P10CH3

Topic

3

Work, Energy and Power

3.1. INTRODUCTION

An important concept that helps us understand and interpret many natural phenomena is 'work'. Closely related to work are energy and power. We use different types of devices in our daily life to make our work easier. A spade is used to dig field, a broom is used to sweep and a hammer is used to pass a nail. All these simple things or devices are used to make our work easier and convenient to do. Many such devices, which are used in our daily life are called *simple machines*. The combination of simple machines forms a compound machine. In this unit we shall study these concepts.

3.2. WORK

What is work? There is a difference in the way we use the term 'work' in day-to-day life and the way we use it in science. To make this point clear let us consider a few examples.

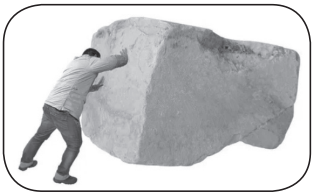


Fig. 3.1.

You are working hard to push a huge rock. Let us say the rock does not move despite all the effort. You get completely exhausted. However, you have not done any work on the rock as there is no displacement of the rock.

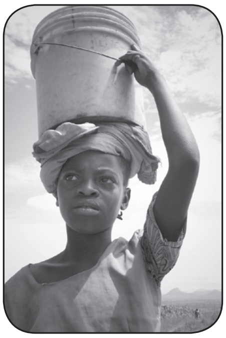


Fig. 3.2.

You stand still for a few minutes with a heavy load on your head. You get tired. You have exerted yourself and have spent quite a bit of your energy. Are you doing work on the load? The way we understand the term 'work' in science, work is not done.

You climb up the steps of a staircase and reach the second floor of a building just to see the landscape from there. You may even climb up a tall tree. If we apply the scientific definition, these activities involve a lot of work.

Fig. 3.3.

3.2.1 Scientific Conception of Work

Let us consider some situations:

Push a pebble lying on a surface. The pebble moves through a distance. You exerted a force on the pebble and the pebble got displaced. In this situation work is done.

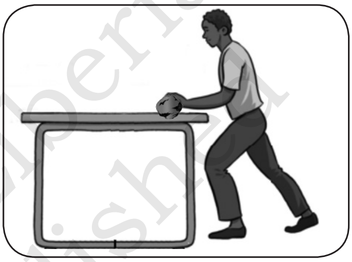


Fig. 3.4.

A girl pulls a trolley and the trolley moves through a distance. The girl has exerted a force on the trolley and it is displaced. Therefore, work is done.

Fig. 3.5.

Lift a book through a height. To do this you must apply a force. The book rises up. There is a force applied on the book and the book has moved. Hence, work is done.

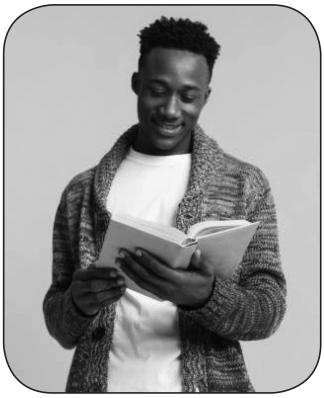


Fig. 3.6.

A closer look at the above situations reveals that two conditions need to be satisfied for work to be done: (*i*) a force should act on a object, and (*ii*) the object must be displaced.

If any one of the above conditions does not exist, work is not done. This is the way we view work in science.

A bullock is pulling a cart. The cart moves. There is a force on the cart and the cart has moved. Do you think that work is done in this situation?

ACTIVITY 3.1

- Think of some situations from your daily life involving work.
- List them.
- Discuss with your friends whether work is being done in each situation.
- Try to reason out your response.
- If work is done, which is the force acting on the object?
- What is the object on which the work is done?
- What happens to the object on which work is done?

3.2.2 Work Done by a Constant Force

How is work defined in science? To understand this, we shall first consider the case when the force is acting in the direction of displacement.

Let a constant force, F act on an object. Let the object be displaced through a distance, S in the direction of the force (Fig. 3.7). Let W be the work done. *Work done an object is defined as the product of the force and displacement.*

$$\text{Work done} = \text{force} \times \text{displacement}$$

$$W = F \times S$$

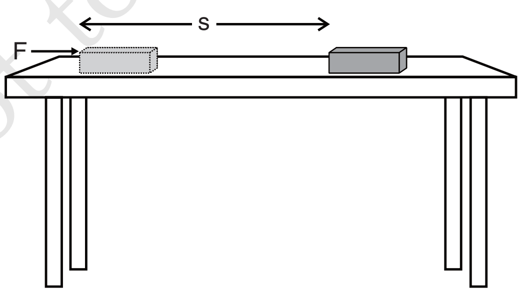


Fig. 3.7.

Thus, work done by a force acting on an object is equal to the magnitude of the force multiplied by the distance moved in the direction of the force. Work has only magnitude and no direction.

If F = 1 N and S = 1 m then the work done by the force will be 1 N m. Here the unit of work is newton metre (N m) or joule (J). Thus, 1 J is the amount of work done on an object when a force of 1 N displaces it by 1 m along the line of action of the force.

Example 3.1: *A force of 5 N is acting on an object. The object is displaced through 2 m in the direction of the force (Fig. 3.8). Calculate the work done.*

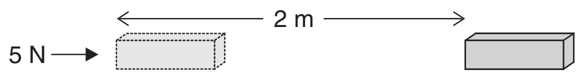


Fig. 3.8.

Solution: The force acts on the object all through the displacement, then work done is 5 N × 2 m = 10 N-m or 10 J.

When the force and the displacement are in the same direction, the work done by the force is taken as positive.

Consider a situation in which an object is moving with a uniform velocity along a particular direction. Now a retarding force, F, is applied in the opposite direction. That is, the angle between the two directions is 180°. Let the object stop after a displacement s. In such a situation, the work done by the force, F is taken as negative and denoted by the minus sign. The work done by the force is $F \times (-S)$ or $(-F \times S)$.

It is clear from the above discussion that the work done by a force can be either positive or negative. To understand this, let us do the following activity:

ACTIVITY 3.2

- Lift an object up. Work is done by the force exerted by you on the object. The object moves upwards. The force you exerted is in the direction of displacement. However, there is the force of gravity acting on the object.
- Which one of these forces is doing positive work?
- Which one is doing negative work?
- Give reasons.

Work done is negative when the force acts opposite to the direction of displacement. Work done is positive when the force is in the direction of displacement.

Example 3.2: *A porter lifts a luggage of 15 kg from the ground and puts it on his head 1.5 m above the ground. Calculate the work done by him on the luggage. Take g = 10 ms^{-2}.*

Solution: Mass of luggage, *m* = 15 kg and displacement, *S* = 1. 5 m.

$$\begin{aligned} \text{Work done, W} &= F \times S = mg \times S \\ &= 15 \text{ kg} \times 10 \text{ ms}^{-2} \times 1.5 \text{ m} \\ &= 225 \text{ kg ms}^{-2} \text{ m} \\ &= 225 \text{ N m} = 225 \text{ J} \end{aligned}$$

Work done is 225 J.

3.3. ENERGY

Energy is anything that makes things work. Thus, ***energy*** *is defined as the ability to do work.*

The word energy is very often used in our daily life. But in science we give it a definite and precise meaning. Let us consider the following examples: when you try to catch a fast moving ball, you feel a jerk. Similarly, an object when raised to a certain height gets the capability to do work. For example, when a raised hammer falls on a nail placed on a piece of wood, it drives the nail into the wood.

In all these examples, the objects acquire, through different means, the capability of doing work. An object having a capability to do work is said to possess energy. The object which does the work loses energy. The object on which the work is done gains energy.

How does an object with energy do work? An object that possesses energy can exert a force on another object. When this happens, energy is transferred from the former to the latter. The second object may move as it receives energy and therefore do some work. Thus, the first object had a capacity to do work. This implies that any object that possesses energy can do work.

The energy possessed by an object is thus measured in terms of its capacity of doing work. The unit of energy is, therefore, the same as that of work, that is, joule (J). 1 J is the energy required to do 1 joule of work. Sometimes a larger unit of energy called kilo joule (kJ) is used. 1 kJ equals 1000 J.

3.4. POWER

Power measures the speed of work done, that is, how fast or slow work is done. ***Power*** *is defined as the rate of doing work or the rate of transfer of energy.*

If an agent does a work W in time t, then power is given by:

$$\text{Power} = \text{Work/Time}$$

or

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

ACTIVITY 3.3

- Consider two children, say A and B. Let us say they weigh the same. Both start climbing up a rope separately. Both reach a height of 8 m. Let us say A takes 15 s while B takes 20 s to accomplish the task.
- What is the work done by each?
- The work done is the same. However, A has taken less time than B to do the work.
- Who has done more work in a given time, say in 1 s?

The unit of power is watt [in honour of James Watt (1736 – 1819)] having the symbol W. 1 watt is the power of an agent, which does work at the rate of 1 joule per second. We can also say that power is 1 W when the rate of consumption of energy is 1 J s^{-1}.

