Concepts & Notes

Introduction

In our day-to-day life, we talk about the term work, energy and power. Out of these energy is most important concept, since all living things need energy to maintain life. The concept of work is closely associated with the concept of energy. When we walk or run, we use the energy that we get from the food we eat. The concept of power is also closely associated with that of work. In our daily life, any physical or mental activity is termed as work done. However in physics, the meaning of work is entirely different. In this chapter, we shall discuss detail about these terms.

Work

Work is said to be done by a force on a body if the force applied causes a displacement in the body or object. In other words the condition which must be satisfied for the work to be done are

- a force must act on the body and
- the body must be displaced from one position to another position.

Examples: (i) *Work is done, when we hit a football. In this case, when we hit the football, force is applied on the football and the football travels a certain distance before landing on the ground,*
(ii) Work is done when we lift a box through a height. In this case the applied force does work in lifting the box.

Factors on Which Work Done Depends

Work done by a force depends upon the following factors

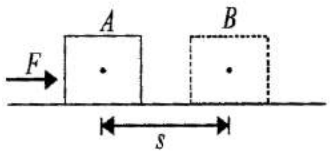
- The magnitude of the applied force. If a small force is applied on a body, less amount of work is done and vice versa. Thus $W \propto F$, where F is the magnitude of force applied.
- The distance travelled by the body in the direction of applied force. If a body travels large distance on the application of force, large amount of work is done and vise versa. Thus $W \propto s$, where s is the magnitude of

Unit of Work

The S.I. unit of work is joule. One joule work is said to be done on an object when a force of one newton displaces it by one metre along the line of action of the force
1 joule = 1 newton x 1 metre or 1 J = 1 N m
Bigger units of work are kilojoule (kJ), megajoule (MJ) and gigajoule (GJ), i.e.,
1 kilojoule = 10^3 J
1 megajoule = 10^6 J
1 gigajoule = 10^9 J
Work is a scalar quantity, and it has only magnitude but no direction.

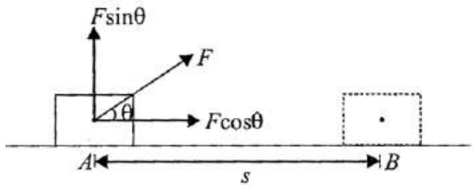
Work Done By A Constant Force

- When a constant force is applied in the horizontal direction:
  Let a constant force F be applied on a wooden block placed at position A on the smooth surface as shown in figure. Suppose the block moves in the direction of applied force to the new position B so that its displacement is s. Then, work done by the force is given by



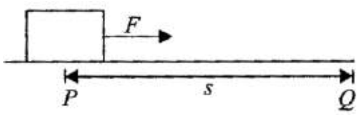
$W = F \times s$ ...(i)
  Thus, work done on the block (or any other object) by a constant force is equal to the product of the magnitude of the applied force and the distance travelled by the body.
- **When force is applied at an angle with the horizontal direction:**

Let a force F be applied on a wooden block at an angle θ with the horizontal direction as shown in figure.
The component of force F in the horizontal direction $= F\cos\theta$.
The component of F in the vertical direction $= F\sin\theta$.



Let the block moves horizontally and occupies a new position B so that it travels a distance s horizontally. Since, Fsin6 does not produce displacement in the block in the upward direction, so the only force which displaces the block is $F\sin\theta$. According to the definition of work done,
W = force applied × distance travelled by the body.
or $W = F\cos\theta \times s = FS\cos\theta$ ...(ii)
or $W = F\cdot s$ ...(iii)
$F\cdot s$ is read as dot product of F and s.
Thus, work done on a body by a force is defined as the product of the magnitude of the displacement and the force in the direction of the displacement.

- **Positive work done:** If force is acting in the direction of displacement then, the work done is positive. In this case $\theta = 0^o$ i.e., the force F acts in the direction of displacements of the body.
Then



$W = Fs\cos\theta$
i.e., $W = Fs$ $(\because \cos 0^o = 1)$

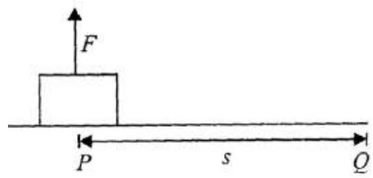
Example: In a tug of war, the work done by a winning team is positive. The winning team applies a force on the rope in the backward direction and the rope is also displaced in the direction of applied force.

ILLUSTRATION

1. A boy pushes a book by applying a force of 5.0 N. Find the work done by this force in displacing the book through 20 cm along the direction of the push.

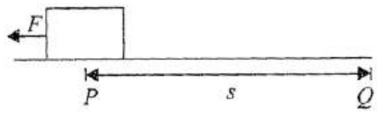
Sol.: Work done is $W = Fs$
$= 5.0\,N \times 20\ cm$
$= 5.0\ N \times 0.2\ m$
$= 1.0\,N\,m = 1.0\,J$

- **Zero work done:** If the force is acting perpendicular to the displacement then work done is zero. In this case $\theta = 90^o$
i.e., force F acts at right angles to the displacement of the body.



Then $W = F\,s\cos 90$
$W = 0$ $(\because \cos 90^o = 0)$
i.e., no work is done by the force.
Example: Work done by the force of gravity on a box lying on the roof of a bus moving with a constant velocity on a straight road is zero. In this case, force of gravity acts vertically downward and the displacement of the box takes place horizontally.

