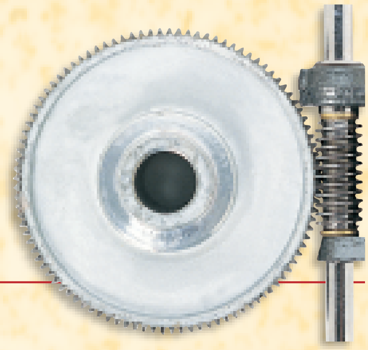
A Not-So-Simple Machine

How does a multispeed bicycle let a cyclist ride over any kind of terrain with the least effort?

Look at the text on page 238 for the answer.

CHAPTER

10 Energy, Work, and Simple Machines



What is energy? Energy is needed to make cars run, to heat or cool our homes, and to make computers hum. Solar energy is required for crops and forests to grow. The energy stored in food gives you the energy needed to play sports or walk to the store. Note, however, all these statements indicate that having energy enables something to perform an action, rather than saying directly what energy is. It is hard to give a good definition of energy without examples of how energy is used and the resulting changes.

In this chapter, you'll concentrate on one method of changing the energy of a system—work. You'll need to be careful here. You may think you're doing work when you put forth a physical effort. For example, you and a friend may try to move a stalled car, but the car doesn't budge. You feel as though you've done work because you're out of breath and your arms ache. However, to a scientist, work is defined in terms of force as well as a change in position. If the car didn't move, no work was done!

For thousands of years, doing work has been of vital concern to the human race. However, the forces the human body can exert are limited by physical strength and body design. Consequently, humans have developed machines that increase the amount of force the human body can produce. A mountain bike is a machine that uses sprockets and a chain to transfer the force of the legs to a force exerted by the rear wheel. Different combinations of sprockets are used to match the forces of the leg to the task of riding at high speed on level ground or while climbing a steep hill. In this chapter, you'll investigate how a few simple machines can make doing work easier.

WHAT YOU'LL LEARN

- You will recognize that work and power describe how energy moves through the environment.
- You will relate force to work and explain how machines make work easier by changing forces.

WHY IT'S IMPORTANT

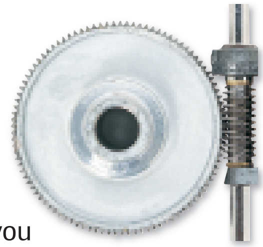
- A little mental effort in identifying the right machine for a task can save you much physical effort. From opening a can of paint to releasing a car stuck in the mud to sharpening a pencil, machines are a part of everyday life.

PHYSICS Online

To find out more about work, energy, and machines, visit the Glencoe Science Web site at **science.glencoe.com**

CLICK HERE

10.1 Energy and Work



If you had a job moving boxes around a warehouse, you would know something about work and energy. It's not easy to lift the boxes onto a truck, slide them across a rough floor, or get them moving quickly on a roller belt, as in Figure 10–1. You have probably thought on more than one occasion that physics is hard work and that you expend a lot of energy solving problems. Your meaning of the words work and energy is different from their meaning in physics. You need to be more specific about the meaning of work and energy to communicate effectively in science.

OBJECTIVES

- **Describe** the relationship between work and energy.
- **Display** an ability to calculate work done by a force.
- **Identify** the force that does work.
- **Differentiate** between work and power and correctly **calculate** power used.

FIGURE 10–1 In physics, work is done only when a force causes an object to move.

F.Y.I.

In physics, work and energy have precise meanings, which must not be confused with their everyday meanings. Robert Oppenheimer wrote, "Often the very fact that the words of science are the same as those of our common life and tongue can be more misleading than enlightening."

Energy

When describing an object, you might say that it is blue, it is 2 m tall, and it can produce a change. This property, the ability to produce change in itself or the environment, is called **energy.** The energy of an object can take many forms, including thermal energy, chemical energy, and energy of motion. For example, the position of a moving object is changing over time; this change in position indicates that the object has energy. The energy of an object resulting from motion is called **kinetic energy.** To describe kinetic energy mathematically, you need to use motion equations and Newton's second law of motion, $F = ma$.

Energy of motion Start with an object of mass m, moving at speed v_0. Now apply a force, F, to the object to accelerate it to a new speed, v_1. In Chapter 5 you learned the motion equation that describes this situation.

$$v_1^2 = v_0^2 + 2ad$$

To see how energy is expressed in this relationship, you need to do some rearranging. First add a negative v_0^2 to both sides.

$$v_1^2 - v_0^2 = 2ad$$

Using Newton's second law of motion, substitute F/m for a.

$$v_1^2 - v_0^2 = 2Fd/m$$

And finally, multiply both sides of the equation by 1/2 m.

$$1/2mv_1^2 - 1/2mv_0^2 = Fd$$

On the left-hand side are the terms that describe the energy of the system. This energy results from motion and is represented by the symbol K, for kinetic.

Kinetic Energy $K = 1/2mv^2$

Because mass and velocity are both properties of the system, kinetic energy describes a property of the system. In contrast, the right-hand side of the equation refers to the environment: a force exerted and the resulting displacement. Thus, some agent in the environment changed a property of the system. The process of changing the energy of the system is called **work,** and it is represented by the symbol W.

Work $W = Fd$

Substituting K and W into the equation, you obtain $K_1 - K_0 = W$. The left-hand side is simply the difference or change in kinetic energy and can be expressed by using a delta.

Work-Energy Theorem $\Delta K = W$

In words, this equation says that when work is done on an object, a change in kinetic energy results. This hypothesis, $\Delta K = W$, has been tested experimentally many times and has always been found to be correct. It is called the **work-energy theorem.** This relationship between doing work and a resulting change in energy was established by the nineteenth-century physicist James Prescott Joule. To honor his work, a unit of energy is called a **joule.** For example, if a 2-kg object moves at 1 m/s, it has a kinetic energy of 1kg·m^2/s^2 or 1 J.

Work

While the change in kinetic energy describes the change in a property of an object, the term Fd, describes something done to the object. An agent in the environment exerted a force F that displaced the object an amount d. The work done on an object by external forces changes the amount of energy the object has.

Energy transfer Remember when you studied Newton's Laws of motion and momentum, that a system was the object of interest, and the environment was everything else. For example, the one system might be a box in the warehouse and the environment is you, gravity, and anything else external to the box. Through the process of doing work, energy can move between the environment and the system, as diagrammed in **Figure 10–2.**

Notice that the direction of energy transfer can go both ways. If the environment does work on the system, then W is positive and the energy of the system increases. If, however, the system does work on the environment, then W is negative, and the energy of the system decreases.

Pocket Lab

Working Out

Attach a spring scale to a 1.0-kg mass with a string. Pull the mass along the table at a slow, steady speed while keeping the scale parallel to the tabletop. Note the reading on the spring scale.

Analyze and Conclude What are the physical factors that determine the amount of force? How much work is done in moving the mass 1.0 m? Predict the force and the work when a 2.0-kg mass is pulled along the table. Try it. Was your prediction accurate?

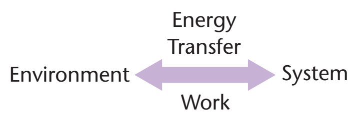


FIGURE 10–2 Work transfers energy between an environment and a system. Energy transfers can go either direction.

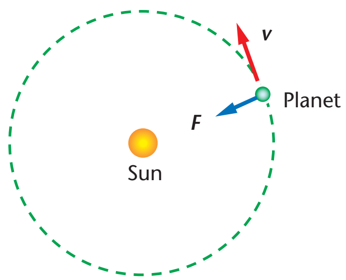


FIGURE 10–3 If a planet is in a circular orbit, then the force is perpendicular to the direction of motion. Consequently, the gravitational force does no work on the planet.

Calculating work The equation for work is $W = Fd$, however this equation holds only for constant forces exerted in the direction of the motion. What happens if the force is exerted perpendicular to the direction of motion? An everyday example is the motion of a planet around the sun, as diagramed in **Figure 10–3.** If the orbit is circular, then the force is always perpendicular to the direction of motion. Remember from Chapter 7 that a perpendicular force does not change the speed of an object, only its direction. Consequently, the speed of the planet doesn't change. Therefore, its kinetic energy is also constant. Using the equation $\Delta K = W$, you see for constant K that $\Delta K = 0$ and thus $W = 0$. This means that if $\boldsymbol{F}$ and $\boldsymbol{d}$ are at right angles, then $W = 0$.

