4 Work and Energy

'Work' and 'energy' are two words we often use. We usually associate energy with work. For example, we may say, "I don't have the energy to do this work right now." In science, too, work and energy are closely related. Let us see what these two words mean in science and how they are related.

WORK

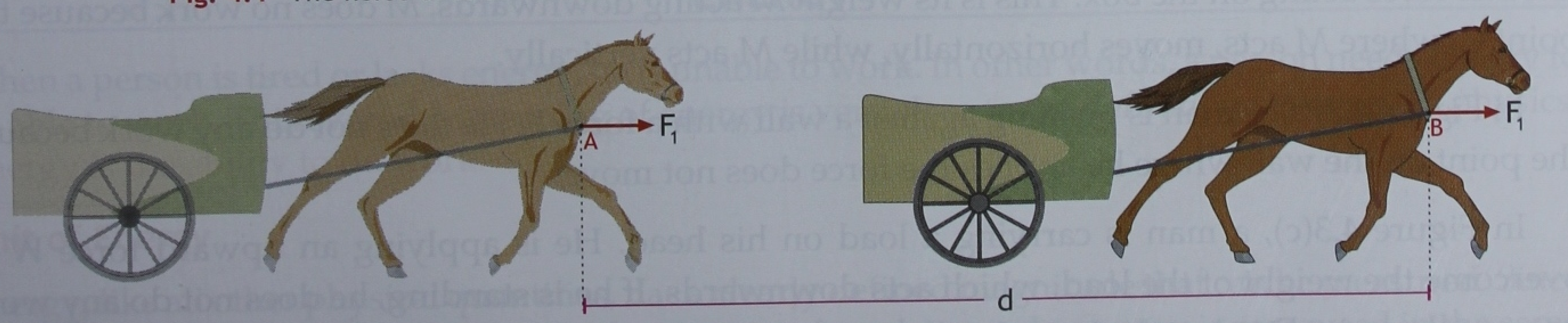
When we speak of 'work', we mean doing something. This 'doing' may have different descriptions or forms. You do your class work and homework, and know of people working (doing things) in offices, factories, and on farms.

In physics, however, work does not have different descriptions. It is a physical quantity that can be measured. Its magnitude can be expressed in terms of numbers and units. It has a precise definition. Work is done when the point of application of a force moves through some distance. To put it simply, work is done when a force acts on a body and moves the body through some distance.

Let us try to understand this with the help of an example. Figure 4.1 shows a cart being drawn by a horse. The horse applies a force F_1 at the point A. As the cart moves, this point (of application of F_1) moves to B. We say that the horse has done some work.

To take another example, the child in Figure 4.2 applies an upward force F_2 on the handle of the bucket. As the bucket moves up, this point on the handle moves up. This means the child does some work, or rather the force applied by the child on the handle does some work.

Fig. 4.1 The horse does some work because the point where it applies force moves from A to B.



Amount of Work

Since work is a physical quantity, it must have a clearly defined magnitude. The work done by a force is equal to the product of the force and the displacement of its point of application in the direction of the force.

This can be expressed as

$$\text{work} = \text{force} \times \text{distance}$$

We can also use symbols to write it as

$$W = F \times d$$

where F is a force, d is the displacement of its point of application in the direction of F and W is the work done.

In Figure 4.1

force = F_1, displacement = d.

$\therefore$ work done = $F_1 \times d$.

In Figure 4.2

force = F_2, displacement = h.

$\therefore$ work done = $F_2 \times h$.

