

Work and Power



We all have our ideas about what the word *work* means. Sometimes we really want to work on something we enjoy—like learning how to play guitar. Other times, we would like to be lazy and do no work. You may also have ideas about the words *efficiency* and *power*. In science, work, efficiency, and power have special meanings. Work means that something is moved by a force. Look at the excavator on this page. What is being moved? What force is involved? Machines like excavators have a lot of power because they help people move more dirt faster. However, is this machine as efficient at moving dirt as the human body machine? Think about these questions as you get to work reading this chapter!

Key Questions:

- ✓ Are you really doing work when you do your science homework?
- ✓ What is the relationship between work and power?
- ✓ How can you produce more power than an excavator?



8.1 Work

Energy is a measure of an object's ability to do work. If you have energy, then you can do work. That means you can make forces that act to move things. Suppose you lift your book over your head. Your arm muscles make forces, and those forces cause the book to move, therefore you do work. Now, suppose you lift your book fast, then lift it again slowly. The work is the same because the force it takes to lift the book (its weight) is the same, and the distance (height) is the same. But it feels different to do the work fast or slow. The difference between doing work fast or slow is described by *power*. Power is the rate at which energy flows or at which work is done. This section is about work and power.

Reviewing the definition of work

What *work* means
in physics

In the last chapter you learned that work has a very specific meaning in physical science. **Work** is the transfer of energy that results from applying a force over a distance (Figure 8.1). If you push a box with a force of 1 newton for a distance of 1 meter, you do 1 joule of work. Both work and energy are measured in the same units (joules) because work is a form of energy.

Work is done by
forces that cause
movement

When thinking about work, remember that work is *done by forces that cause movement*. If nothing moves (distance is zero), then no work is done, even if a huge force is applied. For example, in the scientific sense, you don't do any work if you push a box that stays glued to the table. However, if you push the box 1 meter with a force of 1 newton, you have done 1 joule of work.

WORK

$$\text{Work (J)} \quad W = Fd$$

Force (N) Distance in the direction of the force (m)

VOCABULARY

work - a form of energy that comes from force applied over distance. A force of 1 newton does 1 joule of work when the force causes 1 meter of motion in the direction of the force.



Figure 8.1: Work is a form of energy you either use or get when a force is applied over a distance.

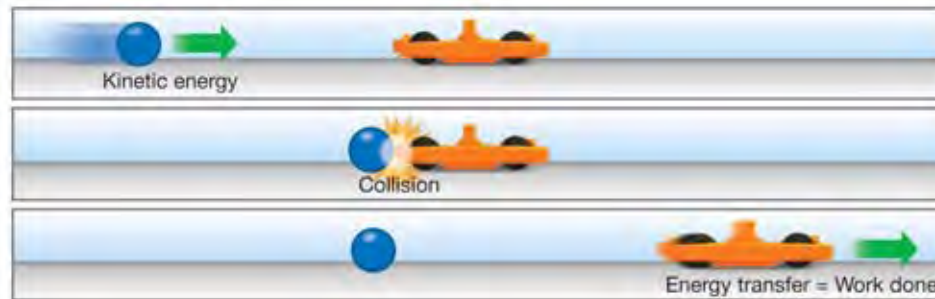
STUDY SKILLS

When studying, remember that the definition for a joule, the unit of energy, is the same as the definition for work!

Definition of **joule** = Definition of **work**

Reviewing work and energy

Energy is needed to do work Recall that energy is always needed to do work. An object that has energy is able to do work; without energy, it is impossible to do work. The more energy you have, the more work you can do. For example, a ball rolling across a table has kinetic energy that can be used to do work. If the ball collides with a toy car, it will do work on the car and change its motion. Some of the ball's kinetic energy is transferred to the car. Collision is a common method of doing work.



Work and energy transfer Doing work always means *transferring* energy. The energy may be transferred to the object to which the force is applied to, or it may go somewhere else. For example, you can increase the potential energy of a rubber band by exerting a force that stretches it. The work you do stretching the rubber band is stored as elastic energy in the rubber band. In this case, the work you do stretching the rubber band is partially transferred to the rubber band itself. The rubber band can then use the elastic energy to do work on a toy car, giving it kinetic energy (Figure 8.2).

Work may not increase the energy of an object The exact amount of energy used to do work is always transferred somewhere. But not all work is transformed to the kind of energy you might initially think about. For example, you can do work on a block by sliding it across a level table. In this example, the work you do does *not* increase the energy of the block. Because the block will not slide back all by itself, it does not gain the ability to do work *itself*, therefore it gains no energy. Your work is done to overcome *friction* and eventually becomes heat and wear.

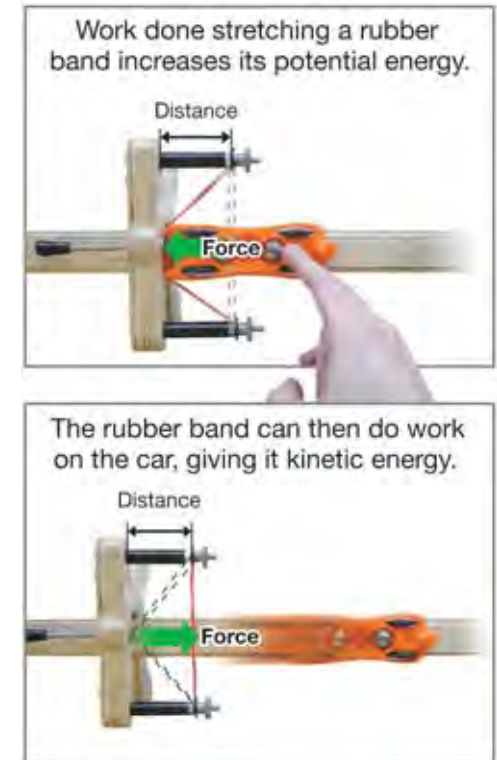
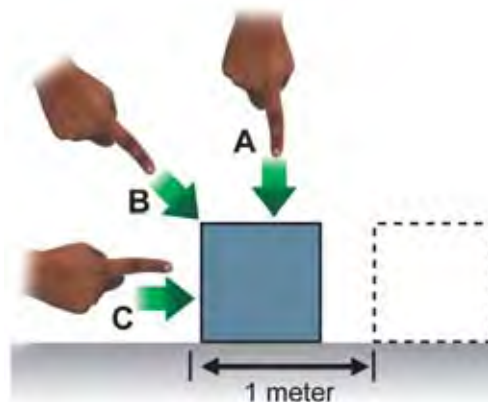


Figure 8.2: You can do work to increase an object's potential energy. Then the potential energy can be converted to kinetic energy.

