Chapter 5 Work, Energy And Power

Student Learning Outcomes

After completing this chapter, students will be able to:

- Define work done
- Use the equation work done = force × distance moved in the direction of the force $W = F \times d$ to solve problems
- Define energy as the ability to do work
- Explain that energy may be stored [Such as in gravitational potential, chemical, elastic (strain), nuclear, electrostatic, and internal (thermal) energies]
- Prove that Kinetic Energy= $\frac{1}{2}mv^2$ [use of equations of motion not needed; proof through kinematic graphs will suffice]
- Prove and use the formula for gravitational potential energy
- Use the formulas for kinetic and gravitational potential energy to solve problems involving simple energy conversions [make use of the conversion of energy from one form to the other, including cases involving loss of energy to the surroundings]
- Describe how energy is transferred and stored during events and processes [e.g. work done during transfer by mechanical work done, electrical work done, and heat]
- State and apply the principle of the conservation of energy
- Justify why perpetual energy machines do not work
- Differentiate between and list renewable and non-renewable energy sources
- Describe how useful energy may be obtained from natural resources [including the cases of (a) chemical energy stored in fossil fuels, (b) chemical energy stored in biofuels, (c) hydroelectric resources, (d) solar radiation, (e) nuclear fuel, (f) geothermal resources, (g) wind, (h) tides, (i) waves in the sea while including references to a boiler, turbine and generator where they are used]
- Describe advantages and disadvantages of methods of energy generation [limited to whether it is renewable, when and whether it is available, and its impact on the environment]
- Define and calculate power [As work done per unit time and also as energy transferred per unit time. This also includes applying the equations: (a) power= work done/time taken $P = W/t$ (b) power = energy transferred/time taken
- Define and calculate efficiency [including: (a) (%) efficiency = (useful energy output)/(total energy input) (x 100%) (b) (%) efficiency = (useful power output)/(total power input) (x 100%)]
- Apply the concept of efficiency to simple problems involving energy transfer
- State that a system cannot have an efficiency of 100% due to unavoidable energy losses that occur.

Work and energy are important concepts in physics as well as in our everyday life. Commonly the word 'work' covers all sort of activities whether mental or physical. If a girl is studying (Fig. 5.1) or a man is standing (Fig. 5.2) with a load of bricks on his head, we say that they are doing work. But according to physics, work has a specific definition. Work is said to be done when a force acts on an object and moves it through some distance.

Fig. 5.1

The concept of energy is closely associated with that of work, when work is done by one system on another, energy is transferred between the two systems.

In this chapter, we will define work, energy, power and efficiency and show how they are related to one another.

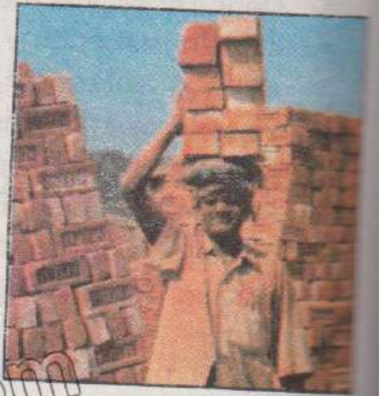


Fig. 5.2

5.1 Work

Force and distance are two essential elements of work. When a constant force acting on a body moves it through some distance, we say that 'the force has done work'.

> Work is defined as the product of magnitude of force and the distance covered in the direction of force.

Consider a block of wood lying on a table (Fig. 5.3). If we exert a force F on the block to move it through a distance S in the direction of force, then the work W done by the force is:

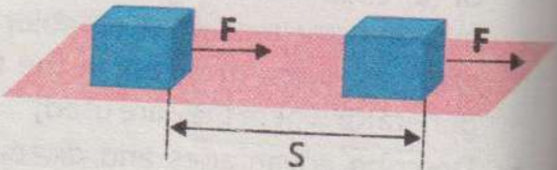


Fig. 5.3

Work = Magnitude of force × Distance

or $W = F \times S$ .... (5.1)

From Eq. (5.1), it can be concluded that if some force is acting on a body but there is no displacement, then no work is done. For example, a man is pushing hard a wall but the wall remains fixed in its place. In this case, the man is doing no work (Fig. 5.4).

Similarly, if a force acting on the body is zero and the body is moving with uniform velocity, work will be zero.

As $F = 0$ so $W = 0 \times S = 0$

Fig. 5.4

What will be the work done when a force is acting on a body making an angle θ with the direction of motion? In this case, work is done due to the component of force which is acting along the direction of motion (Fig. 5.5).

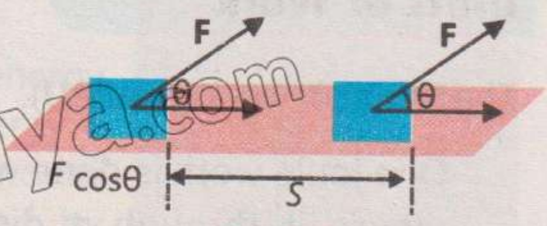


Fig. 5.5

Resolving the force F into its components, we have the component $F\cos\theta$ that acts in the direction of motion. Therefore,

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

or $$W = FS\cos\theta \quad \text{...... (5.2)}$$

If θ is zero, cos 0° = 1, then

$$W = FS\,(1) = FS$$

This is the case when force and distance covered are in the same direction. Now if θ = 90°, then cos 90° = 0 which means the force has zero component in the direction of motion. Thus,

$$W = FS\,(0) = 0$$

Fig. 5.6

This is the case when force is perpendicular to the displacement. Look at Fig. 5.6, it suggests that if a person carries a bag to some distance, this work is zero, because the force applied to hold the load is upward which is perpendicular to the displacement.