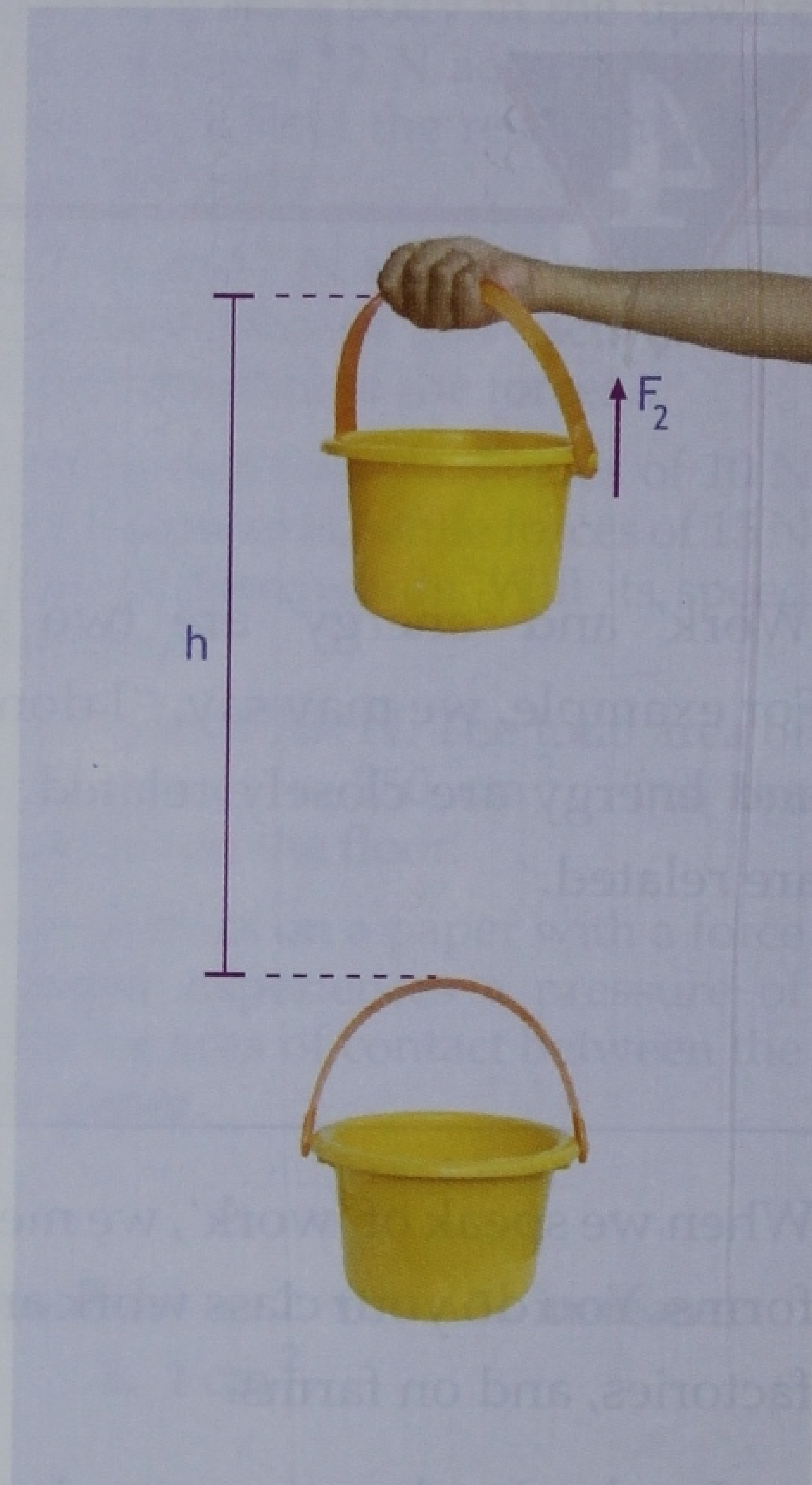


Fig. 4.2 A child does some work when he picks up a bucket.

To find the amount of work done by a force you must consider whether

1. the point of application of the force is displaced, and
2. the displacement is in the direction of the force.

No work is done if there is no displacement or if the displacement is at right angles to the direction in which the force is applied. A few examples will make this clear.

In Figure 4.3(a), the man pushing the box towards the left is applying a horizontal force P to the left. This force moves the box through a distance d, so the work done by this force is $P \times d$. There is another force acting on the box. This is its weight M acting downwards. M does no work because the point C, where M acts, moves horizontally, while M acts vertically.

In Figure 4.3(b), a man is pushing against a wall with a force F. He does not do any work because the point on the wall where he applies the force does not move.

In Figure 4.3(c), a man is carrying a load on his head. He is applying an upward force W to overcome the weight of the load, which acts downwards. If he is standing, he does not do any work because the point D, where he is applying the force W, does not move. Even if he walks, he does not do any work on the load. This is because though D moves, its displacement is at right angles to W.

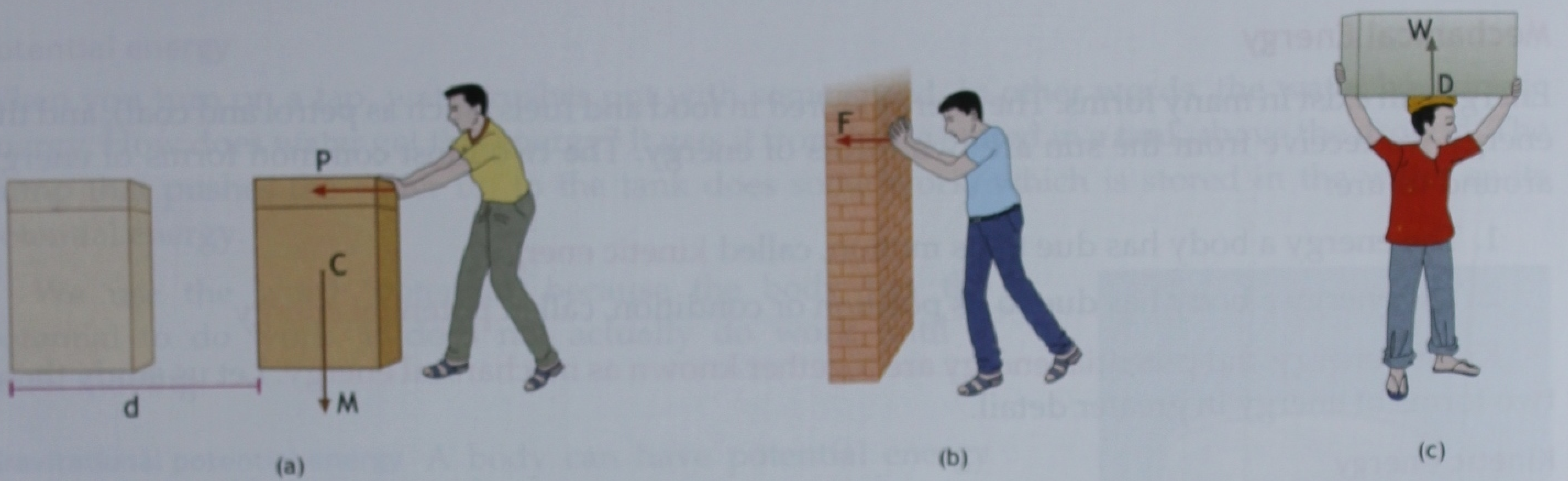


Fig. 4.3 The forces (a) *M*, (b) *F* and (c) *W* do not perform any work.

