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13

WORK AND ENERGY

In previous lesson we have learnt that force changes the motion (i.e. momentum). But during the change in motion the body on which the force is applied also moves through some distance. This leads us to some more basic concepts of science - **work**, **power** and **energy**, which we will discuss in this lesson.

We commonly use the word like work and energy in our daily life. Let us study the lesson and found out how science define these terms.

We will also come to know in this chapter about the various forms of energy, examples of their interconversion and the most basic law of nature which governs these energy transformations – **the law of conservation of energy**.

Sometimes we want the work to be done more quickly. The quantity which measures the rate at which work is done is called **power**. Performance of a machine is usually rated by power.

OBJECTIVES

After studying this lesson you will be able to:

- *define the terms work and energy and their SI units;*
- *compute work done by a constant force;*
- *list various forms of energy-like mechanical, thermal, light, sound, electrical, chemical, and nuclear energy with examples;*
- *define and explain potential and kinetic energy with suitable examples;*
- *cite examples of transformation of energy;*
- *state and explain the law of Conservation of Energy' with the help of suitable examples and*
- *explain the term power and define its SI unit.*

13.1 WORK

Work is a common term we use in our day to day conversation. Ordinarily we include standing, reading, lying etc. in the category of work. But in sciences physical work has a very specific meaning, that is, work is said to be done when force is applied on a body and the body moves through some distance in the direction of force. To elaborate, it implies that:

- If a force is applied on a body and the body does not move then no work is done at all.

Example: When you try to push a wall you do not do any work as distance moved by the wall is zero (Fig. 13.1).

- If no force is applied on a body and the body is either at rest or moving with a constant velocity then again no work is done.

Example: A car moving with a constant velocity on a level road does not do any net work. Because the fuel it consumes is used in doing work against fraction, so that, its velocity may be maintained.

- If the force and displacement are perpendicular to each other, the work done by the force is zero as shown in Fig 13.3.

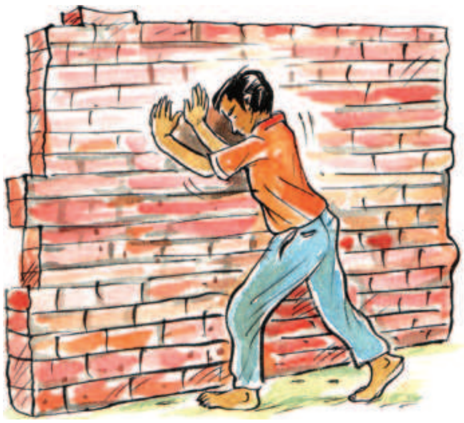


Fig. 13.1 *No displacement, no work is done in case of pushing a wall*

13.2 RELATION BETWEEN WORK, FORCE AND DISPLACEMENT

Work is measured as the product of force and the displacement in the direction of the force.

i.e., work = force × displacement in the direction of the force.

If force and displacement are in the same direction you can easily find work done by finding their product. But if force and displacement are in different directions the work done is obtained by finding the product of force and the projection of displacement in the direction of the force. For the situation shown in Fig. 13.2.

$$\text{work done } W = F \times PR \text{ and not } F \times PQ$$

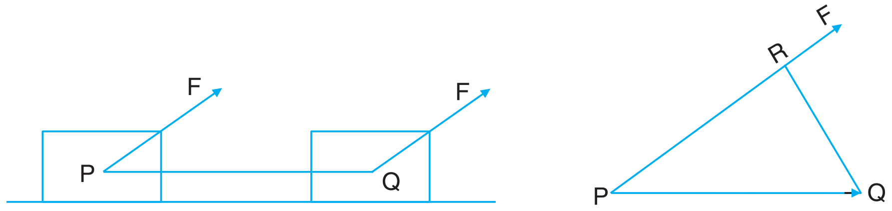


Fig. 13.2 *Work done when force and displacement are in different directions*

Example: A person carrying a heavy load on his head and moving on a level road does no work against gravity, because, there is no component of displacement in the direction of force of gravity as shown in Fig 13.3.

