5 Machines

You have learnt in your history lessons that man has been making and using tools since ancient times. Early man used tools such as scrapers and knives made of stone, and needles made of bone, shown in Figure 5.1(a). Today, we use tools such as those shown in Figure 5.1(b).

(a)

(b)

Fig. 5.1 (a) Prehistoric tools (b) Modern tools

We call the things shown in the pictures tools, and not machines, because we are used to thinking of tools as handy implements that simplify our work, and of machines as far more complex things. However, a machine need not be complex at all.

WHAT IS A MACHINE?

A machine is a device through which a force applied at one point overcomes resistance at some other point. For example, when you scoop up some sugar with a spoon, you apply some force on its handle. Its other end lifts the sugar. To do this, the spoon has to overcome the force of gravity acting on the sugar. This is the resistance offered by the sugar. Thus, a spoon is a machine. Similarly, a knife too is a machine. You apply some force on its handle, while its blade overcomes the resistance offered by the vegetable you are cutting.

A little thought will tell you that most of the common tools we use are, in fact, machines. The devices that we usually refer to as machines, on the other hand, have a large number of sections or pieces, each of which functions as a machine. A sewing machine or a bicycle, for example, has many sections that are themselves simple machines.

FUNCTIONS OF MACHINES

Machines can perform a number of functions, such as (a) changing the point of application of a force, (b) changing the direction in which a force has to be applied, (c) changing the magnitude of the force required, (d) changing the speed of the point of application of a force. The following are some common examples of these functions.

Changing the Point of Application of a Force

When something is too hot or cold, it is difficult to hold it. In other words, we cannot apply a force on it directly. Usually, we use tongs in such situations. We also use tongs, tweezers or forceps when we do not want to contaminate something or want to work on something fine or delicate. We apply force at one end of the tongs, while its other end applies force on the object. Thus, the point of application of force shifts from one end of the tongs to the other.

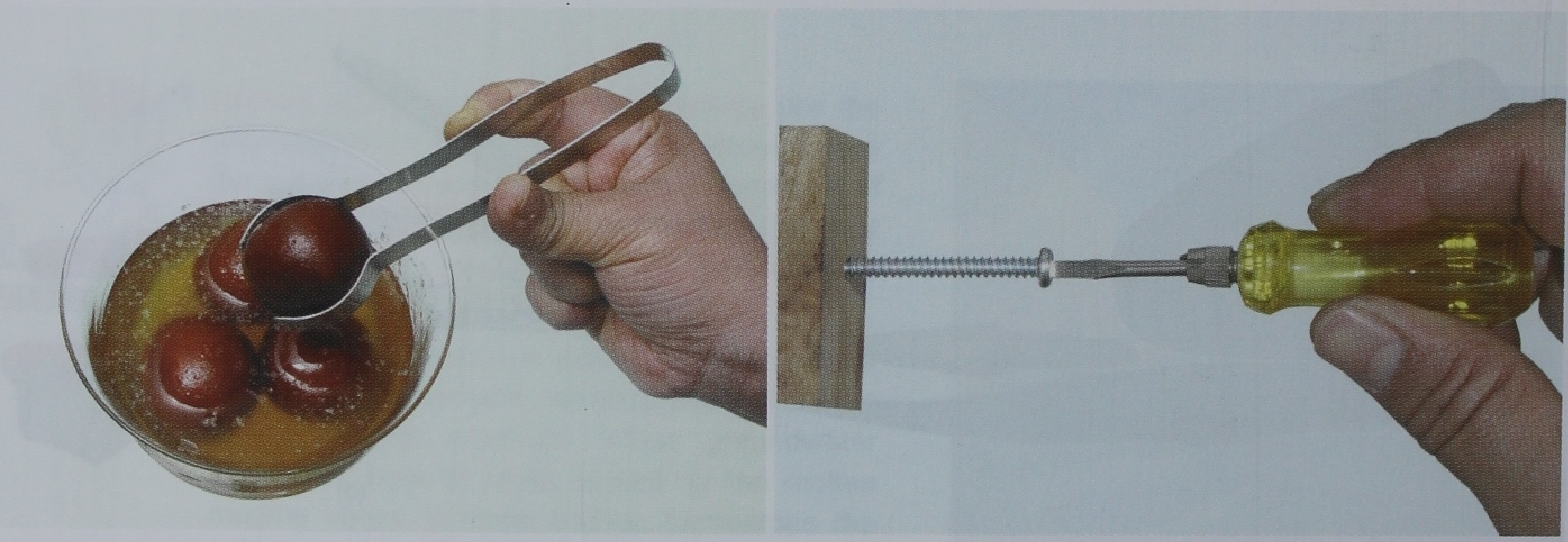


Fig. 5.2 Tongs and screwdrivers change the point of application of a force.