Unit of Work

Since work = force × distance,

the unit of work = the unit of force × the unit of distance

= newton × metre.

This unit of work is called the joule. Its symbol is J.

Thus, joule = newton × metre, or J = N × m or N m.

EXAMPLE 1. A man pushes a cart with a horizontal force of 20 N. How much work does he do in moving the cart through a distance of 50 m?

Work = force × distance. Here, force = 20 N, distance = 50 m.

∴ work = 20 N × 50 m = 1000 N m = 1000 J.

EXAMPLE 2. A boy has to apply an upward force of 4 N on a book to lift it from the floor to a desk. If he does 3 J of work in the process, what is the height of the desk?

Here, work = 3 J, force = 4 N.

Since work = force × distance,

distance = work ÷ force = 3 J ÷ 4 N = 0.75 m = 75 cm.

∴ the height of the desk = 75 cm.

ENERGY

When a person is tired or lacks energy, he is unable to work. In other words, a person needs energy to be able to work. This everyday meaning of energy is very close to the definition of energy in physics. Energy is the ability to do work.

Unit of Energy

Energy, like all other physical quantities, has a clearly defined magnitude that can be measured. Since the energy something has is defined as the amount of work it can do, energy is measured in the same unit as work, i.e., the joule (J).

Mechanical Energy

Energy can exist in many forms. The energy stored in food and fuels (such as petrol and coal), and the energy we receive from the sun are two forms of energy. The two most common forms of energy around us are:

1. The energy a body has due to its motion, called kinetic energy
2. The energy a body has due to its position or condition, called potential energy

Kinetic energy and potential energy are together known as mechanical energy. Let us study these two forms of energy in greater detail.

Kinetic energy

A moving body is capable of doing work. Suppose a box is resting on a floor. To move it, someone will have to apply some force. He will do some work as the point where he applies force moves along the floor. Now, if a heavy ball rolls along the ground and collides with the box, the box will move. Thus, the ball is able to do some work on the box because of its motion. Similarly, a moving striker is able to move counters on a carom board because of its motion.

Anything that has mass and is moving has some kinetic energy. This is true not only of solids, but of liquids and gases as well. The kinetic energy of moving air makes clothes and leaves flutter. It helps to move kites and sailing boats. Earlier, this energy was used to turn windmills.

Fig. 4.4 Windmills were earlier used to lift water and grind grain.

Water flowing down mountains can move rocks and wash away soil. The kinetic energy of flowing water was earlier used in watermills to grind grain and do other kinds of work. Now we use the energy of wind and water to generate electricity.

Amount of kinetic energy Common sense would tell you that all moving bodies do not have the same amount of energy. For instance, when you throw a stone into a pool, the size of the ripples it makes depends on how big the stone is and how hard you throw it. The bigger the stone, the greater will be its energy, and so, the bigger will be the ripples. Also, if you throw stones of the same size (same mass), the size of the ripples will depend on the speed with which each stone moves. This applies to the kinetic energy of any moving body. In general, the kinetic energy of a body depends on its mass and its speed. The actual relationship between these quantities is

$$\text{kinetic energy} = \frac{1}{2}\,\text{mass} \times (\text{speed})^2$$

This relation shows that

1. if two bodies move with the same speed, the one with greater mass has more kinetic energy, and
2. if two bodies have the same mass, the one moving faster has greater kinetic energy.

Potential energy

When you turn on a tap, water rushes out with some speed. In other words, the water has kinetic energy. How does water get this energy? It gets it from being stored in a tank above the ground. The pump that pushes the water up to the tank does some work, which is stored in the water as its potential energy.

We use the word 'potential' because the body has the potential to do work. It does not actually do work until it starts moving.

Fig. 4.5 Water stored in an overhead tank has potential energy.

Gravitational potential energy A body can have potential energy due to different reasons. The kind of potential energy that the water in a tank has is called gravitational potential energy. A body acquires gravitational potential energy when it is raised to some height above the ground. This is because work has to be done against the pull of gravity to raise it. Since the force of gravity acting on a body depends on its mass, the greater the mass of a body, the more you have to work to raise it. Also, since work depends on the distance through which the point of application of a force moves, the higher you raise a body above the ground, the greater is its potential energy. So, the gravitational potential energy of a body depends on

1. its mass, and
2. its height above the ground.