Because the work done on an object equals the change in energy, work is also measured in joules. A joule of work is done when a force of one newton acts on an object over a displacement of one meter. An apple weighs about one newton. Thus, when you lift an apple a distance of one meter, you do one joule of work on it.

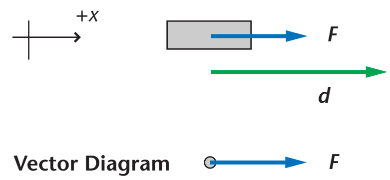
Example Problem

Calculating Work

A 105-g hockey puck is sliding across the ice. A player exerts a constant 4.5-N force over a distance of 0.15 m. How much work does the player do on the puck? What is the change in the puck's energy?

Sketch the Problem

- Establish a coordinate axis.
- Show the hockey puck with initial conditions.
- Draw a vector diagram.



Calculate Your Answer

Known:	Strategy:	Calculations:
$m = 105$ g $F = 4.5$ N $d = 0.15$ m	Use the basic equation for work when a constant force is exerted in same direction as displacement.	$W = Fd$ $W = (4.5\ \text{N})(0.15\ \text{m})$ $W = 0.68\ \text{N·m} = 0.68\ \text{J}$
Unknown: $W = ?$ $\Delta K = ?$	Use the work-energy theorem to determine the change in energy of the system.	$\Delta K = W = 0.68\ \text{J}$

Check Your Answer

- Are the units correct? Work is measured in joules, J = N·m.
- Does the sign make sense? The player does work on the puck, which agrees with a positive sign for work.
- A magnitude of about 1 J fits with the quantities given.

Practice Problems

1. A student lifts a box of books that weighs 185 N. The box is lifted 0.800 m. How much work does the student do on the box?
2. Two students together exert a force of 825 N in pushing a car 35 m.
   a. How much work do they do on the car?
   b. If the force were doubled, how much work would they do pushing the car the same distance?
3. A 0.180-kg ball falls 2.5 m. How much work does the force of gravity do on the ball?
4. A forklift raises a box 1.2 m doing 7.0 kJ of work on it. What is the mass of the box?
5. You and a friend each carry identical boxes to a room one floor above you and down the hall. You choose to carry it first up the stairs, then down the hall. Your friend carries it down the hall, then up another stairwell. Who does more work?

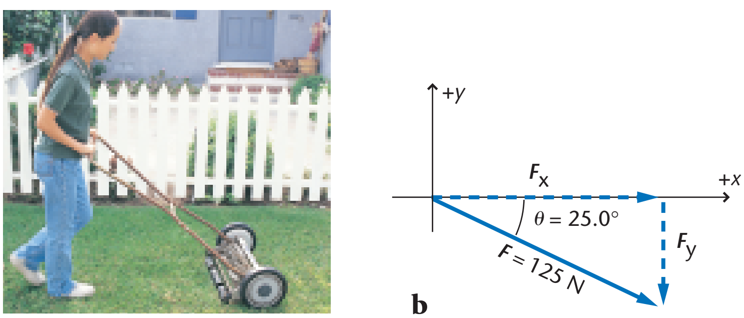
Constant force at an angle You've learned that a force exerted in the direction of motion does an amount of work given by $W = Fd$. A force exerted perpendicular to the motion does no work. What work does a force exerted at an angle do? For example, what work does the person pushing the lawn mower in **Figure 10–4a** do? You know that any force can be replaced by its components. The 125-N force, ***F***, exerted in the direction of the handle has two components. If we choose the coordinate system shown in **Figure 10–4b,** then the magnitude of the horizontal component, F_x, is related to the magnitude of the force, F, by a cosine function: $\cos 25.0° = F_x/F$. By solving for F_x, you obtain $F_x = F \cos 25.0° = 113$ N. Using the same method, the vertical component is $F_y = -F \sin 25.0° = -52.8$ N, where the negative sign shows that the force is down. Because the displacement is in the x direction, only the x-component does work. The y-component does no work. The work you do when you exert a force at an angle to the motion is equal to the component of the force in the direction of the displacement times the distance moved.

Pocket Lab

An Inclined Mass

Attach a spring scale to a 1.0-kg mass with a string. Increase the angle between the string and the tabletop, for example, to 30°. Try to keep the angle constant as you pull the 1.0-kg mass along the table at a slow, steady speed. Note the reading on the scale.

Analyze and Conclude How much force is in the direction of motion? How much work is done when the 1.0-kg mass moves 1.0 m? How does the work compare to the previous value?



a **b**

FIGURE 10–4 If a force is applied to the mower at an angle, the net force doing the work is the component that acts in the direction of the displacement.

CONTENTS

The magnitude of the component force acting in the direction of displacement is found by multiplying the magnitude of force ***F*** by the cosine of the angle between ***F*** and the direction of the displacement, $F_x = F \cos \theta$. Thus, the work done is represented the following way.

$$W = F \cos \theta \, d$$

Work (Angle Between Force and Displacement) $W = Fd \cos \theta$

Other agents exert forces on the lawn mower. Which of these agents do work? Earth's gravity acts downward, the ground exerts a normal force upward, and friction exerts a horizontal force opposite the motion. The upward and downward forces are perpendicular to the motion and do no work. For these forces, $\theta = 90°$, which makes $\cos \theta = 0$, and thus, no work is done.

The work done by friction acts at an angle of 180°. Because $\cos 180° = -1$, the work done by friction is negative. Negative work done by a force in the environment reduces the energy of the system. If the person in **Figure 10–4a** were to stop pushing, the mower would quickly stop moving; its energy of motion would be reduced. Positive work done by a force increases the energy; negative work decreases it.

Problem Solving Strategies

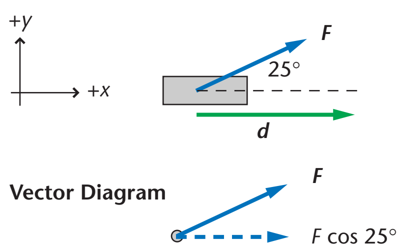
Work Problems

1. Sketch the system and show the force that is doing the work.
2. Diagram the vectors of the system.
3. Find the angle, θ, between each force and displacement.
4. Calculate the work done by each force using $W = Fd \cos \theta$.
5. Check the sign of the work using the direction of energy transfer. If the energy of the system has increased, the work done by that force is positive. If the energy has decreased, then the work done is negative.

Example Problem

Force and Displacement at an Angle

A sailor pulls a boat 30.0 m along a dock using a rope that makes a 25.0° angle with the horizontal. How much work does the sailor do on the boat if he exerts a force of 255 N on the rope?



Sketch the Problem

- Establish coordinate axes.
- Show the boat with initial conditions.
- Draw a vector diagram showing the force and its component in the direction of the displacement.

Calculate Your Answer

Known:	**Strategy:**	**Calculations:**
$F = 255$ N	Use the equation for work when	$W = Fd \cos \theta$
$d = 30.0$ m	there is an angle between force and	$W = (255 \text{ N})(30.0 \text{ m})(\cos 25.0°)$
$\theta = 25.0°$	displacement.	$W = 6.93 \times 10^3$ J
Unknown:		
$W = ?$		

Check Your Answer

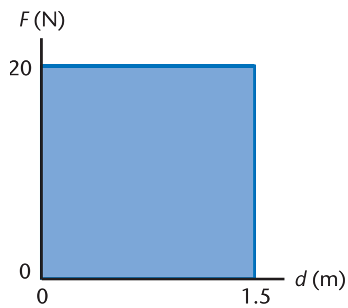
- Are the units correct? N·m = J, and work is measured in joules.
- Does the sign make sense? The sailor does work on the boat, which agrees with a positive sign for work.
- Is the magnitude realistic? Magnitude of about 7000 J fits with the quantities given.

Practice Problems

6. How much work does the force of gravity do when a 25-N object falls a distance of 3.5 m?

7. An airplane passenger carries a 215-N suitcase up the stairs, a displacement of 4.20 m vertically and 4.60 m horizontally.
   a. How much work does the passenger do?
   b. The same passenger carries the same suitcase back down the same stairs. How much work does the passenger do now?