Work done against gravity

What is the most effective force to do work?



Work is *only* done by the part of a force that acts in the same direction as the resulting motion. Force A in the diagram does no work at all because it does not *cause* the block to move sideways. Force B is applied at an angle to the direction of motion of the block. Only part of force B (in the direction the block moves) does work. The most effective force is force C. All of force C does work because force C acts in the same direction the block moves.

Lifting force equals the weight

Many situations involve work done by or against the force of gravity. To lift something off the floor, you must apply an upward force with a strength equal to the object's weight. The work done while lifting an object is equal to its change in potential energy. It does not matter whether you lift the object straight up or you carry it up the stairs in a zig-zag pattern. The work is the same in either case.

Work done against gravity is equal to weight multiplied by the change in height.

Why the path does not matter

The reason the path does not matter is because work is only done by the part of a force that acts *in the direction of the motion*. Gravity acts vertically so only vertical motion counts towards work. If you move an object on a diagonal, only the vertical distance matters, because the force of gravity is vertical. It is much easier to climb stairs or go up a ramp but the work done *against gravity* is the same as if you jumped straight up. Stairs and ramps are easier because you need less force. But you have to apply the force over a longer distance. In the end, the total work done against gravity is the same, no matter what path you take.

STUDY SKILLS

Summarizing Work and Energy

Work

Measured in joules.

The *action* of making things change.

Energy

Measured in joules.

The *ability* to make things change.

Energy moves through the action of work.

Example: When you push a cart up a ramp, some of the energy is transferred to the cart by doing work on it. Your energy decreases by the amount of work done. The energy of the cart increases by the same amount of work (if there is no friction). Whenever work is done, energy moves from the system doing the work to the system on which the work is being done.

For you to do: Make a diagram that illustrates what happens to your energy and the cart's energy as you do work on the cart by pushing it up a hill.



Solving Problems: Work

How much work is done by a person who pushes a cart with a force of 50 newtons if the cart moves 20 meters in the direction of the force (Figure 8.3)?

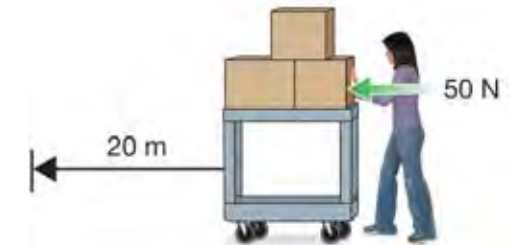


Figure 8.3: How much work is this person doing by pushing the cart?

- 1. Looking for:** You are asked for work.
- 2. Given:** You are given values for force and distance.
- 3. Relationships:** Work = force \times distance.
- 4. Solution:** The work done is: $50 \text{ N} \times 20 \text{ m} = 1,000 \text{ J}$.

Your turn...

- a. How far does a 100-newton force have to move to do 1,000 joules of work?
- b. An electric hoist does 500 joules of work lifting a crate 2 meters. How much force does the hoist use?
- c. An athlete does one push-up. In the process, she moves half of her body weight, 250 newtons, a distance of 20 centimeters. This distance is the distance her center of gravity moves when she fully extends her arms. How much work did she do after one push-up?
- d. You decide to push on a brick wall with all your might for 5 minutes. You push so hard that you begin to sweat. However, the wall does not move. If you end up pushing with a force of 500 newtons, how much work did you do?



Solve first Look later

- a. 10 meters
- b. 250 newtons
- c. 50 joules
- d. You didn't do any work because the wall did not move.

Section 8.1 Review

1. What is the best way to define work?
 - a. applying force for a period of time
 - b. moving a certain distance
 - c. applying a force over a distance
 - d. applying force at a given speed
2. Push a box across a table with a force of 5 newtons and the box moves 0.5 meters. How much work has been accomplished?
3. If you do 200 joules of work using a force of 50 newtons, over what distance was the force applied?
4. A cart was pulled for a distance of 1 kilometer and the amount of work accomplished equaled 40,000 joules. With what force was the work accomplished?
5. In which of these cases is a waiter doing work on the object (Figure 8.4)? Explain your answer.

Situation 1: The waiter is carrying a tray of glasses across a room.
Situation 2: The waiter is pushing a cart across a room.
6. When you climb a flight of stairs, you are moving your body weight (a force) up a certain distance (the vertical height from the bottom to the top stair). In which case does the amount of work you do increase? Explain your answer.
 - a. You run up 10 stairs then you run up 50 stairs.
 - b. You walk slowly up 10 stairs and then you run up 10 stairs really fast.
7. How is work related to potential and kinetic energy?
8. A 2-kilogram object falls 3 meters.
 - a. How much potential energy did the object have before it fell?
 - b. How much work was accomplished by the fall?
9. It takes 300 newtons of force and a distance of 20 meters for a moving cart to come to a stop.
 - a. How much work is done on the cart?
 - b. How much kinetic energy did this cart have?