Spanners are used to tighten or loosen nuts and bolts, while screwdrivers are used to work on screws. One of the advantages of these simple machines is that they help us apply force on things located at points that are difficult to reach.

Changing the Direction in which Force is Applied

It is more convenient to apply a force in some directions than in others. For instance, it is easier to use our body weight to push something down than to pull the same thing up. Some machines make work easier for us by allowing us to apply a force in a direction that is convenient. A hand pump, for example, has a handle attached to a piston inside it. When we apply a downward force at one end of the handle, its other end applies an upward force to pull the piston inside the pump. If a hand pump did not have a handle, we would have to pull the piston up.

Fig. 5.3 The handle of a hand pump and a pulley change the direction in which force is applied.

A pulley used to draw water from a well serves a similar purpose. If we used a bucket tied to a rope to draw water directly from a well, we would have to apply an upward force. When we pass the rope over a pulley, however, we have to apply a downward force.

Changing the Magnitude of the Required Force

It is almost impossible to open the metal cap of a bottle with bare hands as this requires a large force. A bottle opener helps us remove the cap by applying a much smaller force on its handle. Nutcrackers, spanners and (car) jacks also help us the same way. They let us use a much smaller force than we would need to use without these machines. In other words, they magnify the force we apply.

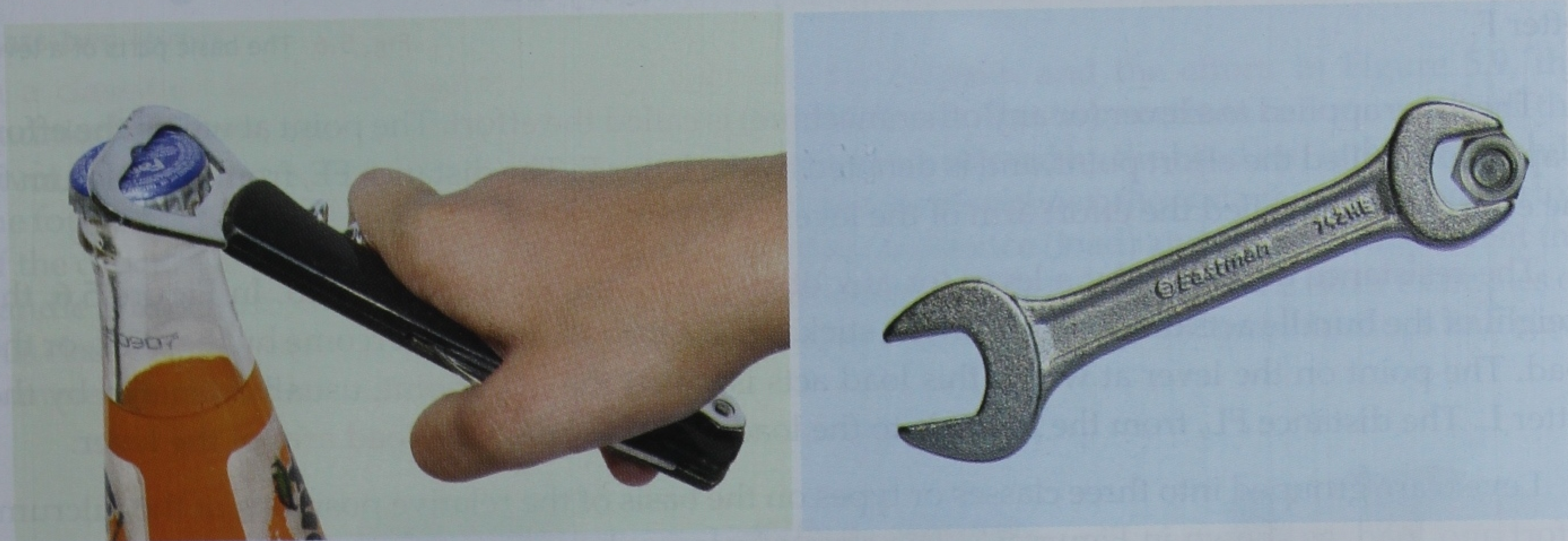


Fig. 5.4 Machines that magnify force

Changing the Speed

When you press the key of a typewriter, a long thin metal arm moves out and its head prints a letter on the paper. The speed of this head is much greater than the speed with which you press the key. Thus, this device increases the speed of the point of application of the force. Similarly, when the wheel attached to the pedals of a bicycle turns, it makes the cogwheel attached to the rear wheel turn much faster. This helps you gain speed.

