Work, Energy and Power

INTRODUCTION

Work and Energy: Work done by a force, energy, power, kinetic energy and Potential energy; law of conservation of energy.

In our day-to day life, we talk about the terms work, energy and power. We usually say the following things: We are doing work. We need energy to do work. He is a powerful man and so on.

In our daily life, *any physi*cal or Mental activity is termed as work done. However, in Physics, the meaning of work is entirely different. In this chapter, we shall discuss the difference between the term work used in our daily life and the term work defined in physics.

CYCLING NEEDS ENERGY

The energy is needed to perform many activities like running, walking, playing, singing, swimming, reading, writing, lifting objects, dragging objects, cycling, fighting etc. We get energy for all these activities from food. Similarly, energy is also needed by animals to perform many activities. Horses need energy to pull carts. Bullocks need energy to plough fields. Donkeys need energy to carry loads.

Different machines also need energy for their operations. Electric drill, food mixer, electric kettle, television, radio, electric bulb, microwave oven, cassette player, microphone, toaster, electric fa, computer etc work only when energy in the form of electricity is provided to them.

We also get energy by burning things in the presence of air (or oxygen). Coal is burnt to heat the things. Car engines burn petrol or diesel fuel or their operation. Energy needed to cook food comes by burning coal or gas. This, we find that all living things and non-living things (machines) need energy.

WORK

In our day to day life, the word **work** means any kind of mental and physical activity. For example, we say that we are doing work while

(i) reading a book.

(ii) cooking a food

(iii) walking on a level road with a box on our head.

(iv) pushing a wall of a house but fails to do so.

In all these cases, either mental or a physical activity is involved.

But in physics, the term work has entirely a different meaning.

WORK DONE ON THE TROLLEY

SCIENTIFIC CONCEPTION OF WORK

In physicis, work is done if a force applied on a body displaces the body in its own direction. In other words, the conditions which must be satisfied for the work done are: (i) a force must act on the body and (ii) the body must be displaced from one position to another position. Thus, no work is done in all cases mentioned above.

Definition. Work is said to be done by a force on a body or an object if the force applied causes a displacement in the body or object.

Examples

(i) Work is done, when a box is dragged on the floor from one position to another. In this case, force is applied on the box to drage it on the floor and the box moves thorugh a certain distance between one position to another position.

(ii) Work is done, when we hit a football. In this case, when we hit the football, force is applied on the football travels a certain distance before landing on the ground.

(iii) Work is done, when a box (say) is lifted from the ground to some height. In this case, force is applied on the box to lift it and the box moves through a distance equal to the height through which it is lifted.

FACTORS ON WHICH WORK DONE DEPENDS

Work done by a force depends upon:

(i) The magnitude of the applied force. If a small force is applied on a body, less amount of work is done. On the other hand, if a large force is applied on the body, more amount of work is done on the body.

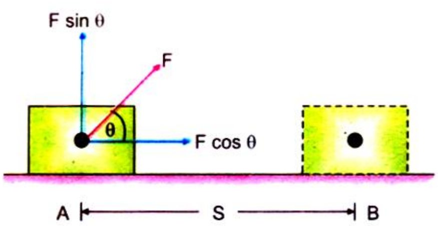
Thus, $W \propto F$, where F is magnitude of applied force.

(ii) The distance traveled by the body in the direction of applied force (i.e., displacement S). If a body travels large distance on the application of force, large amount of work is done. If a body travels a small distance on the application of force, small amount of work is done.

Thus, $W \propto S$

WORK DOEN BY A CONSTANT FORCE

(i) 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 (figure 1). 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

$$W = F \times S$$

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 traveled by the body

(ii) When force is applied at an angle with the horizontal direction.

Let a force $\vec{F}$ be applied on a wooden block at an angle θ with the horizontal direction. The component of force $\vec{F}$ in the horizontal

direction = $F\cos\theta$. The component of $\vec{F}$ 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.

According to the definition of work done,

W = force applied in the direction of the displacement of a body × distance traveled by the body.

Or $W = F\cos\theta \times S = FS\cos\theta$ ....(2)

or $W = \vec{F}.\vec{S}$ ....(3)

$\vec{F}.\vec{S}$ is read as dot product of $\vec{F}$ and $\vec{S}$.