1 watt = 1 joule/second or 1 W = 1 J s^{-1}. We express larger rates of energy transfer in kilowatts (kW).

$$1 \text{ kilowatt} = 1000 \text{ watts}$$

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

$$1 \text{ kW} = 1000 \text{ J s}^{-1}.$$

The power of an agent may vary with time. This means that the agent may be doing work at different rates at different intervals of time. Therefore, the concept of average power is useful. *We obtain average power by dividing the total energy consumed by the total time taken.*

Example 3.3: *Two girls, Akeelah and Mary weighing 400 N climb up a rope through a height of 8 m. Akeelah takes 20 s while Mary takes 50 s to accomplish this task. What is the power expended by each girl?*

Solution:

(i) Power expended by Akeelah

Weight,

$mg = 400$ N

Displacement (height),

$h = 8$ m

Time taken,

$t = 20$ s

Power,

P = Work done/Time taken

$$= \frac{mgh}{t}$$

$$= \frac{400\,\text{N} \times 8\,\text{m}}{20\,\text{s}}$$

= 160 W

(ii) Power expended by Mary

Weight,

$mg = 400$ N

Displacement (height),

$h = 8$ m

Time taken,

$t = 50$ s

Power,

$$P = \frac{mgh}{t}$$

$$= \frac{400\,\text{N} \times 8\,\text{m}}{50\,\text{s}}$$

= 64 W

Power expended by Akeelah is 160 W.

Power expended by Mary is 64 W.

Example 3.4: *Samuel having mass 50 kg runs up a staircase of 45 steps in 9 s. If the height of each step is 15 cm, find his power. Take $g = 10$ m s^{-2}.*

Solution:

Weight of Samuel,

$mg = 50 \text{ kg} \times 10 \text{ m s}^{-2}$

= 500 N

Height of the staircase,

$$h = 45 \times \frac{15}{100} \text{ m}$$

= 6.75 m

Time taken to climb, $t = 9$ s

So, power,

P = Work done/Time taken

$$= \frac{mgh}{t}$$

$$= \frac{500\,\text{N} \times 6.75\,\text{m}}{9\,\text{s}}$$

= 375 W.

Power is 375 W.

3.5. FORMS OF ENERGY

We know that to do work, one form of energy changes into another form. Every activity occurring on earth, happens due to energy change. Thus, we can say that every object has one form of energy that changes into another form when it works. For example, when a raised hammer falls on a nail placed on a piece of wood, it drives the nail into wood. The raised hammer has potential energy, when it falls, its potential energy changes into kinetic energy, Thus, objects possess various forms of energy depending on their position.

Fig. 3.9. The raised hammer has energy stored in it. If this is allowed to fall on a nail, it can do work by driving the nail

A few forms of energy have been listed below.

1. **Mechanical Energy**
   - **(a)** ***Potential Energy:*** It is the energy of a body due to its position.
   - **(b)** ***Kinetic Energy:*** It is the energy of a body due to its motion.
2. **Heat Energy:** It is a form of energy which exists among particles in a substance in form of kinetic energy of those particles. The temperature is the measurement of heat energy.
3. **Sound Energy:** It is the energy produced by sound vibrations in a medium.
4. **Solar Energy:** It is the radiant energy emitted by the sun. It is the most important source of energy on earth.
5. **Electrical Energy:** It is the energy made available by the flow of electric charge through an electric conductor.
6. **Nuclear Energy:** It is the energy released by a nuclear reaction, especially fission or fusion.
7. **Chemical Energy:** It is the energy associated with the work done in making and breaking of bonds during chemical reaction.
8. **Light Energy:** It is the energy due to electromagnetic radiation that is capable of causing a visual sensation.

3.6. POTENTIAL AND KINETIC ENERGY

Every object possesses energy due to its states. There are following two types of energies.

1. Potential energy and
2. Kinetic energy.

3.6.1. Potential Energy

Suppose a stone is lying on the ground. It has no energy, so it cannot do any work. Let us lift this stone to a table top. Now, some work has been done in lifting this stone against the force of gravity. This work gets stored up in the stone in the form of potential energy. Thus, the energy of a stone lying on the table top is due to its higher position with respect to the ground.

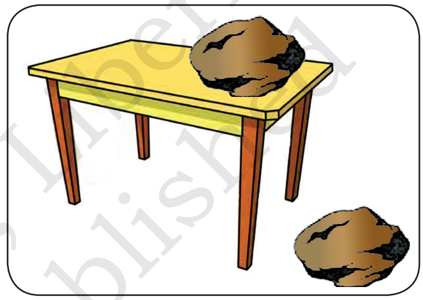


Fig. 3.10. Stone placed on a table top has potential energy in it due to its higher position

The energy transferred to an object is stored as potential energy if it is not used to cause a change in the velocity or speed of the object. You transfer energy when you raise the stone. Thus, *the* ***potential energy*** *possessed by the object is the energy present in it by virtue of its position.* For example, the stone on the table top and a raised hammer have energy due to their position.

3.6.2. Mathematical Expression for Potential Energy

To find out the potential energy of a body lying at a certain height, all that we have to do is to find out the work done in taking the body to that height.

Consider an object of mass, m. Let it be raised through a height, h from the ground. A force is required to do this. This force is equal to the gravitational pull of the earth $m \times g$ which acts on the object in the downward direction.

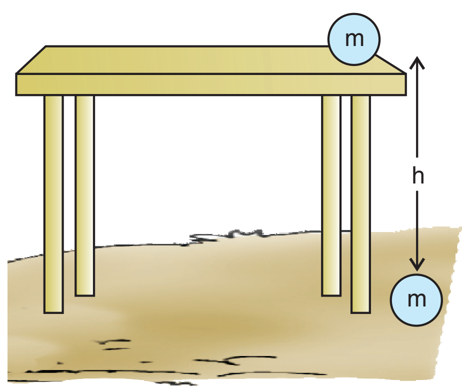


Fig. 3.11.

The object gains energy equal to the work done on it. Let the work done on the object against gravity be W. Now,

$$\text{Work Done} = \text{Force} \times \text{Distance}$$

So, $$W = m \times g \times h$$

Since work done on the object is stored up as potential energy. Thus,

$$\text{Potential Energy} = m \times g \times h$$

where m = mass of the body

g = acceleration due to gravity

h = height of the body above a reference point.

Example 3.5: *Find the energy possessed by an object of mass 10 kg when it is at height of 6 m above the ground (Take g = 9.8 ms^{-2}).*

Solution:

Mass of the object, m = 10 kg

Height h = 6 m

Acceleration due to gravity, g = 9.8 ms^{-2}

Potential energy $= mgh$

$= 10 \text{ kg} \times 9.8 \text{ ms}^{-2} \times 6 \text{ m}$

$= 588$ joule

3.6.3. Kinetic Energy

Take a heavy ball. Drop it on a thick bed of wet sand from a considerable height. What do you observe? The ball creates a depression in the sand. Now drop the ball from different heights and compare the depressions created by each drop. You will observe that some depressions are deep and some are shallow. Can you explain why? What has caused the ball to make a deeper dent? We observed that when the moving ball strikes the wet sand, it creates depressions in the sand. Thus, we can say a moving body is capable of doing work and hence possesses energy.

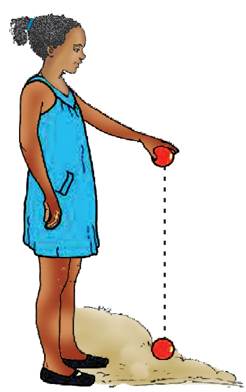


Fig. 3.12. A falling ball possesses kinetic energy

An object moving faster can do more work than an identical object moving relatively slow. A moving bullet, a moving hammer, blowing wind, a rotating wheel, a falling stone can do work. Can you explain how? The moving object possesses energy. We call this energy kinetic energy. ***Kinetic energy*** *of a body is the energy due to its motion.* Mathematically, it can be calculated by the following expression:

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

where m is the mass of the body and v the velocity with which it is moving.

Example 3.6: *Calculate the kinetic energy of a body of mass 2 kg moving with a velocity of 3 metre per second.*

Solution: The formula for calculating kinetic energy is

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

Here mass, m = 2 kg

Velocity, v = 3 m/s

$$\text{Kinetic energy} = \frac{1}{2} \times 2 \times (3)^2$$

$$= 9 \text{ joule}$$

Example 3.7: *An object of mass 15 kg is moving with a uniform velocity of 4 m s^{-1}. What is the kinetic energy possessed by the object?*

Solution: Mass of the object, m = 15 kg, velocity of the object, v = 4 m s^{-1}.

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

$$= \frac{1}{2} \times 15 \text{ kg} \times 4 \text{ m s}^{-1} \times 4 \text{ m s}^{-1}$$

$$= 120 \text{ J}$$

The kinetic energy of the object is 120 J.

Example 3.8: *What is the work to be done to increase the velocity of a car from 30 km h^{-1} to 60 km h^{-1} if the mass of the car is 1500 kg?*

Solution:

Mass of the car,

$$m = 1500 \text{ kg},$$

Initial velocity of car,

$$u = 30 \text{ km h}^{-1}$$

$$= \frac{30 \times 1000 \text{ m}}{60 \times 60 \text{ s}}$$

$$= 8.33 \text{ m s}^{-1}.$$

Similarly, the final velocity of the car,

$$v = 60 \text{ km h}^{-1}$$

$$= 16.67 \text{ m s}^{-1}.$$

Therefore, the initial kinetic energy of the car,

$$E_{ki} = \frac{1}{2} m u^2$$

$$= \frac{1}{2} \times 1500 \text{ kg} \times (8.33 \text{ m s}^{-1})^2$$

$$= 52041.68 \text{ J}.$$

The final kinetic energy of the car.

$$E_{kf} = \frac{1}{2} \times 1500 \text{ kg} \times (16.67 \text{ m s}^{-1})^2$$

$$= 208416.68 \text{ J}$$

Thus, the work done

= Change in kinetic energy

$$= E_{kf} - E_{ki}$$

$$= 156375 \text{ J}$$

3.7. ENERGY TRANSFORMATION

You know that when the hammer is raised it gets energy. Similarly, blowing wind, moving water, burning wood and the food we eat have energy. Thus, energy exists in different forms.

