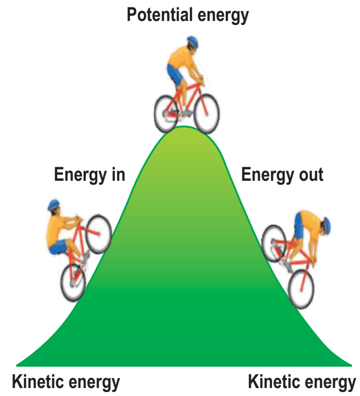
Unit 6

Work and Energy

STUDENT'S LEARNING OUTCOMES

After studying this unit, the students will be able to:

- define work and its SI unit.
- calculate work done using equation
  - Work = force x distance moved in the direction of force
- define energy, kinetic energy and potential energy. State unit of energy.
- prove that kinetic energy K.E. $= \frac{1}{2} mv^2$ and potential energy P.E. = mgh. Solve problems using these equations.
- list the different forms of energy with examples.
- describe the processes by which energy is converted from one form to another with reference to
  - fossil fuel energy
  - hydroelectric generation
  - solar energy
  - nuclear energy
  - geothermal energy
  - wind energy
  - biomass energy
- state mass energy equation $E = mc^2$ and solve problems using it.
- describe the process of electricity generation by drawing a block diagram of the process from fossil fuel input to electricity output.
- list the environmental issues associated with power generation.
- explain by drawing energy flow diagrams through steady state systems such as filament lamp, a power station, a vehicle travelling at a constant speed on a level road.



This unit is built on
Energy - Science-V
Input, output & efficiency - Science-VII

This unit leads to:
Energy & Work - Physics-XI

MAJOR CONCEPTS

6.1 Work
6.2 Energy
6.3 Kinetic energy
6.4 Potential energy
6.5 Forms of energy
6.6 Interconversion of energy
6.7 Major sources of energy
6.8 Efficiency
6.9 Power

- differentiate energy sources as non renewable and renewable energy sources with examples of each.
- define efficiency of a working system and calculate the efficiency of an energy conversion using the formula:

  efficiency = energy output converted into the required form / total energy input
- explain why a system cannot have an efficiency of 100%.
- define power and calculate power from the formula:

  Power = work done / time taken
- define the unit of power "watt" in SI and its conversion with horse power.
- Solve problems using mathematical relations learnt in this unit.

INVESTIGATION SKILLS

The students will be able to:

- investigate conservation of energy of a ball rolling down an inclined plane using double inclined plane and construct a hypothesis to explain the observation.
- compare personal power developed for running upstairs versus walking upstairs using a stopwatch.

SCIENCE, TECHNOLOGY AND SOCIETY CONNECTION

The students will be able to:

- analyse using their or given criteria, the economic , social and environmental impact of various energy sources.[e.g. (fossil fuel, wind, falling water, solar, biomass, nuclear, thermal energy and its transfer(heat)}.
- analyse and explain improvements in sports performance using principles and concepts related to work, kinetic and potential energy and law of conservation of energy (e.g. explain the importance of the initial kinetic energy of a pole vaulter or high jumper).
- search library or internet and compare the efficiencies of energy conversion devices by

comparing energy input and useful energy output.

- explain principle of conservation of energy and apply this principle to explain the conversion of energy from one form to another such as a motor, a dynamo, a photocell and a battery, a freely falling body.
- list the efficient use of energy in the context of the home, heating and cooling of buildings and transportation.

Generally, work refers to perform some task or job. In science, work has precise meaning. For example, a man carrying a load is doing work but he is not doing work if he is not moving while keeping the load on his head. Scientifically, work is done only when an effort or force moves an object. When work is done, energy is used. Thus, work and energy are related to each other. The concept of energy is an important concept in Physics. It helps us to identify the changes that occur when work is done This unit deals with the concepts of work, power and energy.

6.1 WORK

In Physics, work is said to be done when a force acts on a body and moves it in the direction of the force. The question arises how much work is done? Naturally, greater is the force acting on a body and longer is the distance moved by it, larger would be the work done. Mathematically, Work is a product of force F and displacement S in the direction of force. Thus

Work done = Force x displacement

or $W = FS$ … … … … (6.1)

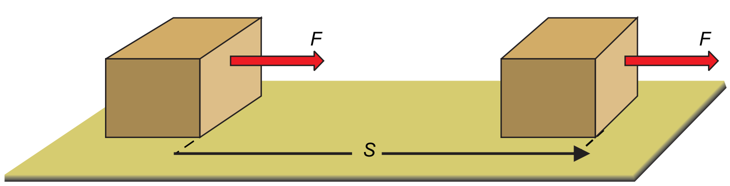


Figure 6.1: Work done in displacing a body in the direction of force.

Sometimes force and displacement do not have the same direction such as shown in figure 6.2. Here the force F is making an angle θ with the surface on which

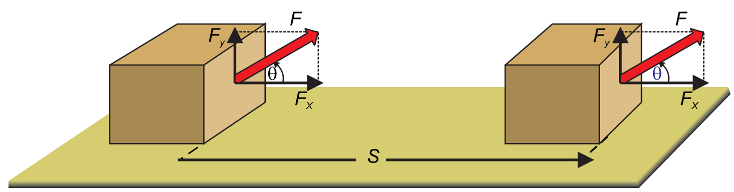


Figure 6.2: Work done by a force inclined with the displacement.

the body is moved. Resolving **F** into its perpendicular components F_x and F_y as;

$$F_x = F\cos\theta$$

$$F_y = F\sin\theta$$

In case when force and displacement are not parallel then only the x-component F_x parallel to the surface causes the body to move on the surface and not the y - component F_y.

Hence $W = F_x S$

$$= (F\cos\theta)\,S$$

$$= F\,S\cos\theta \quad \ldots \quad \ldots \quad \ldots (6.2)$$

Work is done when a force acting on a body displaces it in the direction of a force.

Work is a scalar quantity. It depends on the force acting on a body, displacement of the body and the angle between them.