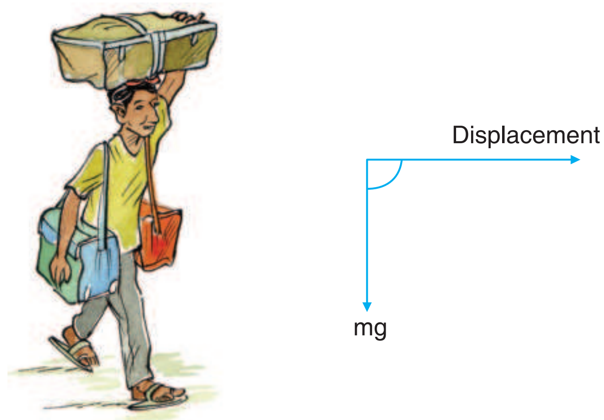


Fig. 13.3 *No work done against gravity when a person moves on a level road carrying a heavy load on his head*

The SI Unit of work is newton-metre (Nm) or joule (J). 1 J work is done when a body moves through a distance of 1m under a force of 1 N, in the direction of force.

INTEXT QUESTIONS 13.1

Choose the correct option

1. (i) Work done is zero:

   (a) When force and displacement are in the same direction.

   (b) When force and displacement of the body are in opposite directions

(c) When force acting on the body is perpendicular to the direction of the displacement of the body.

(d) When force makes an angle with displacement

(ii) 1 J of work is done when a force of 0.01 N moves a body through a distance of :

(a) 0.01 m (b) 0.1 m (c) 1 m (d) 10 m (e) 100 m

(iii) In which of the following situations work is done?

(a) A person is climbing up a stair case.

(b) A satellite revolving around the earth in closed circular orbit

(c) Two teams play a tug of war and both pull with equal force

(d) A person is standing with heavy load on his head

2. A car of mass 500 kg is moving with a constant speed of 10 ms^{-1} on a rough horizontal road. Force expended by the engine of the car is 1000 N. Calculate work done in 10 s by:

(a) net force on the car (b) gravitational force

(c) the engine (d) frictional force

13.3 ENERGY AND ITS RELATION WITH WORK

When you play for a long time or do a lot of physical work at your home or outside you get tired, i.e., your body shows unwillingness or reluctance towards further play or work. At this time you may also feel hungry. After taking rest for some time or/ and eating some thing you may again be ready for work. How does one explain these experiences? In fact, when you do work, you spend energy and more energy is required to do more work. The capacity of a body to do work is determined by the energy possessed by it.

i.e., Energy possessed by a body = Total work that the body can do

Energy has the same unit as work, i.e., joule denoted by J.

However, conversion of 100% of energy may not always be practicable, because, in the process of conversion of energy into work some energy may remain unused or may be wasted. To understand this point perform the following activity.

ACTIVITY 13.1

Alok and Kapil are inflating long (at least 5 cm) balloons in different ways as shown in Fig. 13.4. Alok blows in his balloon with part of its opening ushering in air, while Kapil blows in air in the whole area of the opening.

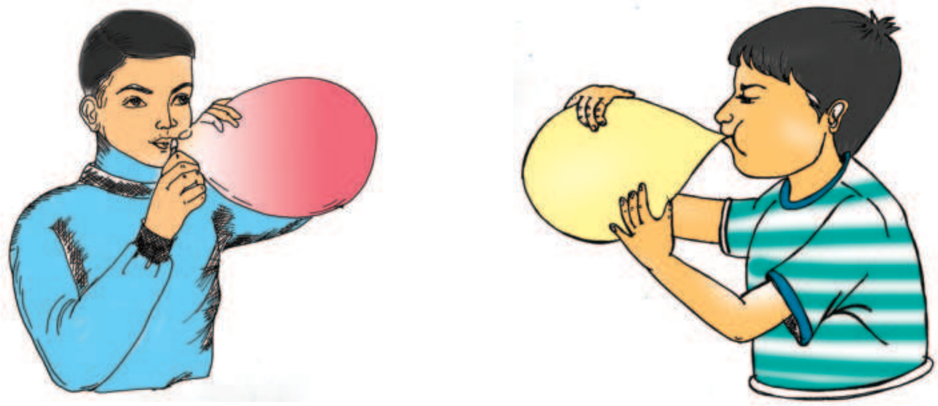


Fig. 13.4 *Alok and Kapil are inflating identical long balloons in different ways*

- Which of them is making more effort?
- Which of them is doing more work?

Do this activity, find out which technique resulted in a bigger baloon can you explain the reason.

On the basis of your conclusion now you can understand why air is blown from a distance in Phukini (metal pipe) to light the fire in Chulhas.

Fig. 13.5 *Use of Phukini (metal pipe) to light the fire*

Note: This cooking practice is unhealthy as it can lead to several health related problem.

