8

Work and Machines

The Big Idea

Work is the transfer of energy to an object, and power is the rate at which work is done. Machines are devices that help make work easier.

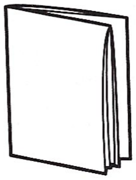
SECTION

About the PHOTO

"One, two, stroke!" shouts the coach as the team races to the finish line. This paddling team is competing in Hong Kong's annual Dragon Boat Races. The Dragon Boat Festival is a 2,000-year-old Chinese tradition that commemorates Qu Yuan, a national hero. The paddlers that you see here are using the paddles to move the boat forward. Even though they are celebrating by racing their dragon boat, in scientific terms, this team is doing work.

PRE-READING ACTIVITY

FOLDNOTES **Booklet** Before you read the chapter, create the FoldNote entitled "Booklet" described in the **Study Skills** section of the Appendix. Label each page of the booklet with a main idea from the chapter. As you read the chapter, write what you learn about each main idea on the appropriate page of the booklet.



SECTION 1

Work and Power

Your science teacher has just given you tonight's homework assignment. You have to read an entire chapter by tomorrow! That sounds like a lot of work!

What You Will Learn

- Determine when work is being done on an object.
- Calculate the amount of work done on an object.
- Explain the difference between work and power.

Vocabulary

work
power
joule
watt

READING STRATEGY

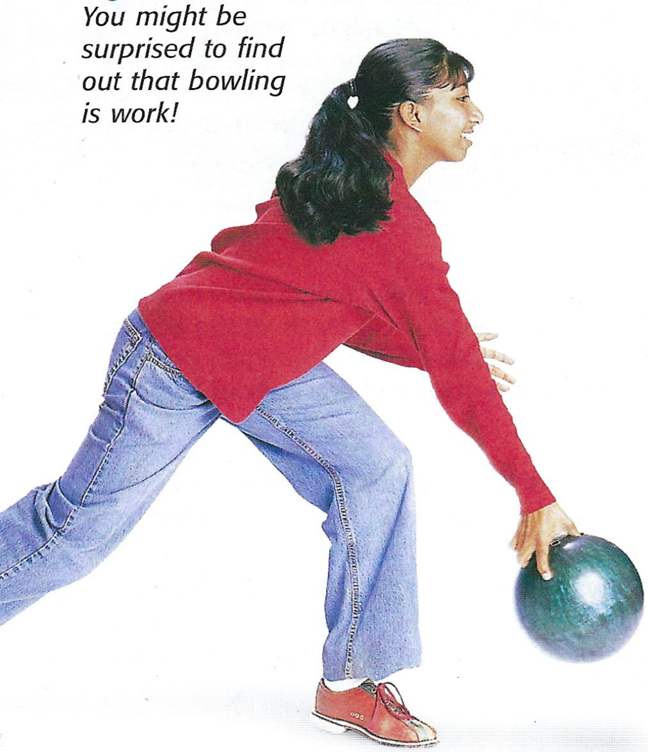
Reading Organizer As you read this section, make a table comparing work and power.

Actually, in the scientific sense, you won't be doing much work at all! How can that be? In science, **work** is done when a force causes an object to move in the direction of the force. In the example above, you may have to put a lot of mental effort into doing your homework, but you won't be using force to move anything. So, in the scientific sense, you will not be doing work—except the work to turn the pages of your book!

What Is Work?

The student in **Figure 1** is having a lot of fun, isn't she? But she is doing work, even though she is having fun. She is doing work because she is applying a force to the bowling ball and making the ball move through a distance. However, she is doing work on the ball only as long as she is touching it. The ball will keep moving away from her after she releases it. But she will no longer be doing work on the ball because she will no longer be applying a force to it.

Figure 1 *You might be surprised to find out that bowling is work!*



Transfer of Energy

One way you can tell that the bowler in **Figure 1** has done work on the bowling ball is that the ball now has *kinetic energy.* This means that the ball is now moving. The bowler has transferred energy to the ball.

Differences Between Force and Work

Applying a force doesn't always result in work being done. Suppose that you help push a stalled car. You push and push, but the car doesn't budge. The pushing may have made you tired. But you haven't done any work on the car, because the car hasn't moved.

You do work on the car as soon as the car moves. Whenever you apply a force to an object and the object moves in the direction of the force, you have done work on the object.

