W_{\text{ext}} = \left( \frac{1}{2}mv^2 - \frac{1}{2}mu^2 \right) + mgh$$

## Conservation of energy

- ▶ Energy appears in many forms, such as heat, motion, height, pressure, electricity, and chemical bonds between atoms.

- ▶ **Energy transformations**

Energy can be converted from one form to another form in different systems, machines or devices.

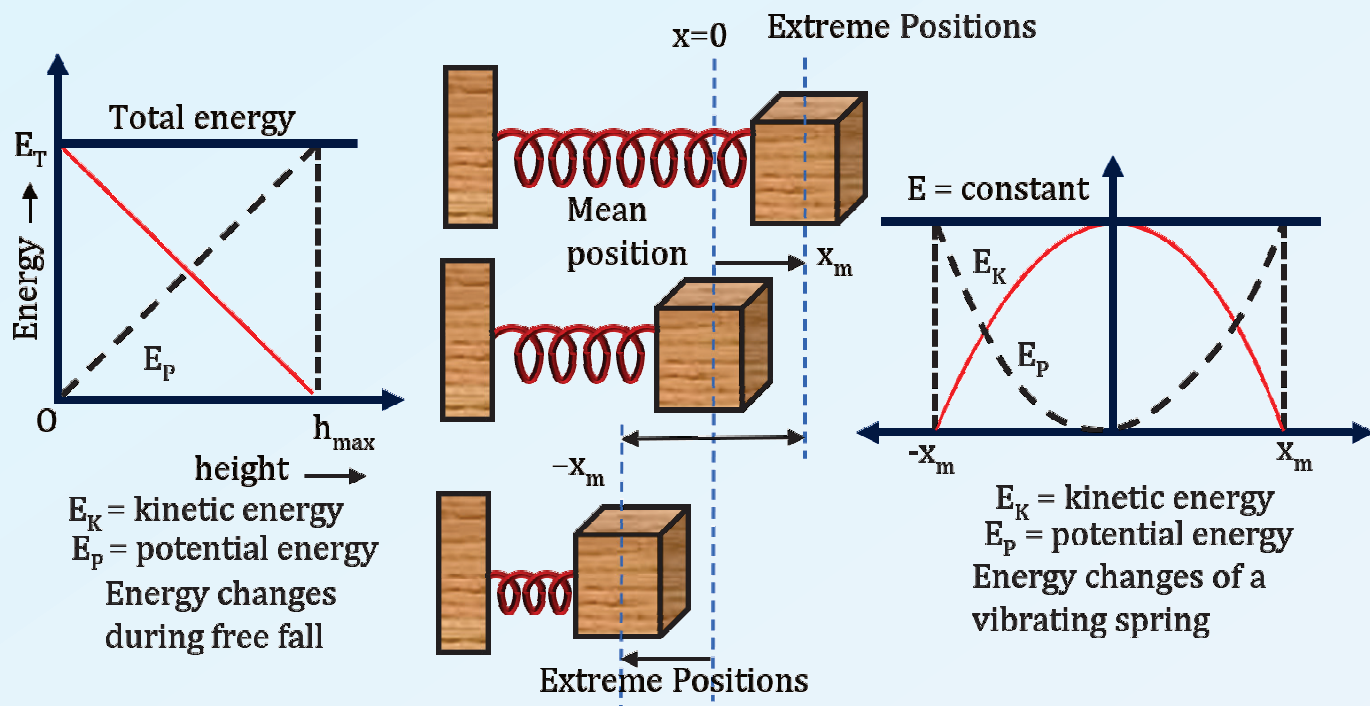
- ▶ **Law of conservation of energy**

Energy can never be created or destroyed, just converted from one form into another. This is called the law of conservation of energy.

- ▶ **Energy has to come from somewhere :**

When a body is dropped from a certain height under gravity then, in the absence of any non-conservative forces like air resistance, the total mechanical energy of the body remains constant.

When a spring fixed at one end and attached with other end is stretched or compressed on a frictionless surface and then allowed to release, it oscillates about its equilibrium position. But its total mechanical energy remains constant.



Conservation of energy during free fall and in a spring-mass system

## Power

Power is the rate at which work is done.

$$P = \frac{\text{Work done}}{\text{time taken}} = \frac{W}{t}$$

$$P = F \times V$$

- ▶ **SI unit of power :** Watt (W)  
or  $1 \text{ W} = 1 \text{ J s}^{-1}$
- ▶ **Commercial unit of energy :**  
Kilowatt hour (kWh). It is called commercial unit of energy.
- ▶ **Definition of 1 kWh :**  
 $1 \text{ kW h} = 1 \text{ kW} \times 1 \text{ h} = 1000 \text{ W} \times 3600 \text{ s} = 3600000 \text{ J}$   
or  $1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$ .