- **Negative work done:** If the force is acting in the direction opposite to displacement then work done is negative. If $\theta = 180^o$
i.e., force F acts just opposite to the displacement s of the body, then
$W = Fs\cos 180$
$W = -Fs$ $(\because \cos 180^o = -1)$



Thus work done by force is negative,
Example: In a tug of war, the work done by the losing team is negative. The losing team applies a force on the rope in the backward direction but the rope is displaced in the forward direction.

Do You Know

A weight lifter does work in lifting the weight off the ground, but does not in holding the weight up.

ILLUSTRATION

2. A ball of mass 1 kg thrown upwards reaches a maximum height of 5.0 m. Calculate the work done by the force of gravity during this vertical displacement.

Soln.: The force of gravity on the ball is

$F = mg = 1\ kg \times 9.8\ m\ s^{-2} = 9.8\ N$

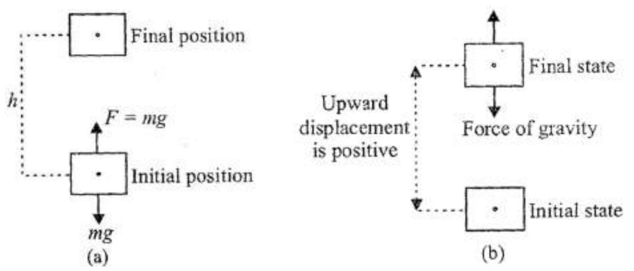
The displacement of the ball is $s = 5.0\ m$.

The force and the displacement are in opposite directions. Hence,

$W = -Fs = -9.8N \times 5.0m = -49\ J$

We can also say that a work of 49 J has been done against the force of gravity.

Work done in lifting a body against gravity



The earth attracts every object (or body) towards it. The force with which the earth attracts a body towards its centre is called its weight. The weight of a body is thus a force acting on it due to the gravitational attraction of the earth. So, if a body is to be lifted up from the surface of the earth, a force equal to the force of gravity (weight) must be applied to the body

Then, the work done in lifting a body through a certain height (h) from the surface of the earth is given by,

Work done in lifting a body = Force of gravity $\times$ Height

= Weigh of the body $\times$ Vertical distance

or $W = m \times g \times h$

where, m is the mass of the body,

g is the acceleration due to gravity, and

h is the vertical distance through which the body is lifted.

Thus, when a body of mass m is lifted to a height h above the ground, work equal to mgh is done on the body. Since the body is moved against the force of gravity, hence the work $W = mgh$, is commonly called as the work done against the gravity.

ILLUSTRATION

3. A person does work equal to 2500 J in climbing a tree of height 5 m. What is the mass of the person? The value of $g = 9.8\ m\ s^{-2}$.

Soln.: Work done by the person, W = 2500 J

Displacement = Height of the tree, $h = 5\ cm$

$g = 9.8\ m\ s^{-2}$

Let the mass of the person be m.

So,

$W = m \times g \times h$

or $2500\ J = m \times 9.8\ m\ s^{-2} \times 5\ m$

or $m = \dfrac{2500\ J}{9.8 m s^{-2} \times 5m} = \dfrac{2500\ N\ m}{9.8 m\ s^{-2} \times 5m}$

$= \dfrac{2500\ kg\ m\ s^{-2}\ m}{9.8 \times 5\ m^2 \times s^{-2}}$

$(\because 1\mathrm{N} = 1\ \mathrm{kg\,m\,s^{-2}})$

or $m = \dfrac{2500}{5 \times 9.8} kg = 51\ kg$

Energy

Energy is defined as the capacity to do work and it is measured by the total quantity of work it can do.

When a car runs, the engine of the car generates a force which displaces the car. In other words, work is done by the car. This work is done on the expense of fuel. Fuel provides the energy needed to run the car. The conclusion is that, if there is no source of energy, no work will be done.

Unit of Energy: The S.I. unit of energy is joule (J). The C.G.S. unit of energy is erg. Other unit of energy are electron volt (eV), calorie (cal), kilowatt hour. $1\ \mathrm{eV} = 1.6 \times 10^{-19} J,\ 1\ cal = 4.186\ J$.

Kilowatt hour is the commercial unit of energy.

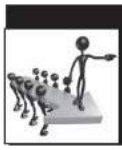
1 kW h = 1000 W x l h

We know, 1 W = 1 J s^{-1}
1 h = 60 x 60 s = 3600 s
So, one can write
1 kilowatt hour = 1000 W x 1 h = 1000 x 1 J s^{-1} x 3600 s
So, 1 kWh = 3,600,000 J = 3.6 x 10^6 J
Therefore, 1 kilowatt-hour (1 kW h) is equal to 3.6×10^6 joules.

Examples:

(i) A man or a horse does work when they pull a load.
(ii) A moving body can set other bodies into motion when it collides with them.
(iii) Compressed air in a cylinder causes the motion of the piston in it and thus performs work. Our life style demands of energy in various forms. Some forms of energy available naturally or created artificially are as follows:

- **Heat or Thermal Energy:** The energy possessed by a body due to its temperature is known as heat or thermal energy.
- **Chemical Energy:** The energy released in chemical reactions is known as chemical energy.
- **Sound Energy:** The energy of a vibrating body producing sound is known as sound energy.
- **Electrical Energy:** The energy of moving electrons in a conductor connected with a battery is known as electrical energy.
- **Nuclear Energy:** The energy released when two nuclei of light elements combine with each other to form a heavy nucleus or when a heavy nucleus breaks into two light nuclei is known as nuclear energy.
- **Solar Energy:** The energy radiated by the sun is known as solar energy.
- **Mechanical Energy:** The energy possessed by a body because of its speed or position or change in shape is called the mechanical energy. It is the sum of kinetic energy and potential energy of a body. In this chapter our focus will be on mechanical energy.



