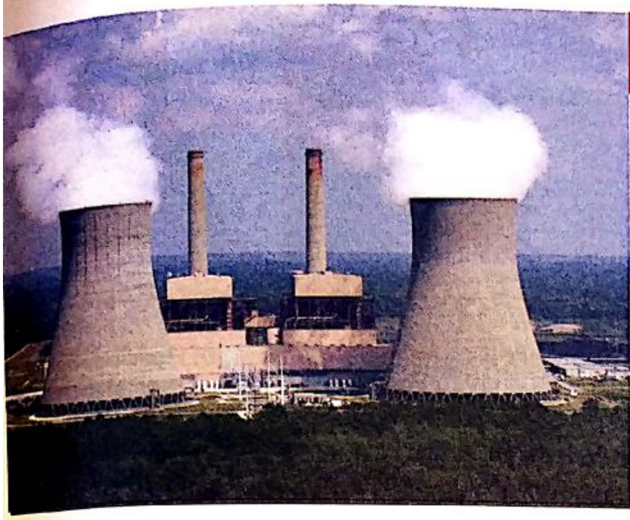


4

Energy

Theme : Building on previous learning on energy, the emphasis in this class is on the introduction of gravitational potential energy to children. Look at a swinging bob of a pendulum. When it is at its extreme position (the highest point of its motion), it has gravitational potential energy. When it reaches its mean position (lowest point), it has maximum speed and it has high kinetic energy. In this case, one form of energy changes into other, according to the law of conservation of energy. Energy is the ability to do work. Work is said to be done when a force acting on an object changes the position of the object. For the special case when the object changes its position along the direction of the force, work is given by the product of the force and distance moved by the object. But different persons may take different time to do the same work. Rate of doing work is called power. So energy and power are two different physical quantities, having different units. In many situations, the focus is on the power and not energy. For e.g. the power of a motor which works is paid for the electricity consumed, is actually paid for the energy consumed.

In this chapter you will learn to

- define work;
- express work in proper unit;
- calculate work done in simple cases;
- define kinetic energy;
- express kinetic energy in proper units;
- solve simple problems based on kinetic energy;
- define potential energy;
- define gravitational potential energy;
- solve simple problems based on gravitational potential energy;
- describe energy transformation in daily life situation;
- distinguish between energy and power;
- plan an experimental investigation or demonstration using scientific processes;
- identify /select on the basis of attributes.

LEARNING OBJECTIVES

- Revising previous concepts learnt by children.
- Building on children's previous learning.
- Explaining concept of work done with examples from daily life.
- Calculating work done in simple cases and expressing result in proper unit.
- Explaining of kinetic energy and potential energy.
- Explaining of gravitational potential energy.
- Solving of problems on kinetic and potential energy.
- Demonstrating kinetic and potential energy using a simple pendulum.
- Engaging children in problem solving tasks on KE and PE.

- Explaining and discussing with children energy transformation in daily life situations / activities.
- Explaining the difference between energy and power.
- Citing examples of different applications of conservation of energy (Roller coaster, Production of hydroelectricity etc.) with children making energy conversion diagrams and deduce that energy is conserved.

KNOWING CONCEPTS

- Concept of work.
- Unit of work (joule).
- Calculation of Work done in simple cases.
- Kinetic energy.
- Basic concept.
- Potential energy.
- Basic concept.
- Gravitational potential energy.
- Calculation of kinetic and potential energies from a set of given data (simple problems and assuming $g = 10\ m/s^2$).
- Energy transformation in common daily life situations.
- Difference between energy and power.

WORK

In everyday life, all of us do some work. We do work when we play, when we go to school, when we go upstairs, when we pedal a bicycle, when we lift a load and so on.

In common language, we use the word work much casually. *For example*, if we push a wall, we say that work is done by us. While reading a book, we say that we are working. But actually no work is done in these activities (Fig. 4.1).

(a) No work is done in case of pushing a wall

(b) Reading is a kind of mental work; no work is done

Fig. 4.1 Examples when no work is done

In Physics, the word work has a special meaning. Work is said to be done only when a body changes its position or moves on applying a force on it. No work is said to be done, if there is no motion produced in the body even when a force acts on it. Thus,

Work is said to be done if the force applied on a body moves it. If no motion takes place, no work is said to be done.

For example, a cyclist pedalling a cycle does work, a horse pulling a cart does work, an engine pulling a train does work, a coolie lifting a box does work, a boy going upstairs does work, a boy lifting a book does work (Fig. 4.2).

Fig. 4.2 A boy lifting a book, does work

When a crane picks up a car involved in an accident and takes it to a workshop, we say that work is done.

In a school playground, while playing football, when a boy hits the ball and runs towards the goal, we say that work is done.

A boy climbing up stairs, does work (Fig. 4.3).

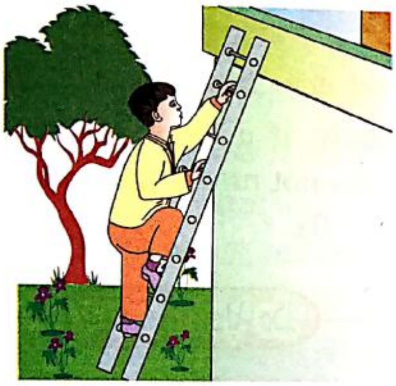
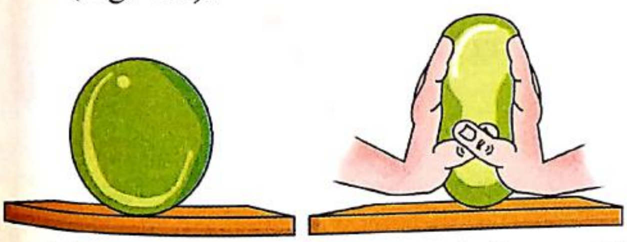


Fig. 4.3 Work is being done when a boy is climbing the stairs

Work is also done by a force if the force applied on a body changes its size or shape.

For example, if a boy squeezes a toothpaste tube or gum tube or a rubber ball, he does work in changing the shape of the tube or ball (Fig. 4.4).



(a) Rubber ball (b) Rubber ball squeezed

Fig. 4.4 Work is done in changing the shape and size of a ball

Similarly, a boy does work in stretching a rubber string in which size of the string increases.

A person does no work if there is no change in position or no motion even after application of force. *For example*, a boy pushing a car or a heavy stone does no work if the car or stone does not move (Fig. 4.5), although he may get tired.

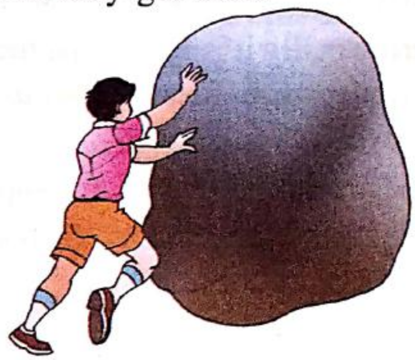


Fig. 4.5 A boy pushing a heavy stone does no work if the stone does not move

A person pushing against a wall also does no work since he is not able to move the wall, Similarly, a coolie does no work while standing with a heavy box on his head, as there is no motion, although he may get tired holding it (Fig. 4.6). But the coolie does work when he raises the heavy box to his head.