13.4 DIFFERENT FORMS OF ENERGY

You do work by spending muscular energy which you gain from the chemical energy of the food you eat. Your fan runs on electrical energy. While playing with magnets you might have seen that a magnet can move a piece of iron so it has magnetic energy. Thus energy is available to us in many different forms like mechanical, thermal, light, electrical, magnetic, sound and nuclear. Let us acquaint ourselves with different forms of energy.

1. Mechanical Energy

This is the capacity of doing work that a body possesses by virtue of its position (potential energy) or by virtue of its motion (kinetic energy).

(a) Potential Energy

A body (say hammer) raised to a certain height above the ground when left to itself, falls down. If it is allowed to fall on a piece of dried clay it may break it into pieces. A body raised above the ground has thus ability to do work i.e. it has energy. This energy possessed by a body raised above the ground is called its potential energy.

When two bodies one lighter and another heavier are dropped from the same height on a pit of sand it will be found that the heavier body penetrates more in sand than the lighter body. Hence a heavier body possesses more potential energy.

If same body is dropped from different heights, we find that the body dropped from a greater height penetrates more, hence it has more potential energy. Potential energy of a body, thus depends on

- Weight of the body ($W = mg$)
- Height of the body (h) above the ground

It is found that the relation between Potential energy PE (E_p), weight (W), and height (h) is $E_p = W \times h = mgh$

(b) Kinetic Energy

Kinetic energy is the capacity of doing work that a body has by virtue of its motion. To understand the factors on which the kinetic energy of a moving body depends perform the following activity.

ACTIVITY 13.2

Make a stack of two thick hard bound books (about 10 cm) as shown in Fig.13.4. Let a hard bound register be placed on it to form a sloping plane. Place a match box near the plane with its length parallel to the horizontal edge of the incline. Let a pencil cell roll down the incline and hit the match box. Does the match box move?

Yes. The rolling cell had some kinetic energy due to which it made the match box move through a distance. Thus a moving object has ability to do work.

Now placing the match box at the same position let a torch cell roll from the same height and strike the match box. Does it move again? Does it move through a longer distance? Why does it do so? The torch cell has more mass than pencil cell so it has more kinetic energy and does more work.

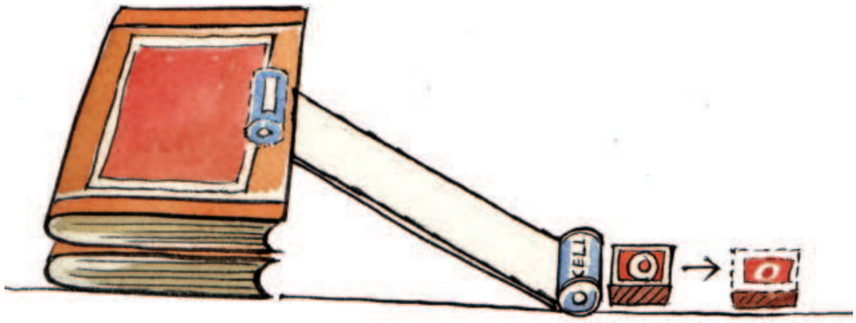


Fig. 13.6 *Experimental setup to demonstrate conversion of potential energy into kinetic energy*

Now repeat the experiment by making the cell roll from a greater height. Does it move the match box through still more distance? From these observations we may conclude:

- When a body comes down from a height its potential energy decreases where as its kinetic energy increases.
- The kinetic energy (KE) of a moving body depends on :
  - (i) its mass (m) – more the mass (for same velocity) more is its kinetic energy.
  - (ii) its velocity (v) – more the velocity (for same mass) more is its kinetic energy.

It is found that the kinetic energy of a moving body, K.E.= $\frac{1}{2}mv^2$

2. Thermal Energy

This is a form of energy which flows into our body to give us sensation of hotness and out of our body to give us sensation of coldness. You shall learn some more details about thermal energy in lesson 14.

3. Light Energy

The form of energy which enables us to see things is called light energy. You will study more about light energy in lesson 15.

4. Electrical Energy

You may be familiar with the energy that lights our bulbs, runs our fans, operates our pumps, heats our rooms, turns on our TV and radio and runs the refrigerator in our homes. The electrical energy is generated due to movement of charged particles. You will learn more about this form of energy in lesson 16.

5. Magnetic Energy

You know that a magnet can attract a piece of iron. Thus magnets have an ability to do work. The energy involved in the functioning of a magnet is called magnetic energy. You will study more about this form of energy in lesson 17.