Fig. 5.5 The cogwheel of a bicycle helps you gain speed.

TYPES OF MACHINES

We have discussed many different types of machines. Depending on the basic principles on which they work, they can be divided into different categories. These are (1) lever, (2) inclined plane, (3) wedge, (4) screw, (5) pulley and (6) wheel and axle. Though we have included the inclined plane in our list, it is not really a simple machine, as you will see.

Levers

A lever is a rigid body capable of rotating about a point on itself. A rigid body is a body which does not change its shape when forces act on it. Thus, a metal rod or a stout wooden stick is a rigid body. When such a body acts as a lever, it rotates or tends to rotate about some point on itself. This point is called the fulcrum. The fulcrum of a lever is the point about which it can rotate.

The stick resting on the man's shoulder in Figure 5.6 acts as a lever. It rests on the man's shoulder, and can rotate about this point. Therefore, this is the fulcrum of the lever, usually denoted by the letter F.

Fig. 5.6 The basic parts of a lever

The force applied *to* a lever (or any other machine) is called the effort. The point at which the effort is applied is called the effort point, and is denoted by the letter E. The distance FE, from the fulcrum to the effort point, is called the effort arm of the lever.

The resistance overcome by a lever (or any other machine) is called the load. In Figure 5.6, the weight of the bundle acts downwards on the stick. This is the resistance overcome by the stick, or the load. The point on the lever at which this load acts is called the load point, usually denoted by the letter L. The distance FL, from the fulcrum to the load point, is called the load arm of the lever.

Levers are grouped into three classes or types on the basis of the relative positions of the fulcrum, effort and load, as shown in Figure 5.7. The class of a lever depends only on the constituent (load, fulcrum or effort) located in the middle. If the two constituents on the two sides are interchanged, the class of the lever does not change.

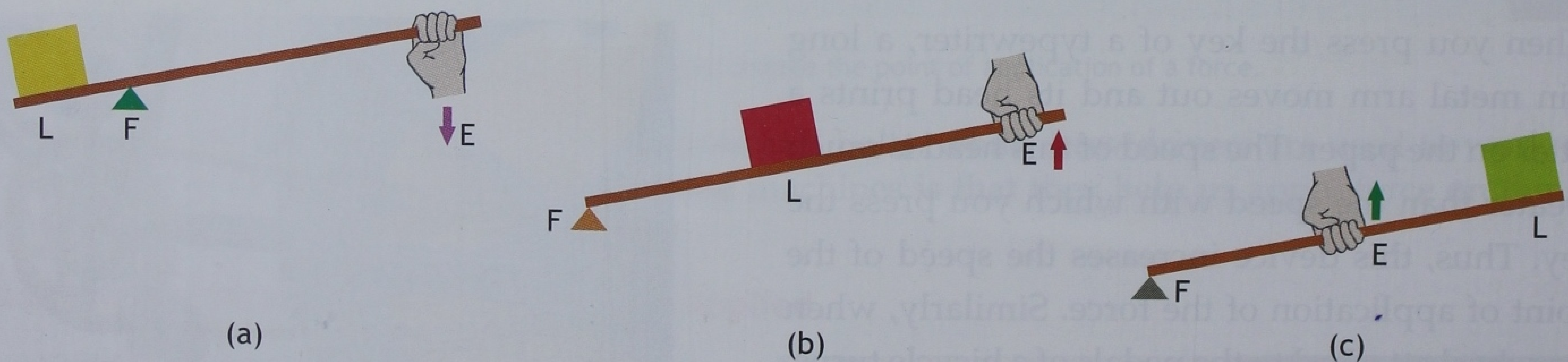


Fig. 5.7 (a) Class-one lever (b) Class-two lever (c) Class-three lever

Class-one levers

In a class-one lever, the fulcrum lies between the load and the effort. The positions of the load and effort with respect to the fulcrum do not matter.

If you look at Figure 5.6 again, you will see at once that the stick acts as a class-one lever, as the fulcrum is in the middle, with the load and the effort on either side. Another common example of a lever of this type is the see-saw. The pivot at the centre is the fulcrum, while the two persons on either side act as the load and effort. The handle of a hand pump is an excellent example of a class-one lever. The pivot about which it moves is the fulcrum, the force applied is the effort, and the force which the piston exerts on its other end is the load. Scissors, pliers and tongs of the type shown in Figure 5.8 are also class-one levers. These are called double levers, since they have two identical levers working together.