ACTIVITY 3.4

To Understand the Transformation of Energy

1. Split into groups of four students.
2. Discuss various ways of energy conversion in nature.
3. Discuss the following questions in your group:
   (a) How do green plants produce food?
   (b) Where do they get their energy from?
   (c) Why does the air move from place to place?
   (d) How are fuels, such as coal and petroleum formed?

One form of energy can be changed into another form. *The change of one form of energy into another form of energy is known as* ***transformation of energy***. There are various instances of energy transformations in our day-to-day lives. Some of them are as follows:

- A kerosene lamp transforms the chemical energy of the fuel to light and heat energy.
- An electric heater converts electrical energy into heat energy.
- A loudspeaker converts electrical energy into sound energy.
- When we strike a match, the chemical energy of the chemicals is converted into heat and light.

- When you are pushing or pulling an object to move it, the energy you obtain from the food you eat is transformed to the energy of the moving object.
- When a wood burns, the chemical energy in it is converted to heat and light.

Thus, we can say, the energy we need to do work is transformed from one form to another. Can you explain how the energy transformation takes place?

3.8. TRANSFORMATION OF POTENTIAL ENERGY TO KINETIC ENERGY AND VICE-VERSA

Consider the example of stone lying on the table top. In this position, all energy of the stone is in the form of potential energy. When the stone is dropped from the table top, it starts moving downwards towards the ground and the potential energy of the stone starts changing into kinetic energy. As the stone continues falling downwards, its potential energy goes on decreasing but its kinetic energy goes on increasing. In other words, the potential energy of the stone gradually gets transformed into kinetic energy. By the time the stone reaches the ground, its potential energy becomes zero and entire energy will be in the form of kinetic energy. The reverse happens when the stone is raised to the table top. The kinetic energy gets transformed to potential energy.

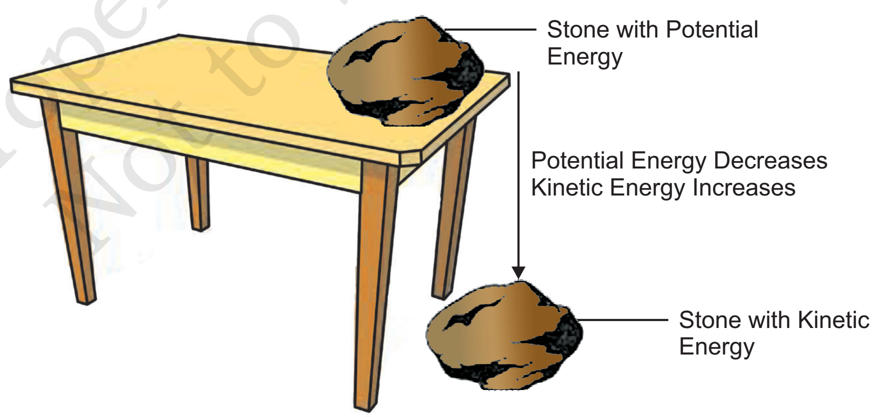


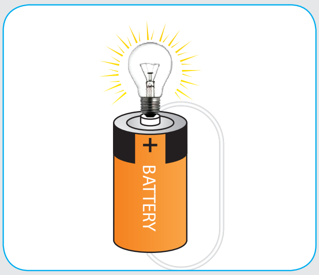
Fig. 3.13. The conversion of potential energy into kinetic energy

ACTIVITY 3.5

To identify Energy Transformations in Our Day-to-day Lives

Procedure

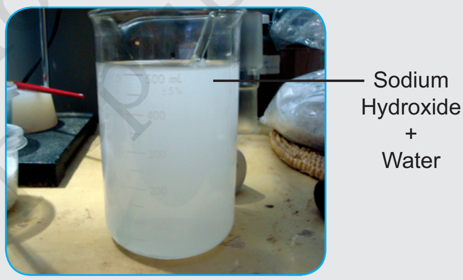
Identify the input energy and output energy in the following activities. Write it down in your notebook.



(a)

(b)

(c)



(d)

Fig. 3.14.

You observe in Activity 3.5 that the battery makes the bulb glow, electricity makes the iron hot and the public address system vibrate, and the reaction of sodium hydroxide and water releases heat in the solution. How they function is explained below:

(a) Flashlight Battery: A battery contains chemicals and supplies electrical energy required to produce light in a bulb. So battery converts chemical energy into electrical energy.

(b) Electric Iron: When we switch on an electric iron, it becomes hot. So, an electric iron converts electrical energy into heat energy.

(c) Public Address System: In public address system, the sound energy first gets converted into electric energy. The electric energy so produced causes the speaker to produce sound. The energy transformations taking place in public address system can be written as

Sound energy → Electrical energy → Sound energy

(d) Dissolving Sodium Hydroxide in Water: When sodium hydroxide is dissolved in water, it breaks into its ions. In this reaction, a lot of heat energy is released. Thus, the energy stored in chemical bonds converts into heat energy.

3.9. LAW OF CONSERVATION OF ENERGY

Whenever energy gets transformed, the total energy remains unchanged. This is the law of conservation of energy. According to this law, *energy can only be converted from one form to another, it can neither be created nor destroyed*. The total energy before and after the transformation remains the same. The law of conservation of energy is valid in all situations and for all kinds of transformations.

This means that potential energy can transform to kinetic energy, or vice versa, but energy will not change (become more or less). For example, in the absence of air resistance, the mechanical energy of an object moving through the air in the Earth's gravitational field, remains constant (is conserved).

Consider a simple example. Let an object of mass, m be made to fall freely from a height, h. At the start, the potential energy is mgh and kinetic energy is zero. Why is the kinetic energy zero? It is zero because its velocity is zero. The total energy of the object is thus mgh. As it falls, its potential energy will change into kinetic energy. If v is the velocity of the object at a given instant, the kinetic energy would be $\frac{1}{2}mv^2$.

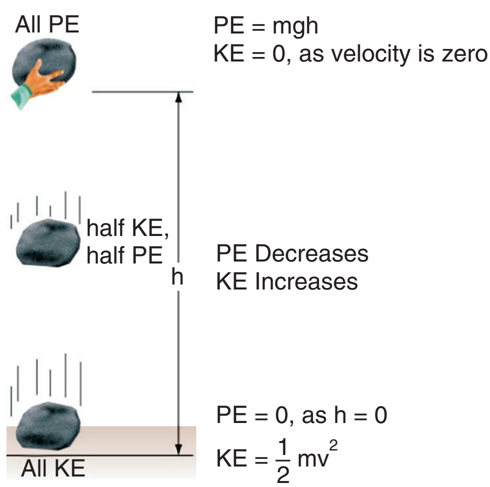


Fig. 3.15.

As the fall of the object continues, the potential energy would decrease while the kinetic energy would increase. When the object is about to reach the ground, $h = 0$ and v will be the highest. Therefore, the kinetic energy would be the largest and potential energy the least.

However, the sum of the potential energy and kinetic energy of the object would be the same at all points. That is,

$$\text{potential energy + kinetic energy = constant}$$

or

$$mgh + \frac{1}{2} mv^2 = \text{constant.}$$

The sum of kinetic energy and potential energy of an object is its total mechanical energy.

We find that during the free fall of the object, the decrease in potential energy, at any point in its path, appears as an equal amount of increase in kinetic energy. (Here the effect of air resistance on the motion of the object has been ignored.) There is thus a continual transformation of potential energy into kinetic energy.

Think it over!

What would have happened if nature had not allowed the transformation of energy? There is a view that life could not have been possible without transformation of energy. Do you agree with this?

3.10. SIMPLE MACHINE

*A **simple machine** is defined as a device, which is used in our daily life to make our work easier, faster and more comfortable.*

Simple machines make our work easier in the following ways:

1. They transfer force from one point to another point. In figure 3.16, a screwdriver is used to open the lid of a can. The applied effort at 'A' is transferred to 'B'.

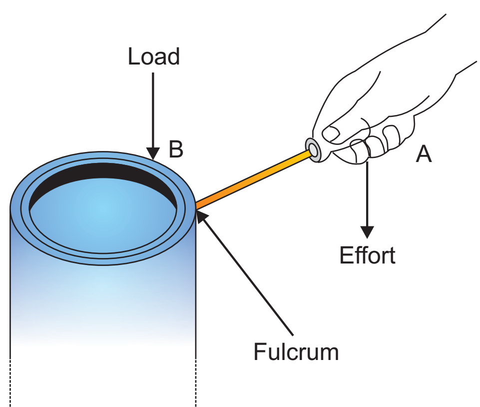


Fig. 3.16. Opening a tin

2. They accelerate rate of doing work.
3. They multiply force, *i.e.*, more load is lifted by applying less effort. For example, a heavy stone can be turned with a crowbar by applying less effort.
4. They change the direction of force. For example, in pulleys, the effort is applied downwards at one end of the rope. The load is lifted upwards.

   Machines help us to do work showing one or more properties as mentioned above.