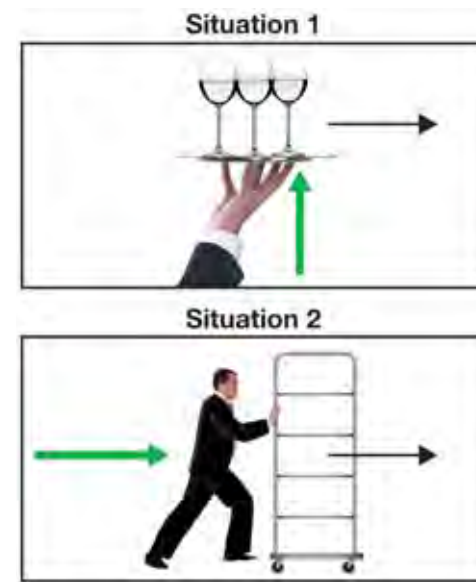


Figure 8.4: Question 5.

SOLVE IT!

Design Your Own Work Problem

To design your work problem, describe a situation involving work and provide the force and distance values. Solve the problem to find the correct answer.

Then, give your problem to a friend and have them solve it. Check and see if they got the right answer.

8.2 Efficiency and Power

One day your science teacher declares, “Today we are going to do our work with greater *efficiency* and greater *power*.” That sounds like a good idea, but what does your teacher mean? Read on and you will find out!

Work input and output

Input work and output work Every process that transforms energy can be thought of as a machine. Work or energy goes in one end and work or energy comes out the other end. The “machine” may be a toaster heating bread which transforms electrical energy into heat, or even a human consuming food in order to have the energy to exercise. Using this concept, the **work input** is the work or energy supplied to the process (or machine). The **work output** is the work or energy that comes out of the process (or machine).



A rope and pulley example As an example, consider using a rope and pulley machine to lift a load weighing 10 newtons (Figure 8.5). If you lift the load a distance of 1 meter, the machine has done 10 joules of work and the work output is 10 joules. For this particular machine, you only need to pull with a force of 5 newtons, but you need to pull the rope a distance of 2 meters. Your work input is 5 newtons \times 2 meters or 10 joules.

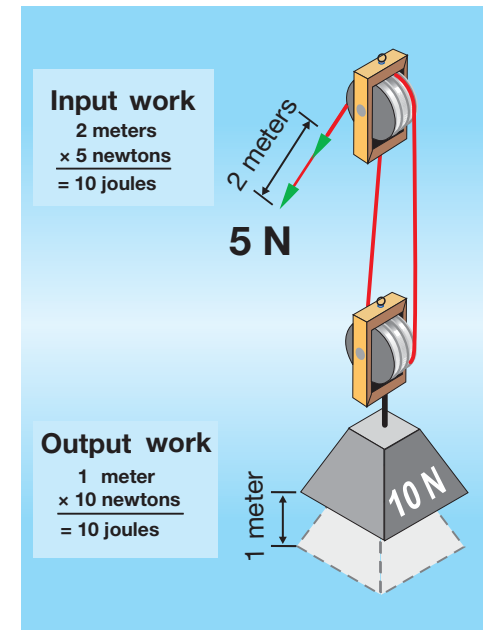


Figure 8.5: The work input of the rope and pulley machine is the same as the work output.

How work input and output are related The example of a rope and pulley machine illustrates a rule that is true for all machines and all processes that transform energy. The total energy of work output can never be greater than the total energy of work input.

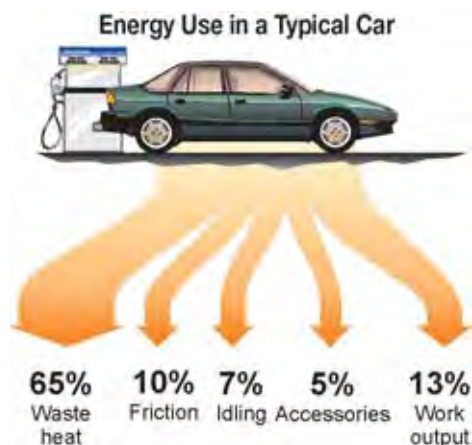
The energy output of a process or machine can never exceed the energy input.

You may recognize this statement as just another way of saying the law of conservation of energy. You are right! If you carefully account for all the work and energy in any process, you find that the total work and energy output of the process is exactly equal to the total work and energy input.

Efficiency

Real machines Suppose you measure the forces on an actual rope and pulley machine. Figure 8.6 shows what you find. Notice that the work input is a little more than the work output! It took 11 joules of input work applied to the rope to produce 10 joules of output work lifting the weight. This kind of behavior is true of all real machines. The work output is less because some work is always converted to heat and other kinds of energy by *friction*.

Everyday machines



The diagram at the left shows how the chemical energy (input) released by burning gasoline is used in a typical car. Only 13 percent of the energy in a gallon of gas is transformed into output work! Car engines in use get hot. That's because 65 percent of the energy in gasoline is converted to heat. As far as moving the car goes, this heat energy is "lost." The energy doesn't vanish, it just does not appear as useful output work.

Efficiency Now we can talk about efficiency. The **efficiency** of a machine is the ratio of usable output work divided by total input work. Efficiency is usually expressed in percent. The car in the diagram has an efficiency of 13 percent. That means 13 joules go to making the car move out of every 100 joules released from gasoline. A "perfect" car would have an efficiency of 100 percent. Since all real machines have some friction, perfect machines are technically impossible.

Calculating efficiency You calculate efficiency by dividing the usable output work by the total input work. The rope and pulley machine in Figure 8.6 has an efficiency of 91 percent. That means that 1 joule out of every 11 (9 percent) is "lost" to friction. The work isn't really "lost," but converted to heat and other forms of energy that are not useful in doing the job the rope and pulley machine is designed to do.

VOCABULARY

efficiency - the ratio of usable output work divided by total input work. Efficiency is often expressed as a percent, with a perfect machine having 100 percent efficiency.