8. A rope is used to pull a metal box 15.0 m across the floor. The rope is held at an angle of 46.0° with the floor and a force of 628 N is used. How much work does the force on the rope do?



Finding work done when forces change A graph of the force versus the displacement lets you determine the work done by a force. This graphical method can be used to solve problems for which the force is changing. **Figure 10–5** shows how to find the work done by a constant force of 20 N that is exerted lifting an object 1.5 m. The work done by this constant force is represented by $W = Fd = (20 \text{ N})(1.5 \text{ m}) = 30$ J. The shaded area under the curve is equal to 20 N × 1.5 m, or 30 J. The area under the curve of a force-displacement graph is equal to the work done by that force. The area is the work done even if the force changes. **Figure 10–5** shows the force exerted by a spring, which varies linearly from 0 to 20 N as it is compressed 1.5 m. The work done by the force that compressed the spring is the area under the curve, which is the area of a triangle, 1/2 (base)(altitude), or $W = 1/2(20 \text{ N})(1.5 \text{ m}) = 15$ J.

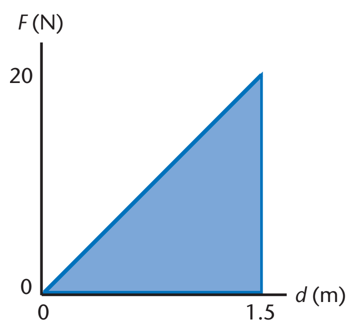


FIGURE 10–5 Work can be obtained graphically by finding the area under a force-displacement curve.

FIGURE 10–6 These students are expending energy at different rates while climbing the stairs.

Power

Until now, none of the discussions of work has mentioned the time it takes to move an object. The work done by a person lifting a box of books is the same whether the box is lifted onto a shelf in 2 seconds or each book is lifted separately, so that it takes 20 minutes to put them all on the shelf. Although the work done is the same, the power is different. **Power** is the rate of doing work. That is, power is the rate at which energy is transferred. Consider the three students in **Figure 10–6,** the girl hurrying up the stairs is more powerful than the boy walking. Even though the same work is accomplished, the girl accomplishes it in less time. In the case of the two students walking up the stairs, both accomplish work in the same amount of time. However, the girl carrying books does more work and, consequently, her power is greater. To calculate power, use the following formula.

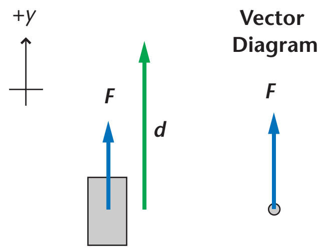
Power $P = \frac{W}{t}$

Power is measured in watts (W). One **watt** is one joule of energy transferred in one second. A machine that does work at a rate of one joule per second has a power of one watt. A watt is a relatively small unit of power. For example, a glass of water weighs about 2 N. If you lift it 0.5 m to your mouth, you do one joule of work. If you lift the glass in one second, you are doing work at the rate of one watt. Because a watt is such a small unit, power is often measured in kilowatts (kW). A kilowatt is 1000 watts.

Example Problem

Calculating Power

An electric motor lifts an elevator 9.00 m in 15.0 s by exerting an upward force of 1.20×10^4 N. What power does the motor produce in watts and kilowatts?



Sketch the Problem

- Establish a coordinate axis, up being positive.
- Show the elevator with initial conditions.
- Draw a vector diagram for the force.

Calculate Your Answer

Known:

$d = 9.00$ m

$t = 15.0$ s

$F = 1.20 \times 10^4$ N

Unknown:

$P = ?$

Strategy:

Use work and time to find power.

Calculations:

$W = Fd$ and $P = \frac{W}{t}$, so

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

$$P = \frac{(1.20 \times 10^4\ \text{N})(9.00\ \text{m})}{15.0\ \text{s}} = 7.20\ \text{kW}$$

Check Your Answer

- Are the units correct? Check algebra on units to ensure that power is measured in watts.
- Does the sign make sense? Positive sign agrees with the upward direction of force.
- Is the magnitude realistic? Lifting an elevator requires a high power. 7200 watts is about right.

Practice Problems

9. A box that weighs 575 N is lifted a distance of 20.0 m straight up by a cable attached to a motor. The job is done in 10.0 s. What power is developed by the motor in watts and kilowatts?

10. A rock climber wears a 7.5-kg knapsack while scaling a cliff. After 30 min, the climber is 8.2 m above the starting point.
a. How much work does the climber do on the knapsack?
b. If the climber weighs 645 N, how much work does she do lifting herself and the knapsack?
c. What is the average power developed by the climber?

11. An electric motor develops 65 kW of power as it lifts a loaded elevator 17.5 m in 35 s. How much force does the motor exert?

12. Your car has stalled and you need to push it. You notice as the car gets going that you need less and less force to keep it going. Suppose that for the first 15 m your force decreased at a constant rate from 210 N to 40 N. How much work did you do on the car? Draw a force-displacement graph to represent the work done during this period.

F.Y.I.

A bicyclist in the *Tour de France* rides at about 20 mph for more than six hours a day. The power output of the racer is about one kilowatt. One quarter of that power goes into moving the bike against the resistance of the air, gears, and tires. Three quarters of the power is used to cool the racer's body.

10.1 Section Review

1. Explain in words, without the use of a formula, what work is.

2. When a bowling ball rolls down a level alley, does Earth's gravity do any work on the ball? Explain.

3. Does the work required to lift a book to a high shelf depend on how fast you raise it? Does the power required for the lift depend on how fast you raise the book? Explain.

4. Explain how the motion of a hockey puck, after having a force applied to it over some distance, supports the work-energy theorem.

5. **Critical Thinking** If three objects exert forces on a body, can they all do work at the same time? Explain.

Your Power

Problem

Can you estimate the power that you generate as you climb stairs? Climbing stairs requires energy. As you move your weight through a distance, you accomplish work. The rate at which you do this work is power.

Hypothesis

Form a hypothesis that relates estimating power to measurable quantities. Predict the difficulties you may encounter as you are trying to solve the problem.

Possible Materials

Determine which variables you will measure and then plan a procedure for taking measurements. Tell your teacher what materials you would like to use to accomplish your plan. Once you have completed your lab, be sure to dispose of, recycle, or put away your materials.

Plan the Experiment

In your group, develop a plan to measure your power as you climb stairs. Be prepared to present your plan, your data, your calculations, and your results to the rest of the class. Take measurements for at least two students.

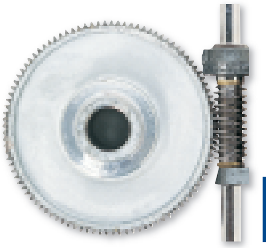
1. Identify the dependent and independent variables.
2. Describe your procedures.
3. Set up data tables.
4. Write any equations that you will need for the calculations.
5. **Check the Plan** Show your teacher your plan before you leave the room to start the experiment.

Analyze and Conclude

1. **Calculating Results** Show your calculations for the power rating of each climber.
2. **Comparing Results** Did each climber have the same power rating?
3. **Analyzing Data** Explain how your power could be increased.
4. **Making Inferences** Explain why the fastest climber might not have the highest power rating. Explain why the largest climber might not have the highest power rating.

Apply

1. Your local electric company charges you about 11 cents for a kilowatt-hour of energy. At this rate, how much money could you earn by climbing stairs continuously for one hour? Show your calculations.



Machines

10.2

Everyone uses some machines every day. Some are simple tools, such as bottle openers and screwdrivers; others are complex, such as bicycles and automobiles. Machines, whether powered by engines or people, make tasks easier. A **machine** eases the load by changing either the magnitude or the direction of a force as it transmits energy to the task.

OBJECTIVES

- **Demonstrate** knowledge of why simple machines are useful.
- **Communicate** an understanding of mechanical advantage in ideal and real machines.
- **Analyze** compound machines and **describe** them in terms of simple machines.
- **Calculate** efficiencies for simple and compound machines.