The work done to push an object is the same whether the object moves north to south or east to west, provided the magnitude of force and the distance moved are not changed. Work does not convey any directional information, so it is a scalar quantity.

Calculation of Work Done by Graph

When a constant force F acts through a distance S, the event can be plotted on a force-distance graph as shown in Fig. 5.7. If the force and distance covered are in the same direction, the work done is $F \times S$.

Clearly the shaded area in the figure is also $F \times S$. Hence, the area under a force-distance curve can be taken to represent the work done by that force.

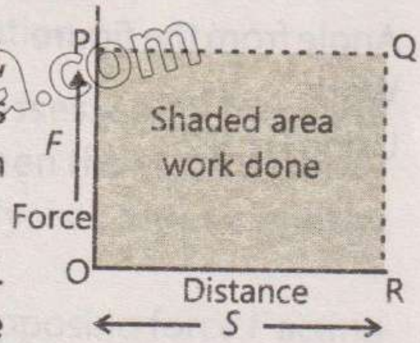


Fig. 5.7

Units of Work

The SI unit of work is joule (J).

One joule work is done when a force of one newton acting on a body moves it through a distance of one metre in its own direction.

From Eq. (5.1)

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

or $\quad 1\,J = N\,m$

Bigger units are also used like $1\,kJ = 10^3\,J$ and $1\,MJ = 10^6\,J$

Example 5.1

A person does 200 J of work in pushing a carton through a distance of 5 metres. How much force is applied by him?

Solution

Work done $\quad W = 200\,J$

Distance $\quad S = 5\,m$

Force $\quad F = ?$

From Eq. (5.1) $\quad W = F \times S \quad$ or $\quad F = \frac{W}{S}$

Putting the values, we get

$$F = \frac{200\,J}{5\,m} = 40\,N$$

Example 5.2

Find the work done by a 65 N force in pulling the suitcase (Fig. 5.8) for a distance of 20 metres.

Solution

Force applied $\quad F = 65\,N$

Distance covered $\quad S = 20\,m$

Angle from the figure $\quad \theta = 30°$

Work $\quad W = ?$

Using Eq. 5.2,

Fig. 5.8

$$W = FS\cos 30°$$

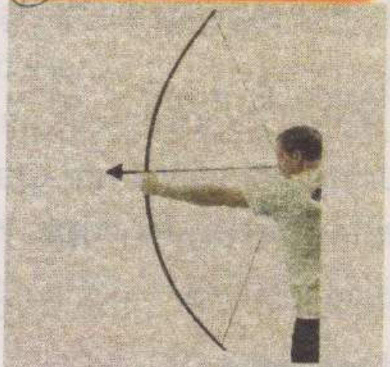
$$W = 65\,N \times 20\,m \times 0.866$$

$$W = 1125.8\,N\,m = 1125.8\,J$$

5.2 Energy

Our body cannot move unless we have energy from food. A car would not run without the energy it obtains from burning fuel. Machines in the factories cannot run without consuming energy supplied by electricity. Any change in motion requires energy. When we say that a certain body has energy, we mean that it has the ability of doing work.

For Your Information!



A stretched bow stores energy, which is transferred to the arrow as it is shot. Some bows store enough energy to shot an arrow even 1 km away.

Energy can be defined as the ability of a body to do work.

When someone does work, energy of the body has to be spent. In fact, energy is transferred to the body on which work is done. In other words, the energy is transferred from one system to another. For example, when you do work pushing a swing, chemical energy in your body is transferred to the swing and appears as energy of the motion of the swing.

Like work, energy is a scalar quantity. Its SI unit is joule (J).

When one joule work is done on a body, the amount of energy spent is one joule.

There are many forms of energy. Electrical energy, chemical energy, nuclear energy, heat energy and light energy are some well-known forms which we shall study later on. There are two basic forms of energy:

(i) Kinetic energy

(ii) Potential energy

The combination of these two types of energies is called mechanical energy.

Kinetic Energy

The kinetic energy of a body is the energy that a body possesses by virtue of its motion.

To find out how much kinetic energy a moving body possesses, an opposite force can be applied on the body to stop its motion. Then the work done by the force will be equal to the kinetic energy of the body. i.e., Kinetic energy (E_k) = Work done (W)

Suppose a body of mass m is moving with velocity v. An opposing force F acting on the body through a distance S brings it to rest. Then,

E_k = Work done = $F \times S$

As $F = ma$ and $S = v_{av} \times \text{time} = \left(\frac{v+0}{2}\right)t = \frac{v}{2} \times t$

Hence, $E_k = ma \times \frac{vt}{2} = \frac{1}{2}\, ma \times vt$

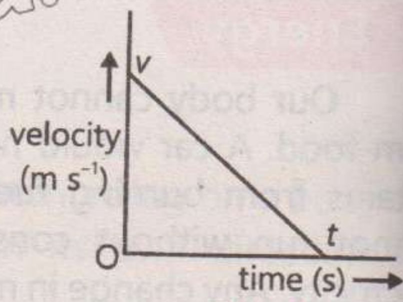


Fig. 5.9

Using velocity-time graph (Fig 5.9), the acceleration 'a' is given by its slope.

Hence, $a = \frac{v}{t}$, the slope is negative as the velocity and force are in opposite direction.

Thus $\quad E_k = \frac{1}{2} m \left(\frac{v}{t}\right) vt$

or $\quad E_k = \frac{1}{2} mv^2 \quad$ -------- (5.3)

Example 5.3

A truck of mass 3000 kg is moving on a road with uniform velocity of 54 km h^{-1}. Determine its kinetic energy.

For Your Information!