Fig. 4.6 A coolie standing with a box on his head, does no work

Thus, following two conditions must be fulfilled for work to be done :

(1) A force must act on the body.

(2) The force must produce change in position *i.e.*, motion or produce change in size or shape of the body.

Factors affecting the amount of work done

Experimentally it is found that the amount of work done by a force depends on the following two factors :

(1) The magnitude of the force applied, and

(2) The distance moved by the body in the direction of force.

(1) Dependence of the amount of work done on the magnitude of the force applied on the body : Work done is more if the force applied to move the body is more.

Example : More work is done by us if we lift a bucket full of water from the ground floor to the first floor than if we lift an empty bucket to the same height. The reason is that we have to apply a greater force to lift the bucket full of water than to lift the empty bucket.

(2) Dependence of the amount of work done on the distance moved by the body in the direction of force : Work done is more if the distance moved by the body in the direction of force is more.

Example : More work is done by us if we lift a bucket of water from the ground floor to the second floor than if we lift the same bucket from the ground floor to the first floor.

DEFINITION OF WORK

We define the work done as follows :

The work done by a force on a body is equal to the product of the force applied and the distance moved by the body in the direction of force i.e.,

Work done = Force × distance moved in the direction of force.

In Fig. 4.7, let a force F be applied on a body which moves it from the position A to the position B by a distance d in the direction of force, then the work done by the force on the body is

$$W = F \times d$$

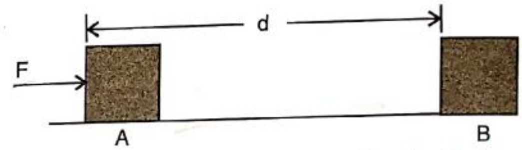


Fig. 4.7 Work done in motion of a body by a force

Obviously, if a force acts on a body and the body does not move, no work is done (*i.e.*, W = 0 if d = 0).

Do You Know ?

The work done by a force is zero if the body moves in a direction perpendicular to the direction of force. *For example*, when a stone tied at the end of a string is whirled in a horizontal circular path, the motion of stone is always normal to the force of tension in the string as shown in Fig. 4.8. Therefore, the work done by the force of tension on the stone is zero.

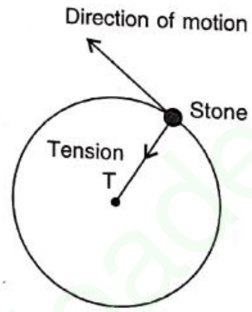


Fig. 4.8 No work is done by the force of tension on the stone

Similarly, in motion of earth around the sun, the force of attraction on earth by the sun is always normal to the direction of motion of earth, so no work is done by the gravitational force of sun on the earth.

Similarly, if a coolie moves on a plane road with luggage on his head, the work done by him against the force of gravity (*i.e.*, weight) is zero. Since, distance moved by him is normal to his weight.

Units of work

(1) We have read that the S.I. unit of force is newton (N) and that of distance is metre (m). Hence, S.I. unit of work is newton × metre (N m) or joule (symbol J). The unit joule has been named after the name of the scientist James Prescott Joule.

Definition of joule : Since,

$$1 \text{ joule} = 1 \text{ newton} \times 1 \text{ metre}$$

or $$1 \text{ J} = 1 \text{ N} \times 1 \text{ m}$$

i.e., one newton × metre is called one joule.

Thus, *one joule of work is said to be done if one newton force when acting on a body moves it by 1 metre in the direction of force.*

A bigger unit of work is kilo joule (symbol kJ) and Mega joule (symbol MJ)

$$1 \text{ kJ} = 1000 \text{ J and } 1 \text{ MJ} = 10^6 \text{ J}$$

(2) If we measure the force in kgf and the distance in metre, the unit of work is kgf × m.

Since, $1 \text{ kgf} = 9{\cdot}8$ newton (precisely),

$$1 \text{ kgf} \times \text{m} = 9{\cdot}8 \text{ newton} \times \text{metre}$$
$$= 9{\cdot}8 \text{ joule.}$$

(Assuming that the force of gravity on a mass of 1 kg is 9·8 N).

In chapter 3, you have learnt that the unit of moment of force is newton × metre (symbol N m). But it is not written as joule (J). Only for work and energy, the product, newton × metre is written as joule. This is to distinguish moment of force from the work or energy.

ENERGY

When work is done on a body, its energy increases. In other words, the work done on the body is stored in it in the form of energy. But if work is done by the body, its energy decreases. In other words, energy is spent when a body does work.

For example, a boy while playing football runs all over the field and he spends energy in doing work [Fig. 4.9]. He will continue to play football till he possesses energy.

A boy playing with football

Fig. 4.9 Energy is spent in doing work

Thus, we can define energy as follows :

Energy is the capacity of doing work.

Relationship between work and energy : It is experienced that more you run on a bicycle or more you run all around the playground, more you feel tired. The reason is that a lot of energy is spent in doing work by you. Thus, to do more amount of work, we need to spend more energy. Hence, we can say that there is a direct relationship between work and energy.

Similarly, *the work done on a body in changing its state is said to be the energy possessed by the body.*

For example, if a body is moved from the ground to a height, work is done on the body against the force of gravity and the body at the height is said to possess energy. Similarly, if a body initially at rest is made to move, work is done on the body and the body in motion is said to possess energy equal to the work done on the body.

UNIT OF ENERGY

Energy is measured in the same unit as work. Therefore the S.I. unit of energy is joule (symbol J).

A body is said to possess an energy of one joule if it can do one joule work or if one joule work is done on it.

MECHANICAL ENERGY

The energy possessed by a body due to its state of rest or state of motion, is called ***mechanical energy***. Mechanical energy is found in two forms :

(1) Potential energy, and

(2) Kinetic energy.

The total mechanical energy of a body is the sum of its potential and the kinetic energies. In Fig. 4.10, a car in motion, an arrow on a stretched bow, moving arms of a clock, a rock on a high hill, a swinging pendulum etc., all have mechanical energy.

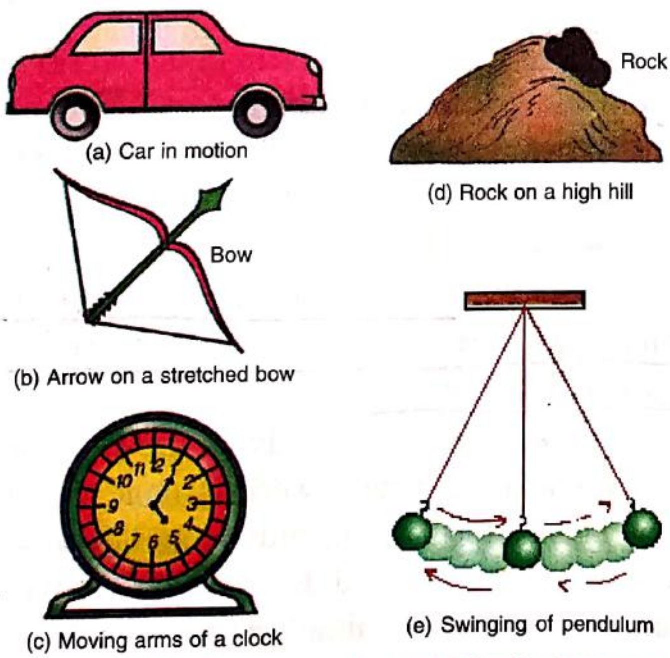


Fig. 4.10 Bodies possessing mechanical energy

(1) Potential Energy (symbol P.E. or U):

Potential is a Latin word which means 'to be able'. *The energy possessed by a body due to its state of rest or position is called* ***potential energy***. This is the energy stored in the body when work has been done by a force in bringing the body to that state of rest or position (*i.e.*, the work done on the body has been stored in it in form of potential energy). *For example*, a stretched bow has potential energy stored in it which is equal to the amount of work done in stretching the bow. When a spring is compressed, the work done in compressing the spring is stored in the spring in the form of its potential energy and the compressed spring is said to possess potential energy. The energy of a stretched bow or compressed spring is also called elastic potential energy.