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

DISCUSSION

(i) Positive Work Done. If $\theta = 0^0$ i.e., the force $(\vec{F})$ acts in the direction of the displacement $(\vec{S})$ of the body. Then

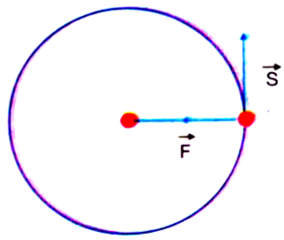
$W = FS\ \cos\ 0^0$ Or $W = FS$ $[\because \cos\ 0^0 = 1]$

Such work doen is known as **positive work done.** Thus, work doen by a force on a body (or an object) is said to be positive work done when the body is displaced in the direction of applied force.

θ	0^0	30^0	60^0	90^0	120^0	180^0
$\cos\theta$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	-1

Examples

(a) When a coolie lifts a box from the ground to put it on his head, work done is said to be positive. In this case, coolie applies the force on the box in the upward direction and the box is also displaced in the upward direction.



(b) In a tug of war, the work doen 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.

(ii) **No work done.** If $\theta = 90^0$ i.e., the force $(\vec{F})$ acts at right angles to the displacement ($\vec{S}$) of the body, then

$W = FS\cos 90^0$

Or $W = 0$ $[\because \cos\ 90^0 = 0]$

That is, no work is done by the force.

Thus, no work is done by the force acting at right angle to the displacement of the body.

Examples

(a) When a stone attached to a string is rotated in a horizontal circular path, the force acting on the stone is always towards the centre of the circular path. This force is called **centripetal force** (i.e. centre-seeking force) $\vec{F}$. Since the stone is displaced from one position to another position of the circular path at right angle to the force acting on the stone, so work done on the stone is given by $W = FS\cos 90^0 = 0$

WORK DONE AGAINST GRAVITY

(b) 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.

(iii) **Negative Work Done.** If $\theta = 180^0$ i.e., force $(\vec{F})$ acts just opposite to the displacement $(\vec{S})$ of the body, then

$$W = FS \cos 180^0 = -FS \qquad (\because \cos 180^0 = -1)$$

Such work done by the force is known as negative work done. Thus, work done by a force on a body is said to be negative work done when the body is displaced in a direction opposite to the direction of the force.

Examples

(a) When an object is lifted upward to a certain height, then the work done by the force of gravity (equal to the weight of the object) on the object is negative. In this case, the force of gravity acts downward on the object and the object is displaced upward so that the angle between the force of gravity and the displacement of the object is 180^0.

(b) 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.

(iv) If S= 0 i.e., the body does not move from its position on the application of force, then

$$W = 0$$

Thus, no work is done by the force if it fails to displace the body.

Example
When a person pushes a wall but fails to move the wall, then work done by the force on the wall is zero.

UNIT OF WORK

In SI, unit of work is **joule (**J). We know, W = F ×S.

Since SI unit of force (F) is newton (N) and that of displacement (S)is metre (m)

$\therefore$ 1J = 1Nm

Definition of joule (J). *Work done is said to be 1 joule if 1 newton force acting on a body displaces the body through 1 metre in itsown direction.*

ENERGY

It is often said that a person **A** is more energetic that a person **B.** The meaning of this statement is that a person **A** can do more work than the person **B.** Similarly, a person after doing a lot of work gets tired and after that he is not able to do much work. It is clear that a person doing work expends something. This 'something' is known as the **energy** of the person. The energy spent by a person is equal to the work done by him. Human beings and animals get energy by eating food.

It may be noted that **anything which is capable of doing work has energy.** For example, the steam pushes up the lid placed on the boiling water container. It means, the steam has the ability or capacity to do work. The work done by the steam on the lid is equal to the energy of the steam.

Definition of energy:

The capacity of doing work by a body or an object is known as the energy of the body or the object.

Unit of Energy. Unit of energy is same as that of the unit of work. So, SI unit of work is **joule (J)**

When we say that energy of a body is 1 joule, it means, this body has the capacity to do 1 joule work.

FORMS OF ENERGY

The various forms of energy are:

1. Mechanical Energy. The sum of kinetic energy and potential energy of a body is known as mechanical energy.

The sun is the ultimate source of all energies.