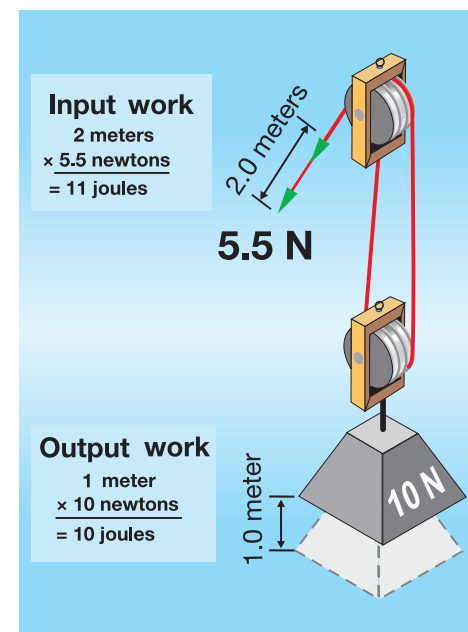


Figure 8.6: If the input work is 11 joules, and the output work is 10 joules, then the efficiency is 91 percent.

Efficiency in natural systems

The meaning of efficiency Energy drives all the processes in nature, from winds in the atmosphere to nuclear reactions occurring in the cores of stars. In the environment, efficiency is interpreted as the fraction of incoming energy that goes into a process. For example, Earth receives energy from the sun. Earth absorbs this solar energy with an average efficiency of 78 percent. The energy that is not absorbed is reflected back into space.

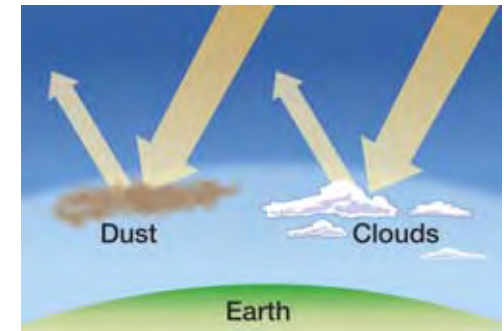
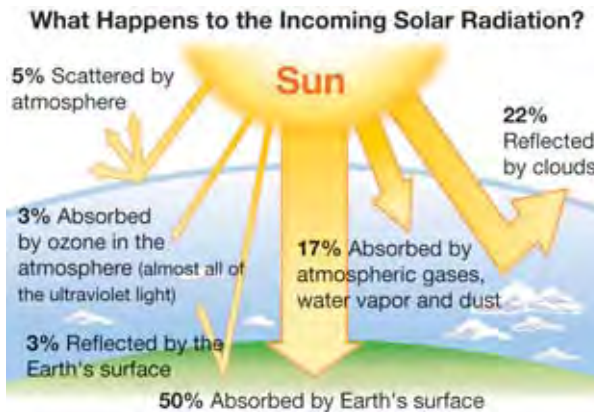


Figure 8.7: Dust and clouds reflect light back into space, decreasing the efficiency with which Earth absorbs energy from the sun.

Earth's temperature Earth's efficiency at absorbing solar energy is critical to living things. If the efficiency decreased by a few percent, Earth's surface would become too cold for life. Some scientists believe that many volcanic eruptions or nuclear war could decrease the absorption efficiency by spreading dust in the atmosphere. Dust reflects solar energy (Figure 8.7). On the other hand, if the efficiency increased by a few percent, it would get too hot to sustain life. Too much carbon dioxide in the atmosphere increases absorption efficiency (Figure 8.8). Scientists are concerned that the average annual temperature of Earth has already warmed 1°C degree since the 1880s as a result of carbon dioxide released by human technology.

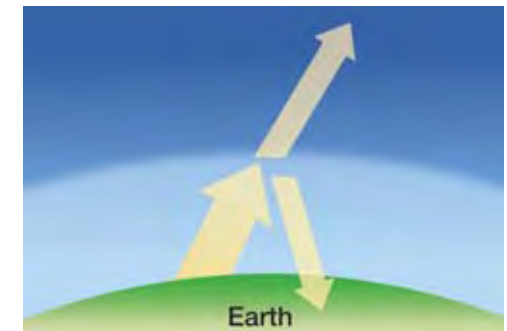


Figure 8.8: Carbon dioxide and other greenhouse gases in the atmosphere absorb some energy that otherwise would have been radiated back into space. This increases the efficiency with which Earth absorbs energy from the sun.

Conservation of energy In any system, all of the energy goes somewhere. Another way to say this is that energy is conserved. For example, rivers flow downhill. Most of the potential energy lost by water moving downhill becomes kinetic energy in motion of the water. Erosion takes some of the energy and slowly changes the land by wearing away rocks and dirt. Friction takes some of the energy and heats up the water. If you could add up the efficiencies for every single process in which water is involved, that total would be 100 percent.



Solving Problems: Efficiency

You see a newspaper advertisement for a new, highly efficient machine. The machine claims to produce 2,000 joules of output work for every 2,100 joules of input work. What is the efficiency of this machine? Is it as efficient as a bicycle (see sidebar)? Do you believe the advertisement's claim? Why or why not?

- 1. Looking for:** You are asked to calculate efficiency.
- 2. Given:** You are given the input work and output work.
- 3. Relationships:** Efficiency is calculated by dividing output work by input work and then multiplying by 100 to get a percentage.

$$\text{Efficiency} = \frac{\text{Output work}}{\text{Input work}} \times 100$$
- 4. Solution:**
$$\text{Efficiency} = \frac{2,000 \text{ J}}{2,100 \text{ J}} \times 100 = 95\%$$

 The efficiency of the machine is 95 percent, which is as efficient as a bicycle. Since a bicycle is the most efficient machine ever invented, I won't believe the advertisement until I see actual scientific data that proves its amazing efficiency.

Your turn...