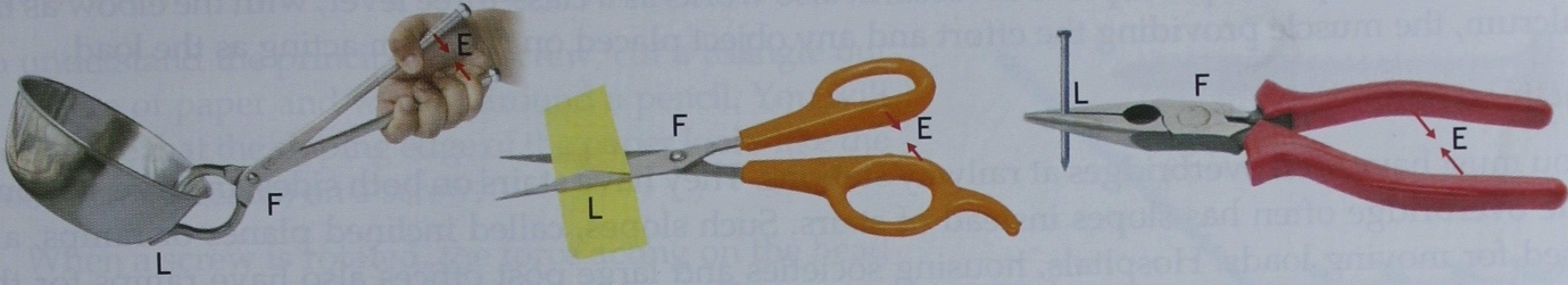


Fig. 5.8 Tongs, scissors and pliers are double levers of class one.

Class-two levers

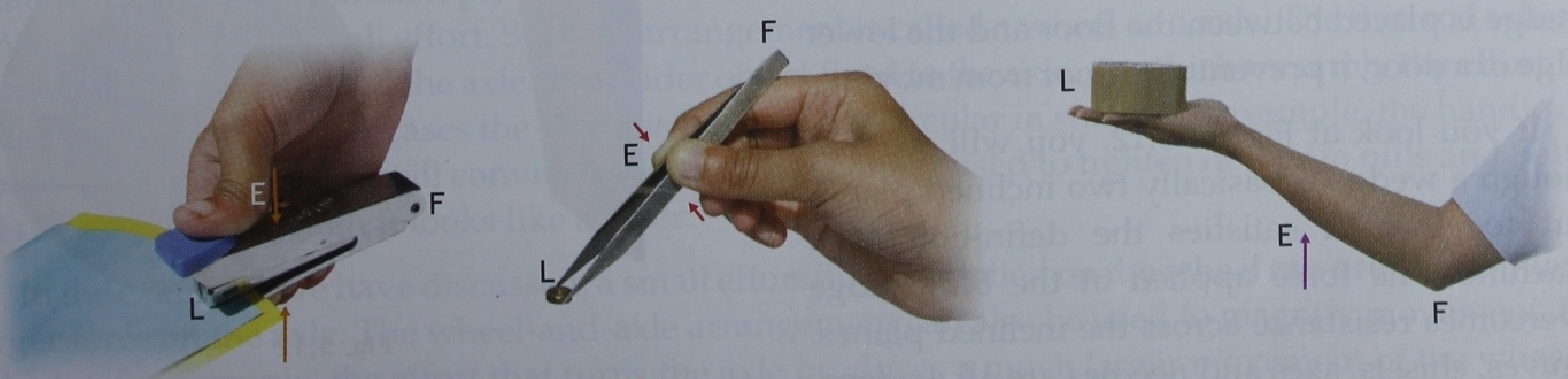
In a class-two lever, the load is situated between the fulcrum and the effort. In Figure 5.9, the traditional *saraota*, used to chop betel nuts, is a double lever. The two sections can move about the pivot, which is at one end. This is the fulcrum. The resistance offered by the betel nut is the load, while the forces applied on its handles constitute the effort. In a bottle opener, the end which rests on the top of the cap acts as the fulcrum, the edge of the cap offers resistance (load) and the force applied at the handle is the effort. The handle of a nail cutter also works as a class-two lever. Some other examples of this class of levers are nutcrackers, wheelbarrows, paper cutters used in photographic shops and claw hammers used to pull out nails.

Fig. 5.9 Class-two levers

Class-three levers

In this class of levers, the effort lies between the load and the fulcrum. Figure 5.10 shows a stapler on the left. Its two sections are pivoted at one end, which is the fulcrum. The fingers pressing from two sides constitute the effort, while the metallic staple is the load. Thread snippers and tweezers are quite

Fig. 5.10 Class-three levers



similar to the stapler in principle. Our forearm also works as a class-three lever, with the elbow as the fulcrum, the muscle providing the effort and any object placed on the palm acting as the load.