Simple machines are of the following six types:

1. Lever
2. Wheel and Axle
3. Pulley
4. Inclined Plane
5. Screw
6. Wedge

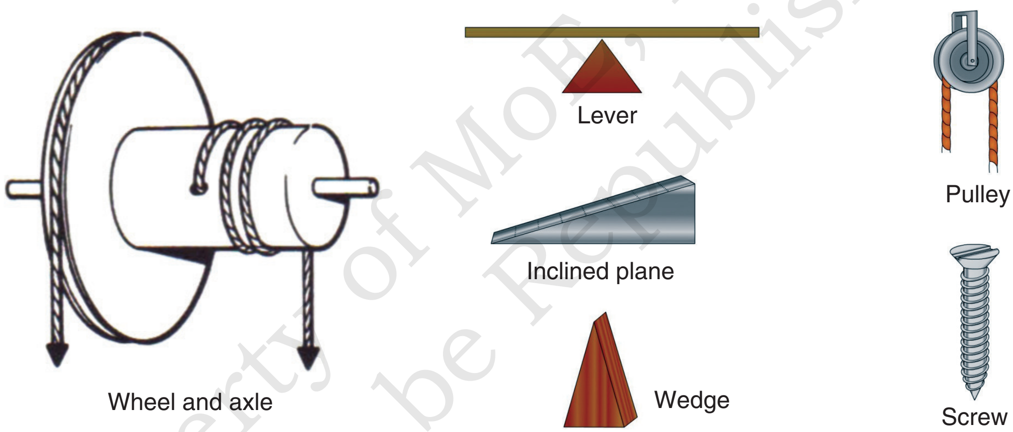


Fig. 3.17. Different types of simple machines

3.10.1. Principle of Simple Machine

A machine does not work by itself. It needs force to do work. The applied force is called input force (F_i) or effort (E) and the resisting force is called output force (F_o) or load (L).

The distance travelled by effort is taken as *Ed*. The distance travelled by load is taken as *Ld*.

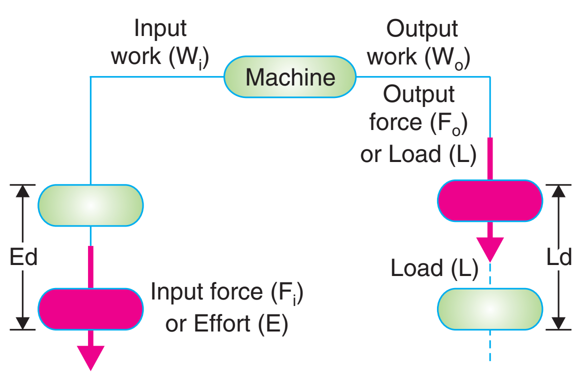


Fig. 3.18.

The work done by effort or work done **on a machine** is called **work input** (W_i) and the work done by load or work done **by the machine** is called **work output** (W_o).

$$\text{Work input } (W_i) = F_i \times Ed \ (E \times Ed)$$

$$\text{Work output } (W_o) = F_o \times Ld \ (L \times Ld)$$

The principle of simple machine states that *"If there is no friction, in balanced condition of a machine, work output and work input are equal"*.

Mathematically,

Work output (W_o)

= Work input (W_i) (in balanced state)

or, $$F_o \times Ld = F_i \times Ed$$

i.e., $$L \times Ld = E \times Ed$$

3.11. MECHANICAL ADVANTAGE

Mechanical advantage *of a machine is defined as the ratio of the load to effort.*

So, mechanical Advantage (MA) = $\dfrac{\text{Load } (L)}{\text{Effort } (E)}$

Mechanical advantage is a measure of the advantage we obtain by using the simple machine. For example, if mechanical advantage of a machine is 5, that means load moved by effort is 5 times the effort.

The mechanical advantage of a simple machine is affected by the following factors:

(a) Friction and (b) Weight of the simple machine

(a) Friction: Friction reduces the mechanical advantage. Each and every machine has friction. Some machines have less friction than the others. Some of the effort applied on the machine is used to overcome the friction produced in it. That makes the waste of effort.

(b) Weight of the Simple Machine: Weight of a simple machine affects the mechanical advantage of the simple machine in some cases. In the case of wheel and axle, inclined plane and screw, the weight of simple machine does not affect the mechanical advantage. Some of the effort is used up to overcome the weight of movable pulley in the combined pulley system. In the case of lever, if effort arm is longer, the extra weight of effort arm helps to lift the load.

3.12. VELOCITY RATIO

When we use effort on a simple machine, load is moved to some distance. At the same time effort will also be moved.

*The ratio of the distance moved by effort to the distance moved by the load is called **velocity ratio** of the machine.*

$$\text{Velocity ratio (VR)} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

Velocity ratio in a machine is neither affected by the friction nor by the weight of the simple machine. Velocity ratio is also called ideal mechanical advantage. It indicates the maximum mechanical advantage possible in a simple machine when the machine is frictionless. But in practice, it is not possible to have the mechanical advantage equal to the velocity ratio. So, the velocity ratio is always greater than the mechanical advantage.

3.13. EFFICIENCY [η]

*When an effort is applied on a machine, some work is done, which is called **work input**.*

*The machine, in turn, does some work which is called **work output**.*

Some of the input work is always "wasted" either through friction, or by acting upon parts of the machine itself. Some of the wastage may be eliminated by better design of the machine, but the friction can never be totally eliminated. Therefore, the output work is always less than the input work. This may be expressed by an equation:

$$\text{Work input} = \text{Energy "wasted"} + \text{Work output}$$

*The ratio of work output to work input in a machine is called **efficiency** of that machine. It is expressed in percentage.*

$$\text{Mathematically, Efficiency } (\eta) = \frac{\text{Work output (joule)}}{\text{Work input (joule)}} \times 100\%$$

In a simple machine, the value of output is always less than input. It is because no machine is frictionless. The friction wastes some of the input energy in the form of heat.

Due to this reason, a real machine does not have the efficiency of 100%.

3.14. RELATION AMONG MA, VR AND η

We know,

$$\eta = \frac{\text{Work output}}{\text{Work input}} \times 100$$

or,
$$\eta = \frac{L \times Ld}{E \times Ed} \times 100$$

[work output = $L \times Ld$ and work input = $E \times Ed$]

or,
$$\eta = \frac{L / E}{Ed / Ld} \times 100\%$$

∴
$$\eta = \frac{MA}{VR} \times 100\% \quad \left[MA = \frac{L}{E} \text{ and } VR = \frac{Ed}{Ld}\right]$$

Due to the friction, the value of *MA* is lesser than the value of VR. Hence, the efficiency of a machine is never 100%. A machine with 100% efficiency is called an ideal or perfect machine. But perfect machine does not exist in practical life.

Example 3.9: *In a certain simple machine with velocity ratio 5, an effort of 1000 N is needed to overcome a load of 4500 N. Calculate*

(*i*) *mechanical advantage* (*ii*) *efficiency of the machine*

Solution:

$$VR = 5$$
$$\text{Effort} = 1000 \text{ N}$$
$$\text{Load} = 4500 \text{ N}$$

(*i*) $MA = \dfrac{\text{Load}}{\text{Effort}} = \dfrac{4500}{1000} = 4.5$

(*ii*) $\text{Efficiency} = \dfrac{MA}{VR} \times 100\% = \dfrac{4.5}{5} \times \dfrac{100}{1} = 90\%$

3.15. WORKING PRINCIPLE OF LEVER

Lever is a rigid bar, may be straight or bend which is capable of rotating about a fixed point called fulcrum or pivot (Fig. 3.19). The distance between fulcrum and load is called as load arm and the distance between fulcrum and effort is called effort arm. It is used to life a heavy load with a small power.

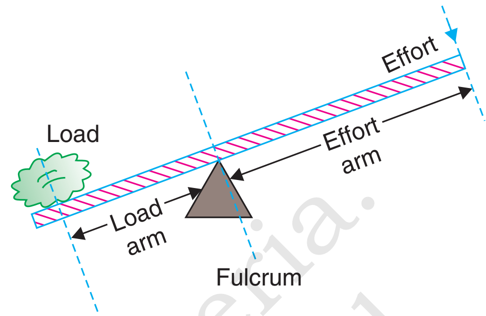


Fig. 3.19. A Lever

Look at the figure 3.20. The load of the stone is 500 N and is being lifted by an effort 20 N. It is possible because the effort arm is longer than the load arm.

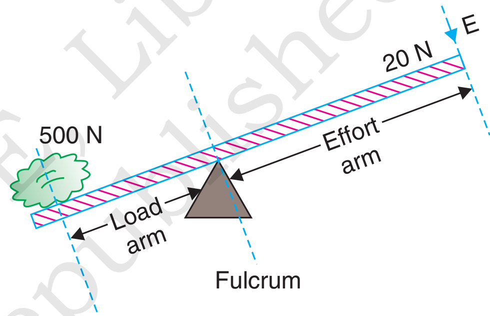


Fig. 3.20.

If effort arm is longer than the load arm, a small effort can lift or balance a heavier load.

The effort and the load always act in opposite direction to each other. In the Fig. 3.21 the effort acts in clockwise direction and the load acts in anticlockwise direction.

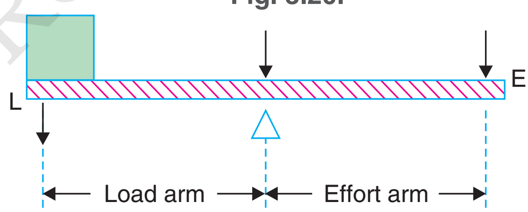


Fig. 3.21.

When the product of effort and effort arm is equal to the product of load and load arm, a lever stays in the state of equilibrium. *i.e.*, at the state of equilibrium in a lever,

$$\text{Effort} \times \text{Effort arm} = \text{Load} \times \text{Load arm}$$

or,
$$\frac{\text{Effort arm}}{\text{Load arm}} = \frac{\text{Load}}{\text{Effort}}$$

It is also called principle of lever.