Reading Check **Is work done every time a force is applied to an object? Explain.** (*See the Appendix for answers to Reading Checks.*)

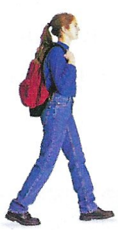
Force and Motion in the Same Direction

Suppose you are in the airport and late for a flight. You have to run through the airport carrying a heavy suitcase. Because you are making the suitcase move, you are doing work on it, right? Wrong! For work to be done on an object, the object must move in the *same direction* as the force. You are applying a force to hold the suitcase up, but the suitcase is moving forward. So, no work is done on the suitcase. But work *is* done on the suitcase when you lift it off the ground.

Work is done on an object if two things happen: (1) the object moves as a force is applied and (2) the direction of the object's motion is the same as the direction of the force. The pictures and arrows in **Figure 2** will help you understand when work is being done on an object.

work the transfer of energy to an object by using a force that causes the object to move in the direction of the force

Figure 2 Work or Not Work?

Example	Direction of force	Direction of motion	Doing work?
	→	→	Yes
	↑	→	No
	↑	↑	Yes
	↑	→	No

CONNECTION TO Biology

WRITING SKILL **Work in the Human Body**

You may not be doing any work on a suitcase if you are just holding it in your hands, but your body will still get tired from the effort because you are doing work on the muscles inside your body. Your muscles can contract thousands of times in just a few seconds while you try to keep the suitcase from falling. What other situations can you think of that might involve work being done somewhere inside your body? Describe these situations in your **science journal.**

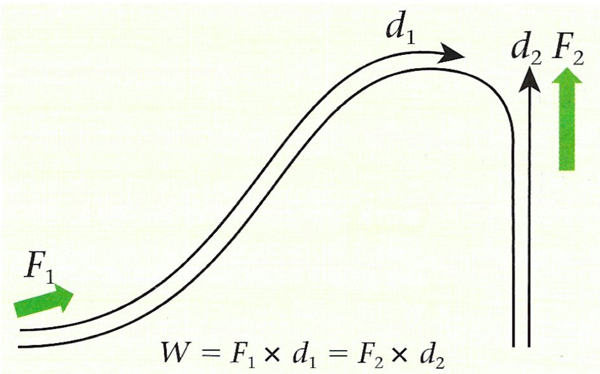


Figure 3 *For each path, the same work is done to move the car to the top of the hill, although distance and force along the two paths differ.*

How Much Work?

Would you do more work on a car by pushing it up a long road to reach the top of a hill or by using a cable to raise the car up the side of a cliff to the top of the same hill? You would certainly need a different amount of force. Common use of the word *work* may make it seem that there would be a difference in the amount of work done in the two cases as well.

Same Work, Different Forces

You may be surprised to learn that the same amount of work is being done to push the car up a road as to raise it up the cliff. Look at **Figure 3.** A certain amount of energy is needed to move the car from the bottom to the top of the hill. Because the car ends up at the same place either way, the work done on the car is the same. However, pushing the car along the road up a hill seems easier than lifting it straight up. Why?

The reason is that work depends on distance as well as force. Consider a mountain climber who reaches the top of a mountain by climbing straight up a cliff, as in **Figure 4.** She must use enough force to overcome her entire weight. But the distance she travels up the cliff is shorter than the distance traveled by hikers who reach the top of the same mountain by walking up a slope. Either way, the same amount of work is done. But the hikers going up a slope don't need to use as much force as if they were going straight up the side of the cliff. This shows how you can use less force to do the same amount of work.