Potential energy due to condition When the elastic band of a catapult is stretched and then released, it can make a stone move with quite some speed. The moving stone has kinetic energy, which it gets from the stretched band of the catapult. The band gets energy from the work you do on it when you stretch it. This work is stored in the band as potential energy. In other words, the band acquires potential energy due to the condition of being stretched from its normal state. Similarly, a spring can acquire potential energy when it is either stretched or compressed from its normal state. A toy pistol, for example, has a long spring inside its barrel. This gets compressed when a dart is pushed into the barrel. The compressed spring stores the work you do, while pushing the dart in, as potential energy. When the spring is released, this energy does the work of making the dart fly out with some speed.

Fig. 4.6 The elastic band of a catapult has potential energy when it is stretched.

Chemical Energy

The energy stored in matter which can become available for work through chemical processes is called chemical energy. The following examples will help you understand the meaning of this definition.

We need energy to walk, run, play, and so on. This energy comes from food, which is digested and stored in our cells. Food has chemical energy stored in it. We can use this energy only when the chemical process of respiration releases it.

The energy needed to move vehicles, trains, aeroplanes and ships comes from fuels like petrol, diesel, CNG (compressed natural gas), coal and kerosene. The energy needed for cooking comes from gas, kerosene, coal and wood. These fuels have chemical energy stored in them. The chemical process of burning releases the energy, which we can then use.

Fig. 4.7 We use the chemical energy stored in these.

Materials that explode when they are ignited or compressed are called explosives. Gunpowder, dynamite and the materials used in firecrackers are explosives. They store large amounts of chemical energy, which is released suddenly when they explode.

Torch cells and car batteries have chemicals that store chemical energy. This energy is released when the chemicals react or combine with each other. The process of chemicals combining with each other is called a chemical reaction. Respiration, combustion (burning) and explosions are chemical reactions.

Muscular energy

The contraction of various muscles in different parts of our body helps us to walk, push, pull, lift things, and so on. This is the reason why we often refer to the energy we use to do manual or physical work as muscular energy. However, it would be more correct to call it chemical energy since muscles get their energy from food.

Electrical Energy

You must be familiar with the everyday uses of electrical energy, such as lighting, and running fans, coolers, TVs and gadgets in the kitchen. Telephones, electric trains, water pumps and industrial machines also run on electrical energy. The main advantages of using electrical energy are as follows.

1. It can be transported easily over large distances through electric wires.
2. It does not cause pollution, and is, therefore, a clean source of energy.
3. It can easily be converted into other forms of energy such as light and heat.

Fig. 4.8 Use of muscular energy

Fig. 4.9 Electricity can be transported easily.

Magnetic Energy

A magnet attracts iron objects near it. It can do this because it creates a magnetic field near it. This region has energy, called magnetic energy. You will learn later that electrical energy and magnetic energy are closely linked.

Heat Energy

Heat is a form of energy that can be produced in many different ways. It can be produced by burning a fuel, by an electrical heater, by rubbing or hammering, and so on. We use heat energy to do many things. We use the heat produced by burning fuels to cook and to drive vehicles. We use the heat produced by electrical heaters and geysers to keep ourselves warm and to heat water.

The earth gets a huge amount of heat energy from the sun every day. There would be no life on earth without this energy. This energy causes rain by evaporating water from the oceans, rivers, lakes, and so on. It also causes winds by heating the air. When the air above a place gets hot, it rises. Colder air from surrounding areas rushes in to take its place, and so there is a wind.