Similarly, when a body is taken from the earth surface to a height, work has to be done on the body against the force of gravity on it. This work done is stored in the body in form of its potential energy. This energy is also called **gravitational potential energy**. Thus the water stored in a dam has gravitational potential energy. A rock lying on top of a high hill has potential energy.

In Fig. 4.11(a), a boy does work in bending the branch of a tree. This work is stored in the branch of tree in form of potential energy. In Fig. 4.11(b), when the boy leaves the branch, it goes back. The work needed for the return of branch of tree is now obtained from the potential energy stored in the branch. When it was bent by the boy.

(a) Boy does work in bending the branch which is stored as potential energy

(b) The branch goes back for which work is obtained from the potential energy

Fig. 4.11 Potential energy

SOME OTHER EXAMPLES OF POTENTIAL ENERGY

(1) A wound up watch spring has potential energy because of wound up state of its coils. As the spring unwinds itself, it does work to move the arms of the watch.

(2) In Fig. 4.12, a compressed spring has potential energy because of its compressed state. If a ball is placed on a compressed spring [Fig. 4.12(a)] and the spring is released, the ball flies away as shown in Fig. 4.12(b). Thus, the spring does work on the ball to make it move.

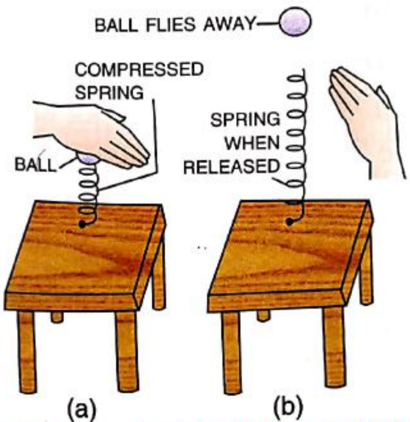


Fig. 4.12 A compressed spring has potential energy

Actually when a spring is compressed (or wound), some work is done on the spring which is stored in it in the form of potential energy.

(3) A stretched rubber band has potential energy. It does work in restoring itself to its original state. In Fig. 4.13, a pebble placed on the stretched rubber catapult, is thrown away when it is released to restore its original state.

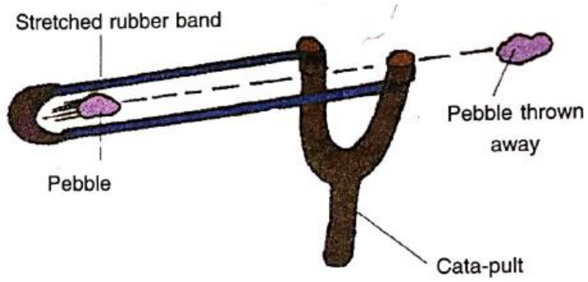


Fig. 4.13 A stretched rubber catapult has the potential energy

In stretching a rubber band, work is done. This work is stored in the rubber band in form of potential energy. This potential energy does work in moving the pebble.

(4) A stone placed at a height has potential energy stored in it. The stone has this energy because of its position at a height. In Fig. 4.14(a), the stone is dropped on a nail fixed on a piece of wood. It drives the nail into the wood as shown in Fig. 4.14(b) due to its potential energy.

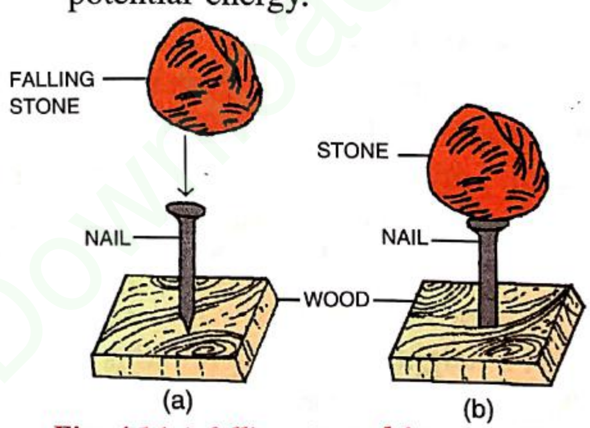


Fig. 4.14 A falling stone drives a nail into the wood

(5) In Fig. 4.15, a falling stone when reaches a pan attached at one end of a pulley, lifts up a weight at its other end because of its potential energy.

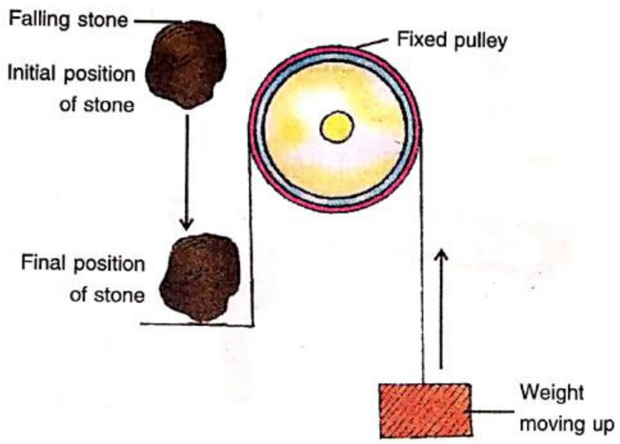


Fig. 4.15 A falling stone lifts a weight up

(6) Water at a height has potential energy stored in it. Thus, falling water from a height can be used to do work like turning a wheel.

Do You Know ?

The potential energy is of two forms: (i) Elastic potential energy, when the work done on the body changes its size or shape (ii) gravitational potential energy, when the work is done to move a body to a height above the earth surface.

EXPRESSION FOR THE GRAVITATIONAL POTENTIAL ENERGY

When a stone (or water) is lifted from the ground to a height, work is done against the force of gravity. This work is stored in the stone (or water) in form of gravitational potential energy.

The gravitational potential energy of a body at a height above the ground is measured by the amount of work done in moving it up to that height against the force of gravity acting on the body.

Let a body of mass m kg be moved from the ground to a height of h m. The minimum upward force required to move the body will be the force of gravity on the body acting vertically downward. If g is the force of gravity on a mass of 1 kg, the force of gravity on mass m kg will be mg N.

Force needed $F = mg$ N

Distance moved $d = h$ m

Work done $W =$ force × distance moved

$= mg \times h$ Joule

This work done against the force of gravity, is stored in the body at height h in form of its gravitational potential energy.

Gravitational potential energy,

$$P.E \text{ (or } U) = mgh$$

The S.I. unit of potential energy is joule (symbol J).