Inclined Plane

You must have seen overbridges at railway stations. They have stairs on both sides. In large stations, one overbridge often has slopes instead of stairs. Such slopes, called inclined planes or ramps, are used for moving loads. Hospitals, housing societies and large post offices also have ramps for the movement of wheelchairs and loads. Labourers engaged in loading and unloading trucks and railway wagons use thick planks to set up temporary inclined planes. The main advantage of an inclined plane over stairs is that objects can be rolled on it, and it is always easier to roll or slide an object than to lift it.

Fig. 5.11 Inclined plane

Although the inclined plane is of great convenience, it is not really a machine, as it does not satisfy the definition of a machine, which says that a force applied at one point overcomes a resistance at *another* point. However, the principle of the inclined plane is used in the screw, which is a machine.

Wedge

A small piece of wood or metal which is thick at one end and thin at the other is called a wedge. Wedges are often used by woodcutters and carpenters for cutting or splitting wood. They are also jammed into logs being sawed so that the ends do not press in on the saw. A wedge can be used as a door stopper. When the thin end of a wedge is placed between the floor and the lower edge of a door, it prevents the door from moving.

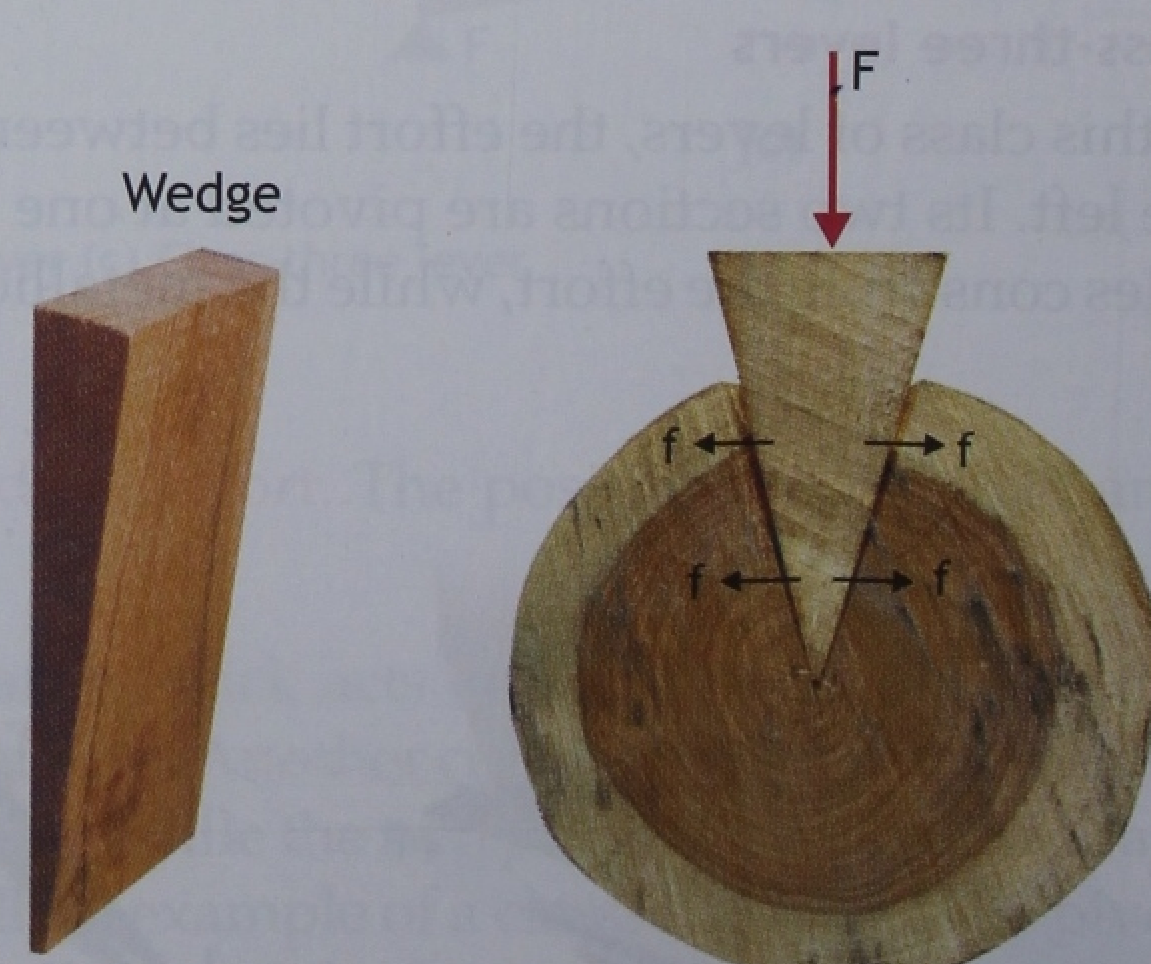


Fig. 5.12

If you look at Figure 5.12, you will see that though a wedge is basically two inclined planes put together, it satisfies the definition of a machine. The force applied at the blunt edge overcomes resistance across the inclined planes. Knives, chisels, axes and needles are all wedges.