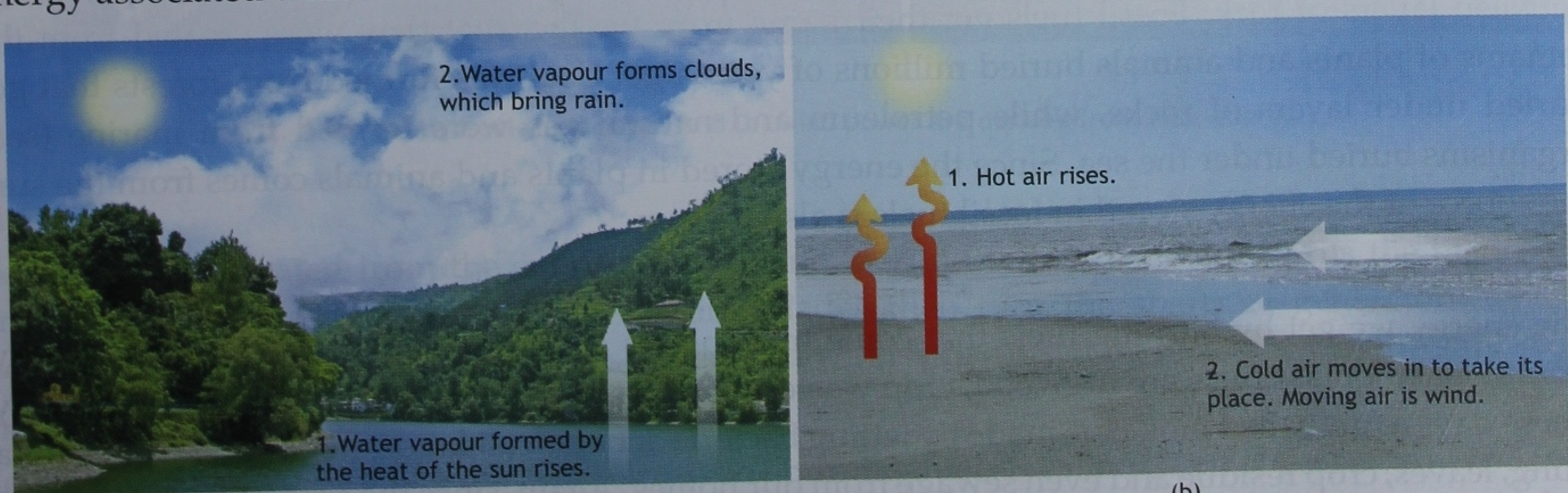
Light Energy

You are able to read this page and see the world around you with the help of light. Like heat, light is a form of energy. Light and heat are, in fact, closely related forms of energy. Quite often, a source of energy that emits light also gives out heat. For example, we get both light and heat from the sun, a table lamp or a burning candle.

Plants use the energy of sunlight to make food from water and carbon dioxide through the process of photosynthesis. The energy stored in this food sustains them and the animals that get food from them.

Sound Energy

When you speak, the voice box inside your throat vibrates. You can feel the vibrations. When someone plays a string instrument, the strings vibrate. If you touch the speaker of an audio system while it is playing, you will feel vibrations. Sound is produced by vibrating bodies. Since vibrating (moving) bodies have kinetic energy, sound must be a kind of energy. You can look at it another way. When you strike the top of a table with your palm, you hear a sound. The harder (more energetically) you strike the table, the louder is the sound. That means the loudness of a sound depends on the energy associated with it.



(a) (b)

Fig. 4.10 The heat energy of the sun causes (a) rain and (b) winds.

Energy Transformations

While discussing the various forms of energy, we have also talked about energy changing from one form to another. Let us look at some of these examples of the transformation of energy in greater detail.

1. Consider a piece of iron falling from some height onto a floor. Initially, it has potential energy. When it begins to fall, this changes into kinetic energy. When it hits the floor, the kinetic energy changes to heat and sound.
2. The running of a motor car involves many energy changes. First, the chemical energy of petrol changes to heat energy. The engine changes this heat to the kinetic energy of the vehicle. Some of the kinetic energy is converted to chemical energy and stored in the battery, while some of it is converted to light energy in the headlights and to sound energy by the horn.

ACTIVITY Make a list of the different ways in which electrical energy is used in your house. In each case, write down the form into which this energy is changed. Next, make a list of other forms of energy used in your house and in your neighbourhood.

Sources of Energy

We get the energy we need from different sources. Ultimately, however, most of the energy we use comes from the sun. Let us study our sources of energy one by one and see where the energy comes from.

Food

The energy our body needs to function comes from food. Food also gives our muscles the energy to do physical labour, such as pushing, pulling and lifting. The energy stored in food comes from the sun because plants manufacture food with the help of sunlight. Even the energy stored in the animal products we eat can be traced back to the sun's energy, since the animals get energy from the plants they eat.

Fossil fuels

We burn coal, natural gas and petroleum products, such as petrol, diesel and kerosene, to get energy. These things are together called fossil fuels. Fossils are the remains of plants and animals preserved between layers of rock. Fossil fuels get their name from the fact that they were created from the remains of plants and animals buried millions of years ago. Coal was formed from forests that got buried under layers of rocks, while petroleum and natural gas were formed from marine (sea) organisms buried under the sea. Since the energy stored in plants and animals comes from the sun, the source of the energy stored in fossil fuels is also the sun.

Energy from biomass

The energy we get by burning fuels that come from plants and animals is called biomass energy. Traditional biomass fuels are firewood, crop waste and cakes of animal dung that are burnt directly. These days a fuel called biogas is made by letting bacteria act upon all kinds of waste, such as animal dung, leaves, crop residue and even sewage from our homes. Again, since the energy stored in plants and animals comes from the sun, the source of biomass energy is ultimately the sun.