- a. Suppose 1,000 joules of input work were applied to a machine with only 8 percent efficiency. What would be its output work?
- b. You do 32 joules of work using a pair of scissors. The scissors do 25 joules of work cutting a piece of fabric. What is the efficiency of the scissors?

SCIENCE FACT

A Most Efficient Machine

The bicycle is the most efficient machine ever invented for turning the work of human muscles into motion. Its efficiency is more than 95 percent!

James Starley of the Coventry Sewing Machine Company in Britain is credited with building the first modern two-wheel bicycle in 1885.

The bicycle played a part in the development of another important invention, the airplane. Wilbur and Orville Wright were bicycle mechanics and inventors. They used their expertise in racing and building lightweight bicycles to create the first successful powered airplane in 1903.

Solve first Look later

- a. 80 joules
- b. About 78 percent

Power

Energy vs. power If you lift a book over your head, the book gets potential energy from your action. Even if you lift the book faster, it has the same amount of potential energy. This is because the height is the same. But it feels different to transfer the energy to the book at different speeds. *Power* describes how fast energy is transferred to an object.

What is power? **Power** is the rate at which work is done. Here's an example. Suppose Michael and Jim each lift a barbell weighing 100 newtons from the ground to a height of 2 meters (Figure 8.9). Michael lifts quickly and Jim lifts slowly. Michael and Jim do the same amount of work ($100 \text{ N} \times 2 \text{ m} = 200 \text{ joules}$ of work). However, Michael's *power* is greater because he gets the work done in less time!

Watts and horsepower Power is calculated in watts. One **watt (W)** is equal to 1 joule of work per second. A *kilowatt*, which you may have heard of, equals 1,000 watts. The watt was named after James Watt, the Scottish engineer who invented the steam engine. Another unit of power is the **horsepower**. Watt expressed the power of his engines as the number of horses an engine could replace. One horsepower equals 746 watts or 746 joules of work per second!

POWER

$$\text{Power (W)} \quad P = \frac{W}{t} \quad \begin{matrix} \text{Work (J)} \\ \text{Time (s)} \end{matrix}$$

Calculating power Now, let's calculate and compare the power output of Michael and Jim. Michael's power is 200 joules divided by 1 seconds, or 200 watts. Jim's power is 200 joules divided by 10 seconds, or 20 watts. Jim takes 10 times as long to lift the barbell, so his power is one-tenth as much. The maximum power output of an average person is a few hundred watts.

VOCABULARY

power - the rate of doing work or moving energy. Power is equal to energy (or work) divided by time.

watt (W) - a unit of power equal to 1 joule per second.

horsepower (hp) - a unit of power equal to 746 watts.

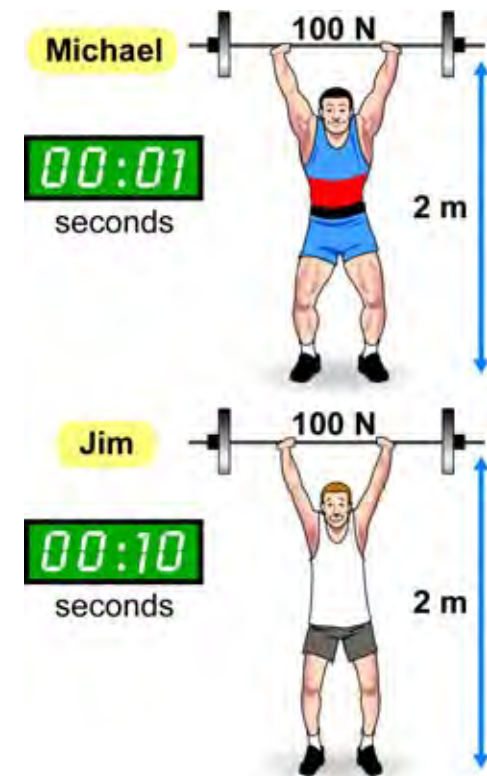


Figure 8.9: Michael and Jim do the same amount of work but do not have the same power.



Solving Problems: Power

Allen lifts his weight (500 newtons) up a staircase that is 5 meters high in 30 seconds. How much power does he use? How does his power compare with a 100-watt light bulb?

1. **Looking for:** You are asked to calculate Allen's power.
2. **Given:** You know force, distance, and time.
3. **Relationships:** Relationships that apply include the formulas for work and power.

$$\text{Work} = \text{Force} \times \text{distance} \quad \text{Power} = \text{Work} \div \text{time}$$

4. **Solution:** Solve for power by replacing the value for "work" in this formula with "force \times distance."

$$P = (F \times d) \div t$$

Now, plug in the numbers. Remember: 1 joule = 1 N \cdot m, and
1 watt = 1 N-m/s

$$P = (500 \text{ N} \times 5 \text{ m}) \div 30 \text{ s} = 2,500 \text{ N} \cdot \text{m} \div 30 \text{ s} = 83 \text{ watts}$$

Allen's power is less than a 100-watt light bulb. Most human activities use less power than a light bulb.

Your turn...

- a. Let's say that Allen did the same amount of work as in the problem above, but he wanted to have the same amount of power as a 100-watt light bulb. How fast would he have to climb the stairs?
- b. What is the minimum time needed to lift a 2,000-newton weight 10 meters using a motor with a maximum power rating of 8,000 watts?

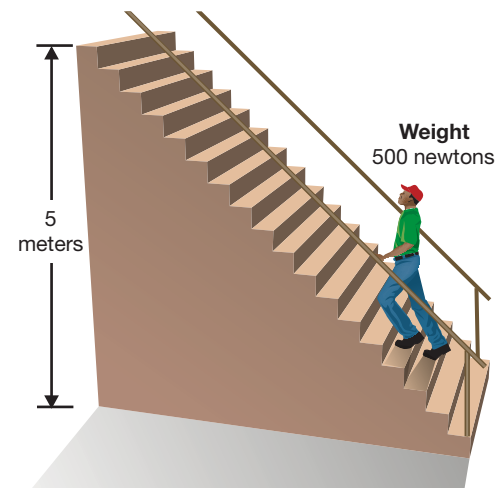


Figure 8.10: How much power does this 500-newton person use?