Thus, the potential energy of a body in the raised position depends upon the following two factors :

(i) The mass of the body.

Greater the mass of the body, greater is the potential energy of the body.

Example : The potential energy of a bucket of water of mass 20 kg at the first floor of house is more (double) than the potential energy of the bucket of water of mass 10 kg at the same floor.

(ii) Its height above the ground.

Higher the height of the body, greater is its potential energy.

Example : The potential energy of a bucket of water of mass 10 kg at the second floor of house at height 6 m is more (double) than the potential energy of the same bucket of water of mass 10 kg at the first floor at height 3 m.

Kinetic energy (Symbol K.E. or K)

The energy of a body in motion is called its kinetic energy. It is defined as follows :

Kinetic energy of a body is the energy possessed by it due to its state of motion.

Examples : (1) Fig. 4.16, shows that a fast moving stone has the capacity of breaking a window pane when it strikes the pane. Thus, the fast moving stone has kinetic energy.

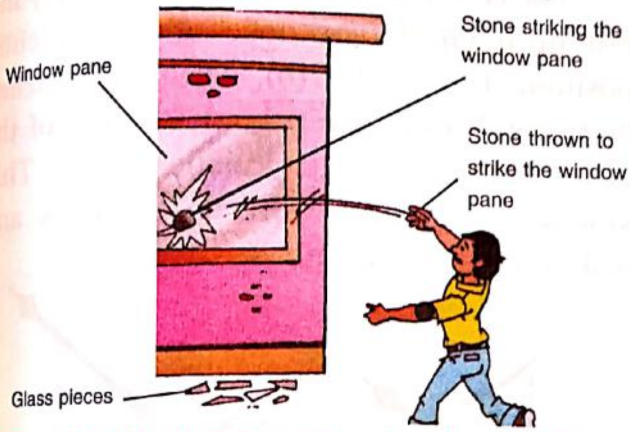


Fig. 4.16 A fast moving stone breaks a window pane due to its kinetic energy

(2) A falling hammer (*i.e.*, a hammer in motion) when strikes a nail fixed on a wooden block, moves it further down into the block. Thus the moving hammer has kinetic energy and it does work on the nail.

(3) A bullet fired from a gun, a rolling ball, an apple falling from a tree, blowing wind, flowing water, swinging pendulum, flying bird etc. all have kinetic energy.

If a body initially at rest is made to move, work is done on the body and the body in motion is said to possess kinetic energy. The kinetic energy of the body will be equal to the work done on the body.

Factors affecting the kinetic energy of a moving body :

The kinetic energy of a moving body depends the following two factors :

(i) The mass of the body.

Greater the mass of the body, higher is its kinetic energy.

Example : The kinetic energy of a body of mass 10 kg moving with some speed is more (or double) the kinetic energy of another body of mass 5 kg moving with the same speed.

(ii) The speed of the body.

More the speed of the body, higher is its kinetic energy.

Example : If a boy increases his speed of motion from 2 m s^{-1} to 4 m s^{-1}, his kinetic energy will increase to four times the initial kinetic energy.

Expression for the kinetic energy

If a body of mass m is moving with a speed v, its kinetic energy is given as

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

The unit of kinetic energy is joule (J).

The dependence of kinetic energy on speed can be demonstrated by the following activities.

ACTIVITY 1

Take a carrom board. Place all the coins in the middle of the board. Hit the coins by a striker. You will notice that more the effort applied to push the striker, more is the gain in kinetic energy of the striker. More the kinetic energy of the striker hitting the coins, longer is the distance covered by the moving coins.

ACTIVITY 2

While watching a cricket match, observe that when a batsman hits the ball with a little effort, the ball goes to a less distance while when he hits the ball hard, the ball goes to a large distance to fetch him four or six runs.

Difference between potential energy and kinetic energy

Potential energy	Kinetic energy
1. It is the energy possessed by a body due to its state of rest or position.	1. It is the energy possessed by a body due to its state of motion.
2. It is the work done on the body to bring it to that state of rest or position.	2. It is equal to the work done in moving the body initially from rest.
3. It can change only in form of kinetic energy.	3. It can change in any form of energy (potential energy, heat energy, light energy etc).

CONVERSION OF POTENTIAL ENERGY INTO THE KINETIC ENERGY

The potential energy changes into kinetic energy when it is put to use. In absence of friction, the sum of potential energy and kinetic enrgy remains constant at each instant. This is called the *law of conservation of mechanical energy.*

Examples : (1) A stone at a height has the potential energy due to its lifted or raised position. In Fig. 4.14, when the stone is dropped from that position, it begins to fall. The falling stone has the kinetic energy. Thus, the potential energy stored in the stone in its raised position changes into kinetic energy when the stone is falling. This kinetic energy does work on the nail as the stone strikes the nail and makes the nail to move into the wood.

(2) In Fig. 4.15, the potential energy possessed by the stone at a height changes into its kinetic energy when it falls. The kinetic energy of the falling stone does work in raising the weight upwards.

(3) A wound up watch spring has the potential energy because of its wound up state. As the spring unwinds itself, the potential energy changes into kinetic energy. This kinetic energy does work in moving the arms of the watch.

(4) A stretched bow in Fig. 4.17(a) has potential energy because of its stretched position. In Fig. 4.17(b), when the stretched bow is released, the potential energy of the bow changes into its kinetic energy. This kinetic energy does work on the arrow and makes the arrow to move.

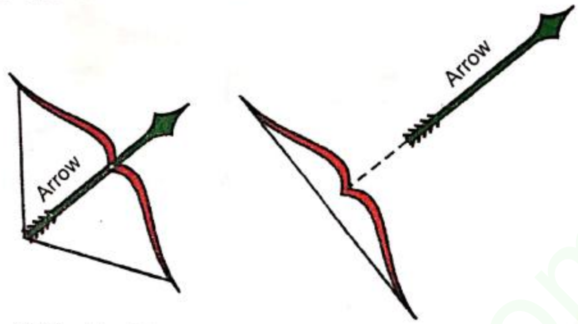


Fig. 4.17 Potential energy of a stretched bow changes into its kinetic energy

(5) A compressed spring in Fig. 4.12(a) has the potential energy in it due to its compressed state. In Fig. 4.12(b), when the compressed spring is released, the potential energy changes into its kinetic energy which does work on the ball placed on it and makes the ball to fly away.

(6) **Falling stone :** Consider a ball placed at a height. It will have only potential energy and no kinetic energy.

If the ball is released from the height, it falls down and the vertical height of the ball from the ground decreases. Therefore, the potential energy decreases and it changes to kinetic energy due to which the speed of ball increases. During the fall, the ball has both the potential energy and the kinetic energy. As the ball reaches the ground, the potential energy becomes zero and it changes entirely into kinetic energy.

Fig. 4.18 shows the conversion of potential energy into kinetic energy during the vertical free fall of a ball at various positions A, B and C.