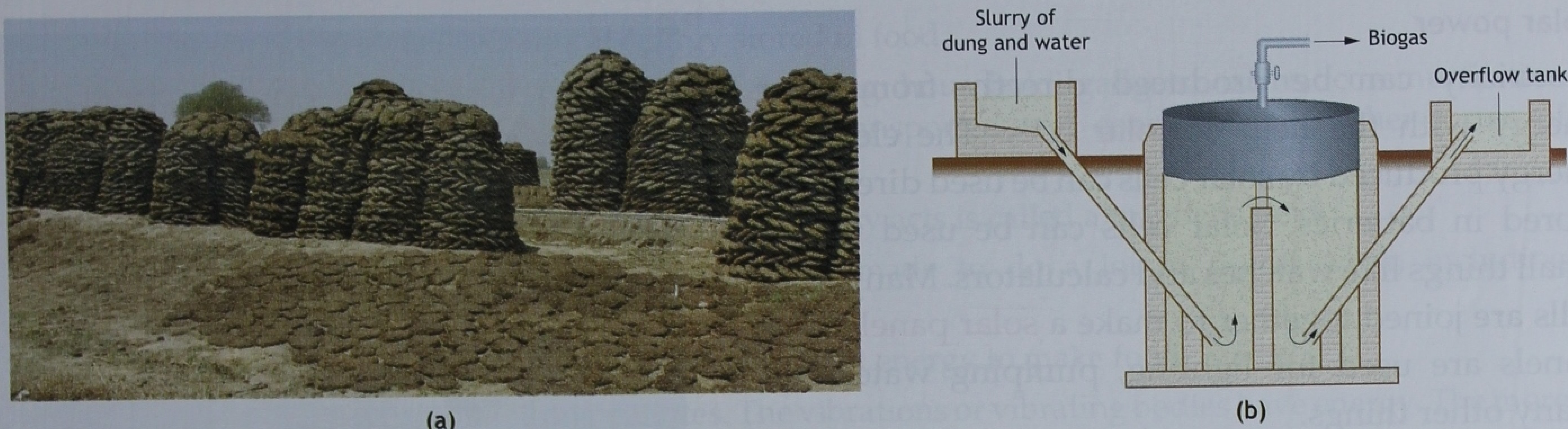


Fig. 4.11 Biomass (a) can be used directly or (b) it can be turned into biogas.

Hydroelectric power

While discussing the kinetic energy of flowing water, we said that this energy is used to produce electricity. Electricity produced this way is called hydroelectric power. In a hydroelectric power station, the water stored behind a dam has potential energy because of the height at which it is stored. This energy also comes from the sun. The sun's energy evaporates water and causes rain, which keeps renewing the supply of water behind the dam.

Fig. 4.12 (a) Hydroelectric power and (b) wind power are derived from solar energy.

Wind power

Electricity is generated from the energy of the wind in wind farms. The wind turns the blades of large fans set up in such farms. The rotating blades then turn the shafts of generators which produce electricity. We have already discussed that winds are caused by the energy of the sun.

Thermal power

Electricity generated by using the heat released by burning fuels is called thermal power. As we have already discussed, the chemical energy stored in fuels is derived from the energy of the sun. Thus, the source of thermal power is also the sun.

Solar power

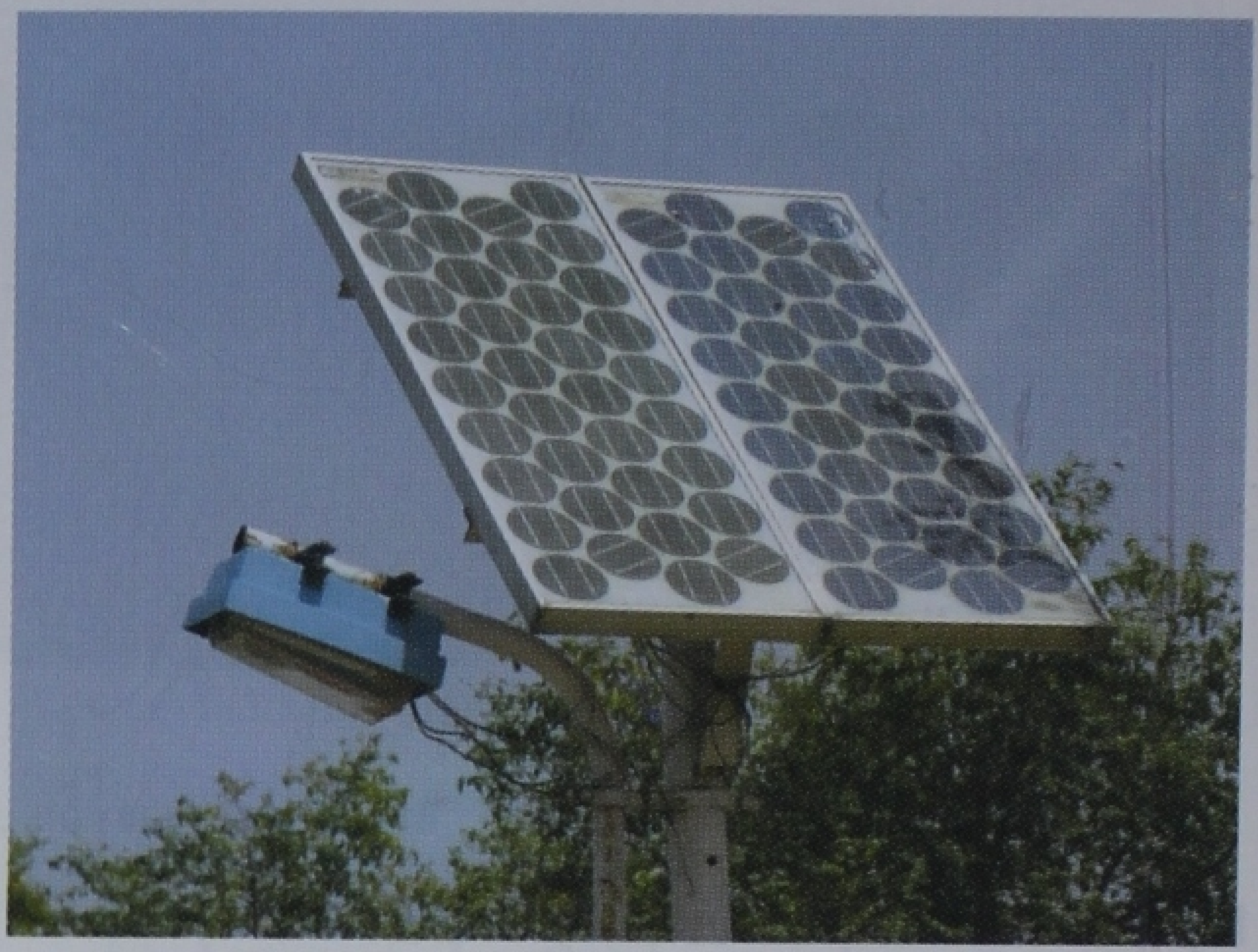


Fig. 4.13 Solar panels are used for lighting.