Screw

To understand the principle of a screw, cut a triangle out of a piece of paper and wrap it around a pencil. You will see at once that the sloping edge of the paper looks like the grooves (or threads) on a screw.

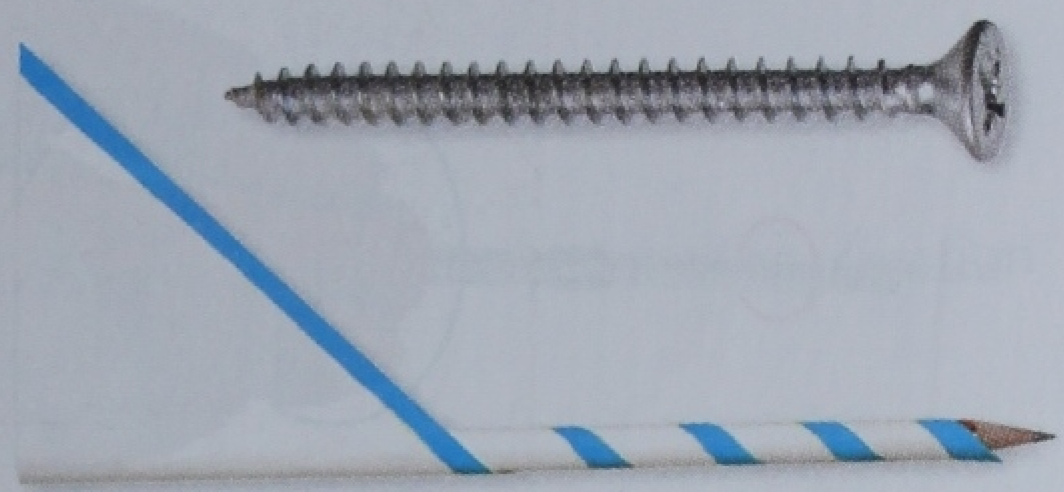
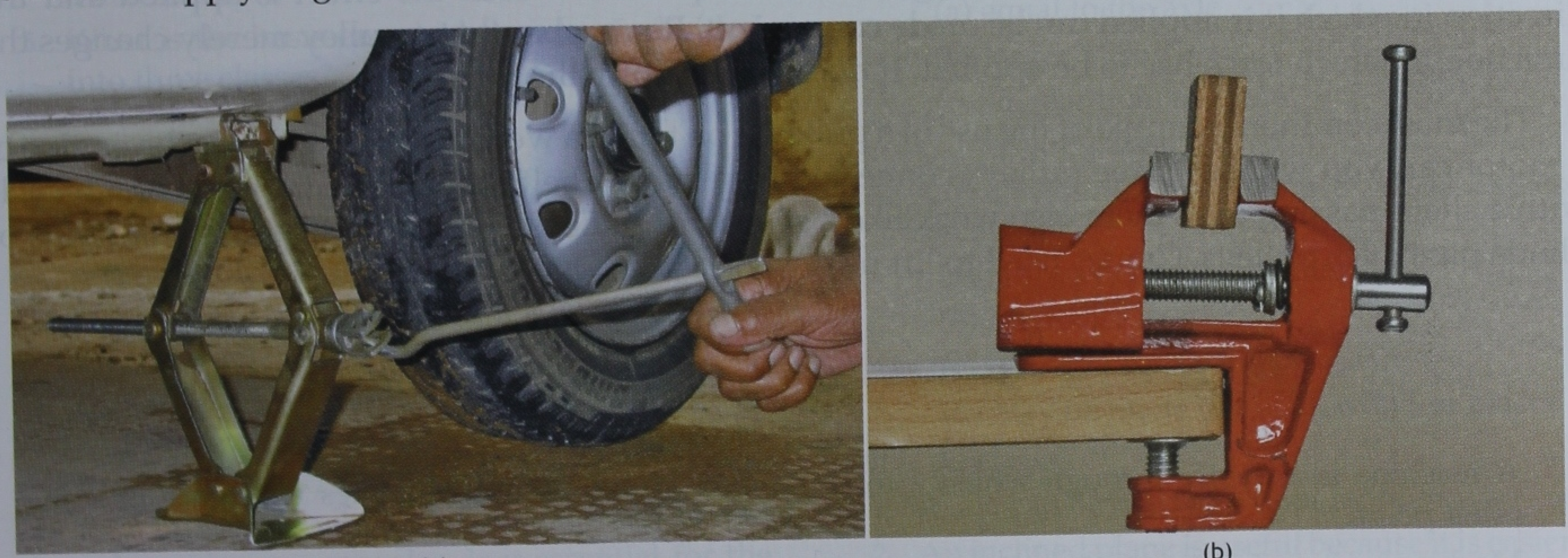