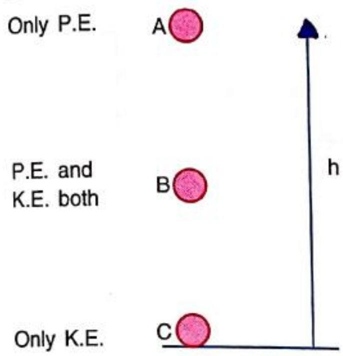


Fig. 4.18 Conversion of P.E. into K.E. during a vertical free fall

(7) **Production of hydroelectricity :** The water collected in a dam at a height has potential energy stored in it. When it is made to fall on a turbine, the potential energy changes to kinetic energy which is transferred to the turbine to rotate it (Fig. 4.19). By connecting the turbine to the armature of a dynamo, electricity (called the hydroelectricity) is produced.

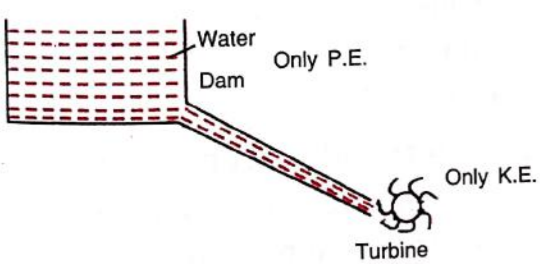


Fig. 4.19 Conversion of P.E. into K.E. of the water falling from a dam

(8) **Swinging pendulum :** Fig. 4.20 shows a simple pendulum suspended from a rigid support O. Its resting position is at A. When the bob of pendulum is slightly moved from A to B, its height increases, so at B, the bob has potential energy stored in it. On releasing the bob at B, it comes back to A during which the potential energy changes into kinetic energy. On reaching at A, whole of the potential energy changes into kinetic energy and due to this kinetic energy, the bob has the maximum speed with which it moves to the other side up to C, at the same vertical height h. In motion from A to C, kinetic energy changes into potential energy and at C, speed becomes zero. So it again returns to A. This motion continues.

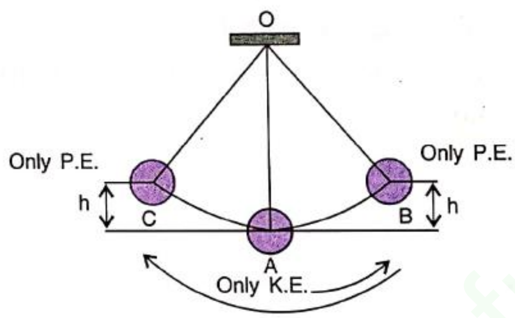


Fig. 4.20 Conversion of P.E. into K.E. in a swinging pendulum

Note : Here friction due to air has been neglected.

(9) **Roller coaster :** Fig. 4.21, the car on a roller coaster at position A has only potential energy (= E) and no kinetic energy. As the car comes to the positon B, whole of the potential energy changes into kinetic energy, so at B it has the kinetic enregy (= E) and no potential energy. Due to this kinetic energy, the car rises to the position C, during which the kinetic energy changes into potential energy and at C, it has the potential

energy (= E_1) and kinetic energy (= $E - E_1$). So the total sum of kinetic energy and potential energy is conserved. Note that the vertical height of C is less than that of A.

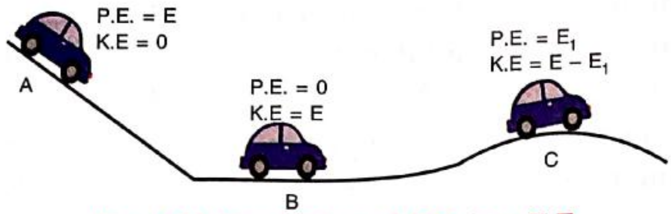


Fig. 4.21 Conversion of P.E. into K.E. in a roller coaster

ACTIVITY 3

Take a ping-pong ball. Release it from a height on a hard, smooth floor. You will observe that the ball after striking the floor bounces several times. Try to answer the following questions :

(a) What is the potential energy and kinetic energy when you release the ball ?

(b) Why does the ball bounce back after striking the floor ?

(c) From where does the ball get the kinetic energy for motion after striking the floor ?

(d) What happens to the energy of the ball when the ball stops bouncing ?

DIFFERENT FORMS OF ENERGY

Apart from mechanical energy, we have other forms of energy as well. These are solar energy, heat energy, light energy, sound energy, electrical energy, chemical energy, nuclear energy, etc. One form of energy can be converted into other useful forms of energy. Now we shall study some examples of transformation of one form of energy into other forms in our daily life.

SOME EXAMPLES OF TRANSFORMATION OF ENERGY

(1) Mechanical energy to electrical energy: The water stored in the reservoir of a dam has the potential energy. When water falls, its potential energy decreases and kinetic energy increases. If the falling water is made to rotate a turbine near the bottom of the dam, the kinetic energy of water is transferred to the turbine in the form of rotational kinetic energy due to which it rotates. The turbine rotates the armature of the generator connected to it and thus the kinetic energy gets transformed into the electrical energy by the generator.

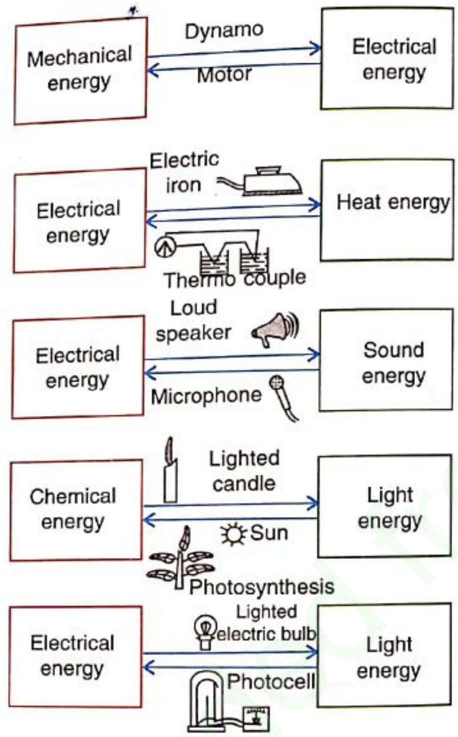


Fig. 4.22 Examples of energy conversion

Thus, an electric generator (or a dynamo) converts the mechanical energy into the electrical energy.

(2) Electrical energy to mechanical energy : In an electric motor, when an electric current is passed in a coil freely suspended (or pivoted) in a magnetic field, a torque acts on the coil due to which it rotates. The shaft attached to the coil also rotates with it. Thus, the electrical energy changes into mechanical energy.

The electric motor is used in many home appliances such as electric fan, washing machine, mixer, grinder, etc. It is also used to run industrial machines.

(3) **Electrical energy to heat energy :** In electric appliances such as heater, oven, geyser, toaster, etc. electrical energy changes into heat energy when a current passes through their resistance wire (or filament).

(4) **Electrical energy to sound energy :** A loudspeaker when in use, receives electrical energy in the form of electrical signals from the microphone and changes it into sound energy.

In an electric bell when an electric current is passed, the electrical energy changes into sound energy.

(5) **Sound energy to electrical energy :** A microphone converts the sound energy into electrical energy in form of varying electric signals.

(6) **Light energy to chemical energy :** The light energy from the sun is absorbed by the green plants and they change it in form of chemical energy during the process of photosynthesis.

(7) **Electrical energy to light energy :** When an electric bulb glows on passing an electric current through it, the electrical energy changes into heat and light energies.

(8) **Light energy to electrical energy :** In a photoelectric cell, the light energy gets converted into electrical energy.