Solve first Look later

- a. He would need to climb the stairs in 25 seconds. To answer this question, you need to divide work by power (work \div power = time).
- b. 2.5 seconds

Section 8.2 Review

1. You read about a rope and pulley machine that was able to produce equal amounts of output work and input work. Was this a realistic example? Why or why not?
2. What do you need to do to calculate the efficiency of any machine?
3. A car's efficiency is only 13 percent.
 - a. If the input work for a car is 200 joules, what is the output work?
 - b. List two things that car manufacturers do to improve a car's efficiency.
4. A simple machine produces 25 joules of output work for every 50 joules of input work. What is the efficiency of this machine?
5. How is work related to power?
6. If you know the power for a machine and the time it takes to produce that power, what value can you calculate?
7. How does 1 horsepower compare to 1 watt of power?
8. A gallon of gasoline contains about 36 kilowatt-hours of energy. Suppose a gallon of gas cost \$4.00 and a kilowatt-hour of electricity costs 8 cents. Which form of energy is less expensive?
9. A 100-newton object is lifted 100 meters in 100 seconds. What is the power generated in this situation?
10. Which situation would produce 200 watts of power?
 - a. 100 J of work done in 2 s
 - b. 400 J of work done in 2 s
 - c. 2,000 J of work done in 5 s
 - d. 2 J of work done in 100 s
11. An average car engine can produce about 100 horsepower. How many 100-watt light bulbs does it take to use the same amount of power?
12. A half-cup of ice cream contains about 200 food Calories. How much power can be produced if the energy in a cup of ice cream is expended over a period of 10 minutes (600 seconds)? Each food Calorie is equal to 4,184 joules. Write your answer in watts and then in horsepower.

JOURNAL

Are You Really Doing Work When You Do Your Homework?

This question was posed at the beginning of the chapter. Answer it in your own words based on what you know about work.

Think about this question from different angles before you answer it!

KEYWORDS

Energy-Efficient Technologies

Engineers are always trying to improve efficiency of the machines we use every day. Do an Internet search using the key phrase "energy efficient technologies" and see what you find. Or, you might want to go directly to the U.S. government Web site, www.energystar.gov. Pick a topic and present your findings to your class.

Extension: Be a roving reporter within your home and see how many energy-efficient appliances you can find.



Prosthetics in Action!

The human leg is a complex and versatile machine. Designing a prosthetic (artificial) device to match the leg's capabilities is a serious challenge. Teams of scientists, engineers, and designers around the world use different approaches and technologies to develop prosthetic legs that help the user regain a normal, active lifestyle.

Studying the Human Gait Cycle

Each person has a unique way of walking. But studying the way humans walk has revealed that some basic mechanics hold true for just about everyone. Scientists analyze how we walk by looking at our "gait cycle." The gait cycle consists of two consecutive strides while walking, one foot and then the other. By breaking the cycle down into phases and figuring out where in the sequence prosthetic devices could be improved, designers have added features and materials that let users walk safely and comfortably with their own natural gait.



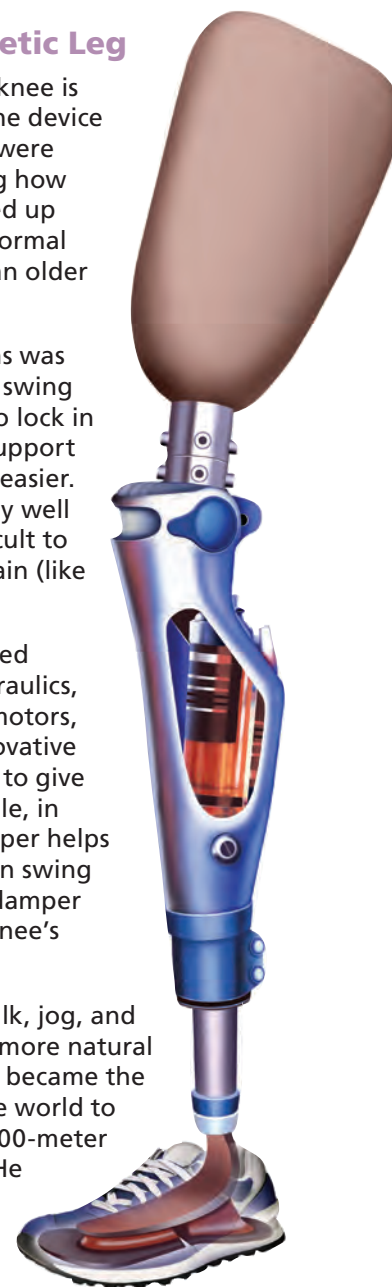
Designing a Better Prosthetic Leg

In many prosthetic leg designs, the knee is the component that controls how the device operates. In the past, most designs were basic and relied on the user learning how to walk properly. This effort required up to 80 percent more energy than a normal gait and often made walking with an older prosthetic leg quite a work out!

The knee joint in those older designs was often a hinge that let the lower leg swing back and forth. The hinge could also lock in place to keep the leg straight and support the user's weight to make standing easier. This type of system worked relatively well on level surfaces, but could be difficult to use on inclines, stairs, irregular terrain (like a hiking trail), or slippery surfaces.

Current prosthetic legs have improved upon old designs by employing hydraulics, carbon fiber, mechanical linkages, motors, computer microprocessors, and innovative combinations of these technologies to give more control to the user. For example, in some designs, a device called a damper helps to control how fast the lower leg can swing back and forth while walking. The damper accomplishes this by changing the knee's resistance to movement as needed.