Do You Know

Wind energy, ocean wave energy, ocean thermal energy, tidal energy, geothermal energy are some natural (non- conventional) sources of energy.

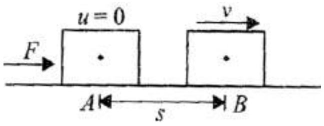
Kinetic Energy

The energy possessed by a body by virtue of its motion is called kinetic energy. So a moving body can do some work due to its kinetic energy. The faster a body is moving, the greater is the its kinetic energy. If a body is at rest, its kinetic energy is zero. Kinetic energy is a scalar quantity.

Examples: (i) ***A high speed bullet, a fast moving cricket ball, a stone thrown with a high speed.***
(ii) ***Flowing wind, and flowing water.***

Expression for Kinetic Energy

Consider a body of mass m lying at rest on a smooth floor. Let a force F be applied on the body so that the body attains a velocity after υ travelling a distance s.



Work done by the force on the body, $W = Fs$ ...(i)
Since the velocity of the body changes from zero to υ, so the body is accelerated. Let a be the acceleration of the body. Then according to Newton's second law of motion.
Substituting the value of $F = ma$ in equation (i), we get
$W = mas$ ...(ii)
Now, using $\upsilon^2 - u^2 = 2as$, we get

$\upsilon^2 - 0 = 2as$ or $s = \dfrac{\upsilon^2}{2a}$ ...(iii)

Substituting the value of s from equation (iii) in equation (ii), we get

$W = ma \times \dfrac{\upsilon^2}{2a} = \dfrac{1}{2} m\upsilon^2$ ...(iv)

This work done is equal to the kinetic energy of the body.

$\therefore$ Kinetic energy, K.E. $= \dfrac{1}{2} m\upsilon^2$

Thus, K.E. $= \dfrac{1}{2}$ mass of body $\times$ (speed of body)^2

Do You Know

Kinetic energy of a body is always positive. This is because mass can never be negative and square of a real value is always positive.

Relationship between kinetic energy and momentum:
We have,

$$K.E.=\frac{1}{2}m\upsilon^2=\frac{1}{2}m\upsilon^2\times\frac{m}{m}=\frac{(m\upsilon)^2}{2m}=\frac{p^2}{2m}$$

$$(\because\ p=m\upsilon)\qquad \therefore\qquad K.E.=\frac{p^2}{2m}$$

ILLUSTRATION

4. A black of mass 2.0 kg slides on a rough surface. At $t=0$, its speed is 2.0 m/s. It stops after covering a distance of 20 cm because of the friction exerted by the surface on it. Find the work done by friction.

Soln.: The kinetic energy of the ball at $t=0$ is

$$K=\frac{1}{2}m\upsilon^2$$

$$=\frac{1}{2}(2.0\ kg)\times(2.0\ m/s)^2=4$$

When the block comes to res, its kinetic energy becomes zero. This loss of energy takes place because friction does negative work on the block.
Thus, the work done by the friction is (- 4 J).

Work-Energy Theorem

Consider a body or an object of mass m moving with velocity u. Let a force F be applied on the body so that the velocity attained by the body after travelling a distance s is υ.
Work done by the force on the body is given by

$W=Fs$ ...(i)

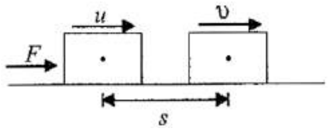
Since velocity of the body changes so the body is accelerated. Let a be the acceleration of the body. Therefore, according to Newton's second law of motion.

$F=ma$ ...(ii)

Using equation (ii) in equation (i), we get

$W=mas$ ...(iii)

Now, using $\upsilon^2-u^2=2as,$ we get



$s=\dfrac{\upsilon^2-u^2}{2a}$ ...(iv)

Using equation (iv) in equation (iii), we get

$$W=ma\left(\frac{\upsilon^2-u^2}{2a}\right)=\frac{1}{2}m(\upsilon^2-u^2)$$

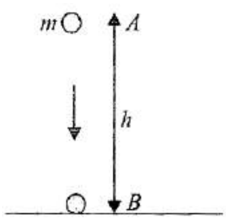
or $W=\frac{1}{2}m\upsilon^2-\frac{1}{2}mu^2$

or $W=$ Final K.E. of body – initial K.E. of body
= Change in K.E. of the body.
Thus, work done by a force on a body is equal to the change in kinetic energy of the body.
The expression shows that kinetic energy of a body depends on two factors.
(i) Mass $(K.E.\propto m)$
(ii) Velocity $(K.E.\propto\upsilon^2)$

Potential Energy

Energy possessed by a body by virtue of its position, {e.g., height above the ground) or configuration (e.g., shape) is called potential energy.
There are two types of potential energies. These are described below:

- **Gravitational Potential Energy:** The potential energy of a body by virtue of its height above ground level is called gravitational potential energy.
  Example, the energy stored in a body held at a certain height from the ground is gravitational potential energy.



- **Elastic Potential Energy:** The potential energy of a body by virtue of its configuration (or shape) is called elastic potential energy.
  Example, the potential energy stored in the coiled spring of a clock is elastic potential energy.