UNIT OF WORK

SI unit of work is joule (J). It is defined as

The amount of work is one joule when a force of one newton displaces a body through one metre in the direction of force.

Thus $1\ J = 1\ N \times 1\ m$

Joule is a small unit of work. Its bigger units are:

1 kilo joule (kJ) = 1000 J = 10^3 J 1

mega joule (MJ) = 1000 000 J = 10^6 J

Mini Exercise

A crate is moved by pulling the rope attached to it. It moves 10 m on a straight horizontal road by a force of 100 N. How much work will be done if

1. the rope is parallel to the road.
2. the rope is making an angle of 30° with the road.

EXAMPLE 6.1

A girl carries a 10 kg bag upstairs to a height of 18 steps, each 20 cm high. Calculate the amount of work she has done to carry the bag. (Take g =10 ms^{-2}).

SOLUTION

Mass of the bag $m = 10$ kg

Weight of the bag $w = mg = 10 \text{ kg} \times 10 \text{ ms}^{-2}$

$= 100$ N

To carry the bag upstairs, the girl exerts an upward force *F* equal to *w*, the weight of the bag. Thus

$$F = 100 \text{ N}$$

$$\text{Height } h = 18 \times 0.2 \text{ m} = 3.6 \text{ m}$$

$$w = F\ h$$

$$= 100 \times 3.6 = 360 \text{ J}$$

The girl has done 360 J of work.

6.2 ENERGY

The energy is an important and fundamental concept in science. It links almost all the natural phenomena. When we say that a body has energy, we mean that it has the ability to do work. Water running down the stream has the ability to do work, so it possesses energy. The energy of running water can be used to run water mills or water turbines.

Figure 6.3: Running water possesses energy.

Energy exists in various forms such as mechanical energy, heat energy, light energy, sound energy, electrical energy, chemical energy and nuclear energy etc. Energy can be transformed from one form into another.

A body possesses energy if it is capable to do work.

Mechanical energy possessed by a body is of two types: kinetic energy and potential energy.

Figure 6.4: Energy of the wind moves the sailing boats.

6.3 KINETIC ENERGY

Moving air is called wind. We can use wind energy for doing various things. It drives windmills and pushes sailing boats. Similarly, moving water in a river can carry wooden logs through large distances and can also be used to drive turbines for generating electricity. Thus a moving body has kinetic energy, because it can do work due to its motion. The body stops moving as soon as all of its kinetic energy is used up.

The energy possessed by a body due to its motion is called its kinetic energy.

Consider a body of mass *m* moving with velocity *v*. The body stops after moving through some distance *S* due to some opposing force such as force of friction acting on it. The body possesses kinetic energy and is capable to do work against opposing force *F* until all of its kinetic energy is used up.

$\therefore$ K.E. of the body = Work done by it due to motion

$$\text{K.E.} = F\,S \quad \dots \dots \dots (6.3)$$

$$v_i = v$$

$$v_f = 0$$

As $$F = ma$$

$$\therefore \quad a = -\frac{F}{m}$$

Since motion is opposed, hence, a is negative. Using 3rd equation of motion:

$$2\,a\,S = v_f^{\,2} - v_i^{\,2}$$

$$2\left(-\frac{F}{m}\right) S = (0)^2 - (v)^2$$

$$F\,S = \frac{1}{2}\,m\,v^2 \quad \dots \dots \dots (6.4)$$

From Eq.6.3 and 6.4, we get

$$\text{K.E.} = \frac{1}{2}\,m\,v^2 \quad \dots \dots \dots (6.5)$$

Equation 6.5 gives the K.E possessed by a body of mass *m* moving with velocity *v*.

EXAMPLE 6.2

A stone of mass 500 g strikes the ground with a velocity of 20vms^{-1}. How much is the kinetic energy of the stone at the time it strikes the ground?

SOLUTION

$$m = 500\text{ g} = 0.5\text{ kg}$$

$$v = 20\ \text{ms}^{-1}$$

Since $$\text{K.E.} = \frac{1}{2}\ mv^2$$

$$\text{K.E.} = \frac{1}{2} \times\ 0.5\ \text{kg} \times (20\ \text{m s}^{-1})^2$$

$$= \frac{1}{2} \times 0.5\ \text{kg} \times 400\ \text{m}^2\ \text{s}^{-2}$$

$$= 100\ \text{J}$$

Thus, the kinetic energy of the stone is 100 J as it strikes the ground.

6.4 POTENTIAL ENERGY

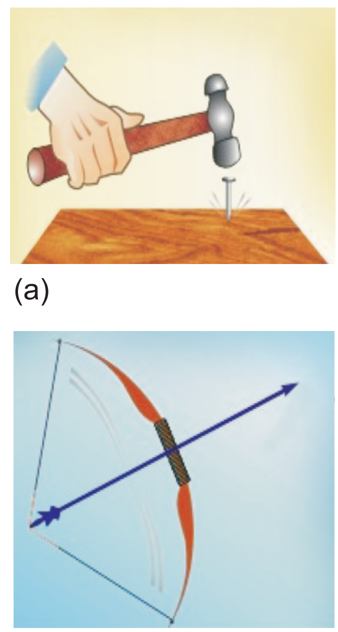
Often a body has the ability to do work although it is at rest. For example, an apple on a tree is capable to do work as it falls. Thus, it possesses energy due to its position. The kind of energy which a body possesses due to its position is called its potential energy.

The energy possessed by a body due to its position is known as its potential energy.

Stored water possesses potential energy due to its height. A hammer raised up to some height has the ability to do work because it possesses potential energy. A stretched bow has potential energy due to its stretched position. When released, the stored energy of the bow pushes the arrow out of it. The energy present in the stretched bow is called elastic potential energy.

The potential energy possessed by a hammer is due to its height. The energy present in a body due to its height is called gravitational potential energy.

Let a body of mass m be raised up through height h from the ground. The body will acquire potential energy equal to the work done in lifting it to height h.