2. Heat or Thermal Energy. The energy possessed by a body due to its temperature is known as heat or thermal energy.

3. Chemical Energy. The energy released in chemical reactions is known as chemical energy.

4. Sound Energy. The energy of a vibrating body producing sound is known as sound energy.

5. Electrical Energy. The energy of moving electrons in a conductor connected with a battery is known as electrical energy.

6. 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.*

7. Solar Energy. The energy radiated by the sun is known as solar energy.

KINETIC ENERGY

When a moving object (say a ball) hits another stationary object (say a small wooden block), then the wooden block is displaced from its position. It means, the moving object has done work on the stationary object. So, moving object has energy which is known as kinetic energy.

FLOWING WATER HAS KINETIC ENERGY

Definition: The energy possessed by a body by virtue of its motion is known as kinetic energy.

Examples:

(i) A moving bus or a car or a train has kinetic energy.

(ii) Moving bullets have kinetic energy.

(iii) Flowing water has kinetic energy.

(iv) A moving ball has kinetic energy.

In other words, we can say that anything which moves has kinetic energy.

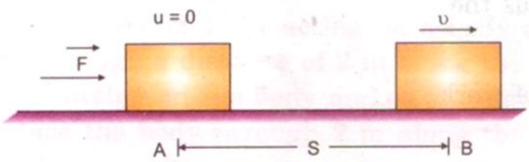
EXPRESSION FOR KINETIC ENERGY

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 υ after traveling a distance S.

$\therefore$ 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



$F = ma$

Substituting the value of F = ma in eqn. (i), we get

$W = (ma)S$ ....(ii)

Now, usng $\upsilon^2 - u^2 = 2aS,$ we get

$\upsilon^2 - 0 = 2aS,$ or $S = \dfrac{\upsilon^2}{2a}$ ....(iii)

Substituting the value of S from eqn. (iii), in eqn. (ii) we get

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

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

$\therefore$ Kinetic Energy, $K = \frac{1}{2}m\upsilon^2$ ……(2)

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

WORK DONE BY A FORCE ON A BODY IS EQUAL TO THE CHANGE IN KINETIC ENERGY OF THE BODY (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 traveling a distance S is υ

Work done by the force on the body is given by

$W = FS$ ……….(i)

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

$F = ma$ …………(ii)

Using eqn. (ii) in eqn. (i), we must

$W = (ma)S$

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

$S = \frac{\upsilon^2 - u^2}{2a}$ ………..(iv)

Using eqn. (iv) in eqn. (iii), we get

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

Or $W = \frac{1}{2}m\upsilon^2 - \frac{1}{2}mu^2$ ……(i)

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.

Remember these Points:

$\Rightarrow$ Kinetic energy of a body, $K.E. \propto$ mass of the body (m). Larger is the mass of a body, greater is its kinetic energy and vice-versa.

$\Rightarrow$ $K.E. \propto \upsilon^2$, where $\upsilon =$ speed of body. If speed of a body is doubled, its kinetic energy is increased four times.

$\Rightarrow$ Speed of a gas molecule increases with the increase in temperature and decreases with the decrease in temperature. So the kinetic energy of the gas increases with increase in temperature and decreases with decrease in temperature

POTENTIAL ENERGY

When a child lifts a football from the ground and place it on the top of a table, some work is done on the ball. Now, if this football falls down from the top of the table and hits another football lying on the ground, then the football lying on the ground is displaced from its position. This simple activity shows that a falling football is able to do work.

Stretched bow has potential energy

We know, anything capable of doing work, possesses energy. Therefore, a football placed on the table also possesses energy. This energy of the football lying on the top of the table is know as *potential energy*. Now the question arises from where this potential energy came in the football lying on the top of the table. In fact, the work done by the child to raise it to the top of table from the ground is stored as energy. This stored energy is known as potential energy.

Definition of potential energy

The energy possessed by an object by virtue of its position or shape or configuration is known as potential energy.

When work is done to change the shape of an object, potential energy stored in the object is known as elastic potential energy.

Examples:

(i) Water stored in a dam has potential energy due to its position

(ii) A stone lying on the top of a hill or a mountain has potential energy due to its position.