New knee designs allow users to walk, jog, and with some models, even run with a more natural gait. In fact, in 2003, Marlon Shirley became the first above-the-knee amputee in the world to break the 11-second barrier in the 100-meter dash with a time of 10.97 seconds! He accomplished this feat with the aid of a special prosthetic leg designed specifically for sprinting.



SC.912.L.16.10—Evaluate the impact of biotechnology on the individual, society and the environment, including medical and ethical issues.

SC.912.N.2.2—Identify which questions can be answered through science and which questions are outside the boundaries of scientific investigation, such as questions addressed by other ways of knowing, such as art, philosophy, and religion.

Designs that Learn

By continuously monitoring the velocities of the upper and lower leg, the angle of the bend of the knee, changes in the terrain, and other data, computer microprocessors in the knee calculate and make adjustments to changing conditions in milliseconds. This makes the prosthetic leg more stable and efficient, allowing the knee, ankle, and foot to work together as a unit. Some designs have built-in memory systems that store information from sensors about how the user walks. These designs “learn” how to make fine tuned adjustments based on the user’s particular gait pattern.

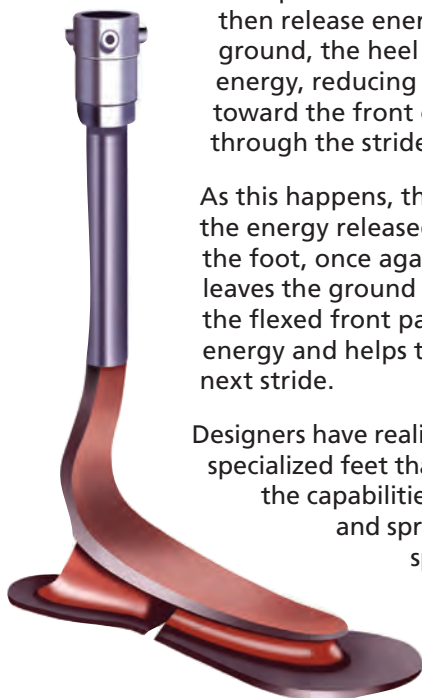
New Foot Designs

New foot designs also reduce the energy required to walk with prosthetic leg systems. They also smooth out the user’s stride. Using composite materials, these designs allow the foot to flex in different ways during the gait cycle. Both the heel and the

front part of the foot act like springs to store and then release energy. When the foot first strikes the ground, the heel flexes and absorbs some of the energy, reducing the impact. Weight gets shifted toward the front of the foot as the walker moves through the stride.

As this happens, the heel springs back into shape and the energy released helps to flex the front part of the foot, once again storing energy. When the foot leaves the ground in the next part of the gait cycle, the flexed front part of the foot releases its stored energy and helps to push the foot forward into the next stride.

Designers have realized the advantage of making highly specialized feet that match and sometimes exceed the capabilities of human feet. Distance running and sprinting feet are built to different specifications to efficiently deal with the forces and demands related to these activities.



Hugh Herr is once again a world-class rock climber, using prosthetic legs which he developed.

A Rock-Climbing Inventor

Hugh Herr, Ph.D., a physicist and engineer at the Harvard-MIT Division of Health Sciences and Technology (Boston, Massachusetts), studies biomechanics and prosthetic technology. In addition to holding several patents in this field, he has developed highly specialized feet for rock climbing that are small and thin—ideal for providing support on small ledges. Being both an accomplished climber and an amputee allows Herr to field test his own inventions. While rock climbing, he gains important insights into the effectiveness and durability of each design.

Questions:

1. What are some technologies used by designers of prosthetic legs to improve their designs?
2. How are computers used to improve the function of prosthetic devices?
3. Explain how new foot designs reduce the amount of energy required to walk with a prosthetic leg.
4. Research the field of biomechanics. In a paragraph:
 - (1) describe what the term biomechanics means; and
 - (2) write about a biomechanics topic that interests you.

Photo of Dr. Herr by Tony Herr

SC.912.L.16.10—Evaluate the impact of biotechnology on the individual, society and the environment, including medical and ethical issues.

SC.912.N.2.2—Identify which questions can be answered through science and which questions are outside the boundaries of scientific investigation, such as questions addressed by other ways of knowing, such as art, philosophy, and religion.

Chapter 8 Assessment

Vocabulary

Select the correct term to complete the sentences.

work	work output	work input
efficiency	horsepower	power
watt		

Section 8.1 and Section 8.2

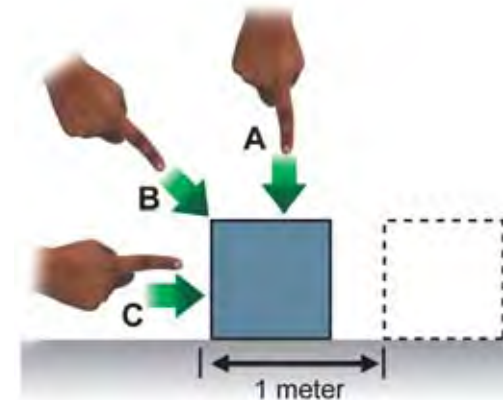
- The rate at which work is done is called ____.
- In physics, ____ is the product of the force applied and the distance moved in the direction of the force.
- A unit of power equal to 746 watts is a(n) ____.
- The unit for one joule per second is one ____.
- You calculate the ____ of a machine by dividing its ____ by its work input and multiplying by 100.
- The work output of a machine can never be less than the ____.

Concepts

Section 8.1

- For each situation, explain whether work (**W**) is done or not (**N**) done.
 - ____ standing still while holding a box of heavy books
 - ____ hitting a baseball with a bat
 - ____ picking up a suitcase
 - ____ pushing hard against a stationary stone wall for an hour
 - ____ falling toward Earth while sky diving
- Why are energy and work measured using the same units?

- Copy the table below onto a piece of paper. Then, use the graphic to fill it in. In the Work Done? column, write *yes*, *no*, or *some*. In the Motion of the Block column, describe how the block would move under each force.