- The work done by the single beat of human heart is 0.5 J.
- The energy content of the nuclear bomb dropped on Hiroshima, Japan, in the second world war was 8.0×10^{13} J.
- The energy output of a power station in one year is 10^{16} J.

Solution

Mass of the truck $m = 3000$ kg

Velocity $v = 54$ km h^{-1} = 15 m s^{-1}

Kinetic energy $E_k = ?$

Putting the values,

$$E_k = \frac{1}{2} mv^2 = \frac{1}{2} \times 3000 \text{ kg} \times (15)^2 \text{ m}^2 \text{ s}^{-2}$$

$$E_k = 337500 \text{ J} = 337.5 \text{ kJ}$$

Potential Energy

In the previous section, we have seen that the work done on a body is used to increase its kinetic energy. Sometimes, the work done on a body does not increase its kinetic energy, rather it is stored in the body as **potential energy**.

Potential energy is defined as the energy that a body possesses by virtue of its position or deformation.

Do You Know?


The train is changing potential energy every moment in the roller coaster.

Forms of Potential Energy

There are many forms of potential energy. As mentioned above, the energy possessed by an object by virtue of its position relative to the Earth is known as **gravitational potential energy**.

The energy stored in a compressed or stretched spring is called **elastic potential energy** and the potential energy in the chemicals of a battery is called **chemical potential energy**, which is changed to electrical energy by chemical reactions. **Thermal or internal energy** is released by burning fossil fuels i.e. coal, oil or gas through chemical reactions.

Nuclear energy is the hidden energy in the nuclei of atoms. When they are broken, energy is released in the form of heat and some other radiations. This is called nuclear fission.

If the block shown in Fig. 5.10 is lifted to a height *h* above the ground, then the block would have potential energy in that raised position. Therefore, it has the ability to do work whenever it is allowed to fall. How should potential energy be measured? Because work is done on the block to put it into the position where it has potential energy, therefore, we can say that the work done is stored in it as potential energy. Thus, **potential energy** E_p is given by

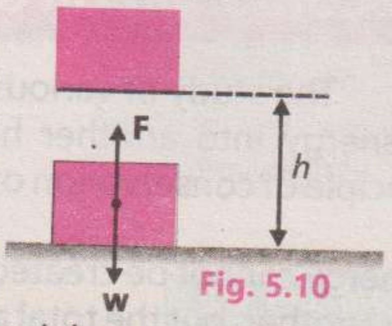


Fig. 5.10

$$E_p = \text{Work done to put the block in elevated position}$$

The applied force necessary to lift the block with constant velocity is equal to weight *w* of the block and since $w = mg$, therefore, potential energy of the block at height *h* becomes,

$$E_p = wh$$

or $$E_p = mgh \quad .... (5.4)$$

The most obvious example of gravitational potential energy is a waterfall (Fig. 5.11), water at the top of the fall has potential energy. When the water falls to the bottom, it can be used to run turbines to produce electricity and thus can do work.


Fig. 5.11 Waterfall

For Your Information!

According to Einstein's theory of relativity, matter and energy are interchangeable under certain conditions. The loss of some mass in nuclear reactions may transform into energy production and similarly energy may be converted into material particles. Hence, now we have conservation of mass and energy rather that conservation of each separately.

Example 5.4

A ball of mass 180 g was thrown vertically upward to a height of 12 m. Find the potential energy gained by the ball.

Solution

Mass of ball $m = 180\text{ g} = 0.18\text{ kg}$
Height $h = 12\text{ m}$

P.E. gained $E_p = ?$

$g = 10\,m\,s^{-2}$

From Eq. (5.4) $E_p = mgh$

Putting the values

$E_p = 0.18\,kg \times 10\,m\,s^{-2} \times 12\,m = 21.6\,J$

5.3 Conservation of Energy

The study of various forms of energy and the transformation of one kind of energy into another has led to a very important principle known as the principle of conservation of energy. Formally, it is stated as:

Energy cannot be created or destroyed. It may be transformed from one form to another, but the total amount of energy never changes.

During energy transfer process, some energy seems to be lost and not accounted for in calculations. This loss of energy is due to work done against friction of the moving parts in the process. This energy appears as heat and is dissipated in the environment. This energy does not remain available for doing some useful work and may be called waste energy.

A process of energy conversion and conservation can be described with the given example.

Let a body of mass m be at rest at a point A above the height h from the ground (Fig.5.12). Its total energy P.E is mgh,

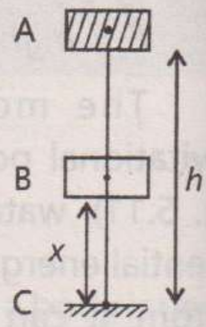


Fig. 5.12

$$E_p = mgh$$

and $$E_k = 0$$

Then the body is allowed to drop to point B at a height x from the ground. The body loses potential energy and gains kinetic energy as it gets speed while falling down. Assuming air resistance negligible.

$$E_p = mg(h - x)$$

The loss of potential energy will appear as the gain in kinetic energy, hence, at point B

$$E_k = mgx$$

Total energy at B $\quad E = mg(h - x) + mgx = mgh$

Just before hitting the ground at point C, the whole of potential energy is changed into kinetic energy. Thus,

$$E_p = 0 \quad \text{and} \quad E_k = mgh$$

Thus, total energy remains the same as mgh. On hitting the ground, this energy is dissipated as heat and sound in the environment.

5.4 Sources of Energy

Fossil Fuel Energy

Fossil fuel energy comes out from burning of oil, coal and natural gas. These materials are known as fossil fuels. The burning of these fuels gives out heat which is used to generate steam that runs the turbines to produce electricity. A block diagram of the process going on in electricity generation by fossil fuels is given in Fig. 5.13.