Examples: (i) Water stored in an overhead tank possesses gravitational potential energy by virtue of its position (height above ground level).

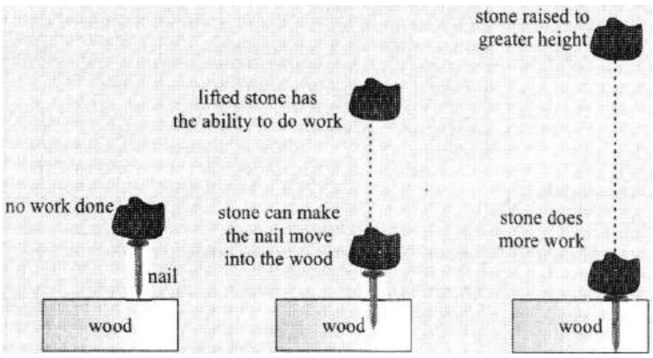
(ii) A raised hammer possesses gravitational potential energy by virtue of its height above the ground level.

ACTIVITY CORNER

Fix a nail on a wooden piece. Now keep a stone at the head of a nail as shown in figure. Can the stone drive the nail into the wood? No. Lift the stone through a certain height and drop this stone on the nail fixed on the wooden piece.

It will be observed that the nail moves into the wood. This shows that the stone has acquired some energy. The stone placed at a height has energy in it because of its position at that height. The stone has potential energy. This form of potential energy is called the gravitational potential energy and it is equal to the amount of work done in lifting the stone to that height against the force due to gravity. Now raise the stone to a greater height, and then drop it on the nail. What do you observe?

It will be seen that the nail moves deeper into the wood. So, we can say that the stone raised to a greater height can do more work and hence possesses greater gravitational potential energy.



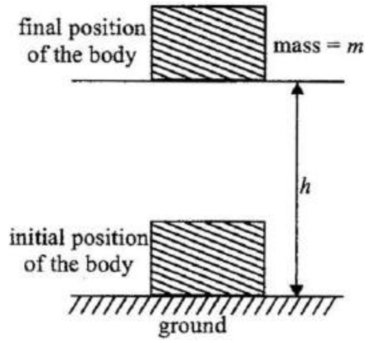
Expression For Gravitational Potential Energy

Suppose a body of mass m is raised to a height h above the surface of the ground as shown figure. The force applied just to overcome the gravitational attraction is

$F = m \times g$ ...(i)

where g = acceleration due to gravity

As the distance moved is in the direction of the forced applied, work is said to be done. The object gains energy equal to the work done on it. Let the work done on the object against gravity be W, so



Work done = Force $\times$ Displacement

$W = F \times h$ ...(ii)

Substituting the value of F from equation (i) in equation (ii), we get

$W = m \times g \times h$

This work gets stored up in the body as gravitational potential energy. Thus,

Work done on the object against gravity

= Gravitational potential energy

Gravitational potential energy $(P.E.) = m \times g \times h$

The expression shows that potential energy depends on

(i) mass m

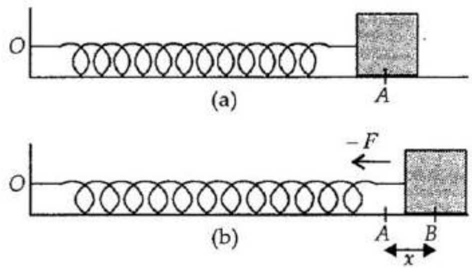
(ii) height h from ground

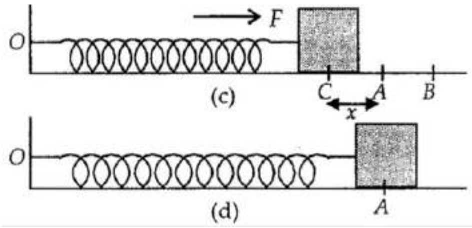
(iii) acceleration due to gravity

Potential Energy Of A Spring

Potential energy of a spring is the energy associated with the state of compression or expansion of an elastic spring.

To calculate it, consider an elastic spring OA of negligible mass. The end O of the spring is fixed to a rigid support and a body of mass m is attached to the free end A. Let the spring be oriented along x-axis and the body of mass m lie on a perfectly frictionless horizontal table as shown in figure.



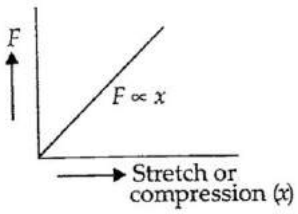


The position of the body A, normal when spring is unstretched is chosed as the origin.
When the spring is compressed or elongated, it is tends to recover its original length, on account of elasticity. The force trying to bring the spring back to its original configuration is called **restoring force or spring force.**
For a small stretch or compression, spring obeys Hook's law, i.e., for a spring.
Restoring Force $\propto$ stretch or compression

$-F \propto x$ ...(i)

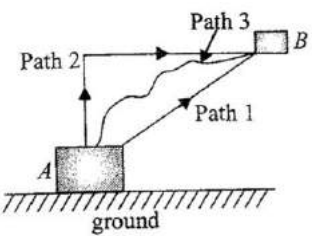
or $-F = kx$

where k is a constant of the spring and is called spring constant.
Equation (i) shows that greater the stretch or compression, greater will be the restoring force and vice-versa as is clear from graph.