(a)

(b)

Figure 6.5: (a) Hammer raised up (b) stretched bow, both possess potential energy.

Thus Potential energy $\text{P.E.} = F \times h$

$$= w \times h$$

(Here weight of the body $= w = mg$)

$$\therefore \qquad P.E. = w\,h = m\,g\,h \quad \ldots \quad \ldots (6.6)$$

Thus, the potential energy possessed by the body with respect to the ground is *mgh* and is equal to the work done in lifting it to height *h.*

EXAMPLE 6.3

A body of mass 50 kg is raised to a height of 3 m. What is its potential energy? ($g = 10\ ms^{-2}$)

SOLUTION

mass $m = 50$ kg

height $h = 3$ m

$g = 10\ ms^{-2}$

as P.E. $= m\,g\,h$

$\therefore$ P.E. $= 50\ kg \times 10\ m\ s^{-2} \times 3\ m$

$= 50 \times 10 \times 3$ J

$= 1500$ J

The potential energy of the body is 1500 J.

EXAMPLE 6.4

A force of 200 N acts on a body of mass 20 kg. The force accelerates the body from rest until it attains a velocity of $50\ ms^{-1}$. Through what distance the force acts?

SOLUTION

Force $F = 200$ N

Mass $m = 20$ kg

Velocity $v = 50\ ms^{-1}$

Distance $S = ?$

Since Work done on the body = K.E. gained by it

$$\therefore \quad F\,S = \frac{1}{2} mv^2$$

$$S = \frac{(20\,kg)\times(50\,ms^{-1})^2}{2\times 200\,N} = 125\ m$$

Thus, the distance moved by the body is 125 m.

6.5 FORMS OF ENERGY

Energy exists in various forms. Some of the main forms of energy are given in figure 6.6.

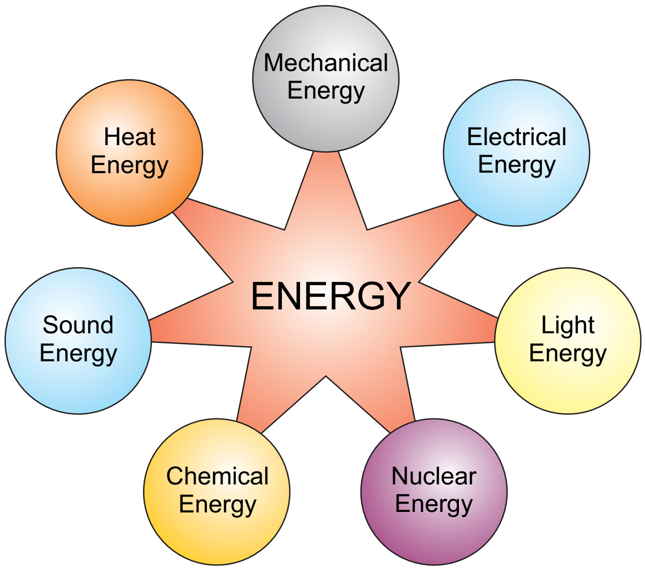


Figure 6.6: Some of the main forms of energy

Figure 6.7: A watermill

MECHANICAL ENERGY

The energy possessed by a body both due to its motion or position is called mechanical energy. Water running down a stream, wind, a moving car, a lifted hammer, a stretched bow, a catapult or a compressed spring etc. possess mechanical energy.

Figure 6.8: Heat energy coming from the Sun.

HEAT ENERGY

Heat is a form of energy given out by hot bodies. Large amount of heat is obtained by burning fuel. Heat is also produced when motion is opposed by frictional forces. The foods we take provide us heat energy. The Sun is the main source of heat energy.

Figure 6.9: Most of the things of our daily use need electrical energy for their operation.

ELECTRICAL ENERGY

Electricity is one of the widely used form of energy. Electrical energy can be supplied easily to any desired place through wires. We get electrical energy from batteries and electric generators. These electric generators are run by hydro power, thermal or nuclear power.

SOUND ENERGY

When you knock at the door, you produce sound. Sound is a form of energy. It is produced when a body vibrates; such as vibrating diaphragm of a drum, vibrating strings of a sitar and vibrating air column of wind instruments such as flute pipe etc.

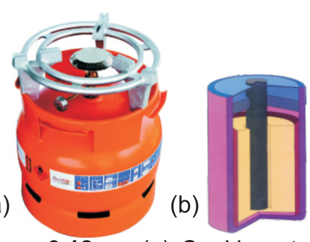
Figure 6.10: Sound energy

LIGHT ENERGY

Light is an important form of energy. Name some sources of light that you come across.

Figure 6.11: Light is needed during night also.

Plants produce food in the presence of light. We also need light to see things. We get light from candles, electric bulbs, fluorescent tubes and also by burning fuel. However, most of the light comes from the Sun.



(a) (b)

Figure 6.12 (a) Cooking stove with compressed gas cylinder (b) Sectional view of electrical cell.

CHEMICAL ENERGY

Chemical energy is present in food, fuels and in other substances. We get other forms of energy from these substances during chemical reactions. The burning of wood, coal or natural gas in air is a chemical reaction which releases energy as heat and light. Electric energy is obtained from electric cells and batteries as a result of chemical reaction between various substances present in them. Animals get heat and muscular energy from the food they eat.

DO YOU KNOW?

Our body gets energy stored in the food we take to perform various activities.

NUCLEAR ENERGY

Nuclear energy is the energy released in the form of nuclear radiations in addition to heat and light during nuclear reactions such as **fission** and **fusion** reactions. Heat energy released in nuclear reactors is converted into electrical energy. The energy coming from the Sun for the last billions of years is the result of nuclear reactions taking place on the Sun.

> **DO YOU KNOW?**
>
> A nuclear power plant uses the energy released in nuclear reactor such as fission to generate electric power.