For Your Information

Before electricity was discovered, one of the primary functions of fossil fuels was to provide light.

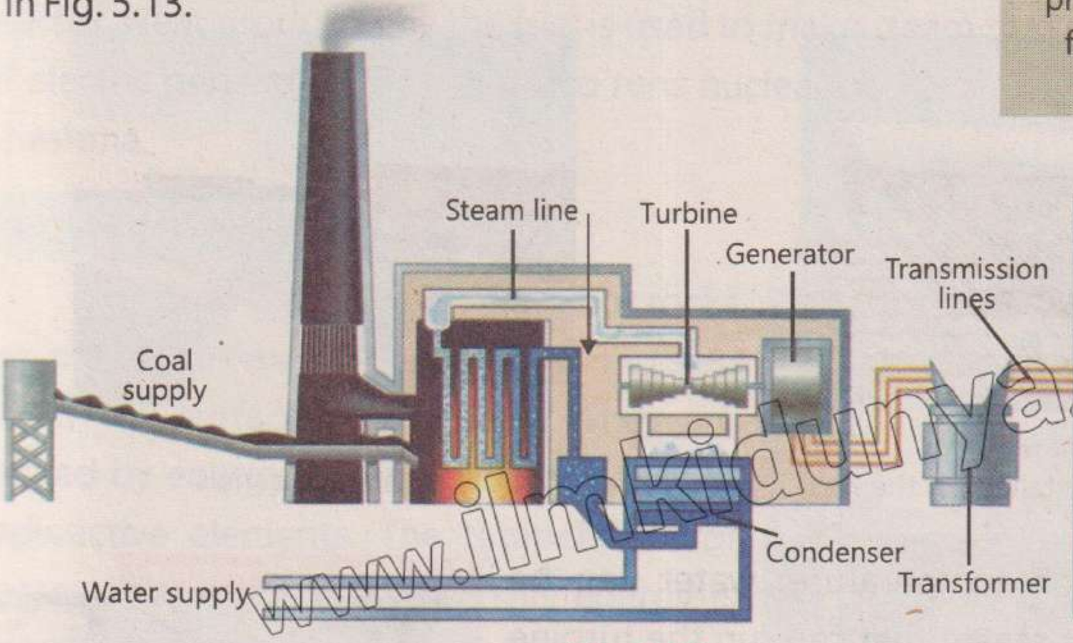


Fig. 5.13

Do You Know?

Thermal energy from coal burning was a major source used in the boilers of steam engines to drive locomotives in the past.

Hydroelectric Generation

Hydroelectric generation is the electricity generated from the power of falling water. Water in a high lake or reservoir possesses gravitational potential energy stored in it. When water is allowed to fall from height, the potential energy is changed into kinetic energy (Fig. 5.14). Tunnels are made for water to flow from the reservoir to a lower place. Such a construction is known as dam.

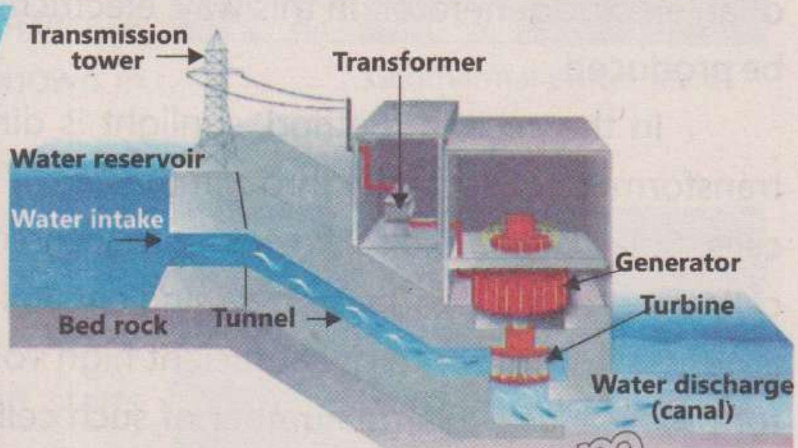


Fig. 5.14

The kinetic energy of running water rotates the turbine which in turn runs the electric generator.

Solar Energy

Sun is the biggest source of energy. The energy obtained from sunlight is referred to as solar energy. Solar energy can be used in two ways. Either it can be used for heating system or can be converted to electricity. In one way, solar panels absorb heat of the Sun. They consist of large metal plates which are painted black (Fig. 5.15). Heat can be used for warming houses or running water heating system. If solar radiation is concentrated to a small surface area by using large reflectors or lenses, reasonably high temperature can be achieved.

Fig. 5.15
Solar panels installed on the roof

Fig. 5.16
Solar cells panels

At this high temperature, water can be boiled to produce steam that can run the turbine of an electric generator. In this way, electricity can be produced.

In the second method, sunlight is directly transformed to electricity through the use of solar cells. Solar cells are also known as photo voltaic cells. The voltage produced by a single voltaic cell is very low. In order to get sufficient high voltage for practical use, a large number of such cells are connected in series to form a solar cell panel as shown in Fig. 5.16.

Solar calculators are also available which work by using the electrical energy provided by solar cells. Large solar panels are also used to power satellites.

For Your Information!

Solar powered car which won the world solar challenge race in Darwin, Australia in 1993.

Earth satellites get solar energy through their solar panels.

Nuclear Energy

Nuclear energy is released in the form of heat when an atomic nucleus breaks. Nuclear power stations make use of nuclear fuels such as uranium and plutonium.

These materials release huge amount of energy as the nuclei of their atoms break during nuclear fission. The process is done in a nuclear reactor. Heat produced by the fuel is used to make steam that runs the turbines of electric generators. Pakistan also runs nuclear power stations at Karachi and Chashma.