In a solar cell, the light (or solar) energy changes into electrical energy.

(9) **Heat energy to mechanical energy :** In a steam engine, the chemical energy of coal first changes to heat energy of steam and then heat energy of steam changes into mechanical energy.

(10) **Mechanical energy to heat energy :** When water falls from a height, the potential energy stored in water at that height changes into kinetic energy of water during the fall. On striking the ground (or bottom), a part of the kinetic energy of water changes into heat energy due to which the temperature of water rises.

The moving parts of a machine get heated due to friction, thus a part of mechanical energy also changes into heat energy.

Do You Know ?

(1) Whenever mechanical energy changes to other forms, it is always in the form of kinetic energy and not in the form of potential energy i.e., the stored potential energy first changes to kinetic energy and then kinetic energy changes to the other form.

(2) While transformation of energy from one form to the other desired form, the entire energy does not change into the desired form, but a part of it changes either to some other undesirable form (usually heat due to friction) or a part is lost to the surroundings due to radiation which is not useful. This conversion of energy to the undesirable (or non-useful) form is called dissipation of energy. Since this part of energy is not available to us for any productive purpose, so we call this energy as the degraded form of energy.

POWER

The power of a body is defined as the rate of doing work by the body.

If a body performs a work W in time t, the power spent by the body is :

$$\text{Power} = \frac{\text{Work done by the body}}{\text{Time taken}}$$

$$\text{or} \quad P = \frac{W}{t}$$

Note : (1) The symbol P is also used to represent pressure. But pressure and power are different quantities.

(2) Different persons may take different time to do the same work.

Power and energy (or work done) are related to each other. If a source of power P is used for time t, the energy spent or work done is $P \times t$.

Thus, when a body does work or spends energy, we often come across the term 'power' spent by the body. All electrical appliances are rated with their power. When an appliance is in use, the electrical energy spent is given by the product of its power and time for which it has been used. We pay the cost for this electrical energy consumed.

For example, if we use an electrical motor of power 1·5 kW to lift water in the overhead tank. For 2 h the electrical energy spent is 1·5 k W × 2 h = 3 kWh for which the cost is paid to the electricity board and we say that the power spent by the pump is 1·5 kW. If we say 9 W LED is glowing, we mean to say that while glowing, LED consumes 9 J of energy per second.

Unit of Power

The S.I. unit of work is joule (symbol J) and the S.I. unit of time is second (symbol s), so the S.I. unit of power is $= \frac{\text{joule}}{\text{second}} = \text{J s}^{-1}$.

The unit joule per second has been named as watt (symbol W) after the name of the scientist James Prescott Watt.

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

The bigger units of power are kilowatt (kw) and megawatt (MW) where

$$1 \text{ kW} = 1000 \text{ W, and}$$

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

Do You Know ?

(1) In mechanical engineering, we often use horse power (symbol H.P.) as the unit of power. It is related to watt as

$$1 \text{ H.P.} = 746 \text{ W}$$

(2) kWh (kilowatt hour) is the unit of energy where

$$1 \text{ kWh} = 3{\cdot}6 \times 10^6 \text{ J}$$

Factors affecting the power of a source

The power spent by a source depends on two factors :

(1) The amount of work done by the source, and

(2) The time taken by the source to do the said work.

If a machine (or a person) does a given amount of work at a faster rate *i.e.* in less time, more power is spent by it (or him).

Example : If a coolie A takes 1 minute to lift a load to the roof of a bus, while another coolie B takes 2 minute to lift the same load to the roof of the same bus, the work done by both the coolies is the same, but the power spent by coolie A is twice the power spent by coolie B because coolie A does work at double the rate (*i.e.*, in half the time) the coolie B works.

Difference between work and power

Work	Power
1. Work done by a force is equal to the product of force and distance moved in the direction of force.	1. Power of a source is the rate of doing work by it (*i.e.*, work done in one second).
2. Work done does not depend on time.	2. Power spent depends on the time in which work is done.
3. S.I. unit of work is joule (J).	3. S.I. unit of power is watt (W).

Difference between energy and power

Energy	Power
1. Energy of a body is its capacity to do work.	1. Power of a source is the rate at which energy is supplied or work is done by it.
2. Energy spent does not depend on time.	2. Power depends on the time in which energy is spent.
3. S.I. unit of energy is joule (J).	3. S.I. unit of power is watt (W).

SOLVED EXAMPLES

1. A force of 200 N moves a body through a distance of 2 m in the direction of force. Calculate the work done by the force.

Solution : *Given*, F = 200 N, d = 2 m

Work done $W = F \times d$

or $W = 200\ N \times 2\ m = 400\ J$

2. A machine moves a load of 520 N by a distance 5·2 m vertically up. Calculate the work done by the machine.

Solution : *Given*, force needed F = load = 520 N,

Distance moved d = 5·2 m

Work done by the machine $W = F \times d$

$= 520\ N \times 5{\cdot}2\ m$

$= 2704\ J$

3. A coolie raises a box of mass 50 kg to a vertical height of 3 m. Calculate the work done by the coolie if force of gravity on 1 kg mass is 10 N.

Solution : *Given*, force $F = mg$

$= 50\ kg \times 10\ N\ kg^{-1}$

$= 500\ N$

$d = 3\ m$

Work done $W = F \times d$

$= 500\ N \times 3\ m = 1500\ J$

4. What is the potential energy of a stone of mass 10 kg that is lifted to a height of 8 m, if g = 10 N kg^{-1} ?

Solution : *Given, m* = 10 kg, *g* = 10 N kg^{-1}, *h* = 8 m

P.E. = mgh

$= 10\ kg \times 10\ N\ kg^{-1} \times 8\ m$

$= 100\ N \times 8\ m$

$= 800\ J$

5. A body of mass 5 kg is taken from a height of 3 m to 6 m. Find the increase in the potential energy of the body. Take *g* = 10 N kg^{-1}.

Solution : *Given*, m = 5 kg, h_1 = 3 m, h_2 = 6 m, g = 10 N kg^{-1}

Increase in potential energy

$= mgh_2 - mgh_1$

$= mg\ (h_2 - h_1)$

$= 5 \times 10 \times (6 - 3)\ J$

$= 150\ J$

6. A body of mass 4·0 kg falls from a height of 2·5 m. How much energy does it possess at any instant ? Take

$g = 10\ N\ kg^{-1}$.

Solution : *Given*, $m = 4{\cdot}0$ kg, $h = 2{\cdot}5$ m,

$g = 10\ N\ kg^{-1}$

The energy possessed by the body at any instant will be equal to the initial potential energy at height h which is

$$U = mgh$$
$$= 4{\cdot}0\ kg \times 10\ N\ kg^{-1} \times 2{\cdot}5\ m$$
$$= 100\ J$$

7. A vessel containing 50 kg of water is placed at a height of 10 m above the ground. What is the potential energy stored in water ? Take $g = 10\ N\ kg^{-1}$.