6.6 INTERCONVERSION OF ENERGY

Energy cannot be destroyed however it can be converted into some other forms. For example, rub your hands together quickly. You will feel them warm. You have used your muscular energy in rubbing hands as a result heat is produced. In the process of rubbing hands, mechanical energy is converted into heat energy.

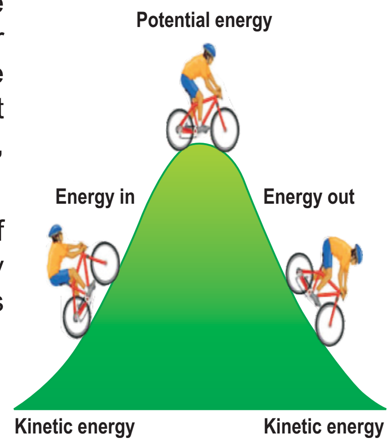


Figure 6.13: Interconversion of kinetic energy into potential energy and potential energy into kinetic energy.

Processes in nature are the results of energy changes. For example, some of the heat energy from the Sun is taken up by water in the oceans. This

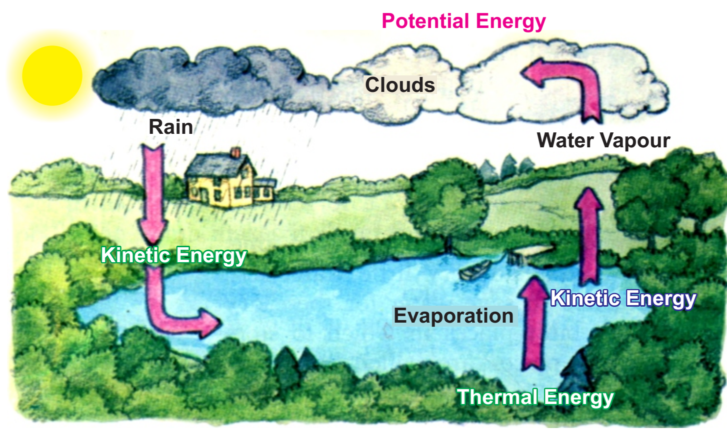


Figure 6.14: Interconversion of Energy

increases the thermal energy. Thermal energy causes water to evaporate from the surface to form water vapours. These vapours rise up and form clouds. As they cool down, they form water drops and fall down as rain. Potential energy changes to kinetic energy as the rain falls This rain water may reach a lake or a dam. As the rain water flows down, its kinetic energy changes into thermal energy while parts of the kinetic energy of flowing water is used to wash away soil particles of rocks known as soil erosion.

DO YOU KNOW?

A pole vaulter uses a flexible vaulting pole made of special material. It is capable to store all the vaulter's kinetic energy while bending in the form of potential energy. The vaulter runs as fast as possible to gain speed. The kinetic energy gained by the pole vaulter due to speed helps him/her to rise up as the vaulter straightens. Thus he attains height as the pole returns the potential energy stored by the vaulter in the pole.

During the interconversion of energy from one form to other forms, the total energy at any time remains constant.

6.7 MAJOR SOURCES OF ENERGY

The energy we use comes from the Sun, wind and water power etc. Actually, all of the energy we get comes directly or indirectly from the Sun.

FOSSIL FUELS

We use fossil fuels such as coal, oil and gas to heat our houses and run industry and transport. They are usually **hydrocarbons** (compounds of carbon and hydrogen). When they are burnt, they combine with oxygen from the air. The carbon becomes carbon

Figure 6.15: A gas field

dioxide; hydrogen becomes hydrogen oxide called water; while energy is released as heat. In case of coal:

Carbon + Oxygen $\rightarrow$ carbon dioxide + heat energy
Hydrocarbon + Oxygen $\rightarrow$ carbon dioxide + water + heat energy

The fossil fuels took millions of years for their formation. They are known as non-renewable resources. We are using fossil fuels at a very fast rate. Their use is increasing day by day to meet our energy needs. If we continue to use them at present rate, they will soon be exhausted. Once their supply is exhausted, the world would face serious energy crisis.

Figure 6.16: Coal

Thus, fossil fuels would not be able to meet our future energy needs. This would cause serious social and economical problems for countries like us. Therefore, we must use them wisely and at the same time develop new energy sources for our future survival.

Figure 6.17: An oil field

Moreover, fossil fuels release harmful waste products. These wastes include carbon mono-oxide and other harmful gases, which pollute the

Figure 6.18: Pollution due to burning of fossil fuel.

environment. This causes serious health problems such as headache, tension, nausea, allergic reactions, irritation of eyes, nose and throat. Long exposure of these harmful gases may cause asthma, lungs cancer, heart diseases and even damage to brain, nerves and other organs of our body.

Figure 6.19: Nuclear fuel pallets used in nuclear reactors.

NUCLEAR FUELS

In nuclear power plants, we get energy as a result of **fission** reaction. During fission reaction, heavy atoms, such as Uranium atoms, split up into smaller parts releasing a large amount of energy. Nuclear power plants give out a lot of nuclear radiations and vast amount of heat. A part of this heat is used to run power plants while lot of heat goes waste into the environment.

RENEWABLE ENERGY SOURCES

Sunlight and water power are the renewable sources of energy. They will not run out like coal, oil and gas.

ENERGY FROM WATER

Energy from water power is very cheap. Dams are being constructed at suitable locations in different parts of the world. Dams serve many purposes. They help to control floods by storing water. The water stored in dams is used for irrigation and also to generate electrical energy without creating much environmental problems.

Figure 6.20: Energy stored in the water of a dam is used to run power plants.

ENERGY FROM THE SUN

Solar energy is the energy coming from the Sun and is used directly and indirectly. Sunlight does not pollute the environment in any way. The sunrays are the ultimate source of life on the Earth. We are dependent on the Sun for all our food and fuels. If we find a suitable method to use a fraction of the solar energy reaching the Earth, then it would be enough to fulfil our energy requirement.