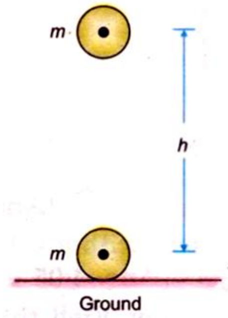
(iii) A stretched or a compressed spring has potential energy due to its shape. When spring is stretched or compressed, work is done on it. This work done is stored as potential energy of the stretched or compressed spring.

(iv) A wound spring of a watch has potential energy due to its shape,
(v) A stretched bow and arrow has potential energy due to its shape.

POTENTIAL ENERGY OF AN OBJECT AT A HEIGHT

The work done in lifting an object of mass m against force of gravity through a certain height h is equal to potential energy of the object at

height h.



Consider an *object* of mass m raised to a height h against gravity (Figure 6).

$\therefore$ force required to lift the object, F = weight of body

or $F = mg$

Distance travelled by the object, $S = h$

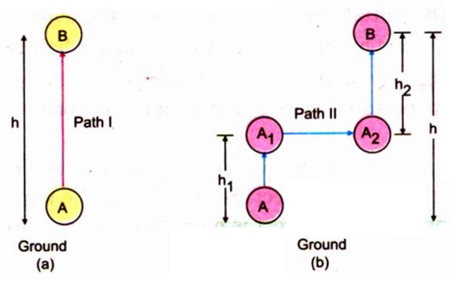
$\therefore$ Work done, $W = F \times S = mgh$

This work done against force gravity is equal to the potential energy or gravitational potential energy of the object.

i.e. $P.E. = mgh$

Thus, gravitational potential energy of an object depends upon (*i*) the weight *(mg)* of the object and (ii) the height (h) of the object from the surface of the earth.

Gravitational potential energy depends upon the difference in heights of the initial position and final position of a body but *is* independent of the path followed by the body while going from Initial position to final position



Consider a ball of mass m raised through height A from position A to position B along path I as shown in figure 7(b).

Then, gravitational potential energy of the ball at height $h = mgh$ ..*(1)*

Now, let the ball is raised through height h along path II as shown in figure 7(b).

When the ball is raised through height h_1, from position A to position A_1 then gravitational potential energy of the ball at height $h_1 = mgh_1$ ...(2)

When the ball is taken from position A_1 to position A_2, then no work is done against gravity because the force of gravity acts perpendicular to the displacement of the ball. Thus, gravitational potential energy of the ball at position A_1 and at position A_2 is same. Hence, there is no change in gravitational potential energy of the ball in going from position A_1, to position A_2.

Now, when the ball is raised through height h_2 from position A_2 to position B, then the gravitational potential energy of the ball at height $h_2 = mgh_2$ ...(3)

Therefore, the total gravitational potential energy of the ball at position B

$$= mgh_1 + mgh_2$$

$$= mg(h_1 + h_2) = mgh$$

$[\because (h_1 + h_2) = h]$ ...(4)

Thus, from eqns, (1) and (4), we conclude that (i) the gravitational potential energy of a body depends upon the difference in height *(h)* of the initial and final positions of the body and *(ii)* the gravitational potential energy of the body does not depend upon the path followed by the body in going from initial and final positions.

ARE VARIOUS ENERGY FORMS INTERCONVERTIBLE?

Energy in one form can be converted into another from. This is known as transformation of energy.

The process of changing or converting one form of energy into another form is known as **transformation of energy.**

Example of Transformation of Energy

1. A stone lying on the roof of a house falls down. A stone lying on the roof of a house has potential energy due to its position. When it falls down, potential energy is converted into *kinetic energy* due to its motion. Thus, during the fall of a stone (or any other body), potential energy is converted into kinetic energy. When the stone hits the ground, sound is heard and the ground where the stone hits becomes hot. So kinetic energy of the stone is converted into sound energy and heat energy.

2. Water stored in a dam falls on a turbine of a generator. Water stored in a dam has potential energy due to its position. When water falls down, potential energy of water is converted into kinetic energy due to the motion of water. This kinetic energy of water is used to rotate the turbine of generator, which produces electricity. Thus, potential energy of water in a dam is converted into kinetic energy which is then converted into electric energy. In other words, mechanical energy (Potential energy + Kinetic energy) is converted into electrical energy.