Conservative And Non-Conservative Forces

Work done by gravity in moving object from one place to another depends only on the initial and final positions. It does not depends on the path taken. The work done by gravity from A to B is same by path 1, path 2 and path 3. Such forces, the work done by which depends only on the initial and final position and not on the path taken are called conservative forces. The forces in which the work done by which depends on the path taken are called **non-conservative forces**.



ILLUSTRATION

5. An object of mass 12 kg is at a certain height above the ground. If the gravitational potential energy of the object is 480 J, find the height at which the object is with respect to the ground.
$(g = 10\ m\ s^{-2})$

Sol.: Mass of the object $m = 12\,kg$

Acceleration due to gravity $g = 10\ ms^{-2}$

Potential energy of the object, P.E. = 480 J

Height $(h) = ?$

We know P.E. $= m \times g \times h$

Now putting the known values in the above formula, we get

$480\,J = 12\ kg \times 10\ m\ s^{-2} \times h$

$$h = \frac{480\,J}{12\,kg \times 10\,m\,s^{-2}}$$

Thus, the object is at a height of 4 m.

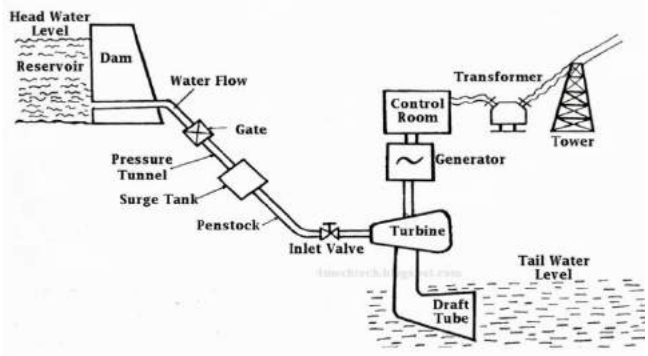
Transformation of Energy

Life on the earth depends on the energy received from the sun. Hydrogen nuclei (protons) fuse together to form helium nuclei in the sun's core. In this process, energy of the nuclei is converted into heat energy. This heat energy is absorbed by the atoms at the surface of the sun, and a part of it is converted into light and other radiations. These radiations travel through millions of kilometers of empty space to reach the earth. On receiving radiation from the sun, the land and air get heated. This, as you know, causes wind. This means that heat energy gets converted into kinetic energy. The energy from the sun also heats up the water of oceans.
Water evaporates from ocean and rises up to form clouds. This is a case of conversion of kinetic energy into potential energy.
We see many other energy conversion in nature. Snow deposited at high altitudes melts and the water so formed flows down to the seas. In the process, the potential energy of the water is converted into kinetic energy. We convert this kinetic energy of water to electrical energy in hydroelectric power plants.
Plants use sunlight for photosynthesis. In this process, light energy gets converted to chemical energy (as the energy stored in plant food). When plants die, the

energy stored in them is not lost. For example, dead plants buried below the earth's surface for millions of years got converted to fuels such as coal, petroleum and gases. These have chemical energy stored in them. When these fuels are burnt, the chemical energy is converted into heat energy.

- **Energy Transformation at Hydroelectric Power House**

At a hydroelectric power house, a dam is built on a river. The river water collects behind the dam to form a reservoir as shown in figure.



Water stored behind the dam has a lot of potential energy but as such this potential energy is of no use to us. If, however, this water is allowed to fall from its great height, the potential energy of water changes into kinetic energy. This kinetic energy of the falling water is used to drive huge water-wheels or turbines which are connected to electricity generators for producing electricity. Thus, at a hydroelectric power house, the potential energy of water is transformed into kinetic energy and then into electrical energy. The transformations of energy taking place at a hydroelectric power house can be written as:

Potential energy $\rightarrow$ Kinetic energy $\rightarrow$ Electrical energy

- **Few artificial devices which convert one form of energy into another are in table:**

	Device	Input energy	Output energy
1.	Fan	Electrical energy	Kinetic energy
2.	Electric lamp	Electrical energy	Light energy
3.	Electrical heaters	Electrical energy	Heat energy
4.	Water pump	Electrical energy	Kinetic energy of impeller to potential energy of water
5.	Cell	Chemical energy	Electrical energy
6.	Microphone	Sound energy	Electrical energy
7.	Rechargeable cell	(a) During discharging Chemical energy (b) During charging Electrical energy	(a) Electrical energy (b) Chemical energy
8.	Loudspeaker	Electrical energy	Sound energy
9.	Elevator moving up	Electrical energy	Potential energy
10.	Television	Electrical energy	Sound energy, light energy
11.	Thermal power plant	Chemical energy of coal	Electrical energy
12.	Car	Chemical energy of petrol/diesel	Mechanical energy
13.	Nuclear power point	Nuclear energy	Electrical energy
14.	Watch	Potential energy of wound spring	K.E. of hands of watch
15.	Generator	Mechanical energy	Electrical energy

Efficiency of a device: In a device, we supply a particular form of energy as input and we get a particular form of energy as output. For example, in an electric heater, we supply electrical energy and get heat energy. The electrical energy is not completely converted into heat energy.

Some energy gets converted into light energy. The percentage of electrical energy converted into heat energy is called the efficiency of the electric heater.