For Your Information!

Geothermal energy is currently used in Japan, Russia, Iceland, Italy, New Zealand and USA. More than 85% of Icelanders use geothermal energy to warm their homes. The cost of heating is only one-third of the cost of burning oil to power electric heaters.

Geothermal Energy

In some parts of the world, hot rocks are present in the semi molten form deep under the surface of the Earth. They are heated by energy released due to decay of radioactive elements. The temperature of these rocks is about 250°C. This energy is known as geothermal energy which can be extracted to run electric generators. A typical geothermal power plant is shown in Fig. 5.17.

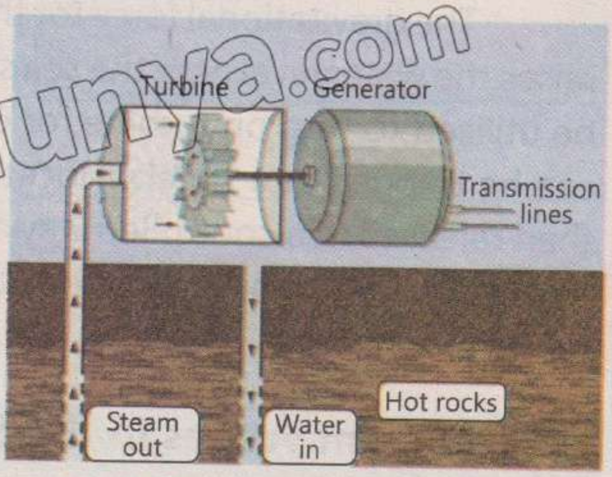


Fig. 5.17 Geothermal power plant

To make use of the heat of the rocks, two holes are drilled up to the rocks. Cold water is pumped down through one of the holes. It is heated up by the hot rocks and starts boiling. Steam is produced that comes out through the other hole. The steam runs the generator which produces electricity. Where there is water already present over the hot rocks, it comes out of the surface of the Earth in the form of hot springs and geysers. Such a geyser is shown in Fig. 5.18.

Fig. 5.18

Wind Energy

For thousands of years, people have been using windmills to draw water from the well or to grind grains into flour. The modern windmill is used to run generators that produce electricity. Wind generators make electricity in the same way as steam generators in power stations. For large scale power generation, a 'wind farm' with a hundred or more windmills is needed. A windmills farm is shown in Fig. 5.19.

Fig. 5.19 Windmills farm

Energy from Tides

The gravitational force for the moon gives rise to tides in the seas. The tide raises the water level near the sea shore twice a day. The rise and fall of water can be utilized to turn on turbine for electricity generation. The water at high tides can be trapped at a suitable location, a basin, by building a dam. The water is then released in a controlled way at low tide to drive the turbines for producing electricity. At next high tide, the dam is filled again and the incoming water also drives turbines.

Energy from Waves in the Sea

The tides and winds blowing over the surface of the sea produce strong water waves.

Their energy can be used to generate electricity. The method to harness wave energy is to use large floats which move up and down with the waves. One such device invented by Prof. Salter is known as Salter's duck (Fig.5.20). It consists of two parts.

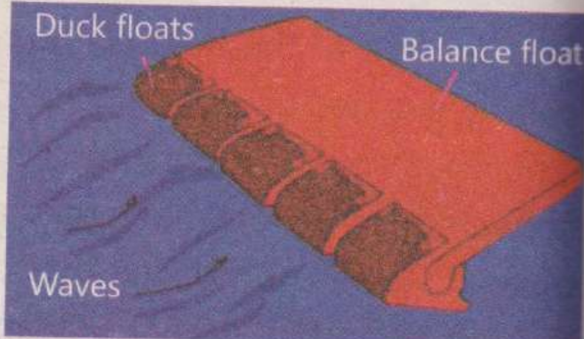


Fig. 5.20

(i) Duck float **(ii) Balanced float**

The energy of the water waves causes duck float to move relative to the balance float. The relative motion of the duck float is used to drive the electricity generators.

Biofuel Energy

It is that energy which is obtained from the biomass. Biomass consists of organic materials such as plants, waste foods, animals dung, sewage, etc. Sewage is that dirt which is left over after staining dirty water. The material can itself be used as fuel or can be converted into other types of fuels.

Direct combustion is a method in which biomass, commonly known as solid waste, is burnt to boil water and produce steam. The steam can be used to generate electricity. In another process, the rotting of biomass in a closed tank called a 'digester' produces methane rich biogas (Fig. 5.21). In this process, micro-organisms break down biomass material in the absence of oxygen.

Biogas produced in the tank is piped out and can be used for heating and cooking like natural gas.

Biofuel such as ethanol (alcohol) can also be obtained from the biomass. It is a replacement of petrol. In this case, bacteria converts it into ethanol.

Do You Know?

The radioactive fallout from the 1986 Chernobyl nuclear accident in Russia (1986) affected people, livestock and crops. Although only 31 people died from direct exposure, about 600,000 people were significantly exposed to the fallout.

Fig. 5.21 Biogas digester

Economic, Social and Environmental Impact of Various Energy Sources

Fossil fuels is a common source of energy but it is very expensive. It also produces pollution that affects the human health badly. On the other hand, hydroelectric energy is the cheapest source of energy. It does not produce pollution. It has only one negative point that it may cause water logging by raising the water table under the nearby lands.

The use of solar energy, wind energy, tidal energy, etc. is pollution free. Only the initial cost is high in the use of these sources.

Nuclear energy is very desirable source. It is cheaper and can meet the increasing demands of energy easily.