3. When electric current passes through an electric bulb, it glows and gives out light and heat. So, electric energy is converted into light energy and heat energy.

4. When coal is burnt, chemical energy stored in coal is converted into heat energy and light energy.

5. The heat energy produced due to the burning of coal changes water into steam. This steam is used to run the steam engine. Thus, chemical energy of coal is converted into heat energy and then heat energy is converted in to mechanical energy (used to run the steam engine.)

CONVERSION OF POTENTIAL ENERGY OF WATER STORED IN A DAM INTO THE KINETIC ENERGY OF FLOWING WATER.

6. When the spring of a watch is wound, work is done which is stored in the form of potential energy. When the watch operates and shows time, the potential energy is converted into kinetic energy of the hands of the watch.

7. A stretched bow and arrow has potential energy. When arrow is released, potential energy is converted into kinetic energy of the moving arrow.

CONVERSION OF MUSCULAR ENERGY INTO KINETIC ENERGY

8. In a thermal power plant, coal is burnt to produce electricity. Thus, chemical energy of the coal is converted into the electric energy.

9. When we rub our hands, they become warm. In this case, mechanical energy is converted into heat energy.

10. A log of wood cut by a saw becomes hot. In this case, mechanical energy is converted into heat energy

11. When a torch is switched on, chemical energy of the torch cell is converted into electrical energy which is then converted into light and heat energy.

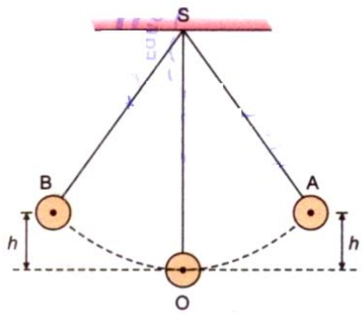
12. The heat of a nail hammered into the wooden plank becomes hot. Here kinetic energy of hammer is converted into heat energy.

13. The explosion of a fire cracker gives out sound, heat and light. In this case, chemical energy of the fire cracker is converted into sound, heat and light energy.

14. The explosion of an atomic bomb gives out heat and light. In this case, chemical energy of the fire cracker is converted into sound, heat and light energy.

15. A boy riding a bicycle. The muscular energy used to pedaling a bicycle is converted into the kinetic energy of the moving bicycle.

16. When a pendulum swings, the potential energy is converted into kinetic energy and vice-versa. This can be explained as follows:



Consider a simple pendulum suspended from a rigid support at S. Let OS be the undisturbed position of A pendulum. Now, let the pendulum be displaced to position A where it is at rest. At position a, the pendulum has potential energy (mgh). When the pendulum is released from position A, it begins to move towards position O. The speed of the bob of the pendulum increases and its height decreases. So potential energy of the pendulum is changed into its kinetic energy. At position O, whole of the potential energy of the pendulum is converted to its kinetic energy.

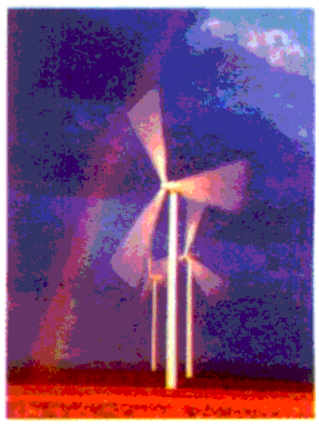
The pendulum swings to another side due to inertia of motion. As the pendulum begins to move towards position B, the speed of the wob of pendulum decreases and its height increase. So the kinetic energy of the pendulum is converted in to its potential energy. At position B, the pendulum comes to rest momentarily. So whole of the kinetic energy of the pendulum is converted into potential energy at position B. Thus, we find that the potential energy is converted into kinetic energy and vice-versa during the swinging of a pendulum. But the total energy of the pendulum at any position during swinging remains the same.

ENERGY FROM THE SUN (THE SUN IS THE ULTIMATE SOURCE OF ALL FORMS OF ENERGY)

The sun is the ultimate source of all forms of energy available on the earth. This can be illustrated as follows:

WIND ENERGY

Solar energy heats up the surface of the earth and the air near it. The hot air rises up and the cool air from above rushes to occupy its space. This makes the air to move. Moving air is known as wind and possesses kinetic energy. Thus, Solar energy + $Air \longrightarrow$ Wind energy. Wind energy is converted into electrical energy in a wind farm using wind mills.