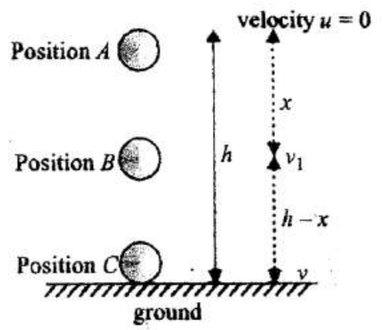
$$\therefore \quad \text{Efficiency, } \eta = \frac{\text{output energy}}{\text{input energy}} = \frac{\text{output power}}{\text{input power}}$$

Conservation of Energy

According to law of conservation of energy, energy can neither be created nor destroyed, it can be converted from one form to another. The law of conservation of energy holds universally, i.e., it is valid in all situations and for all kinds of transformations.

Verification Of Law Of Conservation Of Energy

Let m be the mass of a body held at a position A and at a height h above the ground.



- **At position A**

Kinetic energy of the body, K.E. = 0

($\because$ the body is at rest at A)
Potential energy of the body P.E. $= mgh$
($= mgh$ the body is lifted to a height h)
$\therefore$ Total mechanical energy at A, $M.E_A = K.E. + P.E.$
$= 0 + mgh = mgh$
$\therefore \quad M.E_A = mgh$
Let the body be allowed to fall freely under the action of gravity,
In free fall, let the body reach the point B with a velocity υ_1 where
$AB = x$.

- **At position B**

From the equation of motion,
$\upsilon^2 - u^2 = 2as$
$\upsilon_1^2 - 0 = 2gx$
$\upsilon_1^2 = 2gx$ ...(i)

Kinetic energy of the body $K.E. = \frac{1}{2}m\upsilon_1^2$ ...(ii)

Substituting the value of υ_1^2 from equation (i) in equation (ii), we get
$K.E. = \frac{1}{2}m(2gx) = mgx$
Height of the body at B above the ground
$= CB = (h - x)$
Total mechanical energy at $B(M.E_B) = K.E. + P.E.$
$= mgx + mg(h - x)$
$= mgx + mgh - mgx \quad \therefore \quad M.E_B = mgh$
Let the body be allowed to fall freely under gravity, when it strikes the ground at C with a velocity υ.

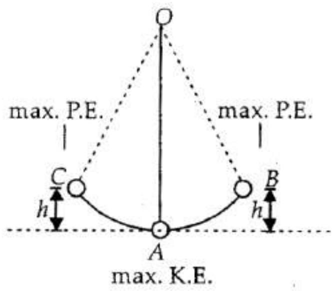
- **At position C**

From $\quad \upsilon^2 - u^2 = 2as$
$\upsilon^2 - 0 = 2gh$
$\upsilon^2 = 2gh$ ...(iii)

Kinetic energy of the body, $K.E. = \frac{1}{2}m\upsilon^2$ ...(iv)

Substituting the value of υ^2 from equation (iii) in equation (iv), we get
$K.E. = \frac{1}{2}m(2gh) = mgh$
Potential energy of the body at C, P.E.
$= mgh = mg\ (0) = 0$ ($\because$ the body is on the ground i.e. $h = 0$)
Total mechanical energy
$(M.E_C) = K.E. + P.E. = mgh + 0 = mgh$
$\therefore \quad M.E_C = mgh$
Thus, we find that
$M.E_A = M.E_B = M.E_C = mgh$
Thus, the total mechanical energy (i.e., sum of kinetic energy and potential energy) always remains constant at each point of motion of a body falling freely under gravity and is equal to mgh (initial potential energy at height h).As the body falls, its potential energy decreases and kinetic energy increases. The potential energy changes into kinetic energy. At A, the energy of the body is entirely potential energy and at C, it is entirely kinetic energy.
At B, the energy is partly kinetic and partly potential. Total mechanical energy stays constant (i.e., mgh) throughout. This proves the law of conservation of mechanical energy.

Conservation Of Energy In Case Of A Simple Pendulum



A small metallic ball (called bob) suspended by a light string (thread) from a frictionless, rigid support is called a simple pendulum. When the bob of the pendulum is displaced to B, through a height h, it is given $P.E. = mgh$, where m is mass of the bob. On releasing the bob at B, it moves towards A. P.E. of the bob is being converted into K.E. On reaching A, the entire P.E. has been converted into K.E. The bob, therefore, cannot stop at A. On account of inertia, it overshoots the positions A and reaches C at the same height h above A. The entire K.E. of the bob at A is converted into P.E. at C. The whole process is repeated and the pendulum vibrates about the equilibrium position OA. At extreme positions B and C, the bob is momentarily at rest. Therefore its K.E. = 0. The entire energy at B and C is potential energy. At A, there is no height and hence no potential energy. The entire energy at A is kinetic energy.
The swinging pendulum finally comes to rest due to friction at the support and friction of the air.

ILLUSTRATION

6. A 10 kg ball is thrown upwards with a speed of $5\ m\ s^{-1}$. (a) Find its potential energy when it reaches the highest point (b) Calculate the maximum height it reaches.

Sol.: (a) The kinetic energy of ball is

$$K.E.=\frac{1}{2}m\upsilon^2=\frac{1}{2}\times(10\,kg)\times(5\,ms^{-2})=125\,J$$

At the highest point, the kinetic energy becomes zero, and hence, the entire kinetic energy of 125 J is converted in to potential energy. So the potential energy at the highest point is 125 J. (b) Suppose the ball reaches a maximum height h. its potential energy there will be mgh. Thus,

$$mgh=125\ J$$

$$\text{or h }=\frac{125\ J}{(10\ kg)\times(9.8\ ms^{-2})}=1.28\ m$$

Power

The rate at which energy is transferred by an object is called the power delivered by that object, or rate of doing work is power.

