7•1 Why We Use Machines

Science Words

- machine
- simple machine
- effort force
- resistance force
- ideal machine
- mechanical advantage

Objectives

- Explain how machines make work easier.
- Calculate mechanical advantage.

What are machines?

Have you used any machines today? You probably know that a bicycle is a machine. Pencil sharpeners and can openers are also machines. If you have turned a doorknob or twisted off a bottle cap, you have used a machine. A **machine** is a device that makes work easier.

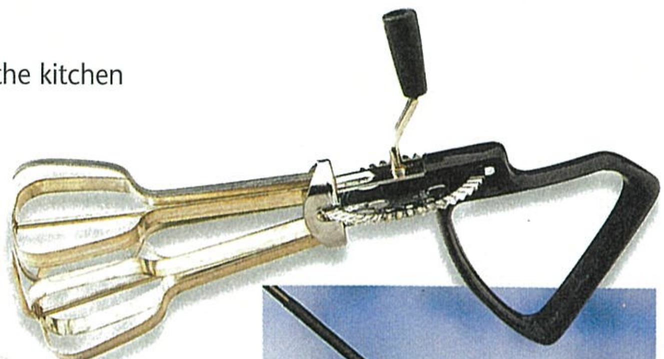
Keeping It Simple

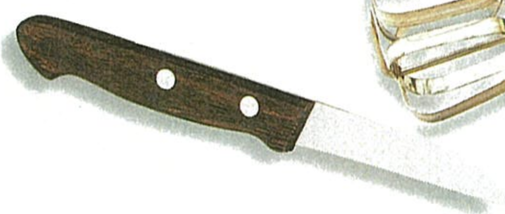
Some machines are powered by engines or electric motors; others are people-powered. Some machines are complex; others are simple. A **simple machine** is a device that does work with only one movement. There are six types of simple machines, examples of which are shown in **Figure 7-1.** You'll learn more about each type in a later section of this chapter.

Figure 7-1

Familiar examples of simple machines can be found in the following places.

A in the kitchen





B in sports

C in construction

Advantages of Simple Machines

Suppose you wanted to pry the lid off a wooden crate with a crowbar. You'd slip the end of the crowbar blade under the edge of the crate lid and push down on the handle. You would do work on the crowbar, and the crowbar would do work on the lid.

Machines make work easier by changing the force you exert in size, direction, or both. **Figure 7-2** shows how the crowbar changes the size and direction of your force as you attempt to lift the lid.

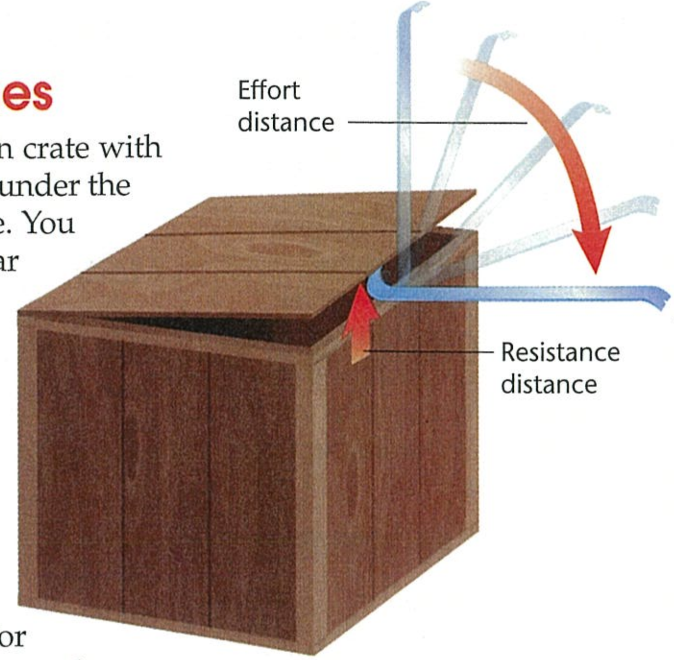


Figure 7-2

The crowbar is used to multiply the effort force and open the crate. However, to gain force, the effort must push through a greater distance than the resistance distance.

Overcoming Gravity and Friction

When you use a simple machine, you are trying to move something that resists being moved. For example, when you use a crowbar to move a large rock, you are working against gravity—the weight of the rock. When you use a crowbar to remove a lid, you are working against friction—the friction between the nails in the lid and the crate.

Applying Force and Doing Work

Two forces are involved when a machine is used to do work. The force applied *to* the machine is called the **effort force (F_e).** The force applied *by* the machine to overcome resistance is called the **resistance force (F_r).** In the crate lid example, you apply the effort force to the crowbar handle. The resistance force is the force the crowbar applies to the lid.

There are also two kinds of work to be considered when a machine is used—the work done *on* the machine and the work done *by* the machine. The work done on the machine is called work input (W_{in}); the work done by the machine is called work output (W_{out}). Recall that work is the product of force and distance: $W = F \times d$. Work input is the product of the effort force and the distance that force is exerted: $W_{in} = F_e \times d_e$. Work output is the product of the resistance force and the distance that force moves: $W_{out} = F_r \times d_r$.