3.15.1 Velocity Ratio in Lever

The velocity ratio in a lever is the ratio of the effort distance to the load distance.

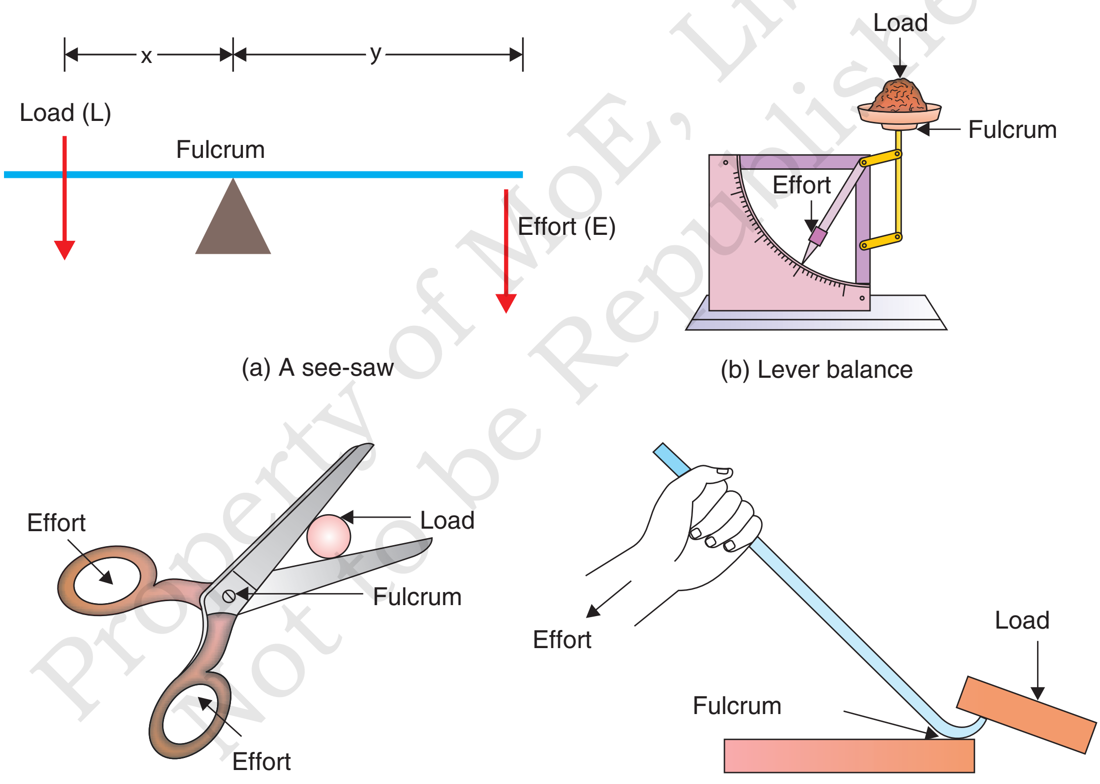
$$VR = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

3.15.2. Classification of Levers

On the basis of position of effort, load and fulcrum, levers are classified into the following three types.

3.15.2.1. First Order Lever or Class I Lever

In this type of lever, fulcrum lies in between load and effort. A *see-saw*, a *lever balance*, a *crowbar*, a *pair of scissors* and a *pair of pliers* are the examples of first order lever.



(a) A see-saw (b) Lever balance

(c) A pair of scissors (d) Crowbar

Fig. 3.22. First order levers

In the figure 3.22(a) 'x' is the load arm and 'y' is the effort arm. According to the principle of lever.

$$x \times L = y \times E$$

In the first order lever, effort arm can be made longer than, or equal to or shorter than the load arm.

In this type of lever all the three advantages of a simple machine can be gained.

For Example

- If effort arm is longer than the load arm, a small effort can lift a heavy load. This type of lever magnifies the effort applied. The load is always greater than the effort applied, so the mechanical advantage is also greater than one.
- When effort arm is equal to the load arm the load balanced will be equal to the effort applied. So, the mechanical advantage is equal to one. This kind of lever does not magnify the effort applied.
- If load arm is longer than the effort arm, greater effort is necessary to lift a small load. It cannot magnify the effort. So, at this condition mechanical advantage is less than one. But this type of lever increases the speed of work. For example, scissors cut cloth faster than a tin cutter does.

3.15.2.2. Second Order Lever or Class II Lever

In a lever of the second order, the load is put in between fulcrum and effort.

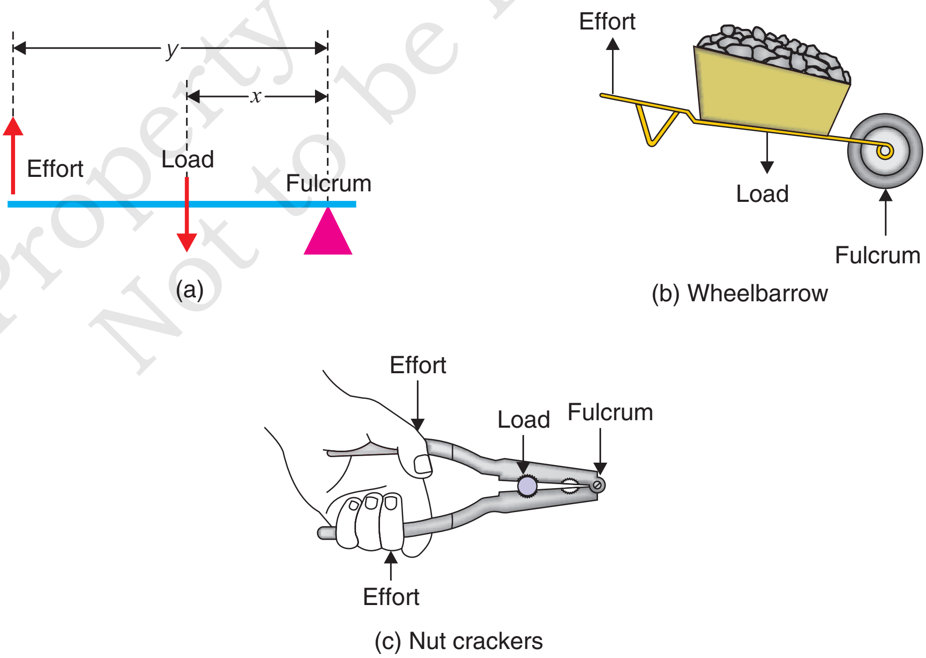


Fig. 3.23. Second order levers

It works on the same principle as the first order lever does.

For equilibrium,

$$x \times L = y \times E$$

where 'x' and 'y' are load arm and effort arm respectively.

In the second order lever, effort arm is always longer than load arm. Therefore, the effort used is always less than the load raised. Thus the mechanical advantage is always greater than one.

To make the work more easier, the load can be shifted towards the fulcrum in this lever.

3.15.2.3. Third Order Lever or Class III Lever

Effort (E) lies in between load and fulcrum in this lever. Effort arm (y) is always shorter than load arm in this type of lever. Again some resistance against the effort is produced at the fulcrum which makes waste of some effort. Due to these two reasons the load raised is always less than the effort used in this lever.

The mechanical advantage is always less than one in third order lever.

This lever works on the same principle as class I and II.

For equilibrium,

$$x \times L = y \times E.$$

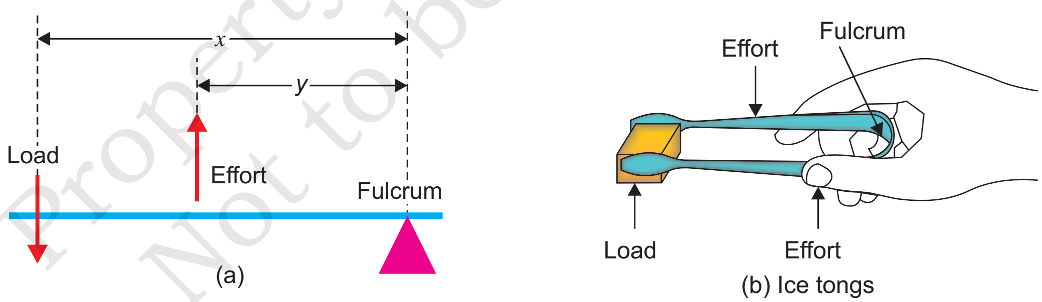


Fig. 3.24. Third order levers

Example 3.10: *Linda applies an effort of 150 N to lift a rock of weight 600 N using a long piece of wood as a lever. Calculate the mechanical advantage of the lever.*

Solution: The load is the weight Linda is trying to lift. This is 600 N.

The effort is the force she exerts of 150 N.

$$\text{Mechanical advantage (MA)} = \frac{\text{Load}}{\text{Effort}} = \frac{600}{150}$$

$$= 4$$

This means that the lever has made Linda's force four times larger. She only needs to put in one-quarter the effort she would otherwise need to apply to do the job.

