SECTION 2

What Is a Machine?

You are in the car with your mom on the way to a party when suddenly—KABLOOM hisssss—a tire blows out. "Now I'm going to be late!" you think as your mom pulls over to the side of the road.

What You Will Learn

- Explain how a machine makes work easier.
- Describe and give examples of the force-distance trade-off that occurs when a machine is used.
- Calculate mechanical advantage.
- Explain why machines are not 100% efficient.

Vocabulary

machine
work input
work output
mechanical advantage
mechanical efficiency

READING STRATEGY

Prediction Guide Before reading this section, write the title of each heading in this section. Next, under each heading, write what you think you will learn.

You watch as she opens the trunk and gets out a jack and a tire iron. Using the tire iron, she pries the hubcap off and begins to unscrew the lug nuts from the wheel. She then puts the jack under the car and turns the jack's handle several times until the flat tire no longer touches the ground. After exchanging the flat tire with the spare, she lowers the jack and puts the lug nuts and hubcap back on the wheel.

"Wow!" you think, "That wasn't as hard as I thought it would be." As your mom drops you off at the party, you think how lucky it was that she had the right equipment to change the tire.

Machines: Making Work Easier

Now, imagine changing a tire without the jack and the tire iron. Would it have been easy? No, you would have needed several people just to hold up the car! Sometimes, you need the help of machines to do work. A **machine** is a device that makes work easier by changing the size or direction of a force.

When you think of machines, you might think of things such as cars, big construction equipment, or even computers. But not all machines are complicated. In fact, you use many simple machines in your everyday life. **Figure 1** shows some examples of machines.

Figure 1 Some Everyday Machines

Work In, Work Out

Suppose that you need to get the lid off a can of paint. What do you do? One way to pry the lid off is to use a common machine known as a *lever*. **Figure 2** shows a screwdriver being used as a lever. You place the tip of the screwdriver under the edge of the lid and then push down on the screwdriver's handle. The tip of the screwdriver lifts the lid as you push down. In other words, you do work on the screwdriver, and the screwdriver does work on the lid.

Work is done when a force is applied through a distance. Look again at **Figure 2.** The work that you do on a machine is called **work input.** You apply a force, called the *input force,* to the machine through a distance. The work done by the machine on an object is called **work output.** The machine applies a force, called the *output force,* through a distance.

machine a device that helps do work by either overcoming a force or changing the direction of the applied force

work input the work done on a machine; the product of the input force and the distance through which the force is exerted

work output the work done by a machine; the product of the output force and the distance through which the force is exerted

How Machines Help

You might think that machines help you because they increase the amount of work done. But that's not true. If you multiplied the forces by the distances through which the forces are applied in **Figure 2** (remember that $W = F \times d$), you would find that the screwdriver does not do more work on the lid than you do on the screwdriver. Work output can never be greater than work input. Machines allow force to be applied over a greater distance, which means that less force will be needed for the same amount of work.

Reading Check **How do machines make work easier?** (*See the Appendix for answers to Reading Checks.*)