5.5 Renewable and Non-Renewable Sources

The resources of energy which are replaced by new ones after their use are called renewable energy source. On the other hand, non-renewable sources are those, which are depleted with the continuous use. Once they run out, they are not easily replaced by new ones. Sources such as hydroelectricity, solar energy, wind energy, tidal energy, wave energy and geothermal energy are renewable. These are replaced by new ones. For example, snow fall and rain fall are continuous processes. Therefore, water supply to the reservoirs of dams for generation of hydroelectric power will never end up. Likewise, solar energy will remain available forever. Same is the case with wind and tidal energy. These are not going to run out in future.

Non-renewable sources include fossil fuels and nuclear energy. The remnants of plants and animals buried under the Earth took millions of years to change into fossil fuels. These fuels are in limited quantity. Once they are used up, it will take further millions of years to form new ones. Similarly, fuels for the nuclear energy are also limited.

As the need for energy is increasing day by day, there is need to develop other non-traditional renewable energy sources.

5.6 The Advantages and Disadvantages of Methods of Energy Production

The production of hydroelectric power is more economical and pollution free. The solar power, wind, tidal and wave power need more initial cost but they do not produce pollution and are also economical as well. On the other hand, power generation by fossil fuels and nuclear fuel adds to the pollution of environment. Burning of fossil fuels produces smoke, carbon dioxide gas and heat (Fig. 5.22). They enhance direct pollution to atmosphere. Windmills are very noisy. Some people think that wind turbines spoil the beauty of landscape.

Fig. 5.22

Do You Know?

Burning fossil fuels release five billion tonnes of carbon dioxide into the atmosphere every year.

Nuclear power generators are also run by steam produced by nuclear heat energy. Heat itself is a form of pollution. Moreover, there is always danger of leakage of the radioactive radiation which is harmful to living bodies. People living around nuclear plants are always at risk. The disposal of nuclear waste is another problem for the nuclear power generation. However, any form of waste energy ends up as thermal energy that goes to the environment. Thus, thermal pollution is increasing day by day causing global warming.

5.7 Power

In many cases, the time to do work is as important as the amount of work done. Suppose you walk up to a height 'h' through upstairs (Fig. 5.26). You do work, because you are lifting your body up the stairs. If you run up, you can reach the same height in a shorter time interval.

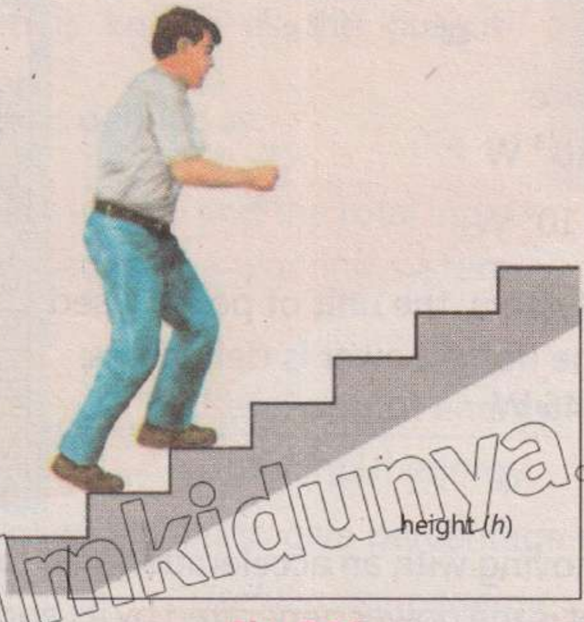


Fig. 5.26

The work done is the same in either case, because the net result is that you lifted up the same weight w to the same height h. But you know that if you run up the stairs, you would be more tired than you walked up slowly. In fact, there is a difference in the rate at which work is done. We say that you expend more energy when you go up the stairs rapidly than when you go slowly.

The concept of power can also be explained with another example of an electric motor or a water pump. A bigger motor draws more water during the same interval of time as compared to a smaller one. It is said that the power of bigger motor is greater than that of smaller one.

> Power is defined as the time rate of doing work.

Mathematically,

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

If W is the work done in time t, then

$$P = \frac{W}{t} \quad .... (5.5)$$

Power of any agency can also be defined as energy transferred per unit time.

Units of Power

Since both work and time are scalar quantities, so according to Eq.(5.5) power is also a scalar quantity. The SI unit of powers is watt (W).

One watt is the work done at the rate of one joule per second.

$$1\ W = \frac{1\ J}{1\ s} \quad \text{or} \quad 1\ J\ s^{-1}$$

Bigger Units of power are:

$$1\ kW = 10^3\ W$$

$$1\ MW = 10^6\ W$$

In British engineering system, the unit of power used is horse-power (hp). The horse power is defined as:

$$1\ hp = 746\ W$$

Do You Know?

Appliance	Av. Power (watts)
Energy saver	23
Tube light	40
Electric fan	80
Bulb	100
T.V.	200
Washing machine	250
Refrigerator	600
Electric iron	1000
Toaster	1000
Microwave oven	1200
Air conditioner	2500

Example 5.5

A 1000 kg car moving with an acceleration of $4\ m\ s^{-2}$ covers a distance of 50 m in 5 seconds. What is the power generated by its engine?

Solution

Mass of car $m = 1000\ kg$

Acceleration $a = 4\ m\ s^{-2}$

Distance $S = 50\ m$

Time taken $t = 5\ s$

Power $P = ?$

First, we shall determine the force applied by Newton's second law.

$$F = ma = 1000\ kg \times 4\ m\ s^{-2} = 4000\ N$$

From Eq. (5.1), Work, $W = FS$

Or $W = 4000\ N \times 50\ m = 2.0 \times 10^5\ J$

From Eq. (5.5), $P = \frac{W}{t}$

Putting the values of W and t, we have

$$P = \frac{2.0 \times 10^5\ J}{5\ s} = 4 \times 10^4\ W = 40\ kW$$

For Your Information!