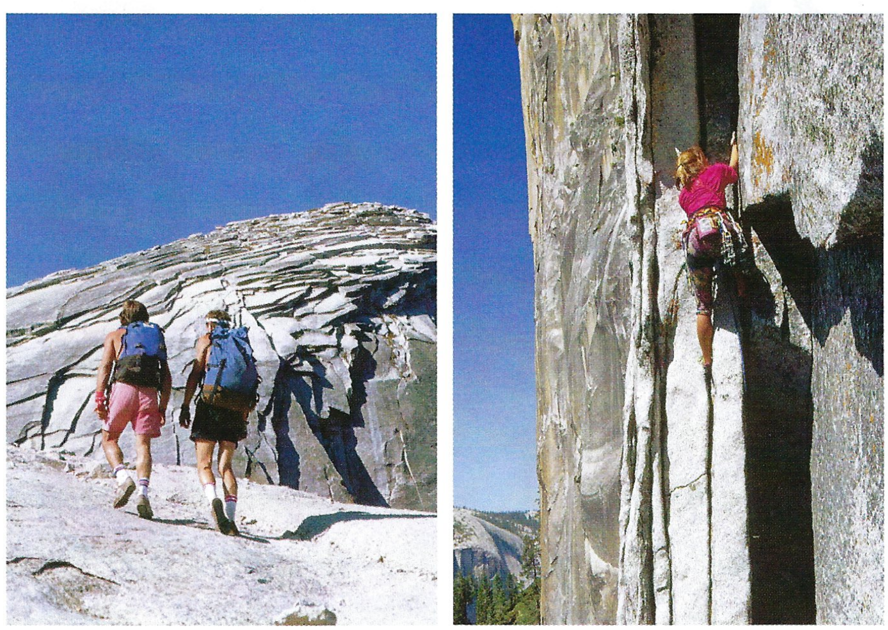


Figure 4 *Climbers going to the top of a mountain do the same amount of work whether they hike up a slope or go straight up a cliff.*

Calculating Work

The amount of work (W) done in moving an object, such as the barbell in **Figure 5,** can be calculated by multiplying the force (F) applied to the object by the distance (d) through which the force is applied, as shown in the following equation:

$$W = F \times d$$

Force is expressed in newtons, and the meter is the basic SI unit for length or distance. Therefore, the unit used to express work is the newton-meter (N × m), which is more simply called the **joule.** Because work is the transfer of energy to an object, the joule (J) is also the unit used to measure energy.

joule the unit used to express energy; equivalent to the amount of work done by a force of 1 N acting through a distance of 1 m in the direction of the force (symbol, J)

Reading Check How is work calculated?

Figure 5 **Force Times Distance**

W = 80 N × 1 m = 80 J
The force needed to lift an object is equal to the gravitational force on the object—in other words, the object's weight.

W = 160 N × 1 m = 160 J
If you increase the weight, an increased force is needed to lift the object. This increases the amount of work done.

W = 80 N × 2 m = 160 J
Increasing the distance also increases the amount of work done.

Quick Lab

Get to Work!

1. Use a **loop of string** to attach a **spring scale** to a **weight.**
2. Slowly pull the weight across a **table** by dragging the spring scale. Record the amount of force that you exerted on the weight.
3. Use a **metric ruler** to measure the distance that you pulled the weight.
4. Now, use the spring scale to slowly pull the weight up a **ramp.** Pull the weight the same distance that you pulled it across the table.
5. Calculate the work you did on the weight for both trials.
6. How were the amounts of work and force affected by the way you pulled the weight? What other ways of pulling the weight could you test?

Power: How Fast Work Is Done

power the rate at which work is done or energy is transformed

watt the unit used to express power; equivalent to joules per second (symbol, W)

Like the term *work,* the term *power* is used a lot in everyday language but has a very specific meaning in science. **Power** is the rate at which energy is transferred.

Calculating Power

To calculate power (P), you divide the amount of work done (W) by the time (t) it takes to do that work, as shown in the following equation:

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

The unit used to express power is joules per second (J/s), also called the **watt.** One watt (W) is equal to 1 J/s. So if you do 50 J of work in 5 s, your power is 10 J/s, or 10 W.

Power measures how fast work happens, or how quickly energy is transferred. When more work is done in a given amount of time, the power output is greater. Power output is also greater when the time it takes to do a certain amount of work is decreased, as shown in **Figure 6.**

Reading Check How is power calculated?