SOLAR HOUSE HEATING

The use of solar energy is not new. However, its use in houses and offices as well as for commercial industrial purposes is quite recent. Complete solar house heating systems are successfully used in areas with a minimum amount of sunshine in winter. A heating system consists of:

- A collector

- A storage device
- A distribution system

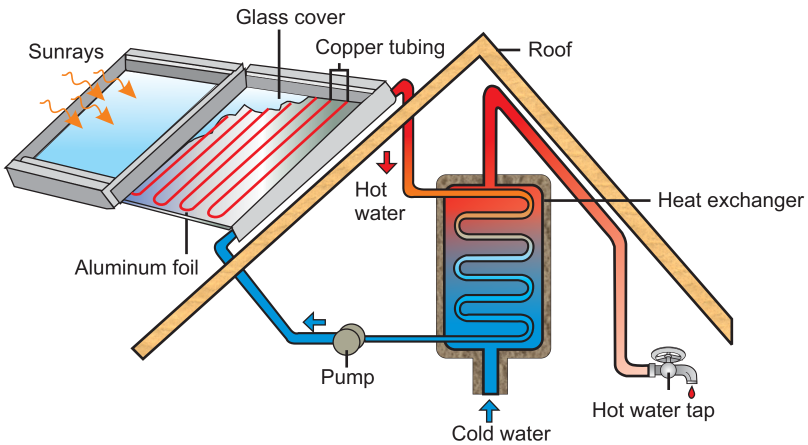


Figure 6.21: A Solar house heating system.

Figure 6.21 shows a solar collector made of glass panels over blank metal plates. The plates absorb the Sun's energy which heats a liquid flowing in the pipes at the back of the collector. The hot water can be used for cooking, washing and heating the buildings.

Solar energy is used in solar cookers, solar distillation plants, solar power plant, etc.

Figure 6.22: A solar car

SOLAR CELLS

Solar energy can also be converted directly into electricity by solar cells. A solar cell also called photo cell is made from silicon wafer. When sunlight falls on a solar cell, it converts the light directly into electrical energy. Solar cells are used in calculators, watches and toys. Large numbers of solar cells are wired together to form solar panels. Solar panels can provide power to telephone booths, light houses and scientific research centres. Solar panels are also used to power satellites.

Figure 6.23: A solar panel fixed at the roof of a house.

Several other methods to trap sunrays are under way. If scientists could find an efficient and inexpensive method to use solar energy, then the people would get clean, limitless energy as long as the Sun continues to shine.

WIND ENERGY

Figure 6.24: Wind turbines

Wind has been used as a source of energy for centuries. It has powered sailing ships across the oceans. It has been used by windmills to grind grain and pump water. More recently, wind power is used to turn wind turbines (Figure 6.24). When many wind machines are grouped together on wind farms, they can generate enough power to operate a power plant. In the United States, some wind farms generate more than 1300 MW of electricity a day. In Europe, many wind farms routinely generate hundred megawatts or more electricity a day.

GEOTHERMAL ENERGY

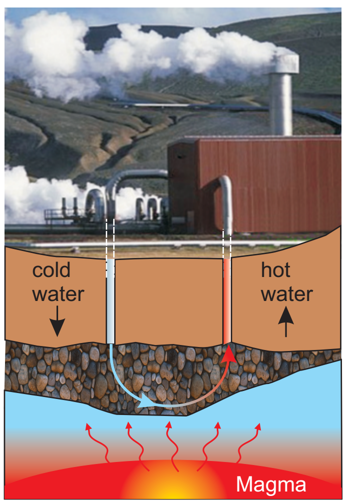


Figure 6.25: A geothermal power station

In some parts of the world, the Earth provides us hot water from geysers and hot springs. There is hot molten part, deep in the Earth called magma. Water reaching close to the magma changes to steam due to the high temperature of magma. This energy is called geothermal energy.

Geothermal well can be built by drilling deep near hot rocks at places, where magma is not very deep. Water is then pushed down into the well. The rocks quickly heat the water and change it into steam. It expands and moves up to the surface. The steam can be piped directly into houses and offices for heating purposes or it can be used to generate electricity.

ENERGY FROM BIOMASS

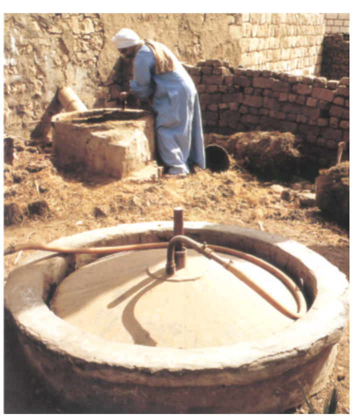


Figure 6.26: A biomass plant using animal dung

Biomass is plant or animal wastes that can be burnt as fuel. Other forms of biomass are garbage, farm wastes, sugarcane and other plants. These wastes are used to run power plants. Many industries that use forest products get half of their electricity by burning bark and other wood wastes. Biomass can serve as another energy source, but problems are there in its use.

When animal dung, dead plants and dead animals decompose, they give off a mixture of methane and carbon dioxide. Electricity can be generated by burning methane.

MASS - ENERGY EQUATION

Einstein predicted the interconversion of matter and energy. According to him, a loss in the mass of a body provides a lot of energy. This happens in nuclear reactions. The relation between mass *m* and energy *E* is given by Einstein's mass-energy equation.

$$E = mc^2 \qquad \ldots\ldots \qquad (6.7)$$

Here *c* is the speed of light ($3\text{x}10^8$ ms^{-1}). The above equation shows that tremendous amount of energy can be obtained from small quantity of matter. It appears that matter is a highly concentrated form of energy. The process of getting energy from our nuclear power plants is based on the above equation. The process is taking place on the Sun and stars for the last millions of years. Only a very small fraction of the Sun's energy reaches the Earth. This very small fraction of the Sun's energy is responsible for life on the Earth.