The watt is named in honour of James Watt (1736-1819), a Scottish engineer who perfected the steam engine.

5.8 Efficiency

The efficiency of a working system tells us what part of the energy can be converted into the required useful form of energy and what part is wasted out of the energy available.

The available energy for conversion is usually called the input energy and the energy converted into the required form is known as the output energy.

The efficiency of a system is defined as:

Do You Know?

Activity	Average Efficiency (%)
Diesel engine	35
Petrol engine	25
Electric motor	80
Bicycle	15

For Your Information!

A machine with its output equal to input is called an ideal machine with efficiency 100%.

The ratio of useful output energy and the total input energy is called the efficiency of a working system.

or

$$\text{Efficiency} = \frac{\text{Useful output energy}}{\text{Total input energy}}$$

Efficiency is often multiplied by 100 to give percentage efficiency. Thus,

$$\text{Percentage Efficiency} = \frac{\textit{Useful output energy}}{\textit{Total input energy}} \times 100$$

It can also be given as:

$$\text{Percentage Efficiency} = \frac{\textit{Useful power output}}{\textit{Total power input}} \times 100 \quad \text{..........} \ (5.6)$$

It is found that the energy output is always less than the energy input. During any conversion of energy, some energy is wasted in the form of heat. No device has yet been invented that may convert all the input energy into required output. That is why a system cannot have an efficiency of 100 %. As the energy losses are inevitable in the working of a machine, hence, an ideal or perpetual machine cannot be constructed.

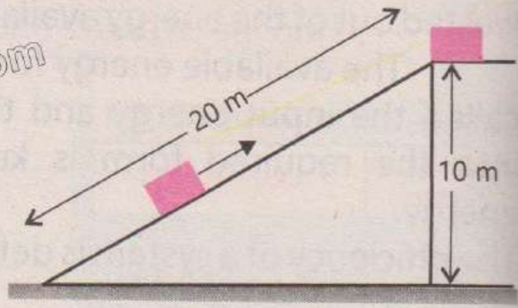
Perpetual Energy Machines

It is a hypothetical machine that can do work indefinitely, without any external source of energy. A perpetual machine would have to generate more energy than it consumes, effectively producing energy from nothing, which is impossible. In any real mechanical system, some energy is always lost as heat due to friction between moving parts and air resistance etc. Thus, making it impossible for a machine to keep moving without an external source of energy. Infact, it is a consequence of the principle of conservation of energy that a perpetual energy machine is not workable.

Example 5.6

A block weighing 120 N is dragged up a slope with a force of 100 N to lift it up a height of 10 m. If the slope is 20 m long, calculate the efficiency of the system.

Solution



Weight of block $W = 120\,\text{N}$

Force applied $F = 100\,\text{N}$

Distance $S = 20\,\text{m}$

Height $h = 10\,\text{m}$

% Efficiency $= ?$

Work done to lift the block up is:

$$W = F \times S = 100\,\text{N} \times 20\,\text{m} = 2000\,\text{J}$$

Now, total input energy = work done on the block = 2000 J

Useful output energy = Gravitational potential energy gained = wh

$$= 120\,\text{N} \times 10\,\text{m} = 1200\,\text{J}$$

$$\text{Percentage Efficiency} = \frac{\textit{Useful output energy}}{\textit{Total input energy}} \times 100$$

$$= \frac{1200\,\text{J}}{2000\,\text{J}} \times 100 = 60\%$$

KEY POINTS

- Work is defined as the product of the magnitude of force and the distance covered in the direction of force.
- Work will be one joule if a force of one newton moves a body through a distance of one metre in the direction of the force.
- Energy is the ability of a body to do work. Its unit is also joule.
- Kinetic energy is the energy of a body by virtue of its motion.
- Gravitational potential energy is defined as the energy that a body possesses by virtue of its position in the gravitational field.
- The potential energy stored in a compressed or stretched spring is known as elastic potential energy.
- Fossil fuel energy is the energy that is released by burning of oil, coal and natural gas.
- Hydroelectric generation is the electricity generated by using the kinetic energy of the falling water.
- Solar energy is the energy of the sunlight that can be converted into electricity.
- The energy released by breaking the nucleus of an atom is known as nuclear energy.
- Geothermal energy is the heat energy of the hot rocks present deep under the surface of the Earth.
- Wind energy is the electrical energy produced by using the kinetic energy of the fast-blowing wind.
- Biofuel energy is that energy which is obtained by fermentation of organic materials in the form of biogas or ethanol.
- Power is defined as the time rate of doing work.
- Power will be one watt, if one joule of work is done in one second.
- The ratio of useful output energy to the total input energy is called the efficiency of a working system.

EXERCISE

A Multiple Choice Questions

Tick (✓) the correct answer.