Fig. 5.13 A screw is a nail with an inclined plane wrapped around it.

When a screw is rotated, the force acting on the head of the screw is 'transmitted' along its grooves. The screw, thus, winds into the material along the grooves. The advantage of a screw over a nail is that one has to use less force to drive it in than to drive in a nail. A bolt rotating inside a fixed nut and a jack used to lift a car work on the same principle. When the screw of a jack is rotated by the long handle, it gradually pushes the car up. The vice used to grip objects firmly in a workshop is another common application of the screw. The object is held between the jaws of the vice. One jaw is fixed while the other moves when the screw is rotated by turning its handle. The jaws can be made to apply large forces on the object by turning the screw.



(a) (b)

Fig. 5.14 (a) A car jack and (b) a vice are applications of the screw.

Wheel and Axle

Many of our everyday actions involve turning something. This could be a tap, a door knob, a screwdriver or the steering wheel of a car. In each case, the actual object which needs to be turned is usually a thin rod, such as the spindle of the tap or the shaft of the screwdriver. Since it is not easy to rotate a thin rod, the common practice is to fix a wider handle or knob or wheel to the rod, so that it can be turned with a small effort. Such an arrangement is called a wheel and axle. The thin rod which needs to be turned is called the axle. The wider object fixed to the axle, on which we apply the effort, is called the wheel. In many cases the wheel is not actually circular in shape, for example, the handle of a bicycle. A little thought will convince you that the spanner used to tighten or loosen nuts and bolts acts like a wheel, though it looks like a lever.

In the examples we have discussed, a small effort (force) applied on the wheel can produce a much larger force on the axle. The wheel-and-axle arrangement can also be used to magnify movement. In vehicles, for example, the effort that turns the axle produces a much larger movement of the wheel.

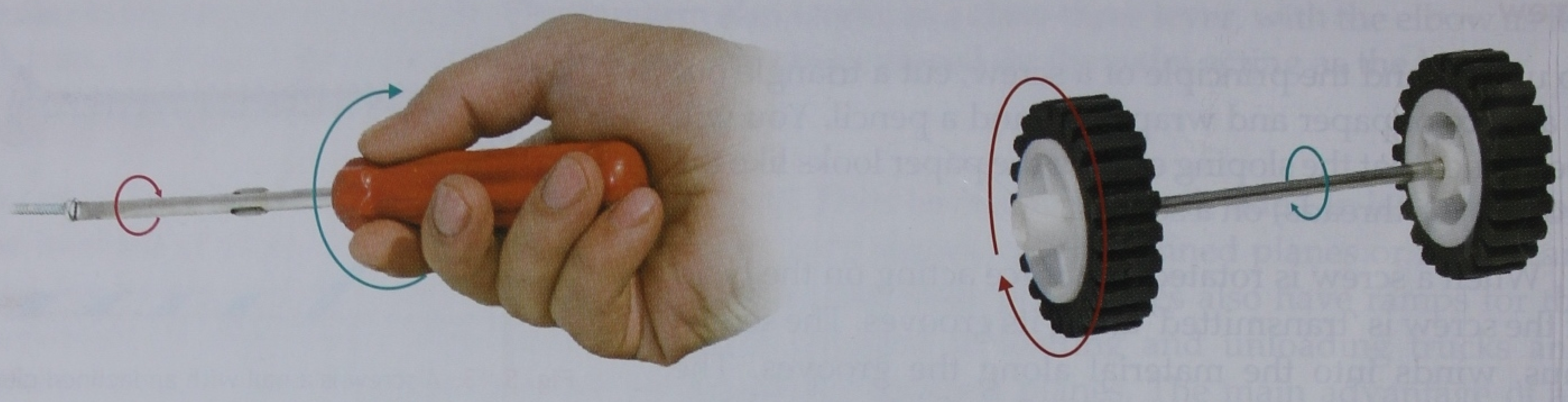


Fig. 5.15 The wheel-and-axle arrangement can be used (a) to magnify force or (b) to magnify movement.