If a force does work W in time t, the average power delivered by the force is

$$P=\frac{W}{t}$$

If the force does work at a constant rate, the average power is the same as the power at any instant during the time the work is being done.

By definition,

$$Power=\frac{Work\ done}{Time\ taken}$$

Therefore, the unit of power depends upon the units of work done, and of the time taken; The

S.I. unit of work done is joule (J), while that of time is second (s).

$$Unit\ of\ power=\frac{Unit\ of\ work}{Unit\ of\ time}=\frac{1\ joule\,(\text{J})}{1\,second\,(s)}=1\,J\ s^{-1}$$

The unit of $1\ J\ s^{-1}$ is called watt (W). So, the S.I. unit of power is watt (W).

or $1\,W=1\ J\ s^{-1}$

Thus, when a body works at the rate of 1 J per second, then its power is 1 watt, (W).

Generally, bigger units called kilowatt (kW), megawatt (MW) and gigawatt (gW) are used.

1 kilowatt 1 kW = 1000 watt

or 1 megawatt = 1 MW = 10^6 W

1 gigawatt = 1 GW = 10^9 W

The unit of power in the British engineering system is horse power, denoted by hp.

1 hp = 746 W = 0.746 kW

- To express large quantities of energy, joule is found to be very small and as such an inconvenient unit. For this purpose, a bigger unit of energy, called a kilowatt hour (kW h) is used.

  One kilowatt hour is the amount of energy consumed (or work done) by an agent in one hour working at a constant rate of one kilowatt. Clearly,

$$1\ kW\ \ h=1000\ W\times h$$

$$=1000\ \ (J\,s^{-1})\times 3600\ s \qquad (1\,W=1\ J\ \ s^{-1})$$

$$=3600000\,J=3.6\times10^6\ J$$

$$=3.6\ MJ$$

A kW h, also called BOTU (Board of Trade Unit) or simply a unit, is used in households, industries and commercial establishments for measuring electric energy consumption. For example, if an electric heater of 1 kW power is used for 2 hours, it consumes 2 kW h or 2 units of electric energy.

ILLUSTRATION

7. A lift is designed to carry a load of 4000 kg through 10 floors of building, average of 6 m per floor, in 10 s. Calculate the power of the lift.

Sol.: Total distance covered by the lift,

$$s=10\times6\ m=60\ m$$

Time in which this distance is covered, $t=0\ s$

Force exerted by the lift, $F=4000\ kg\ wt$

$$=4000\times10\ N \quad (1\ kg\ \ wt=10\ N)$$

$$=4\times10^4\,N$$

Velocity of the lift, $\upsilon=\frac{s}{t}=\frac{60\,m}{10\,s}=6\ m\ s^{-1}$

Power of the lift,

$$P=F\upsilon=(4\times10^4\,N)\ (6\ m\ s^{-1})$$

$$=24\times10^4\ W=240\ kW$$

Power in Terms of Energy

We know, energy is the ability of a body to do work. Power is the rate of doing work. So, for doing a particular work, an equivalent amount of energy is supplied transferred, so Work done = Energy supplied So, the rate of energy supplied by a body is called its power, i.e., $Power = \frac{Energy\, supplied}{Time\, taken} = \frac{E}{t} = \frac{F \times s}{t} = F \times \frac{s}{t} = F \times \upsilon$

where v is the velocity of the body.

Average power is defined as the average amount of work done by a body per unit time,