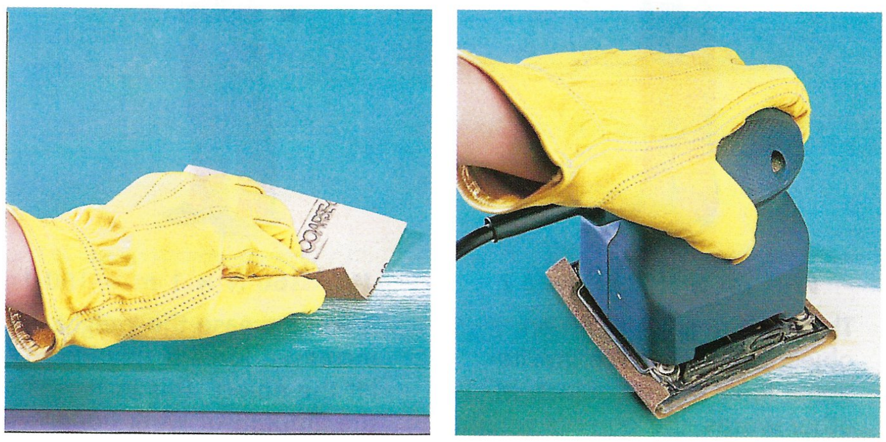


Figure 6 *No matter how fast you can sand by hand, an electric sander can do the same amount of work faster. Therefore, the electric sander has more power.*

Math Focus

More Power to You A stage manager at a play raises the curtain by doing 5,976 J of work on the curtain in 12 s. What is the power output of the stage manager?

Step 1: Write the equation for power.

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

Step 2: Replace W and t with work and time.

$$P = \frac{5{,}976\ \text{J}}{12\ \text{s}} = 498\ \text{W}$$

Now It's Your Turn

1. If it takes you 10 s to do 150 J of work on a box to move it up a ramp, what is your power output?
2. A light bulb is on for 12 s, and during that time it uses 1,200 J of electrical energy. What is the wattage (power) of the light bulb?

Increasing Power

It may take you longer to sand a wooden shelf by hand than by using an electric sander, but the amount of energy needed is the same either way. Only the power output is lower when you sand the shelf by hand (although your hand may get more tired). You could also dry your hair with a fan, but it would take a long time! A hair dryer is more powerful. It can give off energy more quickly than a fan does, so your hair dries faster.

Car engines are usually rated with a certain power output. The more powerful the engine is, the more quickly the engine can move a car. And for a given speed, a more powerful engine can move a heavier car than a less powerful engine can.

CONNECTION TO Language Arts

WRITING SKILL **Horsepower** The unit of power most commonly used to rate car engines is the *horsepower* (hp). Look up the word *horsepower* in a dictionary. How many watts is equal to 1 hp? Do you think all horses output exactly 1 hp? Why or why not? Write your answers in your **science journal.**

SECTION Review

Summary

- In scientific terms, *work* is done when a force causes an object to move in the direction of the force.
- Work is calculated as force times distance. The unit of work is the newton-meter, or joule.
- *Power* is a measure of how fast work is done.
- Power is calculated as work divided by time. The unit of power is the joule per second, or watt.

Using Key Terms

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

1. *work* and *joule*
2. *power* and *watt*

Understanding Key Ideas

3. How is work calculated?
   a. force times distance
   b. force divided by distance
   c. power times distance
   d. power divided by distance
4. What is the difference between work and power?

Math Skills

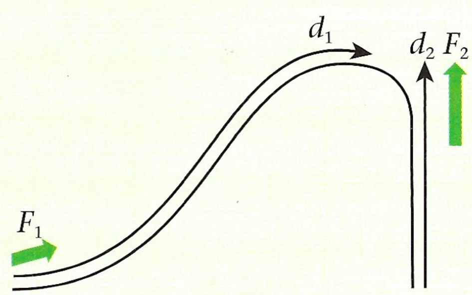
5. Using a force of 10 N, you push a shopping cart 10 m. How much work did you do?
6. If you did 100 J of work in 5 s, what was your power output?

Critical Thinking

7. **Analyzing Processes** Work is done on a ball when a pitcher throws it. Is the pitcher still doing work on the ball as it flies through the air? Explain.
8. **Applying Concepts** You lift a chair that weighs 50 N to a height of 0.5 m and carry it 10 m across the room. How much work do you do on the chair?

Interpreting Graphics

9. What idea about work and force does the following diagram describe? Explain your answer.



$$W = F_1 \times d_1 = F_2 \times d_2$$

SCILINKS NSTA Developed and maintained by the National Science Teachers Association

For a variety of links related to this chapter, go to www.scilinks.org

Topic: Work and Power
SciLinks code: HSM1675