Example 3.11: *Jacob uses a stick to shift a rock. The distance from his hand on the stick to the fulcrum is 120 cm, and the distance from the fulcrum to the rock is 40 cm. Calculate the mechanical advantage of this lever system.*

Solution:

$$\text{Mechanical advantage (MA)} = \frac{\text{Load}}{\text{Effort}}$$

As per the principle of lever,

$$\frac{\text{Load}}{\text{Effort}} = \frac{\text{Effort arm length}}{\text{Load arm length}}$$

So,

$$\text{MA} = \frac{\text{Distance from effort to fulcrum (Effort arm)}}{\text{Distance from load to fulcrum (Load arm)}}$$

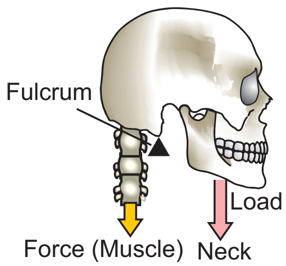
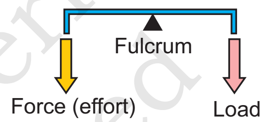
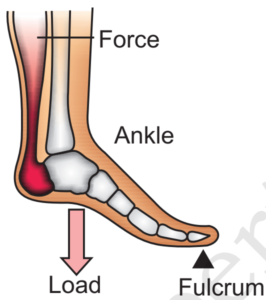
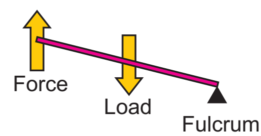
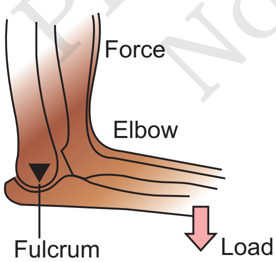
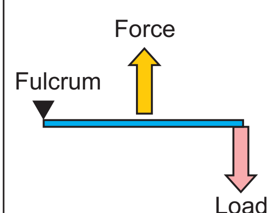
$$= \frac{120}{40} = 3$$

This means Jacob can shift the rock with three times less force than when using his bare hands. It also means that he could lift a rock three times heavier than he normally could.

3.15.2. Levers in the Body

Examples of the three orders of lever are found in the human body. These are given in Table 3.1.

Table 3.1. Levers in the Human Body

Body Part	Fulcrum	Muscle Providing Effort	Load
Head: First order lever 	Joint between head and backbone	Muscle at the back of neck	
Foot: Second order lever 	Toes	Calf muscle (back of leg)	
Arm: Third order lever 	Elbow	Biceps muscle (upper arm)	

3.16. WORKING PRINCIPLE OF WHEEL AND AXLE

The handle of a door, a wrench used to tighten or loose a knot etc. work on the principle of wheel and axle.

In wheel and axle, effort is generally applied on the wheel and load on the axle but they act in the direction opposite to each other. In figure 3.25 (a) the load turns wheel and axle in clockwise direction while the effort turns it in anticlockwise direction. *R* is the radius of the wheel and *r* is the radius of the axle figure 3.25 (b).

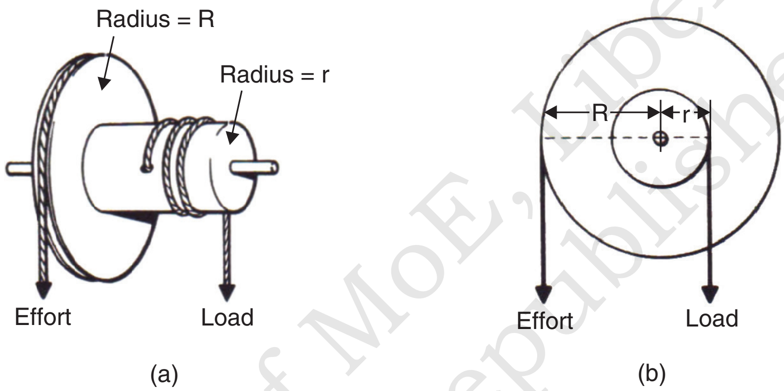


Fig. 3.25. Wheel and axle

When a wheel rotates one turn by the action of effort, the effort distance is equal to circumference ($2\pi R$) of the wheel. The load distance is equal to circumference of axle ($2\pi r$).

$$\text{Therefore, velocity ratio} = \frac{2\pi R}{2\pi r} = \frac{R}{r}$$

where 'R' is the radius of the wheel and '*r*' is the radius of the axle.

ACTIVITY 3.6

Take a wheel and axle and suspend it at the appropriate height. Fit other accessories like string and load.

(*a*) Measure the distance moved by each of the effort and the load when the wheel and axle is rotated one round. Calculate the velocity ratio.

(*b*) Measure the radius of wheel and axle and calculate the VR again. What difference did you find in procedure *a* and *b*?

(*c*) Take various loads in radius and measure the effort necessary for each load. Take at least three readings and calculate mechanical advantage for each reading.

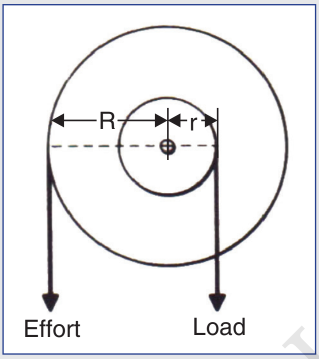


Fig. 3.26.

Wheel and axle is also called continuous lever because it has a co-axial arrangement of wheel and axle and when effort is applied in axle, wheel will rotate. It is a first order lever.

3.17. WORKING PRINCIPLE OF PULLEY

A pulley is mostly used to lift a heavy load to a great height. Pulleys are usually used to lift water from well and to lift loads in a crane.

A pulley has the shape of a wheel which rotates freely about an axis. It has a groove around its circumference to wrap a piece of string or rope. One end of the rope is tied to load while the other end is tied to an effort used. The load and effort work against each other.

There are three main types of pulleys: **fixed, movable**, and **compound**.

A fixed pulley's wheel and axle stay in one place. A good example of a fixed pulley is a flag pole: When you pull down on the rope, the direction of force is redirected by the pulley, and you raise the flag.

A **movable pulley** is a pulley that is free to move up and down, and is attached to a ceiling or other object by two lengths of the same rope. Examples of movable pulleys include construction cranes, modern elevators, and some types of weight lifting machines at the gym.

The third type of pulley is the **compound pulley**, which consists of combination of fixed and movable pulley, for example, block and tackle.

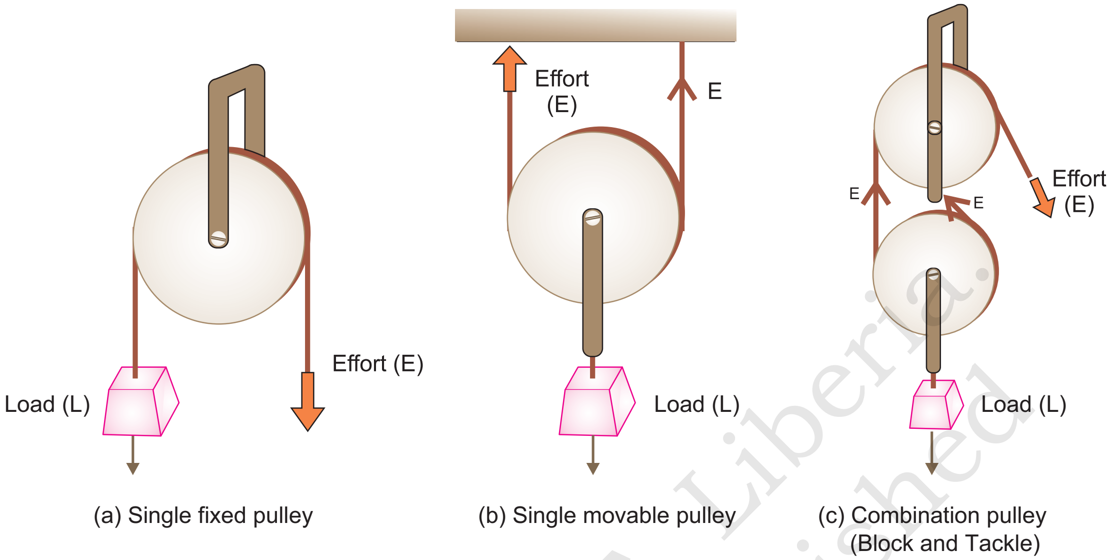


Fig. 3.27.

In case of a **single fixed pulley** [Figure 3.27 (a)], the effort applied is equal to the load. Thus its mechanical advantage is equal to one.

Mechanical advantage (MA) = $L/E = 1$

In the case of a **single movable pulley** [Figure 3.27 (b)], its is clear from the figure that $L = E + E$, or $L = 2E$. Here L and E are load and effort respectively.

Hence, mechanical advantage of a single movable pulley

$$MA = L/E$$
$$= 2E/E = 2$$

In the **combination pulley** [Figure 3.27 (c)], it is clear from the figure that $L = E + E = 2E$. Here L and E are load and effort respectively.

The mechanical advantage,

$$MA = L/E$$
$$= 2E/E = 2$$

So, if there are 'n' number of pulleys, then $MA = n$.

Example 3.12: *A pulley system has a VR of 3 and efficiency 80%*

(i) *calculate the MA of the system*

(ii) *Value of the effort required to raise a load of 300 N.*

(iii) *If the effort moves through a distance of 6 m. Calculate the distance moved by the load.*

Solution:

(i)
$$VR = 3$$
$$\text{efficiency} = 80\%$$
$$\frac{MA}{VR} = \text{efficiency}$$
$$\frac{MA}{3} = \frac{80}{100}$$
$$MA = 3 \times \frac{80}{100} = 2.4$$

(ii)
$$\text{Load} = 300 \text{ N}, \quad MA = 2.4$$
$$\frac{\text{Load}}{\text{Effort}} = MA$$
$$\text{Effort} = \frac{\text{Load}}{MA} = \frac{300}{2.4} = 125 \text{ N}$$

(iii)
$$Ed = 6 \text{ m}, \quad VR = 3$$
$$VR = \frac{Ed}{Ld}$$
$$Ld = \frac{Ed}{VR} = \frac{6}{3} = 2 \text{ m}$$

Distance moved by load = 2 m.