ELECTRICITY FROM FOSSIL FUELS

We are using electricity in houses, offices, schools, business centres, factories and in farms. We have different ways of generating electricity. Most of the electricity is obtained using fossil fuels such as oil, gas and coal. Fossil fuels are burnt in thermal power stations to produce electricity. Various energy conversion processes involved in producing electricity from coal are described in a block diagram as shown in figure 6.27.

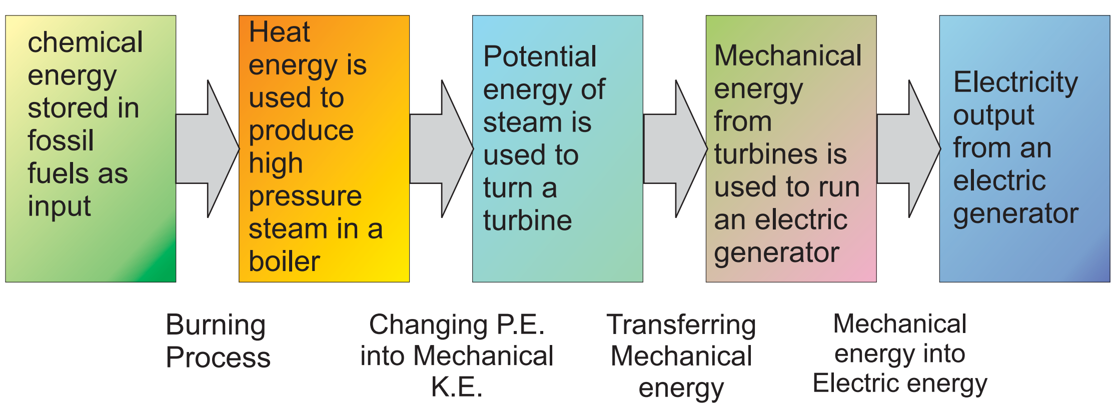


Figure 6.27: Several energy conversion processes are producing electricity.

ENERGY AND ENVIRONMENT

Environmental problems such as pollution that consist of noise, air pollution and water pollution may arise by using different sources of energy such as fossil fuels and nuclear energy. Pollution is the change in the quality of environment that can be harmful and unpleasant for living things. A temperature rise in the environment that disturbs life is called thermal pollution. Thermal pollution upsets the balance of life and endangers the survival of many species.

Air pollutants are unwanted and harmful. Natural processes such as volcanic eruptions, forest fires and dust storms add pollutant to the air. These pollutant, rarely build up to harmful levels. On the other hand, the burning of fuel and solid wastes in homes, automobiles and factories releases harmful amount of air pollutants.

All power plants produce waste heat, but fission plants produce the most. The heat released into a lake, a river or an ocean upsets the balance of life in them. Unlike other power plants, nuclear power plants do not produce carbon dioxide. But they do produce dangerous radioactive wastes.

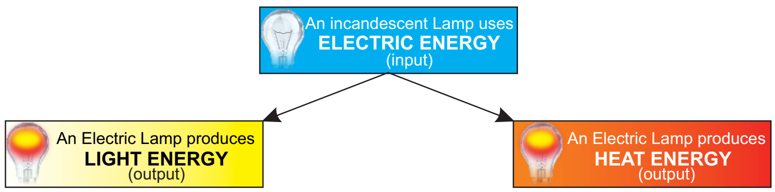
In many countries governments have passed laws to control air pollution. Some of these laws limit the amount of pollution that, power plants, factories and automobiles are allowed to give off. To meet these conditions for automobiles, new cars have catalytic converters. These devices convert some polluting gases. The use of lead free petrol has greatly reduced the amount of lead in the air. Engineers are working to improve new kinds of car engines that use electricity or energy sources other than diesel and petrol.

Many individual communities have laws which protect their areas from pollution. Individuals can help to control air pollution simply by reducing the use of cars and other machines that burn fuel. Sharing rides and using public transportation are the ways to reduce the number of automobiles in use.

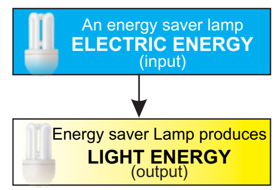
FLOW DIAGRAM OF AN ENERGY CONVERTER

In an energy converter, a part of the energy taken (used up) by the system is converted into useful work. Remaining part of the energy is dissipated as heat energy, sound energy (noise) into the environment. Energy flow diagrams given below show the energy taken up by an energy converter to transform it into other forms of energy.