Pulley

A pulley is a wheel or disc which can rotate freely about its axle. A string or rope passing over the pulley fits into a slight depression along its rim. One end of the string is attached to the load. The effort is applied at its other end. The advantage is that the point at which the effort is applied and the direction in which it is applied can be made convenient. Remember that a pulley merely changes the direction in which force has to be applied. It does not magnify the force.

The most common example of the use of a pulley is on top of a well. If you look inside the engine of a motor car, you will see three pulleys connected by a rubber belt. The toothed wheels of a bicycle with a chain passing over them also work like a system of pulleys. Strings used to draw curtains or blinds pass over pulleys. Cranes used to lift heavy objects also have pulleys.

POINTS TO REMEMBER

- A machine is a device through which a force applied at one point overcomes resistance at some other point.
- Machines can perform a number of functions, such as
  (a) changing the point of application of a force, e.g., a pair of tongs,
  (b) changing the direction in which a force is applied, e.g., the handle of a hand pump,
  (c) changing the magnitude of the required force, e.g., a bottle opener, and
  (d) changing the speed of the point of application of a force, e.g., the arm of a typewriter.
- The main categories of machines are (1) lever, (2) wedge, (3) screw, (4) pulley and (5) wheel and axle.
- A lever is a rigid body capable of rotating about a point on itself. The fulcrum of a lever is the point about which it can rotate.
- The effort is the force applied to a machine, and the load is the resistance (force) overcome by a machine.
- There are three classes of levers. A class-one lever has the fulcrum in the middle, e.g., scissors. A class-two lever has the load in the middle, e.g., bottle opener. A class-three lever has the effort in the middle, e.g., the forearm.
- An inclined plane or ramp is a slope along which loads can be moved by rolling or sliding. It does not satisfy the definition of a machine.
- A wedge consists of two inclined planes put together. It acts as a machine.

- A screw is a nail with grooves or threads going round it. Jacks used to lift cars, and vices work on the principle of the screw.
- A wide handle or wheel fixed to a rod is called a wheel-and-axle arrangement. The rod is called the axle. The wider object fixed to the axle is called the wheel.
- A pulley is a wheel or disc which can rotate freely about its axle. It can change the point of application and direction of the effort.

EXERCISE

Short-Answer Questions

1. Define a machine.
2. Name four categories of machines.
3. What is a lever? What is meant by its fulcrum?
4. What is meant by the load and effort for a machine?
5. What is the basis on which levers are divided into three classes?

Long-Answer Questions

1. Name four functions which machines can perform. Explain each function with one example.
2. Describe the different parts of a lever. Describe the different classes of levers with examples.
3. Explain the relation between an inclined plane and a screw. Describe the working of (a) a jack used to lift a car, and (b) a vice.
4. Explain clearly what is meant by a wheel and axle, with two examples. Is it essential for the wheel section to be circular? Give one example.
5. What is a wedge? How is it similar to an inclined plane? How does it function as a machine? Mention two applications of a wedge.

Objective Questions

Choose the correct option.

1. Which of the following is a class-three lever?
   (a) See-saw (b) Bottle opener
   (c) Stapler (d) Betel nut cutter
2. Which of the following pairs of levers do not belong to the same class?
   (a) Stapler and human forearm
   (b) Bottle opener and betel nut cutter
   (c) See-saw and handle of tube well
   (d) Nail cutter and scissors
3. A vice used to grip objects firmly works on the principle of the
   (a) screw (b) wedge
   (c) pulley (d) lever
4. In a wheel-and-axle arrangement, the wheel must be
   (a) equal to the axle
   (b) larger than the axle
   (c) smaller than the axle
   (d) of circular shape
5. A pulley is different from a wheel and axle since it
   (a) is always circular in shape
   (b) is smaller in size
   (c) is free to rotate about its axle
   (d) may be made of metal, wood or plastic

Fill in the blanks.

1. A ...... can be used as a door stopper.
2. An inclined plane is useful because it is easier to ...... an object than to lift it.
3. A screwdriver changes the point of application of a force and also acts as a ....
4. A jack used to lift a car is an application of the ....
5. A lever is a ...... body capable of rotating about a point on itself.

Write true or false.

1. In a lever, the load and the effort can never act in the same direction.
2. The handle and shaft of a screwdriver act as a wheel-and-axle arrangement.
3. The handle of a bicycle acts as a class-one lever.
4. A single machine may be made up of a number of machines.
5. A pulley can reduce the effort needed to overcome a particular load.

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