3.18. WORKING PRINCIPLE OF INCLINED PLANE

It is a simple slope along which a load is pushed or pulled up. A wooden plank is used to load goods onto a truck. A mountain road is another example of an inclined plane.

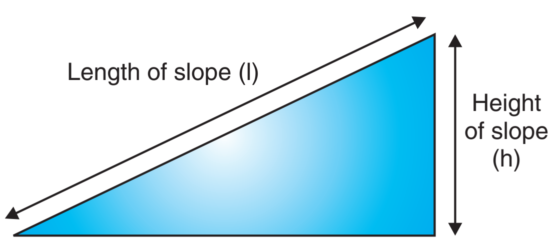


Fig. 3.28. Inclined plane

It is easier to drag a load along an inclined plane than to lift and put on a truck. In an inclined plane, the small effort has to travel a longer distance, while the larger load is raised only through a small distance vertically upward.

Here, velocity ratio or Ideal mechanical advantage

$$= \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

$$= \frac{\text{Length of the slope } (l)}{\text{Height of slope } (h)}$$

or $$VR = \frac{l}{h}$$

Because of the friction, actual mechanical advantage will be reduced and so it is less than the velocity ratio/ideal mechanical advantage.

The longer the length of the slope is made keeping its height constant, the greater will be the velocity ratio and also increase the mechanical advantage. Due to longer effort arm, inclined plane is also called second order lever.

DO YOU KNOW ?

The ancient Egyptians used inclines to help in the construction of the great pyramids.

ACTIVITY 3.7

Take a wooden plank of about 1 metre long. Raise one of its ends to the height of about 30 cm with its other end resting on the ground. Pull a kinetic trolley on the inclined plane with a spring balance graduated in Newton. Read the effort necessary to pull the trolley up the slope. Measure the weight of trolley in the unit Newton. Calculate mechanical advantage and velocity ratio as follows.

$$VR = \frac{\text{Length of slope}}{\text{Height of slope}} = \frac{AB}{BC} = ?$$

$$MA = \frac{\text{Weight of trolley}}{\text{Effort necessary to pull}} = ?$$

You will find that the mechanical advantage is less than the velocity ratio, why?

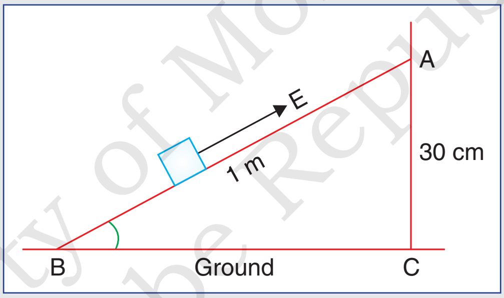


Fig. 3.29.

3.19. WORKING PRINCIPLE OF SCREW

A screw is a spirally winding inclined plane. A screw has a spiral ridge called thread of the screw.

The distance between two successive threads is called the pitch of the screw.

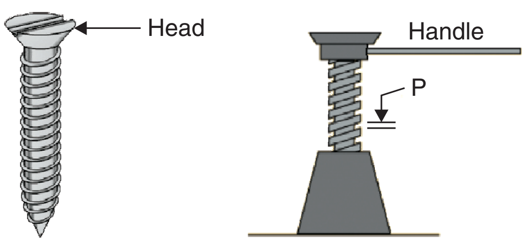


Fig. 3.30. Screw lifts lead gradually

When a screw is rotated to one revolution, the distance covered by the screw is equal to its pitch. So, the distance moved by load is also equal to the pitch. But the distance moved by the effort is equal to the circumference of the head of the screw or distance covered by effort in one revolution.

Therefore, velocity ratio $= \dfrac{\text{Circumference of head}}{\text{Pitch}} = \dfrac{2\pi r}{P}$

where r is the radius of head of the screw.

The jack screw, which is used for lifting heavy loads such as trucks, car etc. is also a kind of screw. It is provided with a handle to rotate the thread. When the handle is turned, the screw will move up and the load will be lifted. The load is lowered by turning handle in opposite direction. It is very efficient. A 10 kg screw can lift 1000 kg weight.

3.20. WORKING PRINCIPLE OF WEDGE

A wedge is a simple machine which has sharp edge with gradually thickened back part. It is usually used to cut, split or pierce a body. Axe, knife, needle, etc. are examples of the wedge.

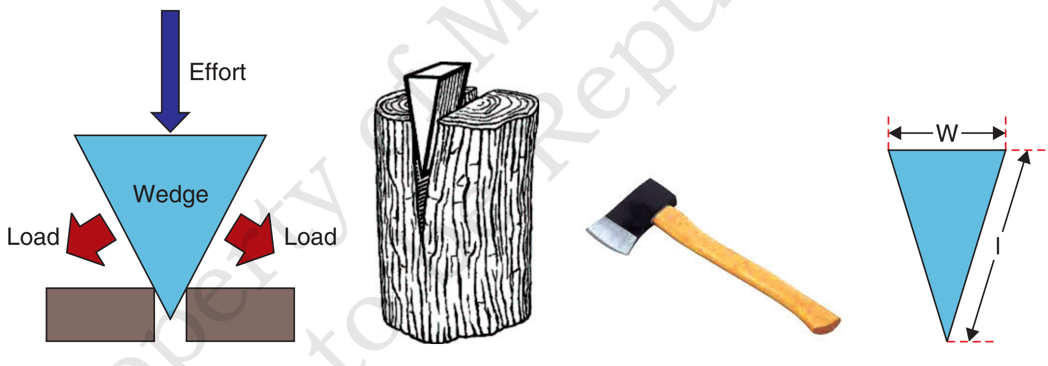


Fig. 3.31. A wedge

When an axe is struck against a log of wood the axe will stick into the wood.

The deeper the axe sticks the wider will be the splitting.

The distance moved by the load is equal to the width (w) of the wedge. Distance moved by the effort is equal to the length of the slope of the wedge.

Therefore,

$$\text{Velocity ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

or,

$$\text{VR} = \frac{\text{Length of its slope } (l)}{\text{Width } (w)}$$

or,

$$\text{VR} = \frac{l}{w}$$

Example 3.13: *Which wedge, A or B, being used to split logs, has the greater mechanical advantage?*

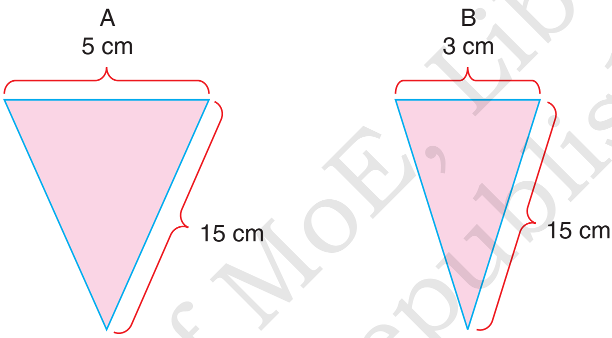


Fig. 3.32.

Solution:

MA for wedge A = 15 cm/5 cm = 3

MA for wedge B = 15 cm/3 cm = 5

Wedge B has the greater mechanical advantage.

GLOSSARY

Axle: Shaft on which a wheel rotates.

Block and tackle: A system of two or more pulleys using rope or cable to lift heavy objects.

Chemical Energy: It is the energy associated with the work done in making and breaking of bonds during chemical reaction.

Circumference: It is the length of the edge around a circle.

Efficiency: The ratio of work output to work input in a machine is called efficiency of that machine.

Effort arm: The distance between effort and fulcrum.

Electrical Energy: It is the energy made available by the flow of electric charge through an electric conductor.

Energy: It is defined as the ability to do work.

Fossils: These are the preserved remains or traces of animals, plants and other organisms from the remote past.

Inclined plane: A simple machine that reduces the effort needed to lift a load by increasing the distance it acts.

Kinetic Energy: An object in motion possesses what is known as the kinetic energy of the object. An object of mass, *m* moving with velocity *v* has a kinetic energy of $\frac{1}{2} mv^2$.

Lever: It is a rigid bar which is capable to rotate about a fixed point called fulcrum or pivot.

Light Energy: It is the energy due to electromagnetic radiation that is capable of causing a visual sensation.

Load arm: The distance between load and fulcrum.

Mechanical advantage: The ratio of the load moved by a simple machine to the effort applied on it is called mechanical advantage.

Mechanical Energy: The sum of the kinetic and potential energies of an object is called its mechanical energy.

Nuclear Energy: It is the energy released by a nuclear reaction, especially fission or fusion.

Pitch of the screw: The distance between two successive threads is called the Pitch of the Screw.

Potential Energy: The energy possessed by a body due to its change in position or shape is called the potential energy. The gravitational potential energy of an object of mass, *m* raised through a height, *h* from the earth's surface is given by $m\,g\,h$.

Power: It is defined as the rate of doing work or the rate of transfer of energy.

Public Address System: A system of microphones, amplifiers and loudspeakers used to amplify speech or music in a large building or at an outdoor gathering.

Ramp: An inclined plane used to help lift an object.

Screw: A spiral-shaped inclined plane.

Simple machine: Simple machine is defined as a device, which is used in our daily life to make our work easier faster and more comfortable.

Solar Energy: It is the radiant energy emitted by the sun. It is the most important source of energy on earth.

Sound Energy: It is the energy produced by sound vibrations in a medium.