Electricity can be produced directly from solar energy with the help of solar cells. The electrical energy produced by solar cells can be used directly or stored in batteries. Solar cells can be used to run small things like watches and calculators. Many solar cells are joined together to make a solar panel. Solar panels are used for lighting, pumping water and many other things.

Solar energy (heat) can also be used for cooking and heating with the help of solar cookers and solar heaters.

WORK–ENERGY RELATIONSHIP

You have learnt earlier that energy is defined in terms of work, and that energy and work have the same unit, i.e., the joule. Work and energy are closely related, as you will see in the following examples. They can be converted into each other.

1. When we rub our hands, we do work against friction. Some of this work is converted into heat (energy), which warms our hands. We can look at it in another way. The chemical energy of food stored in our muscles gets converted to work when we rub our hands.
2. In an electric train, electrical energy gets converted into the work involved in moving the train.
3. When a body does some work, its energy decreases. Thus, when you do some work, the energy stored in your muscles decreases. That is why you feel tired.
4. When some work is done on a body, its energy increases. Thus, when you do the work of lifting something, its potential energy increases.

POINTS TO REMEMBER

- Work is done when the point of application of a force moves through a distance.
  Work = force × distance. The SI unit of work is the joule (J).
- Energy is the ability to do work. Its SI unit is the joule (J).
- The energy a body has due to its motion is called its kinetic energy. It depends on the mass of the body and its speed.
- The energy a body has due to its position or condition is called its potential energy. The gravitational potential energy of a body depends on its mass and its height above the ground.
- Chemical energy is the energy stored in matter which can become available for work through chemical processes, such as respiration and combustion (burning). Food, fuels, explosives and batteries have chemical energy.

- Muscular energy is actually chemical energy stored in food.
- Electrical energy is used for lighting, and running household gadgets, trains, communication systems and industries. It is clean, and can be transported and converted into other forms of energy conveniently.
- The region around a magnet in which magnetic energy acts is called a magnetic field.
- Heat energy produced by burning fuels can be made to do a lot of useful work, including generating electricity.
- Light energy is related to heat energy. Plants use light energy to make food.
- Sound is produced when something vibrates. The vibrations or vibrating bodies have energy. The more energetic the vibrations, the louder is the sound produced by them.
- Energy can change from one form to another.
- The energy of almost all our energy sources is derived from the sun.
- Work and energy can be converted into each other.

EXERCISE

Short-Answer Questions

1. When is work done by a force?
2. A man pushing against a wall does not do any work. Explain briefly.
3. Name two things which store chemical energy.
4. Name any five different forms of energy other than mechanical energy.
5. Where did the chemical energy stored in coal and petroleum come from?

Long-Answer Questions

1. No work is done by a force when its point of application moves in a direction at right angles to it. Explain with an example.
2. What is potential energy? In what ways can a body acquire potential energy? Give one example to show how potential energy can be converted to kinetic energy.
3. What is kinetic energy? What does the kinetic energy of a body depend on? Give one example to illustrate how kinetic energy can be utilised to do useful work.
4. What is chemical energy? Give one example each to show how it can be converted to work, heat energy and mechanical energy.
5. Explain the statement that almost all the energy that we use is ultimately derived from the sun.
6. Give one example each of solar energy being converted to electrical energy directly and indirectly.
7. Describe the ways in which plants help us make use of solar energy.

Objective Questions

Choose the correct option.

1. Which of the following has both kinetic energy and potential energy?
   (a) A flying bird
   (b) A bent bow about to shoot an arrow
   (c) An athlete running at full speed
   (d) None of the above
2. In which of the following situations is no work done?
   (a) A boy pulls the bands of a catapult
   (b) A man climbs up a ladder
   (c) A box slides on a smooth floor
   (d) A flower vase falls from a balcony onto the ground below
3. Which of the following does not store any chemical energy?
   (a) A torch cell
   (b) A stretched spring
   (c) A firecracker
   (d) A potato
4. Which of the following is not a fossil fuel?
   (a) Kerosene (b) Natural gas
   (c) Coal (d) Wood

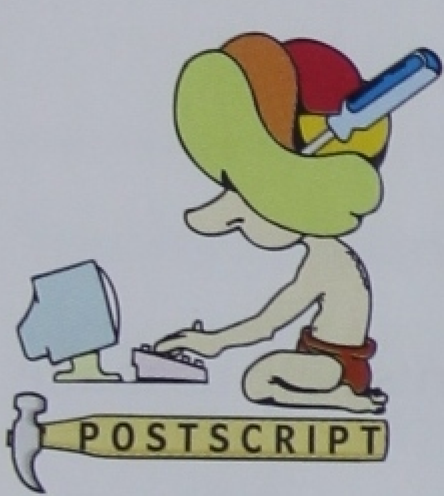
5. In which of the following does the evaporation of water play an important role?
   (a) Thermal power
   (b) Hydroelectric power
   (c) Solar power
   (d) Wind power

Fill in the blanks.