6. Sound Energy

The form of energy which enables us to hear is called sound. Sound originates when a body vibrates giving out waves which travel to our ear through a material medium. You will study more about sound in lesson 18.

7. Nuclear Energy

The nuclear energy is a non-conventional form of energy which is released in nuclear reactions by conversion of mass into energy. You must have read in lesson 12 that India is trying to generate electrical power through nuclear energy.

INTEXT QUESTIONS 13.2

1. Explain the terms work and energy with one example each.
2. The ability to do work is called ....
3. The SI unit of all forms of energy is ....
4. Energy possessed by a spring is .... energy.
5. The energy possessed by a body due to its position is called .... energy.
6. The energy possessed by a body due to its motion is called .... energy.
7. At height h the potential energy is E_p at height $\frac{h}{2}$ the potential energy would be ....
8. At height h the potential energy of a body of mass m is E_p. At the same height the potential energy of a body of mass $\frac{m}{2}$ would be ....
9. A body of mass m moving with a speed v has kinetic energy, E_k. The body if moves with speed $2v$, will have kinetic energy equal to ....
10. A body of mass m moving with a speed v has kinetic energy E_k. A body of mass $2m$ moving with the same speed will have a kinetic energy..............

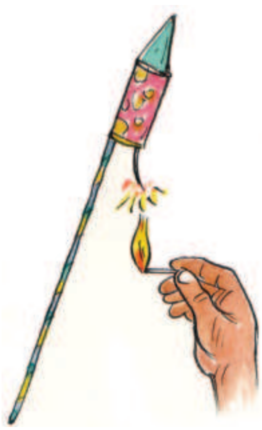
13.5 ENERGY TRANSFORMATIONS AND CONSERVATION

The various forms of energy mentioned in section 13.4 get converted from one form to another in different situations. This phenomenon of converting one form of energy to another form is called energy transformation. The following examples will make the point clear.

- Potential energy of water stored in a dam changes into kinetic energy as water falls from a height. The kinetic energy of flowing water changes into kinetic energy of rotation of a turbine. The coil attached with the shaft of the turbine rotates in a magnetic field to convert kinetic energy of rotation of the turbine into electrical energy.
- In our homes an electric bulb (or tube light) converts electrical energy into light energy, electric oven (or heater or iron or soldering iron) convert electrical energy into heat energy and electric pump (or motor) converts electrical energy into mechanical energy.
- An electric cell converts chemical energy into electrical energy; solar cell converts light energy into electrical energy and a thermocouple changes heat energy into electric energy.
- A microphone converts sound energy into electrical energy and a loudspeaker changes electrical energy into sound energy.
- Heat engine converts heat energy into work (mechanical energy) and work done against friction is converted into heat.

During transformation of energy from one form to another it remains constant. This is known as **Law of Conservation of Energy**.

(a) Photosynthesis (Solar energy → chemical energy of food)



(b) Bursting of fireworks (chemical energy → heat, light and sound energy)

(c) Electric bulb (electrical energy → light energy)

(d) Loudspeaker (electrical energy → sound energy)

(e) Table fan (electrical energy → kinetic energy)

(f) Physical exercise (chemical energy of food → muscular energy)

Fig. 13.7 *Some examples of energy transformation*

INTEXT QUESTIONS 13.3

Give one example each of the following energy transformations.

1. (i) Light energy into chemical energy.
   (ii) Chemical energy into heat.
   (iii) Chemical energy into electrical energy.
   (iv) Mechanical energy into electrical energy.
   (v) Thermal energy into electrical energy.
   (vi) Light energy into electrical energy.
2. (i) A motor converts electrical energy into ....
   (ii) An electric heater converts electrical energy into ....
   (iii) A microphone converts sound energy into ....
   (iv) A loudspeaker converts sound energy into ....
   (v) A heat engine converts heat energy into ....
   (vi) When we rub our hands together we change work into ....

13.6 POWER AND ITS UNIT

Have you ever heard statements such as : Quarter horse power motor is enough for the pump of a room cooler, one horse power motor will fill the tank in half the time a half horse power motor does. Horse power is a unit of power. And what is power? Power is a quantity which tells us how fast the work is done. **Power is defined as the time rate of doing work** i.e., the amount of work done in unit time.

or $$\text{Power} = \frac{\text{work done}}{\text{time taken}}$$

SI Unit of power is watt. One watt is the power spent when 1 J work is done in 1 s. It is also measured in horse power. 1 horse power (H.P.) = 746 watts.