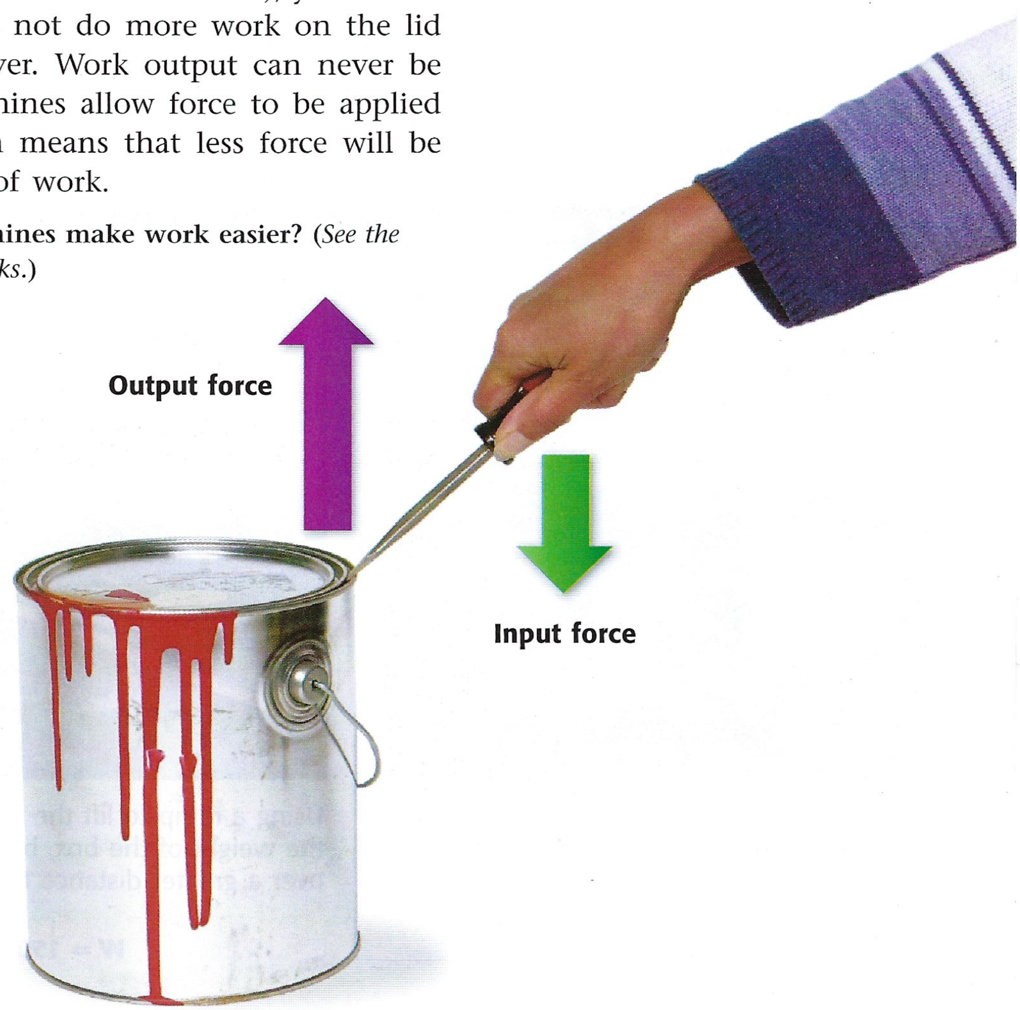


Figure 2 *When you use a machine, you do work on the machine, and the machine does work on something else.*

Same Work, Different Force

Machines make work easier by changing the size or direction (or both) of the input force. When a screwdriver is used as a lever to open a paint can, both the size and direction of the input force change. Remember that using a machine does not change the amount of work you will do. As **Figure 3** shows, the same amount of work is done with or without the ramp. The ramp decreases the size of the input force needed to lift the box but increases the distance over which the force is exerted. So, the machine allows a smaller force to be applied over a longer distance.

INTERNET ACTIVITY

For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HP5WRKW.**

The Force-Distance Trade-Off

When a machine changes the size of the force, the distance through which the force is exerted must also change. Force or distance can increase, but both cannot increase. When one increases, the other must decrease.

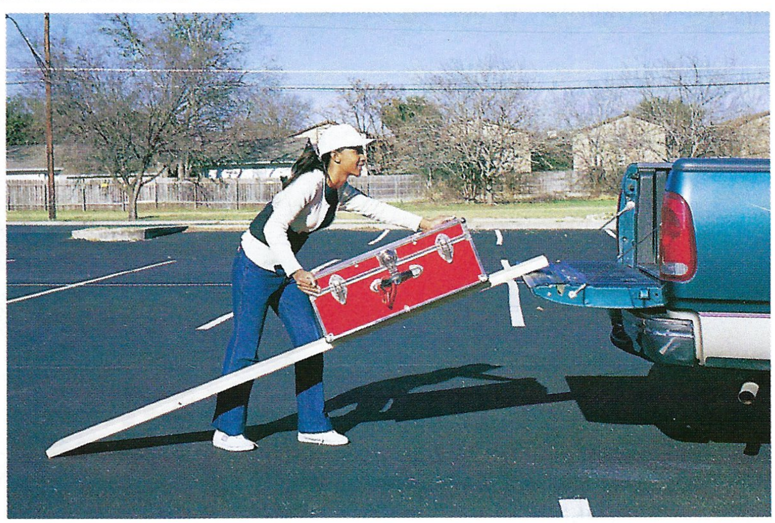
Figure 4 shows how machines change force and distance. Whenever a machine changes the size of a force, the machine also changes the distance through which the force is applied. **Figure 4** also shows that some machines change only the direction of the force, not the size of the force or the distance through which the force is exerted.

Reading Check **What are the two things that a machine can change about how work is done?**

Figure 3 Input Force and Distance

Lifting this box straight up requires an input force equal to the weight of the box.