Remember that energy is always conserved. So, you can never get more work out of a machine than you put into it. In other words, W_{out} can never be greater than W_{in}. In fact, whenever a machine is used, some energy is changed to heat due to friction. So, W_{out} is always smaller than W_{in}.

Although a perfect machine has never been built, it helps to imagine a frictionless machine in which no energy is converted to heat. Such an **ideal machine** is one in which work input equals work output. For an ideal machine,

$$W_{in} = W_{out}$$

$$F_e \times d_e = F_r \times d_r$$

CONNECT TO

LIFE SCIENCE

Birds fly using their wings to move them through the air. ***Identify*** the resistance and effort forces for this simple machine by making a labeled drawing.

In most cases, a machine multiplies the force applied to it—F_r is greater than F_e. So, in order for W_{in} to equal W_{out}, the effort force must travel farther than the resistance force—d_e must be greater than d_r.

Mechanical Advantage

Think again about the crate lid example. The distance you move the crowbar handle (d_e) is greater than the distance the crowbar moves the lid (d_r). So, the end of the crowbar must exert more force on the lid (F_r) than you exert on the handle (F_e). The machine multiplies your effort, but you must move the handle a greater distance.

The number of times a machine multiplies the effort force is the **mechanical advantage (MA)** of the machine. To calculate mechanical advantage, you divide the resistance force by the effort force.

$$MA = \frac{\text{resistance force}}{\text{effort force}} = \frac{F_r}{F_e}$$

Work the problems below to see how mechanical advantage is related to effort force and resistance force.

Some machines don't multiply force. They simply change the direction of the effort force. For example, when you pull

USING MATH

Calculating Mechanical Advantage

Example Problem:

A worker applies an effort force of 20 N to pry open a window that has a resistance force of 500 N. What is the mechanical advantage of the crowbar?

Problem-Solving Steps:

1. What is known?
resistance force, $F_r = 500$ N
effort force, $F_e = 20$ N

2. What is unknown?
mechanical advantage, *MA*

3. Choose the equation.

$$MA = \frac{F_r}{F_e}$$

4. Solution: $MA = \frac{500 \text{ N}}{20 \text{ N}} = 25$

Practice Problem

Find the effort force needed to lift a 2000-N rock, using a jack with a mechanical advantage of 10.

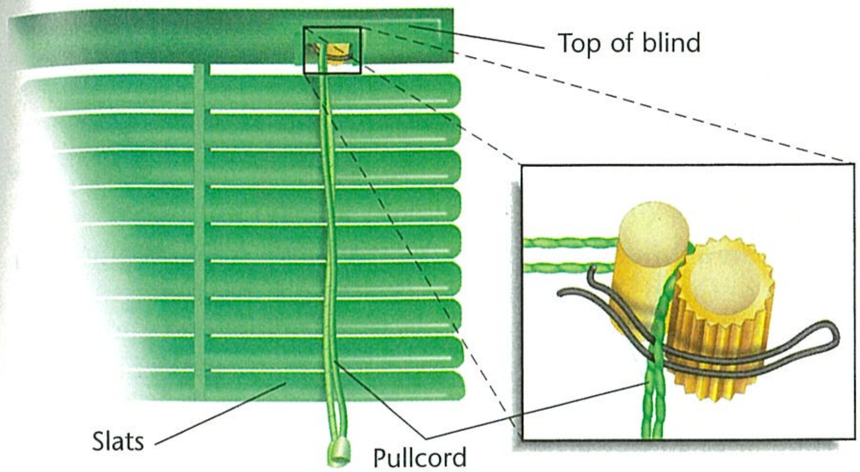


Figure 7-3

Miniblinds are a familiar example of a simple machine that changes the direction of a force.

down on the cord of window blinds, such as those in **Figure 7-3,** the blinds go up. Only the direction of the force changes; the effort force and resistance force are equal, so the mechanical advantage is 1.

Other machines, such as third-class levers, have mechanical advantages that are less than 1. Such machines are used to increase the distance an object moves or the speed at which it moves.

Section Wrap-up

Review

1. Explain how simple machines can make work easier without violating the law of conservation of energy.
2. A carpenter uses a claw hammer to pull a nail from a board. The nail has a resistance of 2500 N. The carpenter applies an effort force of 125 N. What is the mechanical advantage of the hammer?
3. **Think Critically:** Give an example of a simple machine you've used recently. How did you apply effort force? How did the machine apply resistance force?

Skill Builder

Recognizing Cause and Effect

When you operate a machine, it's often easy to observe cause and effect. For example, when you turn a doorknob, the latch in the door moves. Give five examples of machines and describe one cause-and-effect pair in the action of each machine. If you need help, refer to Recognizing Cause and Effect in the **Skill Handbook.**

USING MATH

Suppose you want to use a simple machine to lift a 6000-N log from a fallen tree. What effort force will you need if your machine has a mechanical advantage of 25? Of 15? Of 1? Show your calculations.