ACTIVITY 13.3

Move up a staircase slowly and then run up on it to the same height. In which case do you get tired more? Why?

Your answer would be that it has to be more in the second case. Why so, because, in the second case you took lesser time and hence spent more power.

Do you know

- About 1J of work is done when you take a glass of water (200 mL) from your dinning table to your lips – a distance of about half metre.
- A football player spends about 150 J of energy when he/she kicks a ball of about 1/2kg to a height of 3 m.
- A normal adult weighing about 50 kg does about 5000 J of work in ascending up the staircase of a single storey building.
- In pulling out a 20 litre bucket of water from a 20 m deep well approximately 4000 J of work is done.

INTEXT QUESTIONS 13.4

1. Kamya climbs up a staircase in 5 minutes, Suraiya takes only 3 minutes in going up the same staircase. The weight of Kamya is equal to the weight of Suraiya.

   (i) Which of the two does more work?

   (ii) Which of the two spends more power?

2. Express 1.5 H.P. in SI Unit of power.
3. One cricket ball and One plastic ball are dropped from the same height. Which will reach the ground with

   (a) more energy, (b) less power?

WHAT YOU HAVE LEARNT

- Work is done when a force is applied on a body and the body has some displacement in the direction of the force.
- Work is defined as the product of force and the displacement in the direction of force.
- Ability to do work is called energy. The capacity of a body to do work is determined by the energy possessed by it.
- There are various forms of energy: mechanical, thermal, light, electrical, sound, magnetic and nuclear.
- Mechanical energy may be of two types: kinetic and potential.
- Energy can be changed from one form to another. The process is called energy transformation.
- During energy transformation energy is neither created nor destroyed. This fact is due to the Law of Conservation of Energy.
- The rate of doing work is called **power**. SI unit of power is watt.

TERMINAL EXERCISE

1. Define the following terms and give their SI units. (a) Work (b) Power (c) Energy
2. List different forms of energy.
3. State Law of Conservation of Energy. Explain with the help of examples.
4. List the energy transformation taking place in a thermal power plant.
5. A ball of mass 0.5 kg has100 J of kinetic energy. What is the velocity of the ball?
6. A body of mass 100 kg is lifted up by 10 m. Find

   (a) The amount of work done.

   (b) Potential energy of the body at that height (g =10 ms^{-2})

7. Why road accidents at high speeds are much worse than the accidents at low speeds?
8. Two bodies of equal mass move with uniform velocities u and 4 u respectively. Find the ratio of their kinetic energies.
9. What would you like to prefer a ramp or a staircase to reach at the third floor of your hospital? Justify.

ANSWER TO INTEXT QUESTIONS

13.1

1. (i) c (ii) e (iii) a
2. (i) Zero (ii) Zero (iii) 10^5J (iv) -10^{+5} J

13.2

1. **Work:** Work is said to be done when force is applied on a body and the body moves through some distance in the direction of force. Example: A person climbing up a staircase.

   Energy: The ability to do work is called energy. Example: A weightlifter lifts the weight.

2. energy 3. joule 4. potential
5. potential 6. kinetic 7. $E_p/2$
8. $E_p/2$ 9. $4E_k$ 10. $2E_k$

13.3

1. (i) In photosynthesis green plants transform light energy into chemical energy of carbohydrates.

   (ii) In digestion of food chemical energy of food is converted into heat.

   (iii) Electrical cells convert chemical energy into electrical energy.

   (iv) In electric generators mechanical energy is converted into electrical energy.

   (v) In thermal power plants heat energy is converted into electrical energy.

   (Note: a still better example would be a thermocouple which directly converts heat energy into electrical energy)

   (vi) In Solar Cells Light energy is converted into electrical energy.

2. (i) mechanical energy
   (ii) heat energy
   (iii) electrical energy
   (iv) electrical energy
   (v) mechanical energy
   (vi) heat energy

13.4

1. (i) They both do work against gravity. Because both of them have equal weight and climb equal height they do equal work.

   (ii) Because Suraiya takes lesser time in climbing up the staircase and power is inversely proportional to time so, Suraiya spends more power.

2. SI unit of power is watt

   and $1 \text{ H.P.} = 746 \text{ watt}$

   $1.5 \text{ H.P.} = 746 \times 1.5 = 1119.0 \text{ watt} = 1.12 \text{ kW}$

3 (a) Cricket ball (b) Plastic ball