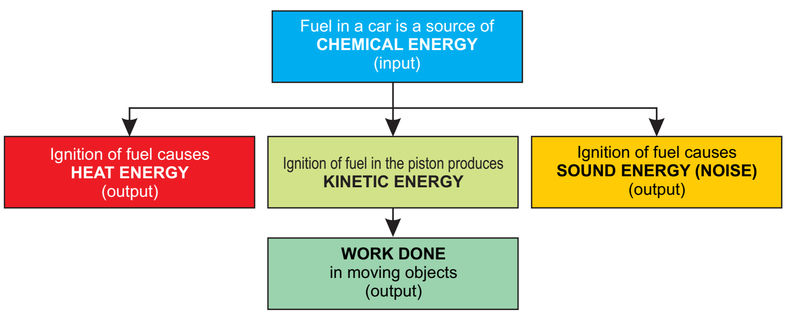
ELECTRIC LAMP



ENERGY SAVER LAMP



VEHICLE RUNNING WITH CONSTANT SPEED ON A LEVEL ROAD



POWER STATION

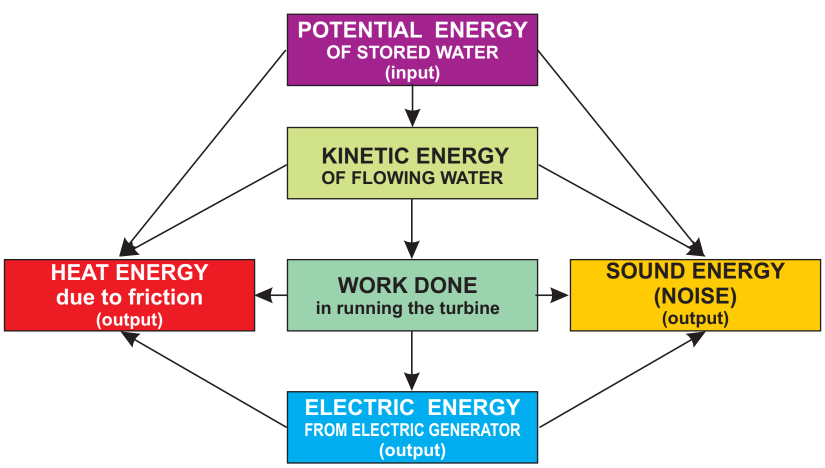


Figure 6.28: An electric drill

6.8 EFFICIENCY

How to get work done from a machine? We provide some form of energy to a machine. This is necessary for the machine to work. Human machine also needs energy to do a variety of work. We take food to fulfil the energy needs of our body.

We give some form of energy to machines as input to get useful work done by them as output. For example, electric motors may be used to pump water, to blow air, to wash clothes, to drill holes, etc. For that depends how much output we obtain from it by giving certain input. The ratio of useful output to input energy is very important to judge the working of a machine. It is called the efficiency of a machine defined as

Efficiency of a system is the ratio of required form of energy obtained from a system as output to the total energy given to it as input.

$$\text{Thus Efficiency} = \frac{\text{required form of output}}{\text{total input energy}} \quad \ldots (6.8)$$

$$\text{or \% Efficiency} = \frac{\text{required form of output}}{\text{total input energy}} \times 100 \quad \ldots (6.9)$$

For Your Information

Efficiencies of some typical devices/machines

Energy Input	Device or Machine	Useful Work done	% Efficiency
100 J	Electric Lamp	5 J	5 %
100 J	Petrol Engine	25 J	25 %
100 J	Electric Motor	80 J	80 %
100 J	Electric Fan	55 J	55 %
100 J	Solar Cell	3 J	3 %

An ideal system is that which gives an output equal to the total energy used by it. In other words, its efficiency is 100 %. People have tried to design a working system that would be 100 % efficient. But practically such a system does not exist. Every system meets energy losses due to friction that causes heat, noise etc. These are not the useful forms of energy and go waste. This means we cannot utilize all the energy given to a working system. The energy in the required form obtained from a working system is always less than the energy given to it as input.

EXAMPLE 6.5

A cyclist does 12 joules of useful work while pedalling his bike from every 100 joules of food energy which he takes. What is his efficiency?

SOLUTION

Useful work done by the cyclist = 12 J

Energy used by the cyclist = 100 J

$$\text{Efficiency} = \frac{12\text{ J}}{100\text{ J}}$$

$$= 0.12$$

$$\text{or } \% \text{ efficiency} = 0.12 \times 100 = 12\ \%$$

The efficiency of the cyclist is 12 %.

6.9 POWER

Two persons have done equal work, one took one hour to complete it and the other completed it in five hours. No doubt, both of them have done equal work but they differ in the rate at which work is done. One has done it faster than the other. The quantity that tells us the rate of doing work is called power. Thus

Power is defined as the rate of doing work.

Mathematically,

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

$$\text{or} \quad P = \frac{W}{t} \qquad \ldots \quad \ldots \ (6.10)$$

Since work is a scalar quantity, therefore, power is also a scalar quantity. SI unit of power is **watt** (W). It is defined as

The power of a body is one watt if it does work at the rate of 1 joule per second (1 Js^{-1}).

Bigger units of power are kilowatt (kW), megawatt (MW) etc.

$$1\text{kW} = 1000\text{ W} = 10^3\text{ W}$$

$$1\text{MW} = 1000\,000\text{ W} = 10^6\text{ W}$$

$$1\text{ horse power} = 1\text{hp} = 746\text{ W}$$

EXAMPLE 6.6

A man takes 80 s in lifting a load of 200 N through a height of 10 m. While another man M_2 takes 10 s in doing the same job. Find the power of each.

SOLUTION

$F = 200\text{ N}$

$S = 10\text{ m}$

Time taken by man $M_1 = t_1 = 80\text{ s}$

Time taken by man $M_2 = t_2 = 10\text{ s}$

As work done $= F \times S$

$= 200\text{ N} \times 10\text{ m}$

$= 2000\text{ J}$

Power of man $M_1 = \dfrac{\text{Work}}{t_1}$

$= \dfrac{2000\text{ J}}{80\text{ s}} = 25\text{ Js}^{-1}$

$= 25\text{ watts}$

and Power of man $= \dfrac{\text{Work}}{t_2}$

$= \dfrac{2000\text{ J}}{10\text{ s}} = 200\text{ Js}^{-1}$

$= 200\text{ watts}$

Thus the power of man M_1 is 25 watts and that of man M_2 is 200 watts.

EXAMPLE 6.7

Calculate the power of a pump which can lift 70 kg of water through a vertical height of 16 metres in 10 seconds. Also find the power in horse power.

SOLUTION

Mass of water $m = 70\text{ kg}$

Height $S = 16\text{ m}$

Time taken $t = 10\text{ s}$

Force required $F = w = m\,g$

$= 70\text{ kg} \times 10\text{ ms}^{-2}$

$= 700\text{ N}$

Work done $W = F \times S$

or $W = 700\text{ N} \times 16\text{ m}$

$$= 11200\ \text{J}$$

$$\text{Power} = \frac{W}{t}$$

$$P = \frac{11200\ \text{J}}{10\ \text{s}} = 1120\ \text{Js}^{-1}$$

$$= 1120\ \text{watts}$$

As $\quad 1\ \text{hp} = 746\ \text{watts}$

$$P = \frac{1120\ \text{watts}}{746\ \text{watts}}\ \text{hp}$$

$$= 1.5\ \text{hp}$$

Thus, power of the pump is 1.5 hp.