i.e., $Average\ power = \frac{Average\ amount\ of\ work\ done}{Time\ taken}$

In terms of energy,

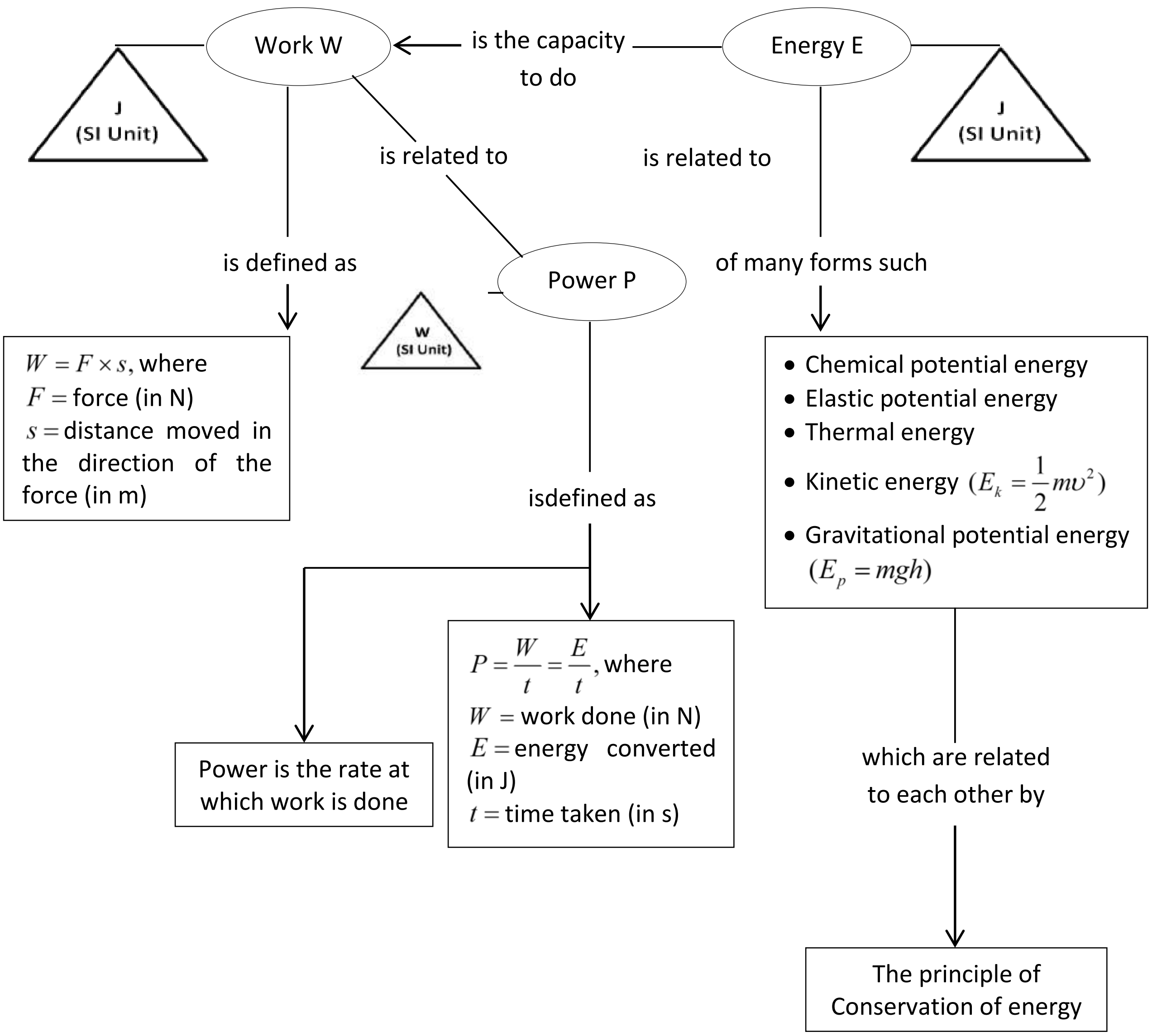
$Average\ power = \frac{Average\ amount\ of\ energy\ supplied}{Time\, taken}$

Since power is the ratio of energy to time, both being scalar quantities, power is also a scalar quantity.

Essential Points

- **Work:** Work is done when a force produces motion.
  Work = Force $\times$ Displacement
  i.e., $W = Fs\cos\theta$
  where θ is the angle between the direction of force and displacement.
- S.I. unit of work is joule (J). One joule is defined as the work done in displacing an object in 1 m by applying a force of 1 newton.
- Bigger units of work
  Kilojoule (kJ) = 103 J
  Megajoule (MJ) = 106 J
  Gigajoule (GJ) = 109 J
- When the applied force cause displacement is its own direction, the work done is said to be positive work.
- When a force acting on a body is opposite to the direction of displacement of the body, then the work done is said to be negative.
- When a force acts at right angle to the direction of displacement, then work is done is zero.
- **Energy:** The capacity or ability of a body to do work is called energy.
- The S.I. unit of energy is joule.
- **Mechanical Energy:** The energy possessed by a body due to a displacement caused in it by the application of a force, is called mechanical energy.
- **Kinetic Energy:** The energy possessed by a body by virtue of its motion is called kinetic energy
  Kinetic energy, $K.E. = \frac{1}{2}m\upsilon^2$
- **Potential Energy:** The energy possessed by a body on account of its position or configuration, is called potential energy.
  Potential energy, $P.E. = mgh$
- Mechanical energy is the sum of both potential energy and kinetic energy.
  M.E. = K.E. + P.E.
- The conversion of energy from one form to another is called transformation of energy.
- **Law of Conservation of Energy:** The energy in a system can neither be created nor be destroyed. It may be transformed from one form to another, but total energy of the system remains constant.
- **Power:** The rate of doing work is called power.
  $P = \frac{W}{t}$
  The S.I. unit of power is watt.
  $1W = \frac{1J}{1s} = 1J\,s^{-1}$
- The bigger unit of power are
  (i) Kilowatt $(kW) = 10^3\,W$
  (ii) Megawatt (MW) = 10^6 W
  (iii) Gigawatt (GW) = 10^9 W
- **Commercial unit of Energy:** It is the amount of energy used/produced at a rate of one kilowatt (kW) for one hour.
  $1\,kW\ h = 1\,kW \times 1\,h = 1000\ W \times 3600\,s$
  $= 1000\ J\,s^{-1} \times 3600\ s = 3600000\ J$
  $1\,kW\ h = 3.6 \times 10^6\ J = 3.6\ MJ$
- One kilowatt hour is commonly referred as one unit of electricity.

CONCEPT MAP


Work W
is the capacity to do
Energy E
J (SI Unit)
J (SI Unit)
is related to
is related to
is defined as
Power P
W (SI Unit)
of many forms such
$W = F \times s$, where
F = force (in N)
s = distance moved in the direction of the force (in m)
Chemical potential energy
Elastic potential energy
Thermal energy
Kinetic energy $(E_k = \frac{1}{2}mv^2)$
Gravitational potential energy $(E_p = mgh)$
isdefined as
$P = \frac{W}{t} = \frac{E}{t}$, where
W = work done (in N)
E = energy converted (in J)
t = time taken (in s)
Power is the rate at which work is done
which are related to each other by
The principle of Conservation of energy