1. Light energy from the sun can be converted directly into electrical energy by a ....
2. Our body makes use of the chemical energy of food through the process of ....
3. Plants absorb ...... energy to make food.
4. Sound is produced when something ....
5. The SI unit of work and energy is the ....

Write true or false.

1. The kinetic energy of a body depends on its height above the ground.
2. When a body does some work, its energy decreases.
3. The energy produced in wind farms is not derived from the sun.
4. Heat is produced whenever work is done against friction.
5. Muscular energy is a form of chemical energy.



Nuclear energy and geothermal energy are the only sources of energy that are not derived from the sun. Nuclear energy comes from the atoms of matter. Geothermal energy comes from the heat energy stored inside the earth (geo: related to the earth; thermal: related to heat).

You know that there is a layer of molten rocks, or magma, inside the earth, which comes out as lava during volcanic eruptions. When groundwater reaches a layer of rocks heated by the molten magma below, it starts boiling. Sometimes the boiling water and steam rush out through a crack in the rocks to form a geyser. And sometimes hot water bubbles out more gently in the form of a hot spring.

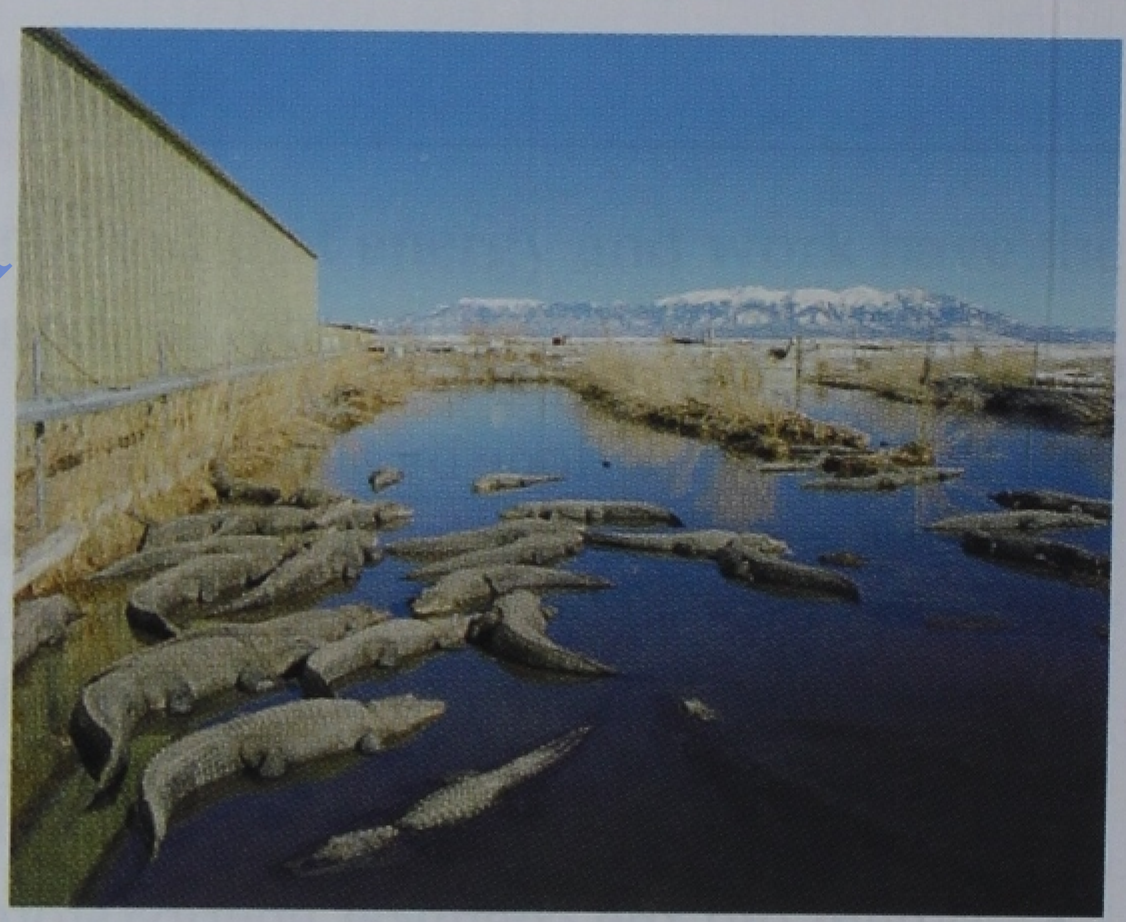


Fig. 4.14 A breeding centre for alligators in Colorado, USA, uses water from a hot spring to keep the animals warm.

The heat energy of hot springs and geysers can be used in many ways. At Yamunotri, near the source of the Yamuna, for example, pilgrims cook rice in the boiling water of hot springs. In the USA, New Zealand and Iceland geothermal energy is being used to provide heating and generate electricity.

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