Simple and Compound Machines

Consider the bottle opener in **Figure 10–7.** When you use the opener, you lift the handle, thereby doing work on the opener. The opener lifts the cap, doing work on it. The work you do is called the input work, W_i. The work the machine does is called the output work, W_o.

Work, as you recall, is the transfer of energy by mechanical means. You put work into a machine, in this case, the bottle opener. That is, you transfer energy to the opener. The opener, in turn, does work on the cap, transferring energy to it. The opener is not a source of energy, so the cap cannot receive more energy than you put into the opener. Thus, the output work can never be greater than the input work. The machine simply aids in the transfer of energy from you to the bottle cap.

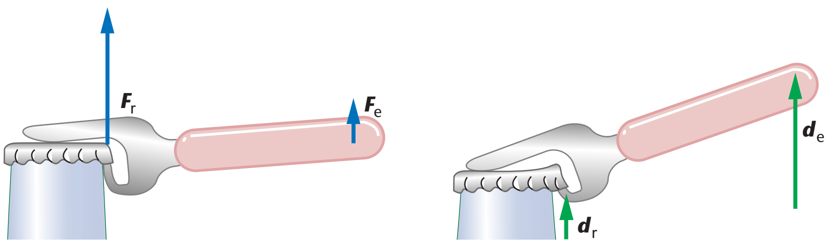


FIGURE 10–7 A bottle opener is an example of a simple machine. It makes opening a bottle easier, but not less work than it would be otherwise.

Mechanical advantage The force you exert on a machine is called the **effort force,** F_e. The force exerted by the machine is called the **resistance force,** F_r. **Figure 10–8** shows a typical pulley setup, where F_e is the downward force exerted by the man and the F_r is the upward force exerted by the rope. The ratio of resistance force to effort force, F_r/F_e, is called the **mechanical advantage** (MA) of the machine.

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

Many machines, such as the bottle opener, have a mechanical advantage greater than one. When the mechanical advantage is greater than one, the machine increases the force you apply. In the case of the pulley system in **Figure 10–8,** the forces F_e and F_r are equal, consequently MA is 1. So what is the advantage? The usefulness of this pulley arrangement is not that the effort force is lessened, but that the direction is changed; now the direction of effort is in the same direction as displacement.

FIGURE 10–8 The pulley system makes work easier not by increasing the force the man can apply to the resistance, but by allowing him to apply the force parallel to displacement.

HELP WANTED

CHIROPRACTOR

Do you like to work on "the human machine?" A group practice in a small city desires a new partner to expand services. A belief in the holistic (nondrug, nonsurgical) approach to medicine and a positive, professional demeanor are required for one to be a successful chiropractor. Completion of an accredited, six-year Chiropractic College program with a Doctor of Chiropractic (D.C.) degree and a state license are required. For information contact:

International Chiropractors Association
1110 N. Glebe Road
Suite 1000
Arlington, VA 22201

F.Y.I.

Efficiency Statistic: Most automobiles get about 28% more miles per gallon of fuel at 50 miles per hour than at 70 miles per hour.

You can write the mechanical advantage of a machine in another way using the definition of work. The input work is the product of the effort force you exert, F_e, and the distance your hand moved, d_e. In the same way, the output work is the product of the resistance force, F_r, and the displacement of the object, d_r. A machine can increase force, but it cannot increase energy. An ideal machine transfers all the energy, so the output work equals the input work.

$$W_o = W_i$$

or

$$F_r d_r = F_e d_e$$

This equation can be rewritten $F_r/F_e = d_e/d_r$. We know that the mechanical advantage is given by $MA = F_r/F_e$. For an ideal machine, $MA = d_e/d_r$. Because this equation is characteristic of an ideal machine, the mechanical advantage is called the **ideal mechanical advantage,** *IMA*.

Ideal Mechanical Advantage $IMA = \dfrac{d_e}{d_r}$

Note that you measure distances moved to calculate the ideal mechanical advantage, *IMA*, but you measure the forces exerted to find the actual mechanical advantage, *MA*.

Efficiency In a real machine, not all of the input work is available as output work. Some of the energy transferred by the work may be "lost" to thermal energy. Any energy removed from the system means less output work from the machine. Consequently, the machine is less efficient at accomplishing the task.

The **efficiency** of a machine is defined as the ratio of output work to input work.

Efficiency $\text{efficiency (\%)} = \dfrac{W_o}{W_i} \times 100$

An ideal machine has equal output and input work, $W_o/W_i = 1$, and its efficiency is 100%. All real machines have efficiencies less than 100%. We can express the efficiency in terms of the mechanical advantage and ideal mechanical advantage.

$$\text{efficiency (\%)} = \frac{F_r/F_e}{d_e/d_r} \times 100$$

Efficiency $\text{efficiency (\%)} = \dfrac{MA}{IMA} \times 100$

The *IMA* of most machines is fixed by the machine's design. An efficient machine has an *MA* almost equal to its *IMA*. A less efficient machine has a small *MA* relative to its *IMA*. Lower efficiency means that a greater effort force is needed to exert the same resistance force as a comparable machine of higher efficiency.

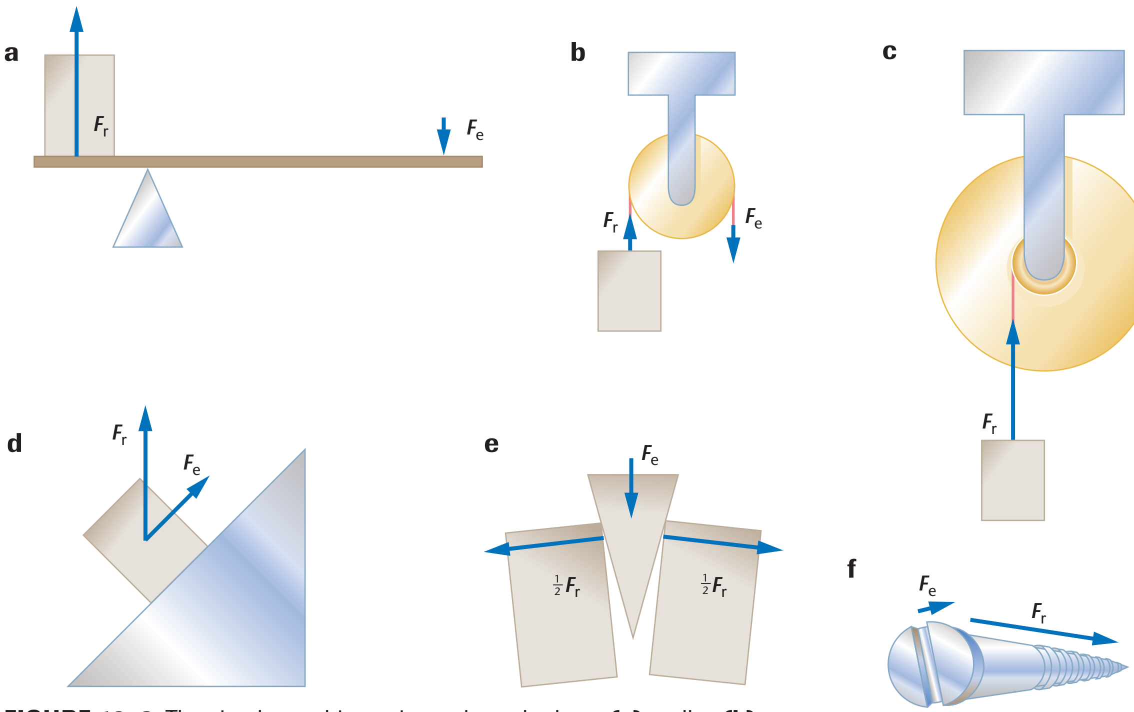


FIGURE 10–9 The simple machines pictured are the lever **(a)**; pulley **(b)**; wheel and axle **(c)**; inclined plane **(d)**; wedge **(e)**; and screw **(f).**

Simple machines Most machines, no matter how complex, are combinations of one or more of the six simple machines shown in **Figure 10–9.** They are the lever, pulley, wheel and axle, inclined plane, wedge, and screw. Gears, one of the simple machines used in a bicycle, are really a form of the wheel and axle. The *IMA* of all machines is the ratio of distances moved. **Figure 10–10** shows that for levers and wheel and axles this ratio can be replaced by the ratio of the distance between the place where the force is applied and the pivot point. A common version of the wheel and axle is a pair of gears on a rotating shaft. The *IMA* is the ratio of the radii of the two gears.