5.1. Work done is maximum when the angle between the force *F* and the displacement *d* is:

(a) 0° (b) 30° (c) 60° (d) 90°

5.2. A joule can also be written as:

(a) kg m s^{-2} (b) kg m s^{-1} (c) kg m^2s^{-3} (d) kg m^2s^{-2}

5.3. The SI unit of power is:

(a) joule (b) newton (c) watt (d) second

5.4. The power of a water pump is 2 kW. The amount of water it can raise in one minute to a height of 5 metres is:

(a) 1000 litres (b) 1200 litres

(c) 2000 litres (d) 2400 litres

5.5. A bullet of mass 0.05 kg has a speed of 300 m s^{-1}. Its kinetic energy will be:

(a) 2250 J (b) 4500 J (c) 1500 J (d) 1125 J

5.6. If a car doubles its speed, its kinetic energy will be:

(a) the same (b) doubled

(c) increased to three times (d) increased to four times

5.7. The energy possessed by a body by virtue of its position is:

(a) kinetic energy (b) potential energy

(c) chemical energy (d) solar energy

5.8. The magnitude of momentum of an object is doubled, the kinetic energy of the object will:

(a) double (b) increase to four times

(c) reduce to one-half (d) remain the same

5.9. Which of the following is not renewable energy source?

(a) Hydroelectric energy (b) Fossil fuels

(c) Wind energy (d) Solar energy

B Short Answer Questions

5.1. What is the work done on an object that remains at rest when a force is applied on it?

5.2. A slow-moving car may have more kinetic energy than a fast-moving motorcycle. How is this possible?

5.3. A force F_1 does 5 J of work in 10 s. Another force F_2 does 3 J of work in 5 s. Which force delivers greater power?

5.4. A woman runs up a flight of stairs. The gain in her gravitational potential energy is 4500 J. If she runs up the same stairs with twice the speed, what will be her gain in potential energy?

5.5. Define work and its SI unit.

5.6. What is the potential energy of a body of mass *m* when it is raised through a height *h*?

5.7. Find an expression for the kinetic energy of a moving body.

5.8. Define efficiency of a working system. Why a system cannot have 100% efficiency?

5.9. What is power? Define the unit used for it.

5.10. Differentiate between renewable and non-renewable energy sources.

C Constructed Response Questions

5.1. Can the kinetic energy of a body ever be negative?

5.2. Which one has the greater kinetic energy; an object travelling with a velocity *v* or an object twice as heavy travelling with a velocity of ½ *v*?

5.3. *A car is moving along a curved road at constant speed. Does its kinetic energy change?*

5.4. Comment on the statement. "An object has one joule of potential energy."

5.5. While driving on a motorway, tyre of a vehicle sometimes bursts. What may be its cause?

5.6. While playing cricket on a street, the ball smashes a window pane. Describe the energy changes in this event.

5.7. A man rowing boat upstream is at rest with respect to the shore. Is he doing work?

5.8. A cyclist goes downhill from the top of a steep hill without pedalling and takes it to the top of the next hill.

(i) Draw a diagram of what happened.

(ii) Analyse this event in terms of potential and kinetic energy. Label your diagram using these terms.

5.9. Is timber or wood renewable source of heat energy? Comment.

D Comprehensive Questions

5.1. What is meant by kinetic energy? State its unit. Describe how it is determined.

5.2. State the law of conservation of energy. Explain it with the help of an example of a body falling from certain height in terms of its potential energy and kinetic energy.

5.3. Differentiate between renewable and non renewable sources of energy. Give three examples for each.

5.4. Explain what is meant by efficiency of a machine. How is it calculated? Why there is a limit for the efficiency of a machine?

5.5. Describe the process of electricity generation by drawing a block diagram of the process in the following cases.

(i) Hydroelectric power generations (ii) Fossil fuels

E Numerical Problems

5.1. A force of 20 N acting at an angle of 60° to the horizontal is used to pull a box through a distance of 3 m across a floor. How much work is done?

(30 J)

5.2. A body moves a distance of 5 metres in a straight line under the action of a force of 8 newtons. If the work done is 20 joules, find the angle which the force makes with the direction of motion of the body.

(60°)

5.3. An engine raises 100 kg of water through a height of 80 m in 25 s. What is the power of the engine?

(3200 W)

5.4. A body of mass 20 kg is at rest. A 40 N force acts on it for 5 seconds. What is the kinetic energy of the body at the end of this time?

(1000 J)

5.5. A ball of mass 160 g is thrown vertically upward. The ball reaches a height of 20 m. Find the potential energy gained by the ball at this height.

(32 J)

5.6. A 0.14 kg ball is thrown vertically upward with an initial velocity of 35 $m s^{-1}$. Find the maximum height reached by the ball.

(61.25 m)

5.7. A girl is swinging on a swing. At the lowest point of her swing, she is 1.2 m from the ground, and at the highest point she is 2.0 m from the ground. What is her maximum velocity and where?

(4 m s^{-1}, at the lowest position)

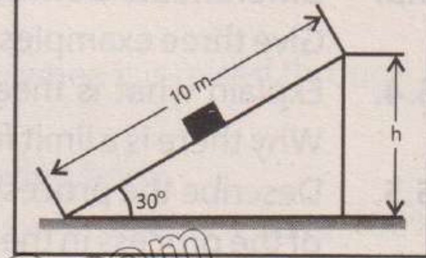
5.8. A person pushes a lawn mower with a force of 50 N making an angle of 45° with the horizontal. If the mower is moved through a distance of 20 m, how much work is done?

(707 J)

5.9. Calculate the work done in

(i) Pushing a 5 kg box up a frictionless inclined plane 10 m long that makes an angle of 30° with the horizontal.

(250 J)



(ii) Lifting the box vertically up from the ground to the top of the inclined plane.

(250 J)

5.10. A box of mass 10 kg is pushed up along a ramp 15 m long with a force of 80 N. If the box rises up a height of 5 m, what is the efficiency of the system?

(41.7%)

5.11. A force of 600 N acts on a box to push it 5 m in 15 s. Calculate the power.

(200 W)

5.12. A 40 kg boy runs up-stair 10 m high in 8 s. What power he developed.

(500 W)

5.13. A force F acts through a distance L on a body. The force is then increased to $2F$ that further acts through $2L$. Sketch a force-displacement graph and calculate the total work done.

($5FL$ or 5 units)