WIND ENERGY

HOW DO GREEN PLANTS MAKE THEIR FOOD?

Green leaves of plants make their food using sunlight (i.e., Sun's energy) by the process of *photosynthesis*. The cells in green leaves of plants contain chloroplasts. Each chloroplast contains chlorophyll (a green pigment) which converts carbon dioxide into sugar in the presence of sunlight by the process of photosynthesis. Process of photosynthesis is represented as follows:

$$Carbon\ dioxide + Water \xrightarrow[Sunlight]{chlorophyll} Sugar + Oxygen$$

The energy stored in the food is known as chemical energy. The food eaten by a man or an animal provides him the muscular energy. This muscular energy is used to do work. In other words, muscular energy is converted into mechanical energy. Thus,

$$Solar\ energy + Green\ leaves \longrightarrow Food\ (Chemical\ energy) \longrightarrow$$

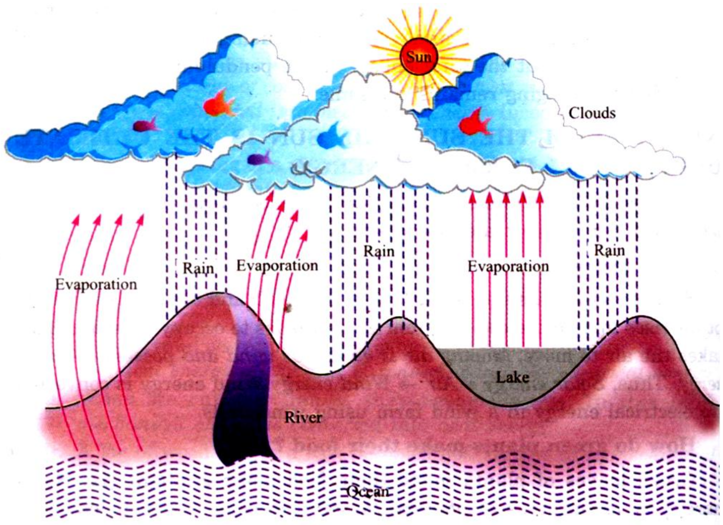
$$Muscular\ energy \longrightarrow Mechanical\ energy\ (work)$$

WATER CYCLE

The solar energy evaporates the water in oceans, rivers, takes and ponds. The evaporated water is converted into clouds (having both kinetic energy and potential energy). These clouds on cooling give rain. The water cycle in nature in shown in figure 9.

The rain water flows through rivers and has kinetic energy. This water is stored in dams and hence possesses potential energy. When this water is allowed to fall from some height, potential energy of water is converted into its kinetic energy. The kinetic energy of flowing water rotates the turbine of a generator. The generator in turn produces the hydro-electricity or hydro electric power. Thus, hydro-electric energy is also derived from the solar energy.

Solar energy + Water $\longrightarrow$ Water $\longrightarrow$ Clouds (K.E.+P.E.) $\longrightarrow$ Rain (flowing water, K.E.) $\longrightarrow$ Hydro-electricity (electric energy)



WATER CYCLE

How are coals and petroleum (fuels) are formed?

Even the energy of fossil fuels like coal, petroleum and natural gas also come form the solar energy. Long ago, plants and animals which had derived the energy from the sun in the form of food were buried under the earth after their death. Due to high temperature and pressure under the surface of the earth, the bio-mass of dead animals and plants was converted into the fossil fuels like coal, petroleum and natural gas. These fuels store chemical energy which is converted in to heat energy when the fuel of heat engines. Moreover, the heat energy produced by burning the fuel is also used to produce electricity.

Thus, we conclude that all forms of energy are derived from a single source- the Sun.