Compound machines A **compound machine** consists of two or more simple machines linked so that the resistance force of one machine becomes the effort force of the second. For example, in the bicycle, the pedal and front sprocket (or gear) act like a wheel and axle. The effort force is the force you exert on the pedal, $F_{\text{on pedal}}$. The resistance is the force the front sprocket exerts on the chain, $F_{\text{on chain}}$, as illustrated in **Figure 10–11.**

The chain exerts an effort force on the rear wheel sprocket, $F_{\text{by chain}}$, equal to the force exerted on the chain. This sprocket and the rear wheel act like another wheel and axle. The resistance force is the force the wheel exerts on the road, $F_{\text{on road}}$. According to Newton's third law of motion, the ground exerts an equal forward force on the wheel. This force accelerates the bicycle forward.

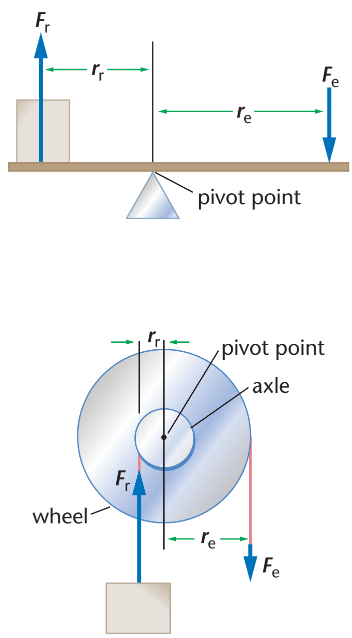


FIGURE 10–10 For levers and wheel and axles, the *IMA* is r_e/r_r.

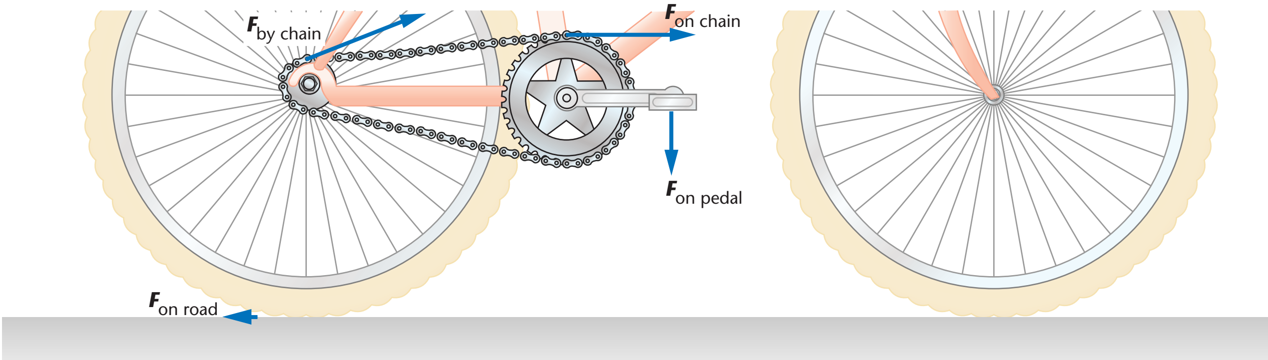


FIGURE 10–11 A series of simple machines combines to transmit the force the rider exerts on the pedal to the road.

The mechanical advantage of a compound machine is the product of the mechanical advantages of the simple machines it is made up of. For example, **Figure 10–11** illustrates the case of the bicycle.

$$MA = MA_{\text{machine 1}} \times MA_{\text{machine 2}}$$

$$MA = \frac{F_{\text{on chain}}}{F_{\text{on pedal}}} \times \frac{F_{\text{on road}}}{F_{\text{by chain}}} = \frac{F_{\text{on road}}}{F_{\text{on pedal}}}$$

The *IMA* of each wheel and axle machine is the ratio of the distances moved. For the pedal sprocket,

$$IMA = \frac{\textit{pedal radius}}{\textit{front sprocket radius}}.$$

For the rear wheel,

$$IMA = \frac{\textit{rear sprocket radius}}{\textit{wheel radius}}.$$

For the bicycle, then,

$$IMA = \frac{\textit{pedal radius}}{\textit{front sprocket radius}} \times \frac{\textit{rear sprocket radius}}{\textit{wheel radius}}$$

$$= \frac{\textit{rear sprocket radius}}{\textit{front sprocket radius}} \times \frac{\textit{pedal radius}}{\textit{wheel radius}}.$$

Because both sprockets use the same chain and have teeth of the same size, you can simply count the number of teeth on the gears and find that

$$IMA = \frac{\textit{teeth on rear sprocket}}{\textit{teeth on front sprocket}} \times \frac{\textit{pedal arm length}}{\textit{wheel radius}}.$$

Shifting gears on your bicycle is a way of adjusting the ratio of sprocket radii to obtain the desired *IMA*. *MA* depends on forces. You know that if the pedal is at the top or bottom of its circle, no matter how much downward force you exert, the pedals will not turn. The force of your foot is most effective when the force is exerted perpendicular to the arm of the pedal. Whenever a force on a pedal is specified, you should assume that it is applied perpendicular to the arm.

Pocket Lab

Wheel and Axle

The gear mechanism on your bicycle multiplies the distance that you travel. What does it do to the force? Try this activity to find out. Mount a wheel and axle on a solid support rod. Wrap a string clockwise around the small diameter wheel and a different string counterclockwise around the large diameter wheel. Hang a 500-gram mass from the end of the string on the larger wheel. Pull the string down so that the mass is lifted by about 10 cm.

Analyze and Conclude What did you notice about the force on the string in your hand? What did you notice about the distance that your hand needed to move to lift the mass? Explain the results in terms of the work done on both strings.

Example Problem

Bicycle Wheel

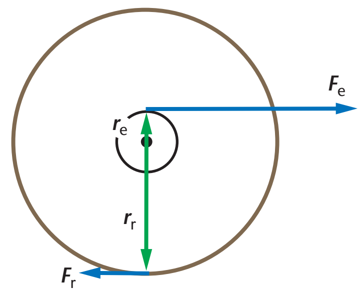
You are studying the rear wheel on your bicycle. It has a radius of 35.6 cm and has a gear with radius of 4.00 cm. When the chain is pulled with a force of 155 N, the wheel rim moves 14.0 cm. The efficiency of this part of the bicycle is 95.0%.

a. What is the *IMA* of the wheel and gear?

b. What is the *MA* of the wheel and gear?

c. What is the resistance force?

d. How far was the chain pulled to move the rim that amount?



Sketch the Problem

- Diagram the wheel and axle.
- Add the force vectors and distance vectors.

Calculate Your Answer

Known:

$r_e = 4.00$ cm

$r_r = 35.6$ cm

$F_e = 155$ N

$e = 95.0\%$

$d_r = 14.0$ cm

Unknown:

$IMA = ?$

$MA = ?$

$F_r = ?$

$d_e = ?$

Strategy:

a. For a wheel and axle machine, *IMA* is represented by the ratio of radii.

b. Use efficiency ratio to obtain *MA*.

c. Use *MA* equation to find force.

d. Use *IMA* equation to find distance.

Calculations:

$$IMA = \frac{r_e}{r_r}$$

$$IMA = \frac{4.00 \text{ cm}}{35.6 \text{ cm}} = 0.112$$

$$e = \frac{MA}{IMA} \times 100$$

$$MA = (e/100) \times IMA$$

$$MA = (95.0\%/100) \times 0.112 = 0.106$$

$$F_r = (MA)(F_e)$$
$$F_r = (0.106)(155 \text{ N}) = 16.4 \text{ N}$$

$$d_e = (IMA)(d_r)$$
$$d_e = (0.112)(14.0 \text{ cm}) = 1.57 \text{ cm}$$

Check Your Answer

- Are the units correct? Perform the algebra with the units to confirm that the answer's units are correct.
- Does the sign make sense? All answers should be positive.
- Is the magnitude realistic? **a.** Expect a low *IMA* for a bicycle because you want to trade greater F_e for a greater d_r. **b.** *MA* is always smaller than *IMA*. **c.** Expect low F_r because *MA* is low. **d.** Expect d_e to be very small: Small distance of the axle results in a large distance of the wheel.