Solution : *Given*, $m = 50$ kg, $g = 10\ N\ kg^{-1}$,

$h = 10$ m

Potential energy $U = mgh$
$$= 50 \times 10 \times 10$$
$$= 5000\ J$$

8. The mass of a body is 20 kg. It is moving with a speed of $10\ m\ s^{-1}$. What is its kinetic energy ?

Solution : *Given*, mass (m) = 20 kg,

speed (v) = $10\ m\ s^{-1}$

$$K.E. = \frac{1}{2} mv^2$$
$$= \frac{1}{2} \times 20 \times (10)^2\ J$$
$$= 10 \times 100\ J = 1000\ J$$

9. A bullet of mass 40 g has its kinetic energy equal to 200 J. Find the speed of the bullet.

Solution : *Given*, K.E. = 200 J,

mass $m = 40\ g = \frac{40}{1000}\ kg = 0{\cdot}04\ kg$

From the relation $K.E. = \frac{1}{2} mv^2$,

$$\text{Speed } v = \sqrt{\frac{2\ K.E.}{m}} = 2 \times \sqrt{\frac{2 \times 200}{0{\cdot}04}}$$
$$= \sqrt{100 \times 100} = 100\ m\ s^{-1}.$$

10. Find the increase in kinetic energy of a body of mass 500 g, when its speed increases from $2\ m\ s^{-1}$ to $4\ m\ s^{-1}$.

Solution : *Given*, $m = 500\ g = \frac{500}{1000}\ kg = 0{\cdot}5\ kg$

$V_1 = 2\ m\ s^{-1}$, $V_2 = 4\ m\ s^{-1}$

Increase in kinetic energy

$$= \frac{1}{2} mv_2^2 - \frac{1}{2} mv_1^2$$
$$= \frac{1}{2} m (v_2^2 - v_1^2)$$
$$= \frac{1}{2} \times 0{\cdot}5 \times [(4)^2 - (2)^2]$$
$$= \frac{1}{2} \times 0{\cdot}5 \times 12 = 3\ J$$

11. A boy has to do 300 J of work in time 0·5 minute to lift a luggage to the roof of a bus. How much power does he spend ?

Solution : *Given*, W = 300 J,

$t = 0{\cdot}5\ min = 0{\cdot}5 \times 60\ s = 30\ s$

$$\text{Power } P = \frac{\text{Work } W}{\text{Time } t} = \frac{300\ J}{30\ s} = 10\ W$$

12. An electric heater of power 3 kW is used for 1 minute. Find the energy supplied by the heater.

Solution : *Given*, Power P = 3 kW = 3000 W,

time t = 1 minute = 60 s

From relation $P = \frac{W}{t}$

Energy supplied $W = P \times t$
$$= 3000\ W \times 60\ s$$
$$= 180000\ J$$

13. A pump is used to lift 100 kg of water from a well 60 m deep, in 20 s. If force of gravity on 1 kg is 10 N, find :

(a) work done by the pump

(b) potential energy stored in the water

(c) power spent by the pump

(d) power rating of the pump. State the assumption if any.

Solution : *Given*, m = 100 kg, g = 10 N kg^{-1}

h = 60 m, t = 20 s

(a) Work done by the pump

= force × distance moved

$= (100 \text{ kg} \times \frac{10 \text{ N}}{\text{kg}}) \times 60 \text{ m}$

= 60,000 J

(b) Potential energy stored in water

$= mgh = 100 \text{ kg} \times \frac{10 \text{ N}}{\text{kg}} \times 60 \text{ m}$

= 60000 J

(c) Power of the pump

$$P = \frac{W}{t} = \frac{60000 \text{ J}}{20 \text{ s}}$$

= 3000 W (or 3 kW)

(d) Power rating of the pump = 3 kW.

Assumption : The pump is 100% efficient.

RECAPITULATION

- Work is said to be done if the force applied on a body, moves it. If no motion takes place, no work is said to be done. Work done is zero if the motion of body is normal to the force.
- The amount of work done depends on : (1) the magnitude of the force applied (greater the force applied, greater is the work done), and (ii) the distance moved in the direction of force (greater the distance moved, greater is the work done).
- The work done by a force on a body is equal to the product of the force and the distance moved by the body in the direction of force, *i.e.*

  Work done = Force × Distance moved in the direction of force

  or $W = F \times d$
- The S.I. unit of work is joule (J), where

  1 joule (J) = 1 newton (N) × 1 metre (m).
- One joule of work is said to be done if one newton force when acts on a body, moves it by 1 metre in the direction of force.
- Other unit of work is kgf × m where 1 kgf × m = 9·8 joule (precisely).
- The energy of a body is its capacity (or ability) to do work. The energy of a body in a state is equal to the work done on the body to bring it to that state.
- The S.I. unit of energy is joule (J), whether it is potential energy or kinetic energy.
- Mechanical energy is of two kinds : potential energy and kinetic energy.
- Potential energy of a body is the energy possessed by it due to its state of rest or position. This is equal to the work done on the body to bring it to that state of rest or position.
- Potential energy can be : (i) elastic potential energy (*i.e.* the energy stored when the size or shape of a body is changed) and (ii) gravitational potential energy (*i.e.* the energy when a body is taken to a height above the ground).

- The gravitational potential energy of a body in the raised (or lifted) position depends on two factors : (1) the mass of the body (greater the mass of the body, greater is the potential energy of the body), and (ii) the height of the body above the ground (greater the height of the body, greater is its potential energy).

  It is given as P.E. (U) = mgh

  where g is the force of gravity on a mass of 1 kg. Its value is nearly 10 N kg^{-1}.
- Kinetic energy of a body is the energy possessed by it due to its motion.
- Kinetic energy of a moving body depends on two factors : (i) on the mass of the body (greater the mass of the body, greater is its kinetic energy), and (ii) on the speed of the body (more the speed of the body, higher is its kinetic energy).

  Kinetic energy K.E. (or K) = $\frac{1}{2}$ mv^2
- It is the kinetic energy which can change into any other form of energy such as heat, light etc. Potential energy does not directly change into any other form of energy except kinetic energy when it is put to use.
- The energy exists in different forms such as mechanical, heat, light, sound, electrical, chemical, solar, nuclear etc.
- One form of energy can be changed into other useful forms of energy.
- Power is defined as the rate of doing work or the energy spent in one second *i.e.* P = $\frac{W}{T}$ or energy spent = power × time.
- Power spent by a source depends upon time for which work is done. Power spent is more if same work is done in less time.
- The S.I. unit of power is joule per second (J s^{-1}) or watt (W).

TEST YOURSELF

A. Objective Questions :

1. Write **true** or **false** for each statement :

   (a) A coolie does no work against the force of gravity while carrying a luggage on a plane road.

   (b) The energy stored in water of a dam is kinetic energy.

   (c) The energy of a flying kite is kinetic energy.

   (d) Work done by a boy depends on the time in which he does work.

   (e) Power spent by a body depends on the time for which it does work.

   Ans. True—(a), (c), (e), **False**—(b), (d)

2. Fill in the blanks :

   (a) Work is said to be done by a force only when ....

   (b) Work done = Force × ....

   (c) The energy of a body is its capacity to do ...work.....

   (d) The S.I. unit of energy is ...Joule.....

   (e) The potential energy of a body is due to its ..position... and kinetic energy of body is due to its ...motion..

   (f) Gravitational potential energy U = mass × force of gravity on unit mass × ....

   (g) Kinetic energy = $\frac{1}{2}$ × mass × ...v^2.......

   (h) Power P = ...Work...... / time taken.

   (i) The S.I. unit of power is ....Watt.......