DEVICES USED TO TRANSFORM ENERGY FROM ONE FORM TO ANOTHER

1. Heat engine converts heat energy into mechanical energy.

2. A Thermal Power Plant converts chemical energy of the coal into electrical energy

3. Generator converts mechanical energy into electrical energy.

4. Electric motor converts electrical energy into mechanical energy

5. An electric heater converts electrical energy into electrical energy.

6. Dry cell converts chemical energy into electrical energy.

7. Microphone converts sound energy into electrical energy.

8. Photocell converts light energy into electrical energy.

9. Lever transforms muscular energy into useful mechanical work

LAW OF CONSERVATION OF ENERGY

MICROPHONE

According to this law, " energy can neither be created nor be destroyed, but can be changed from one form to another form." **Or**

When one form of energy is changed or transformed into other forms of energy, the total energy of an isolated system remains the same i.e., the total energy before transformation = the sun of the different energies transformed.

ADDITIONAL INFORMATION

System: Any part of the universe under investigation is known as a system

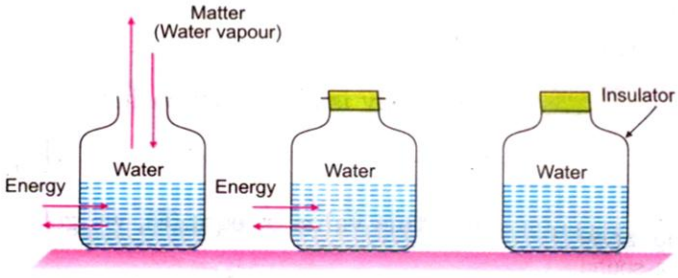
Surroundings: All matters or part of the universe left outside the system that can interact with the system are known as surroundings.

Types of system:

(i) Open system: A system is said to be an open system if it can exchange both matter and energy with the surroundings.

(ii) Closed system: A system is said to be closed system if it can exchanged only energy and not matter with the surroundings

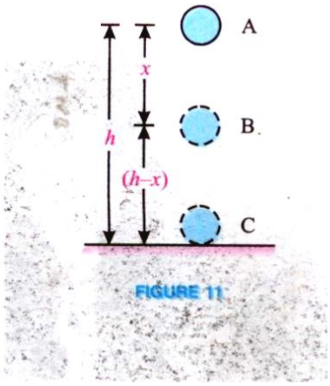
(iii) Isolated system: A system is said to be an isolated system if it can neither exchange energy nor matter with the surroundings.



(a) Open system (b) Closed system (c) Isolated system

THE LAW OF CONSERVATION OF ENERGY OF A FREELY FALLING BODY

Consider a body of mass m at a height h above the ground. Suppose this position of the body is A. Suppose the body at A is at rest i.e.,



$\upsilon = 0$

At position A

Potential energy of the body, $P.E. = mgh$

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

$\therefore$ Total energy of the body at $A = P.E. + K.E.$

$= mgh + 0 = \mathbf{mgh}$

Let the body falls freely under the action of gravity to position B through a height x. Now, the height of the body from the ground = $(h - x)$

At position B

Potential energy of the body, $P.E. = mg\ (h - x)$

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

Where, υ is the velocity of the body at position B.

Calculation of υ

We know, $\upsilon^2 - u^2 = 2aS$

Here, $u = 0$ $\quad [\because body\ at\ A\ is\ at\ rest]$

$a = g$ and $S = x$

$\therefore$ from eqn. (4),

$\upsilon^2 - 0 = 2gx$ or $\upsilon^2 = 2gx$

Put this value in eqn. (3), we get

Kinetic energy of the body, $K.E. = \frac{1}{2} m \times 2gx = \mathbf{mgx}$

$\therefore$ Total energy of the body at $B = P.E. + K.E.$

$= mg(h - x) + mgx$

$= mgh - mgx + mgx$

$= \mathbf{mgh}$ …….(5)

Finally, let the body touches the ground at C, so that the distance through which it falls = h

At position C

Potential energy of body, $P.E. = mg\,(0) = 0$

Kinetic energy of the body, $K.E. = \frac{1}{2} m\upsilon^2$ ……..(6)

Where, υ is the velocity of the body just at position C.

Calculation of υ

We know, $\upsilon^2 - u^2 = 2aS$ ………(7)

Here, $u = 0$

($\because$ body is at rest at position A), $a = g$ and $S = h$ $\therefore$ from eqn. (7),

$$\upsilon^2 - 0 = 2gh$$

Or $$\upsilon^2 = 2gh$$

Put this value in eqn. (6), we get

Kinetic energy of the body at C, $K.E. = \frac{1}{2} m \times 2gh = mgh$

$\therefore$ Total energy of the body at $C = P.E. + K.E.$

$= 0 + mgh = \mathbf{mgh}$ ....(8)

From eqns.(1), (5) and (8), it is clear that the total energy of a body at any instant during free fall of the body remains constant. Hence, the law of conservation of energy is verified.