A Not-So-Simple Machine

Answers question from page 222.

On a multigear bike, the rider can change the mechanical advantage of the machine by choosing the size of one or both sprockets. When accelerating or climbing a hill, the rider increases the ideal mechanical advantage to increase the force the wheel exerts on the road. Looking at the *IMA* equation on page 236, to increase the *IMA*, the rider needs to make the rear sprocket radius large compared to the front sprocket radius.

Practice Problems

c. Calculate the efficiency of the wedge as a machine.

14. A worker uses a pulley system to raise a 24.0 kg carton 16.5 m. A force of 129 N is exerted and the rope is pulled 33.0 m.
  a. What is the mechanical advantage of the pulley system?
  b. What is the efficiency of the system?

15. A boy exerts a force of 225 N on a lever to raise a 1.25×10^3-N rock a distance of 13 cm. If the efficiency of the lever is 88.7%, how far did the boy move his end of the lever?

16. If the gear radius in the bicycle in the Example Problem is doubled, while the force exerted on the chain and the distance the wheel rim moves remain the same, what quantities change, and by how much?

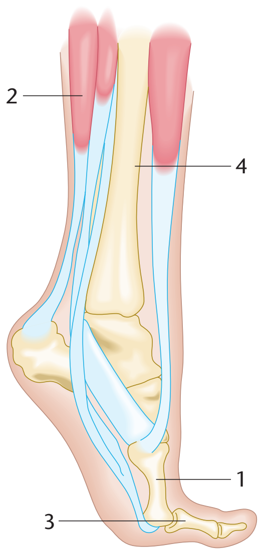


FIGURE 10–12 The human walking machine.

BIOLOGY CONNECTION

The Human Walking Machine

Movement of the human body is explained by the same principles of force and work that describe all motion. Simple machines, in the form of levers, give us the ability to walk and run. Lever systems of the body are complex, but each system has four basic parts: (1) a rigid bar (bone), (2) a source of force (muscle contraction), (3) a fulcrum or pivot (movable joints between bones), and (4) a resistance (the weight of the body or an object being lifted or moved), as shown in **Figure 10–12.** Lever systems of the body are not very efficient, and mechanical advantages are low. This is why walking and jogging require energy (burn calories) and help individuals lose weight.

When a person walks, the hip acts as a fulcrum and moves through the arc of a circle centered on the foot. The center of mass of the body moves as a resistance around the fulcrum in the same arc. The length of the radius of the circle is the length of the lever formed by the bones of the leg. Athletes in walking races increase their velocity by swinging their hips upward to increase this radius.

A tall person has lever systems with less mechanical advantage than a short person does. Although tall people can usually walk faster than short people can, a tall person must apply a greater force to move the longer lever formed by the leg bones. Walking races are usually 20 or 50 km long. Because of the inefficiency of their lever systems and the length of a walking race, very tall people rarely have the stamina to win.

10.2 Section Review

1. Many hand tools are simple machines. Classify the tools below as levers, wheel and axles, inclined planes, wedges, or pulleys.
   a. screwdriver
   b. pliers
   c. chisel
   d. nail puller
   e. wrench
2. If you increase the efficiency of a simple machine, does the
   a. *MA* increase, decrease, or remain the same?
   b. *IMA* increase, decrease, or remain the same?
3. A worker exerts a force of 20 N on a machine with $IMA = 2.0$, moving it 10 cm.
   a. Draw a graph of the force as a function of distance. Shade in the area representing the work done by this force and calculate the amount of work done.
   b. On the same graph, draw the force supplied by the machine as a function of resistance distance. Shade in the area representing the work done by the machine. Calculate this work and compare to your answer above.
4. **Critical Thinking** The mechanical advantage of a multigear bike is changed by moving the chain to a suitable back sprocket.
   a. To start out, you must accelerate the bike, so you want to have the bike exert the greatest possible force. Should you choose a small or large sprocket?
   b. As you reach your traveling speed, you want to rotate the pedals as few times as possible. Should you choose a small or large sprocket?
   c. Many bikes also let you choose the size of the front sprocket. If you want even more force to accelerate while climbing a hill, would you move to a larger or smaller front sprocket?

How It Works

Zippers

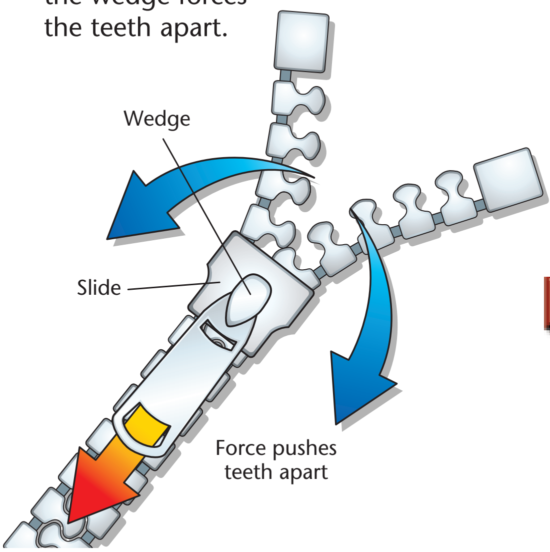
The 1893 World's Columbian Exposition introduced the first patented clasp locker to the public. Whitcomb Judson, a mechanical engineer, had devised a series of hooks and eyes that opened and closed when a slide clasp passed over them. His idea sprung from the desire to replace the button-hooked shoelaces of the 1890s and decrease the amount of time and energy required to close the high boots of the time.

Two decades later, the modern zipper (and its name) emerged from the workbench of B. F. Goodrich. Originally, Goodrich's device was confined to boots. Today, however, the zipper is an integral part of garments, handbags, tents, backpacks, boots, and many other items.

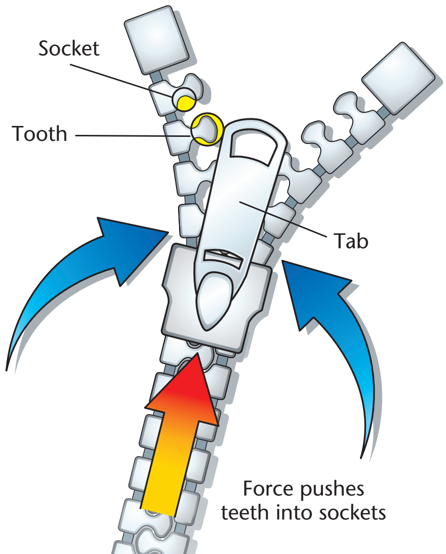
1. Most zippers consist of a slide and two rows of interlocking metal or plastic teeth. In some zippers, intermeshing spirals replace the teeth. Some sort of tab or pull is usually attached to the slide.

2. Wedges are at the heart of the operation of all zippers. The wedges change the direction of the force applied to the zipper.

3. As a zipper opens, a downward force acts on the wedge in the upper part of the slide. As a result of this force, the wedge forces the teeth apart.



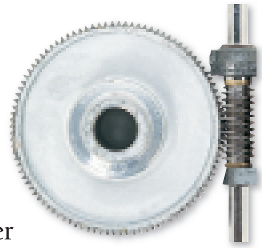
4. As a zipper closes, an upward force acts on the wedges at either side of the lower part of the slide. As a result of this force, the zipper's teeth are pushed into sockets, one after the other. In some plastic zippers, two spirals mesh as the zipper slide passes over them.



Thinking Critically

1. Classify the zipper as either a simple or compound machine. Justify your answer.
2. Look closely at a zipper slide. What prevents a zipper from opening unintentionally?
3. What role does the tab on a zipper's slide play?

CHAPTER 10 REVIEW



Summary

10.1 Energy and Work

- Work is the transfer of energy by means of forces. The work done on the system is equal to the change in energy of the system.
- Work is the product of the force exerted on an object and the distance the object moves in the direction of the force.
- The area under the force-displacement graph is work.
- Power is the rate of doing work. That is, power is the rate at which energy is transferred.