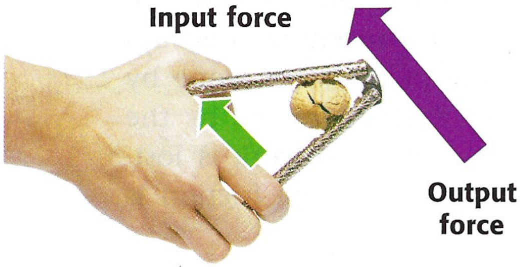
$W = 450\ \text{N} \times 1\ \text{m} = 450\ \text{J}$



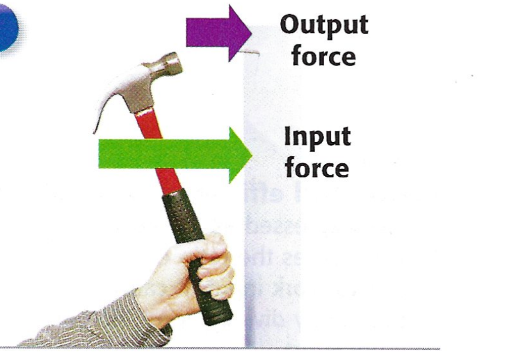
Using a ramp to lift the box requires an input force less than the weight of the box, but the input force must be exerted over a greater distance than if you didn't use a ramp.

$W = 150\ \text{N} \times 3\ \text{m} = 450\ \text{J}$

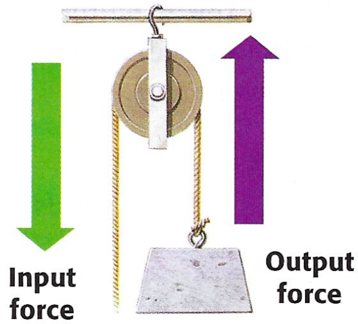
Figure 4 Machines Change the Size and/or Direction of a Force



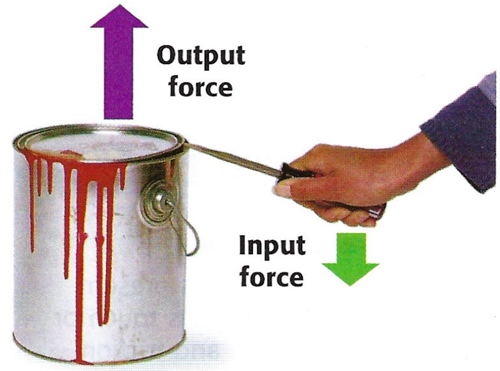
A nutcracker *increases* the force but applies it over a *shorter* distance.



A hammer *decreases* the force, but applies it over a *greater* distance.



A simple pulley changes the *direction* of the input force, but the size of the output force is the same as the input force.



When a screwdriver is used as a lever, it *increases* the force and *decreases* the distance over which the force is applied.

Mechanical Advantage

Some machines make work easier than others do because they can increase force more than other machines can. A machine's **mechanical advantage** is the number of times the machine multiplies force. In other words, the mechanical advantage compares the input force with the output force.

mechanical advantage a number that tells how many times a machine multiplies force

Calculating Mechanical Advantage

You can find mechanical advantage by using the following equation:

$$\textit{mechanical advantage (MA)} = \frac{\textit{output force}}{\textit{input force}}$$

For example, imagine that you had to push a 500 N weight up a ramp and only needed to push with 50 N of force the entire time. The mechanical advantage of the ramp would be calculated as follows:

$$MA = \frac{500\text{ N}}{50\text{ N}} = 10$$

A machine that has a mechanical advantage that is greater than 1 can help move or lift heavy objects because the output force is greater than the input force. A machine that has a mechanical advantage that is less than 1 will reduce the output force but can increase the distance an object moves. **Figure 4** shows an example of such a machine—a hammer.

MATH PRACTICE

Finding the Advantage

A grocer uses a handcart to lift a heavy stack of canned food. Suppose that he applies an input force of 40 N to the handcart. The cart applies an output force of 320 N to the stack of canned food. What is the mechanical advantage of the handcart?

Mechanical Efficiency

The work output of a machine can never be greater than the work input. In fact, the work output of a machine is always less than the work input. Why? Some of the work done by the machine is used to overcome the friction created by the use of the machine. But keep in mind that no work is lost. The work output plus the work done to overcome friction is equal to the work input.

mechanical efficiency a quantity, usually expressed as a percentage, that measures the ratio of work output to work input; it can be calculated by dividing work output by work input

The less work a machine has to do to overcome friction, the more efficient the machine is. **Mechanical efficiency** (muh KAN i kuhl e FISH uhn see) is a comparison of a machine's work output with the work input.