Note:

When a freely falling body strikes the ground, then sound is produced and the surface of the ground becomes warm where the body strikes. It means, the total energy (K.E.+P.E.) of the freely falling body is converted into sound and heat energy, when the body strikes the ground.

POWER (RATE OF DOING WORK)

It is usually said that a machine is more powerful than a man. This means, a machine can do more work than a man. Moreover, a machine can do the same work in a lesser time than a man. Thus, power depends not only on the work done but also the time taken to do it.

Definition: Power is defined as the rate of doing work

i.e., $P = \frac{Work\ done}{Time\ taken} = \frac{W}{t}$

However, the work done by a person or a machine (i.e. an agent) may be different in different intervals of time. For example, let us suppose a person is climbing the stairs of a very high building. When be begins to climb, he may climb many stairs in a small interval of time. After some time, he gets tired, so he climbs only few stairs in a large interval of time. This shows that the power of the person varies with time.

Hence, his **average power** is calculated when he is on the top of the building.

Definition of average power. Average power of an agent is defined as the ratio of total work done to the total time taken.

i.e. $$P = \frac{Total\ work\,done}{Total\ time}$$

Since, Total work done =Energy supplied $\therefore$ $P = \frac{Energy\ \sup plied}{Total\ time}$

UNITS OF POWER

SI unit of power is watt (W).

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

$\therefore$ 1 watt (W) = $\frac{1\,joule}{1\sec ond} = \frac{1J}{1s}$ or $1W = 1J\,s^{-1}$

Thus, power of a machine or an agent is 1 watt if it does 1 joule work in 1 second.

BIGGER UNITS OF POWER	
1. 1 kilowatt (kW) = 1000	W = $10^3 W$
2. 1 megawatt (MW) = 1000,000 =	$W = 10^6 W$
3. 1 gigawatt (GW) = 1000,000,000	
$W = 10^9 W$	

PRACTICAL UNIT OF POWER

The power of machines (like engine of a scooter or a car a bus) is usually expressed in **horse power** (h.p.). So the practical unit of power is **horse power** (h.p.)

1 horse power (h.p.) = 746 W

Power in terms of force (F) and velocity (υ)

$$P = \frac{W}{t} \qquad \text{But} \qquad W = F \times S$$

$$\therefore \quad P = \frac{F \times S}{t} = F \times \left(\frac{S}{t}\right)$$

But $\left(\frac{S}{t}\right) = \upsilon$

$$\therefore \quad P = F \times \upsilon$$

Thus, power of an agent is also defined as the product of force applied and the velocity of the body.

COMMERCIAL UNIT OF ENERGY: KILOWATT-HOUR (KWH)

Electric energy is required to operate the electric lamps, heaters, refrigerators, televisions and other electric appliances. The department of electricity sells the electric energy to the consumers in units called *kilowatt-hours (kWh).* If our electricity bill shows that we have to pay for 10 units, then it means the electric appliances of our house have consumed 10 kilowatt-hours. So, 1 unit = 1 kWh.

A kilowatt-hour is the amount of electric energy used by 1000 watt electric appliances (say a heater) when it operates for one hour.

kWh is also known as "**Board of Trade Unit"** (B.O.T)

RELATION BETWEEN kWh AND joule

$$1kWh = 1000Wh \quad [\because 1kW = 1000W]$$

Now $1W = 1\,Js^{-1}$ and $1h = 60 \times 60s = 3600s$

$$\therefore \; 1kWh = 1000\,Js^{-1} \times 3600\,s$$

$$= 3600000J = 3.6 \times 10^6\,J$$

$$\therefore \; 1kWh = 3.6 \times 10^6\,J$$

HOW TO CALCULATE THE ELECTRICITY BILL?

Suppose electric appliances of a house have consumed 100 kWh of electricity in a month and the cost of one unit is 50 paise. Then the total bill for a month = $100 \times 50 =$ Rs 50.00. Here 1kWh = 1 unit.