SUMMARY

- Work is said to be done when a force acting on a body moves it in the direction of the force.
  - Work $= FS$
  - SI unit of work is joule (J).
- When we say that a body has energy, we mean that it has the ability to do work. SI unit of energy is also joule, the same as work.
- Energy exists in various forms such as mechanical energy, heat energy, light energy, sound energy, electrical energy, chemical energy and nuclear energy etc. Energy from one form can be transformed into another.
- The energy possessed by a body due to its motion is called kinetic energy.
- The energy possessed by a body due to its position is called potential energy.
- Energy cannot be created nor destroyed, but it can be converted from one form to another.
- Processes in nature are the result of energy changes. Heat from the Sun causes water of oceans to evaporate to form clouds. As they cool down, they fall down as rain.
- Einstein predicted the interconversion of matter and energy by the equation $E = mc^2$.
- Fossil fuels are known as non renewable resources because it took millions of years for them to attain the present form.
- Sunlight and water power are the renewable resources of

energy. They will not run out like coal, oil and gas.

- Environmental problems such as polluting emission consisting of noise, air pollution and water pollution may arise by using different sources of energy such as fossil fuels, nuclear energy.
- The ratio of the useful work done by a device or machine to the total energy taken up by it is called its efficiency.
- Power is defined as the rate of doing work.
- The power of a body is one watt which is doing work at the rate of one joule per second.

QUESTIONS

6.1 Encircle the correct answer from the given choices:

i. The work done will be zero when the angle between the force and the distance is

(a) 45° (b) 60°

(c) 90° (d) 180°

ii. If the direction of motion of the force is perpendicular to the direction of motion of the body, then work done will be

(a) Maximum

(b) Minimum

(c) zero

(d) None of the above

iii. If the velocity of a body becomes double, then its kinetic energy will

(a) remain the same

(b) become double

(c) become four times

(d) become half

iv. The work done in lifting a brick of mass 2 kg through a height of 5 m above ground will be

(a) 2.5 J (b) 10 J

(c) 50 J (d) 100 J

v. The kinetic energy of a body of mass 2 kg is 25 J. Its speed is

(a) 5 ms^{-1} (b) 12.5 ms^{-1}

(c) 25 ms^{-1} (d) 50 ms^{-1}

vi. Which one of the following converts light energy into electrical energy?

(a) electric bulb

(b) electric generator

(c) Photocell

(d) Electric cell

vii. When a body is lifted through a height h, the work done on it appears in the form of its:

(a) kinetic energy

(b) potential energy

(c) elastic potential energy

(d) geothermal energy

viii The energy stored in coal is

(a) heat energy

(b) kinetic energy

(c) chemical energy

(d) nuclear energy

ix. The energy stored in a dam is

(a) electric energy

(b) potential energy

(c) kinetic energy

(d) thermal energy

x. In Einstein's mass-energy equation, c is the

(a) speed of sound

(b) speed of light

(c) speed of electron

(d) speed of Earth

xi. Rate of doing work is called

(a) energy (b) torque

(c) power (d) momentum

6.2 Define work. What is its SI unit?

6.3 When does a force do work? Explain.

6.4 Why do we need energy?

6.5 Define energy, give two types of mechanical energy.

6.6 Define K.E. and derive its relation.

6.7 Define potential energy and derive its relation.

6.8 Why fossils fuels are called non-renewable form of energy?

6.9 Which form of energy is most preferred and why?

6.10 How is energy converted from one form to another? Explain.

6.11 Name the five devices that convert electrical energy into mechanical energy.

6.12 Name a device that converts mechanical energy into electrical energy.

6.13 What is meant by the efficiency of a system?

6.14 How can you find the efficiency of a system?

6.15 What is meant by the term power?

6.16 Define watt.

PROBLEMS

6.1 A man has pulled a cart through 35 m applying a force of 300 N. Find the work done by the man. (10500 J)

6.2 A block weighing 20 N is lifted 6 m vertically upward. Calculate the potential energy stored in it. (120 J)

6.3 A car weighing 12 kN has speed of 20 ms^{-1}. Find its kinetic energy. (240 kJ)

6.4 A 500 g stone is thrown up with a velocity of 15ms^{-1}. Find its

(i) P.E. at its maximum height

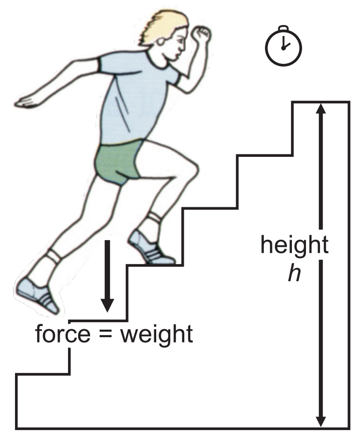
(ii) K.E. when it hits the ground (56.25 J, 56.25 J)

6.5 On reaching the top of a slope 6 m high from its bottom, a cyclist has a speed of 1.5 ms^{-1}. Find the kinetic energy and the potential energy of the cyclist. The mass of the cyclist and his bicycle is 40 kg. (45 J, 2400 J)

6.6 A motor boat moves at a steady speed of 4 ms^{-1}. Water resistance acting on it is 4000 N. Calculate the power of its engine. (16 kW)

6.7 A man pulls a block with a force of 300 N through 50 m in 60 s. Find the power used by him to

6.8 A 50 kg man moved 25 steps up in 20 seconds. Find his power, if each step is 16 cm high. (100 W)



6.9 Calculate the power of a pump which can lift 200 kg of water through a height of 6 m in 10 seconds. (1200 watts)

6.10 An electric motor of 1hp is used to run water pump. The water pump takes 10 minutes to fill an overhead tank. The tank has a capacity of 800 litres and height of 15 m. Find the actual work done by the electric motor to fill the tank. Also find the efficiency of the system.

(Density of water = 1000 kgm^{-3})

(Mass of 1 litre of water = 1 kg)

(447600 J, 26.8 %)