10.2 Machines

- Machines, whether powered by engines or humans, do not change work, but make it easier.
- A machine eases the load either by changing the magnitude or the direction of the force exerted to do work.
- The mechanical advantage, *MA*, is the ratio of resistance force to effort force.
- The ideal mechanical advantage, *IMA*, is the ratio of the distances. In all real machines, *MA* is less than *IMA*.

Key Terms

10.1
- energy
- kinetic energy
- work
- work-energy theorem
- joule
- power
- watt

10.2
- machine
- effort force
- resistance force
- mechanical advantage
- ideal mechanical advantage
- efficiency
- compound machine

Key Equations

10.1

$K = 1/2mv^2$ $\quad W = Fd\cos\theta$

$W = Fd$ $\quad P = \dfrac{W}{t}$

$\Delta K = W$

10.2

$MA = \dfrac{F_r}{F_e}$ $\quad \text{efficiency (\%)} = \dfrac{W_o}{W_i} \times 100$

$IMA = \dfrac{d_e}{d_r}$ $\quad \text{efficiency (\%)} = \dfrac{MA}{IMA} \times 100$

Reviewing Concepts

Section 10.1

1. In what units is work measured?
2. A satellite revolves around Earth in a circular orbit. Does Earth's gravity do any work on the satellite?
3. An object slides at constant speed on a frictionless surface. What forces act on the object? What work is done by each force?
4. Define work and power.
5. What is a watt equivalent to in terms of kg, m, and s?

Section 10.2

6. Is it possible to get more work out of a machine than you put in?
7. How are the pedals of a bicycle a simple machine?

Applying Concepts

8. Which requires more work, carrying a 420-N knapsack up a 200-m hill or carrying a 210–N knapsack up a 400-m hill? Why?
9. You slowly lift a box of books from the floor and put it on a table. Earth's gravity exerts a force, magnitude *mg*, downward, and you exert a force, magnitude *mg*, upward. The two forces have equal magnitudes and opposite directions. It appears that no work is done, but you know you did work. Explain what work is done.

10. Grace has an after-school job carrying cartons of new copy paper up a flight of stairs, and then carrying recycled paper back down the stairs. The mass of the paper does not change. Grace's physics teacher suggests that Grace does no work all day, so she should not be paid. In what sense is the physics teacher correct? What arrangement of payments might Grace make to ensure compensation?

11. Grace now carries the copy paper boxes down a level, 15-m-long hall. Is Grace working now? Explain.

12. Two people of the same mass climb the same flight of stairs. The first person climbs the stairs in 25 s; the second person does so in 35 s.
- **a.** Which person does more work? Explain your answer
- **b.** Which person produces more power? Explain your answer.

13. Show that power delivered can be written as $P = Fv$.

14. Guy has to get a piano onto a 2.0-m-high platform. He can use a 3.0-m-long frictionless ramp or a 4.0-m-long frictionless ramp. Which ramp will Guy use if he wants to do the least amount of work?

15. How could you increase the ideal mechanical advantage of a machine?

16. A claw hammer is used to pull a nail from a piece of wood. How can you place your hand on the handle and locate the nail in the claw to make the effort force as small as possible?

17. How could you increase the mechanical advantage of a wedge without changing the ideal mechanical advantage?

18. Explain why a planet orbiting the sun does not violate the work-energy theorem.

Problems

Section 10.1

19. Lee pushes a 20-kg mass 10 m across a floor with a horizontal force of 80 N. Calculate the amount of work Lee does.

20. The third floor of a house is 8 m above street level. How much work is needed to move a 150-kg refrigerator to the third floor?

21. Stan does 176 J of work lifting himself 0.300 m. What is Stan's mass?

22. Mike pulls a 4.5-kg sled across level snow with a force of 225 N along a rope that is 35.0° above the horizontal. If the sled moves a distance of 65.3 m, how much work does Mike do?

23. Sau-Lan has a mass of 52 kg. She rides the up escalator at Ocean Park in Hong Kong. This is the world's longest escalator, with a length of 227 m and an average inclination of 31°. How much work does the escalator do on Sau-Lan?

24. Chris carries a carton of milk, weight 10 N, along a level hall to the kitchen, a distance of 3.5 m. How much work does Chris do?

25. A student librarian picks up a 2.2-kg book from the floor to a height of 1.25 m. He carries the book 8.0 m to the stacks and places the book on a shelf that is 0.35 m above the floor. How much work does he do on the book?

26. Brutus, a champion weightlifter, raises 240 kg of weights a distance of 2.35 m.
- **a.** How much work is done by Brutus lifting the weights?
- **b.** How much work is done by Brutus holding the weights above his head?
- **c.** How much work is done by Brutus lowering them back to the ground?
- **d.** Does Brutus do work if he lets go of the weights and they fall back to the ground?
- **e.** If Brutus completes the lift in 2.5 s, how much power is developed?

27. A force of 300.0 N is used to push a 145-kg mass 30.0 m horizontally in 3.00 s.
- **a.** Calculate the work done on the mass.
- **b.** Calculate the power developed.

28. Robin pushes a wheelbarrow by exerting a 145-N force horizontally. Robin moves it 60.0 m at a constant speed for 25.0 s.
- **a.** What power does Robin develop?
- **b.** If Robin moves the wheelbarrow twice as fast, how much power is developed?

29. A horizontal force of 805 N is needed to drag a crate across a horizontal floor with a constant speed. You drag the crate using a rope held at an angle of 32°.
- **a.** What force do you exert on the rope?
- **b.** How much work do you do on the crate when moving it 22 m?
- **c.** If you complete the job in 8.0 s, what power is developed?

30. Wayne pulls a 305-N sled along a snowy path using a rope that makes a 45.0° angle with the ground. Wayne pulls with a force of 42.3 N. The sled moves 16 m in 3.0 s. What power does Wayne produce?
31. A lawn roller is pushed across a lawn by a force of 115 N along the direction of the handle, which is 22.5° above the horizontal. If you develop 64.6 W of power for 90.0 s, what distance is the roller pushed?
32. A crane lifts a 3.50×10^3-N bucket containing 1.15 m^3 of soil (density = 2.00×10^3 kg/m^3) to a height of 7.50 m. Calculate the work the crane performs. Disregard the weight of the cable.
33. In **Figure 10–13,** the magnitude of the force necessary to stretch a spring is plotted against the distance the spring is stretched.
    a. Calculate the slope of the graph and show that $F = kd$, where $k = 25$ N/m.
    b. Find the amount of work done in stretching the spring from 0.00 m to 0.20 m by calculating the area under the curve from 0.00 m to 0.20 m.
    c. Show that the answer to part b can be calculated using the formula $W = 1/2kd^2$, where W is the work, $k = 25$ N/m (the slope of the graph), and d is the distance the spring is stretched (0.20 m).
34. The graph in **Figure 10–13** shows the force needed to stretch a spring. Find the work needed to stretch it from 0.12 m to 0.28 m.