Transformation of Energy: The change of one form of energy into another form of energy is know as transformation of energy.

Velocity ratio: The ratio of the distance moved by the effort to the distance moved by the load is called velocity ratio.

Wedge: A double inclined plane, such as a knife or an axe.

Work: Work is defined as the product of the force and displacement.

REVIEW EXERCISES

Do the review exercises in your notebook.

A. Multiple Choice Questions.

1. When force causes a displacement in its own direction, __________.

(a) work is done (b) energy is generated

(c) no work is done (d) work and energy are generated

2. According to the equation of work, when a boy sits in one place and studies for the whole night, he does __________.

(a) very little work (b) too much work

(c) lot of work (d) no work

3. Work may be done by __________.

(a) only non-living objects

(b) both living organisms and non-living objects

(c) only vehicles

(d) only living organisms

4. If the magnitude of force applied is increased, the work done will __________.

(a) have no change (b) be increased
(c) become zero (d) be decreased

5. Potential and kinetic energies are types of __________ energy.

(a) heat (b) nuclear
(c) sound (d) mechanical

6. In a freely falling body, the interchange of potential to kinetic energy takes place __________.

(a) alternately between kinetic and potential
(b) gradually from potential to kinetic
(c) like that in a pendulum
(d) gradually from kinetic to potential

7. The _________ is the main source of energy on planet Earth.

(a) wind (b) moon
(c) fire (d) sun

8. _________ are capable of performing work.

(a) Only some forms of force
(b) Only some forms of energy
(c) Only the difference forms of mechanical energy
(d) All forms of energy

9. A roller skate could be an example of ________.

(a) wheel and axle (b) lever
(c) inclined plane (d) pulley

10. A wedge may be used to ________.

(a) split a plank (b) lift a plank
(c) balance a plank (d) join two planks

11. The kitchen knife used in the kitchen everyday is actually ________.

(a) a pulley (b) a wedge
(c) a fulcrum (d) an inclined plane

12. For a ________ pulley, the MA is 1.

(a) movable (b) fixed
(c) system of two movable (d) system of fixed and movable

13. To lift a huge block of granite through a certain height, you should choose a ________.

(a) lever (b) inclined plane
(c) crowbar (d) screw jack

14. Which of the following is not true of inclined planes?
(a) A wedge and a screw both incorporate the use of inclined planes.
(b) When a screw is used to lift objects, its mechanical advantage is greater than that of any simple machine.
(c) Inclined planes and other simple machines reduce the effort required to perform a task.
(d) A needle is an example of a wedge.

15. The ________ is the part of a lever that bears the load to be raised.
(a) fulcrum (b) effort arm
(c) load arm (d) None of these

16. A pencil sharpener is an example of an object that can be used as which type of simple machine?
(a) wedge (b) wheel and axle
(c) lever (d) pulley

17. A block and tackle is:
(a) a form of fixed pulley
(b) a form of moveable pulley
(c) a combination of a fixed and moveable pulley
(d) used to suspend a pulley

18. In scissors the MA is
(a) greater than 1 (b) less than 1
(c) equal to 1 (d) None of these

B. Fill in the Blanks.

1. The metric unit of power is the _____________.
2. Energy is the ability to do _____________.
3. When energy is transferred in a system, the total amount of energy before the transfer is _____________ after the transformation is complete, just in different forms.
4. The energy of position-such as a rock on a hill is__________ energy.
5. Fission and fusion are examples of ______energy.
6. ___________ is a device which is used to transmit force to change the direction of force or to obtain gain in speed.

7. __________ is a straight or bent rod which can turn about a fixed point called fulcrum or pivot.
8. In a lever of first order, __________ is in the middle.
9. In a lever of second order, __________ is in the middle.
10. In a lever of third order, __________ is in the middle.

C. Answer the following Questions.

1. Explain the concepts of work, power and energy.
2. Name the different forms of energy.
3. Explain transformation of energy.
4. Explain how potential energy changes to kinetic energy and vice-versa.
5. State the law of conservation of energy.
6. A battery lights a bulb. Describe the energy changes involved in the process.
7. What is a simple machine? What are the three advantages of a simple machine?
8. What factors affect the mechanical advantage of a machine? How can it be increased?
9. Define velocity ratio. What does a VR of a machine indicate?
10. Give the advantages of a first order lever.
11. How is velocity ratio measured in a wheel and axle?
12. Draw a diagram of a wedge. How can its VR be increased?
13. What is a perfect machine?
14. Draw a wheel and axle.
15. What is efficiency of a machine? It is not 100%, why?
16. Give differences between input and output work.
17. Classify lever with 2 examples each.

D. Numericals.

1. Certain force acting on a 20 kg mass changes its velocity from 5 m s^{-1} to 2 m s^{-1}. Calculate the work done by the force.
2. An object of mass 40 kg is raised to a height of 5 m above the ground. What is its potential energy? If the object is allowed to fall, find its kinetic energy when it is half-way down.
3. Calculate the work required to be done to stop a car of 1500 kg moving at a velocity of 60 km/h.

4. A crane pulls up car having a mass of 1000 kg to a vertical height of 5 m. Calculate the work done by the crane.

5. A force of 10 N displaces a body by 2 m distance horizontally. Calculate amount of work done.

6. Calculate the kinetic energy (KE) of a 1500 kg automobile with a speed of 30 m/s.

7. A car having a mass of 500 kg is initially travelling with a speed of 80 km/hr. It slows down at a constant rate, coming to a stop in a distance of 50 m. What is the change in the car's kinetic energy over the 50 m distance it travels while coming to a stop?

8. Find the energy possessed by an object of mass 20 kg when it is at height of 12 m above the ground (Take $g = 9.8 \text{ ms}^{-2}$).

9. Calculate the time taken by a water pump of power 500 W to lift 2000 kg of water to a tank, which is at a height of 15 m from the ground?

10. A stone of mass 5 kg is lying at the edge of a cliff, which is 80 m above the ground. Calculate the energy possessed by the stone.

11. How much effort is needed to lift a load of 100 N placed at a distance of 20 cm from fulcrum, if effort is applied at 60 cm from the fulcrum on opposite side of the load? Calculate mechanical advantage of the lever.

12. If the length of an inclined plane is 2 metres and its height is 50 cm, find the velocity ratio of the machine. If the plane is frictionless, how much load can be pulled along the plane by an effort 50 N?

13. If 200 N load is lifted by 50 N in a system of double pulley, calculate the mechanical advantage and velocity ratio of the system.

14. To lift a load of 300 N in a second class lever an effort of 50 N is applied at a distance 90 cm from the fulcrum, at what distance should the load be put? Draw a diagram of the lever system.

15. A man uses a pulley system to raise a 150 N load to a height of 10 m. If he exerts a force on the rope of 50 N through a distance of 35 m to accomplish the work, (*a*) how much work does he do? (*b*) what is the efficiency of the machine?

16. A pulley system with a VR of 4 requires a force of 15 N to lift a load of 50 N. Find the efficiency of the machine.

17. A ramp 20 m in length is 5 m in height. What is the mechanical advantage of this simple machine?

18. Using the wheel and axle shown in Fig. 3.33, a 400 N load can be raised by a force of 50 N applied to the rim of the wheel. The radii of the wheel and axle are 85 cm and 6 cm, respectively. Determine the VR, MA and efficiency of the machine.

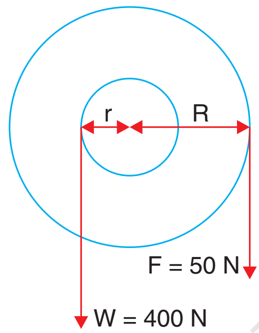


Fig. 3.33.

19. A student is able to lift a bag containing books of 20 kg, by applying a force of 5 kg, Find the mechanical advantage.

20. Find the mechanical advantage if Musa lifts a load of 30 kg by applying a force of 10 kg.

E. Questions based on Higher Order Thinking Skills (HOTS).

1. Look at the activities listed below. Reason out whether or not work is done in the light of your understanding of the term 'work'.

(a) Juliet is swimming in a pond.

(b) A donkey is carrying a load on its back.

(c) A wind-mill is lifting water from a well.

(d) A green plant is carrying out photosynthesis.

(e) An engine is pulling a train.

(f) Food grains are getting dried in the sun.

(g) A sailboat is moving due to wind energy.

2. The potential energy of a freely falling object decreases progressively. Does this violate the law of conservation of energy? Why?

3. Can there be displacement of an object in the absence of any force acting on it? Think. Discuss this question with your friends and teacher.

4. Alex holds a bundle of hay over his head for 30 minutes and gets tired. Has he done some work or not? Justify your answer.

5. In each of the following a force, F is acting on an object of mass, m. The direction of displacement is from west to east shown by the longer arrow. Observe the diagrams carefully and state whether the work done by the force is negative, positive or zero.

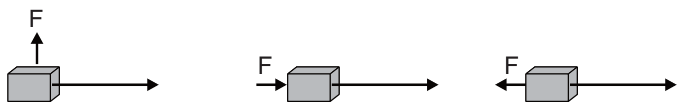


Fig. 3.34.

6. Manila says that the acceleration in an object could be zero even when several forces are acting on it. Do you agree with her? Why?

7. A freely falling object eventually stops on reaching the ground. What happens to its kinetic energy?

8. What two variables determine the mechanical advantage of a simple machine?

9. A screwdriver can be used to open a can of paint. In which form of a simple machine is the screwdriver being used?

10. Name the simple machines which come in the category of inclined plane.