SCHOOL to HOME

Useful Friction

Friction is always present when two objects touch or rub together, and friction usually slows down moving parts in a machine and heats them up. In some cases, parts in a machine are designed to increase friction. While at home, observe three situations in which friction is useful. Describe them in your **science journal.**

ACTIVITY

Calculating Efficiency

A machine's mechanical efficiency is calculated using the following equation:

$$\textit{mechanical efficiency} = \frac{\textit{work output}}{\textit{work input}} \times 100$$

The 100 in this equation means that mechanical efficiency is expressed as a percentage. Mechanical efficiency tells you what percentage of the work input gets converted into work output.

Figure 5 shows a machine that is used to drill holes in metal. Some of the work input is used to overcome the friction between the metal and the drill. This energy cannot be used to do work on the steel block. Instead, it heats up the steel and the machine itself.

Reading Check **How is mechanical efficiency calculated?**

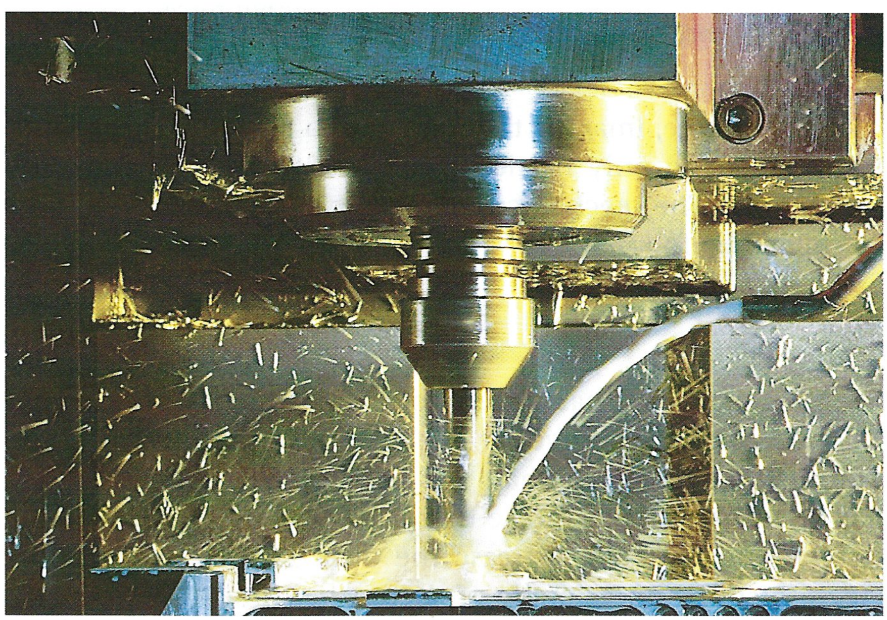


Figure 5 *In this machine, some of the work input is converted into sound and heat energy.*

Perfect Efficiency?

An *ideal machine* would be a machine that had 100% mechanical efficiency. An ideal machine's useful work output would equal the work done on the machine. Ideal machines are impossible to build, because every machine has moving parts. Moving parts always use some of the work input to overcome friction. But new technologies help increase efficiency so that more energy is available to do useful work. The train in **Figure 6** is floating on magnets, so there is almost no friction between the train and the tracks. Other machines use lubricants, such as oil or grease, to lower the friction between their moving parts, which makes the machines more efficient.

Figure 6 *There is very little friction between this magnetic levitation train and its tracks, so it is highly efficient.*

SECTION Review

Summary

- A machine makes work easier by changing the size or direction (or both) of a force.
- A machine can increase force or distance, but not both.
- Mechanical advantage tells how many times a machine multiplies force.
- Mechanical efficiency is a comparison of a machine's work output with work input.
- Machines are not 100% efficient because some of the work done is used to overcome friction.

Using Key Terms

For each pair of terms, explain how the meanings of the terms differ.

1. *work input* and *work output*
2. *mechanical advantage* and *mechanical efficiency*

Understanding Key Ideas

3. Which of the following is the correct way to calculate mechanical advantage?
   a. input force ÷ output force
   b. output force ÷ input force
   c. work input ÷ work output
   d. work output ÷ work input
4. Explain how using a ramp makes work easier.
5. Give a specific example of a machine, and describe how its mechanical efficiency might be calculated.
6. Why can't a machine be 100% efficient?

Math Skills

7. Suppose that you exert 60 N on a machine and the machine exerts 300 N on another object. What is the machine's mechanical advantage?
8. What is the mechanical efficiency of a machine whose work input is 100 J and work output is 30 J?

Critical Thinking

9. **Making Inferences** For a machine with a mechanical advantage of 3, how does the distance through which the output force is exerted differ from the distance through which the input force is exerted?
10. **Analyzing Processes** Describe the effect that friction has on a machine's mechanical efficiency. How do lubricants increase a machine's mechanical efficiency?