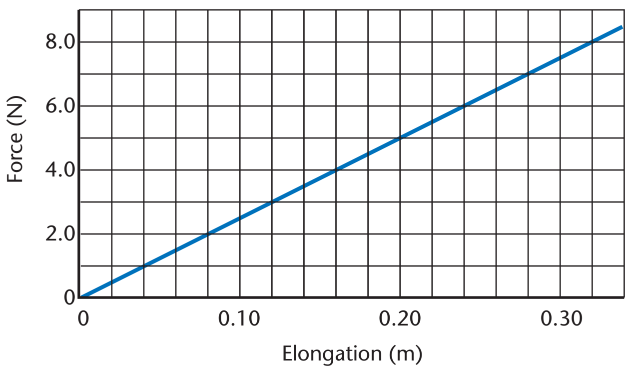


FIGURE 10–13

35. John pushes a crate across the floor of a factory with a horizontal force. The roughness of the floor changes, and John must exert a force of 20 N for 5 m, then 35 N for 12 m, and then 10 N for 8 m.
    a. Draw a graph of force as a function of distance.
    b. Find the work John does pushing the crate.
36. Sally expends 11 400 J of energy to drag a wooden crate 25.0 m across a floor with a constant speed. The rope makes an angle of 48.0° with the horizontal.
    a. How much force does the rope exert on the crate?
    b. What is the force of friction acting on the crate to impede its motion?
    c. What work is done by the floor through the force of friction between the floor and the crate?
37. An 845-N sled is pulled a distance of 185 m. The task requires 1.20×10^4 J of work and is done by pulling on a rope with a force of 125 N. At what angle is the rope held?
38. You slide a crate up a ramp at an angle of 30.0° by exerting a 225-N force parallel to the ramp. The crate moves at constant speed. The coefficient of friction is 0.28. How much work have you done on the crate when it is raised a vertical distance of 1.15 m?
39. A 4.2-kN piano is to be slid up a 3.5-m frictionless plank at a constant speed. The plank makes an angle of 30.0° with the horizontal. Calculate the work done by the person sliding the piano up the plank.
40. Rico slides a 60-kg crate up an inclined ramp 2.0-m long onto a platform 1.0 m above floor level. A 400-N force, parallel to the ramp, is needed to slide the crate up the ramp at a constant speed.
    a. How much work does Rico do in sliding the crate up the ramp?
    b. How much work would be done if Rico simply lifted the crate straight up from the floor to the platform?
41. A worker pushes a crate weighing 93 N up an inclined plane. The worker pushes the crate horizontally, parallel to the ground, as illustrated in **Figure 10–14.**
    a. The worker exerts a force of 85 N. How much work does he do?
    b. How much work is done by gravity? (Be careful with the signs you use.)

c. The coefficient of friction is $\mu = 0.20$. How much work is done by friction? (Be careful with the signs you use.)

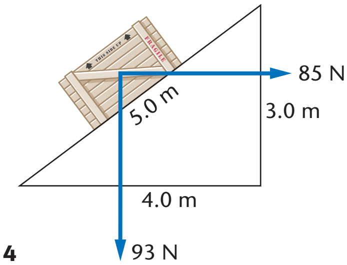


FIGURE 10–14

42. The graph in **Figure 10–15** shows the force and displacement of an object being pulled.

a. Calculate the work done to pull the object 7.0 m.

b. Calculate the power developed if the work were done in 2.0 s.

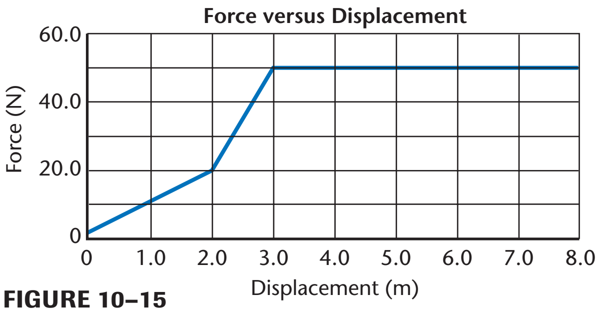


FIGURE 10–15

43. In 35.0 s, a pump delivers 0.550 m^3 of oil into barrels on a platform 25.0 m above the pump intake pipe. The density of the oil is 0.820 g/cm^3.

a. Calculate the work done by the pump.

b. Calculate the power produced by the pump.

44. A 12.0-m-long conveyor belt, inclined at 30.0°, is used to transport bundles of newspapers from the mailroom up to the cargo bay to be loaded on to delivery trucks. Each newspaper has a mass of 1.0 kg, and there are 25 newspapers per bundle. Determine the power of the conveyor if it delivers 15 bundles per minute.

45. An engine moves a boat through the water at a constant speed of 15 m/s. The engine must exert a force of 6.0×10^3 N to balance the force that water exerts against the hull. What power does the engine develop?

46. A 188-W motor will lift a load at the rate (speed) of 6.50 cm/s. How great a load can the motor lift at this rate?

47. A car is driven at a constant speed of 76 km/h down a road. The car's engine delivers 48 kW of power. Calculate the average force that is resisting the motion of the car.

Section 10.2

48. Stan raises a 1200-N piano a distance of 5.00 m using a set of pulleys. Stan pulls in 20.0 m of rope.

a. How much effort force would Stan apply if this were an ideal machine?

b. What force is used to balance the friction force if the actual effort is 340 N?

c. What is the work output?

d. What is the input work?

e. What is the mechanical advantage?

49. A mover's dolly is used to transport a refrigerator up a ramp into a house. The refrigerator has a mass of 115 kg. The ramp is 2.10 m long and rises 0.850 m. The mover pulls the dolly with a force of 496 N up the ramp. The dolly and ramp constitute a machine.

a. What work does the mover do?

b. What is the work done on the refrigerator by the machine?

c. What is the efficiency of the machine?

50. A pulley system lifts a 1345-N weight a distance of 0.975 m. Paul pulls the rope a distance of 3.90 m, exerting a force of 375 N.

a. What is the ideal mechanical advantage of the system?

b. What is the mechanical advantage?

c. How efficient is the system?

51. Because there is very little friction, the lever is an extremely efficient simple machine. Using a 90.0% efficient lever, what input work is required to lift an 18.0-kg mass through a distance of 0.50 m?

52. What work is required to lift a 215-kg mass a distance of 5.65 m using a machine that is 72.5% efficient?

53. The ramp in **Figure 10–16** is 18 m long and 4.5 m high.

a. What force parallel to the ramp (F_A) is required to slide a 25-kg box at constant speed to the top of the ramp if friction is disregarded?

b. What is the *IMA* of the ramp?

c. What are the real *MA* and the efficiency of the ramp if a parallel force of 75 N is actually required?

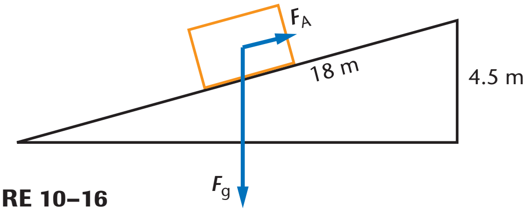


FIGURE 10–16

54. A motor having an efficiency of 88% operates a crane having an efficiency of 42%. With what constant speed does the crane lift a 410-kg crate of machine parts if the power supplied to the motor is 5.5 kW?

55. A compound machine is constructed by attaching a lever to a pulley system. Consider an ideal compound machine consisting of a lever with an *IMA* of 3.0 and a pulley system with an *IMA* of 2.0.

a. Show that the *IMA* of this compound machine is 6.0.

b. If the compound machine is 60.0% efficient, how much effort must be applied to the lever to lift a 540-N box?

c. If you move the effort side of the lever 12.0 cm, how far is the box lifted?

Extra Practice For more practice solving problems, go to Extra Practice Problems, Appendix B.

Critical Thinking Problems

56. A sprinter, mass 75 kg, runs the 50-meter dash in 8.50 s. Assume that the sprinter's acceleration is constant throughout the race.

a. What is the average power of the sprinter over the 50.0 m?

b. What is the maximum power generated by the sprinter?

c. Make a quantitative graph of power versus time for the entire race.

57. A sprinter in problem 56 runs the 50-meter dash in the same time, 8.50 s. However, this time the sprinter accelerates in the first second and runs the rest of the race at a constant velocity.

a. Calculate the average power produced for that first second.

b. What is the maximum power the sprinter now generates?

Going Further

Task Analysis You work at a store carrying boxes to a storage loft, 12 m above the ground. You have 30 boxes with a total mass of 150 kg that must be moved as quickly as possible, so you consider carrying more than one up at a time. If you try to move too many at once, you know you'll go very slowly, resting often. If you carry only one, most of the energy will go into raising your own body. The power (in watts) that your body can develop over a long time depends on the mass you carry as shown in **Figure 10–17.** This is an example of a power curve that applies to machines as well as people. Find the number of boxes to carry on each trip that would minimize the time required. What time would you spend doing the job? (Ignore the time needed to go back down the stairs, lift and lower each box, etc.)

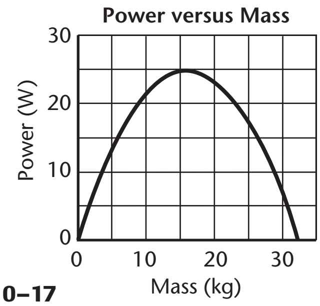


FIGURE 10–17

Critical Thinking Describe how simple machines impact and shape future careers. Evaluate the impact of improving simple and compound machines on society and the environment.

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