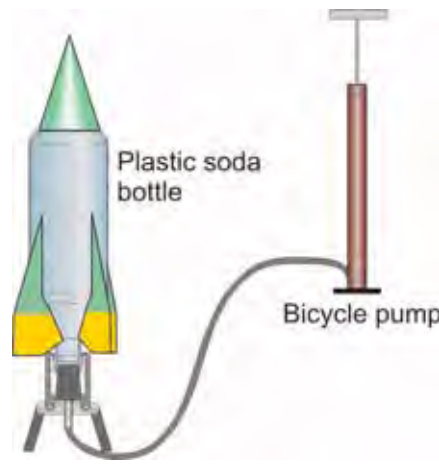


Force	Work Done?	Motion of the Block
A		
B		
C		

- It's moving day and you need to move boxes and furniture from your old second-floor apartment on Main Street to your new fifth-floor apartment on Harmony Street. You have to take the stairs to move your furniture down from the old apartment. But, you can use the elevator to get up to your new apartment on the fifth floor.
 - Describe one way in which your muscles **DO** do work while moving your boxes and furniture down from the second floor.
 - Describe one way in which your muscles **DON'T** do work while moving your boxes and furniture down from the second floor.
 - Does the elevator do work moving your boxes and furniture up to the fifth-floor apartment?

- d. Which involves more work in the scientific sense: moving the boxes and furniture down from the second floor or up to the fifth floor. Explain your reasoning.
- e. You take one box up to the fifth floor by taking the stairs. If the elevator had taken the same box up to the fifth floor, would it have done more, less, or the same amount of work as you? Explain your reasoning.

Section 8.2

5. Your lab partner shows you results from an experiment with a simple machine. The output work is 10 joules and the input work is 8 joules. She asks, “Does this data look correct?” What would be your response and why?
6. A bicycle is considered to be one of the most efficient human-powered machines. Explain why.
7. At the beginning of the chapter, there was the question: How can you produce more power than an excavator? Answer this question using your understanding of work and power. Give an example that illustrates your answer.
8. Mikhail lifts a 500-newton weight 2 meters in 2 seconds. Tobias lifts the same 500-newton weight 2 meters in 4 seconds.
 - a. Which boy does more work?
 - b. Which boy uses greater power?
 - c. The human body is only 8 percent efficient. To obtain the amount of work accomplished by Mikhail or Tobias, how much input work was required?
2. A 2-kilogram object falls a distance of 5 meters. How much potential energy does this object have before it falls? How much work is done on it by gravity as it falls?
3. Sara’s mother gets a flat tire on her car while driving Sara to school. They use a jack to change the tire. It exerts a force of 5,000 newtons to lift the car 0.25 meters. How much work is done by the jack?
4. How far does Isabella lift a 50-N box if she does 40 joules of work in lifting the box from the floor to a shelf?
5. A man pushes a television crate across the floor with a force of 200 newtons. How much work does he do if the crate moves 20 meters in the same direction as the force?
6. A bottle rocket is a toy that is made from an empty soda bottle. A bicycle pump is used to pump air into the bottle. The rocket shoots upward when it is released from the launcher, allowing the high-pressure air to come out.
 
 - a. Work is done as the pump is pushed, forcing air into the bottle. What happens to this work? Does it just disappear?
 - b. Suppose a person does 2,000 joules of work using the pump. What is the maximum kinetic energy the rocket can have after it is launched?
 - c. Do you think the rocket could actually have this much kinetic energy? Explain why or why not.

Problems

Section 8.1

1. How much work can be done with 10 joules of energy?

Section 8.2

7. A certain battery contains 20 joules of energy. The battery is connected to a perfect motor which uses 100 percent of the energy to make force.
 - a. Suppose the motor made a 2-newton force. Over how much distance could this force be applied?
 - b. How large a force can be sustained for 5 meters?
 - c. If the battery was 80 percent efficient, what would the answers be for questions a and b?
8. A machine is used to lift an object a distance of 2 meters. If the power of the machine is increased, what happens to the time it takes for the object to be lifted 2 meters?
9. During construction, a crane lifts a 2,000-newton weight to the top of a 50-meter-tall building. How much power must the crane have to perform this task in 5 seconds? Give your answer in watts, kilowatts, and horsepower.
10. What is the minimum time needed to lift a 1,000-newton weight 20 meters using a motor with a maximum power rating of 8,000 watts?

Applying Your Knowledge**Section 8.1**

1. Spend one day recording a variety of tasks that you do that involve doing work in the scientific sense. Also record the machines that allow you do certain tasks. Then, spend the next day doing one or two of these tasks without using the machine. Answer the following questions.
 - a. Was more or less work done using the machine? How do you know?
 - b. Was the power output more or less with the machine? How do you know?
 - c. What are your thoughts about using machines to accomplish work?

Section 8.2

2. A water-powered turbine makes electricity using the energy of falling water. At the location of one turbine, 100 kilograms of water falls every second from a height of 20 meters.
 - a. How much potential energy does 100 kilograms of water have at a height of 20 meters?
 - b. How much power in watts could you get out of the turbine if it was perfectly efficient?
 - c. Research the efficiency of modern water-powered turbines. How efficient are these devices?
3. In this chapter, you learned the scientific meanings of *work*, *efficiency*, and *power*. Create a superhero cartoon character and draw a comic strip story that illustrates the scientific meanings of these words.
4. Choose an appliance in your house that you use on a regular basis. It may be a television, stereo, fan, or other device.
 - a. The power of an appliance is a measure of the number of joules of electrical energy it converts into other forms of energy each second. What type or types of energy are converted from electrical energy by your appliance?
 - b. There should be a label on the appliance that indicates its power in watts. Record the power. Then, estimate the amount of time you use the appliance in an average day. Convert this time to seconds. Now, calculate the number of joules of energy used by the appliance in a day.