   (j) I H.P. = ...746...........W

   Ans: (a) the body moves (b) distance moved in direction of force (c) work (d) joule (e) state of rest or position, state of motion (f) vertical height (g) $(speed)^2$ (h) work done (i) watt (j) 746

3. Match the following :

Column A	Column B
(a) A stone at a height	(i) power
(b) A moving ball	(ii) joule
(c) Energy	(iii) work done in 1 sec.
(d) Power	(iv) potential energy
(e) watt	(v) kinetic energy

Ans.: (a)–(iv), (b)–(v), (c)–(ii), (d)–(iii), (e)–(i)

4. Select the correct alternative :

(a) The S.I. unit of work is

(i) second (ii) metre

(iii) joule (iv) newton.

(b) No work is done by a force if the body

(i) moves in direction of force

(ii) does not move

(iii) moves in opposite direction

(iv) none of these

(c) Two coolies A and B do some work in time 1 minute and 2 minute respectively. The power spent is

(i) same by both coolies

(ii) is more by coolie A than by B

(iii) is less by coolie A than by B

(iv) nothing can be said.

(d) The expression of power P is

(i) $P = mgh$ (ii) $P = \frac{1}{2} mv^2$

(iii) $P = F \times d$ (iv) $P = F \times \frac{d}{t}$

(e) 1 H.P. is equal to

(i) 1 W (ii) 1 J

(iii) 764 J (iv) 746 W

(f) When a boy doubles his speed, his kinetic energy becomes

(i) half (ii) double

(iii) four times (iv) no change.

(g) A boy lifts a luggage from height 2 m to 4 m. The potential energy will become

(i) half (ii) double

(iii) one-third (iv) one-fourth.

Ans.: (a)–(iii), (b)–(ii), (c)–(ii), (d)–(iv), (e)–(iv), (f)–(iii), (g)–(ii)

B. Short/Long Answer Questions :

1. Define work.
2. When does a force perform work ?
3. State two conditions when no work is done by a force.
4. In which of the following cases is work being done :
   (a) A boy pushing a heavy rock
   (b) A boy climbing up the stairs
   (c) A coolie standing with a box on his head
   (d) A girl moving on the road.
   Ans. (b), (d)
5. A coolie is moving on a road with a luggage on his head. Does he perform work against the force of gravity? Give reason for your answer. 62
6. The moon is revolving around the earth in a circular path. How much work is done by the moon ? 62
7. Write the expression for work done by a force.
8. State the S.I. unit of work and define it.
9. State two factors on which the work done on a body depends.
10. Define the term energy.
11. State the S.I. unit of energy.
12. Define 1 joule of energy.
13. How is work related to energy ? 63
14. What are the two kinds of mechanical energy ?
15. What is potential energy ? State its unit.
16. Give one example of a body that has potential energy, in each of the following :
    (a) due to its position at a height,
    (b) due to its elongated stretched state.

17. State two factors on which the potential energy of a body at a certain height above the ground depends.

18. Two bodies A and B of masses 10 kg and 20 kg respectively are at the same height above the ground. Which of the two has greater potential energy ?

19. A bucket full of water is on the first floor of your house and another identical bucket with same quantity of water is kept on the second floor. Which of the two has greater potential energy ?

20. Write the expression for the gravitational potential energy explaining the meaning of the symbols used.

21. A body of mass m is moved from ground to a height h. If force of gravity on mass of 1 kg is g newton, find : (a) the force needed to lift the body, (b) the work done in lifting the body and (c) the potential energy stored in the body.

22. Define the term kinetic energy. Give one example of a body which possesses kinetic energy.

23. State two factors on which the kinetic energy of a moving body depends.

24. Two toy-cars A and B of masses 200 g and 500 g respectively are moving with the same speed. Which of the two has greater kinetic energy ?

25. A cyclist doubles his speed. How will his kinetic energy change : increase, decrease or remain same ?

26. Write the expression for the kinetic energy of a body explaining the meaning of the symbols used.

27. A ball of mass m is moving with a speed v. What is its kinetic energy ?

28. Name the form of energy stored in a wound up spring of a watch.

29. Can a body possess energy even when it is not in motion ? Explain your answer with an example.

30. Name the type of energy (kinetic or potential) possessed by the following :
    (a) A moving cricket ball.
    (b) A stone at rest on the top of a building.
    (c) A compressed spring.
    (d) A moving bus.
    (e) A bullet fired from a gun.
    (f) Water flowing in a river.
    (g) A stretched rubber band.

31. Give an example to show the conversion of potential energy to kinetic energy when put in use.

32. State the energy changes that occur in a watch spring while it unwinds.

33. Give reasons for the following :
    (a) No work is done if a man is pushing against a wall.
    (b) Hammer drives a nail into the wood only when it is lifted up and then struck.
    (c) A horse and a dog are running with the same speed. Which one of them has more kinetic energy than the other ?
    (d) A teacher moving around in the class is doing work but a child standing and reading a book is not doing any work.

34. State the energy changes in the following while in use.
    (a) An electric bulb
    (b) An electric oven
    (c) A loud speaker
    (d) A microphone
    (e) An electric motor

C. Numericals :

1. A force of 30 N acts on a body and moves it through a distance of 5 m in the direction of force. Calculate the work done by the force.
   Ans. 150 J

2. A man lifts a mass of 20 kg to a height of 2·5 m. Assuming that the force of gravity on 1 kg mass is 10 N, find the work done by the man.
   Ans. 500 J

3. A body when acted upon by a force of 10 kgf moves to a distance 0·5 m in the direction of force. Find the work done by the force. Take 1 kgf = 10 N.
   Ans. 50 J

4. Two bodies of same masses are placed at height h and 2 h. Compare their gravitational potential energy.

Ans. 1 : 2

5. Find the gravitational potential energy of 2·5 kg mass kept at a height of 15 m above the ground. The force of gravity on mass 1 kg is 10 N.

Ans. 375 J

6. The gravitational potential energy stored in a box of weight 150 kgf is $1{\cdot}5 \times 10^4$ J. Find the height of the box. Take 1 kgf = 10 N.

Ans. 10 m

7. The potential energy of a body of mass 0·5 kg increases by 100 J when it is taken to the top of a tower from ground. If force of gravity on 1 kg is 10 N, what is the height of the tower ?

Ans. 20 m

8. A body of mass 60 kg is moving with a speed 50 m s^{-1}. Find its kinetic energy.

Ans. $7{\cdot}5 \times 10^4$ J

9. A truck of mass 1000 kg, increases its speed from 36 km h^{-1} to 72 km h^{-1}. Find the increase is its kinetic energy.

Ans. $1{\cdot}5 \times 10^5$ J

10. A car is moving with a speed of 15 km h^{-1} and another identical car is moving with a speed of 30 km h^{-1}. Compare their kinetic energy.

Ans. 1 : 4

11. A pump raises water by spending 4×10^5 J of energy in 10 s. Find the power of pump.

Ans. 4×10^4 W

12. It takes 20 s for a girl A to climb up the stairs while girl B takes 15 s for the same job. Compare : (i) the work done and (ii) the power spent by then.

Ans. (i) 1 : 1 (ii) 3 : 4

Project Work

Working in small groups (say, 5 students in each group), make a list of activities which they have seen with transformation of energy from one form to another, stating these changes.