



Work and Simple Machines

chapter preview

sections

1 Work and Power

Lab Building the Pyramids

2 Using Machines

3 Simple Machines

Lab Pulley Power



Virtual Lab What is the relationship between work, force, and distance?

Heavy Lifting

It took the ancient Egyptians more than 100 years to build the pyramids without machines like these. But now, even tall skyscrapers can be built in a few years. Complex or simple, machines have the same purpose. They make doing work easier.

Science Journal Describe three machines you used today, and how they made doing a task easier.

Start-Up Activities



Compare Forces

Two of the world's greatest structures were built using different tools. The Great Pyramid at Giza in Egypt was built nearly 5,000 years ago using blocks of limestone moved into place by hand with ramps and levers. In comparison, the Sears Tower in Chicago was built in 1973 using tons of steel that were hoisted into place by gas-line-powered cranes. How do machines such as ramps, levers, and cranes change the forces needed to do a job?



1. Place a ruler on an eraser. Place a book on one end of the ruler.
2. Using one finger, push down on the free end of the ruler to lift the book.
3. Repeat the experiment, placing the eraser in various positions beneath the ruler. Observe how much force is needed in each instance to lift the book.
4. **Think Critically** In your Science Journal, describe your observations. How did changing the distance between the book and the eraser affect the force needed to lift the book?

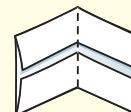
FOLDABLES™ Study Organizer

Simple Machines Many of the devices that you use every day are simple machines. Make the following Foldable to help you understand the characteristics of simple machines.

- STEP 1** Draw a mark at the midpoint of a sheet of paper along the side edge. Then **fold** the top and bottom edges in to touch the midpoint.



- STEP 2** Fold in half from side to side.



- STEP 3** Turn the paper vertically. **Open and cut** along the inside fold lines to form four tabs.



- STEP 4** Label the tabs *Inclined Plane, Lever, Wheel and Axle, and Pulley*.



Read for Main Ideas As you read the chapter, list the characteristics of inclined planes, levers, wheels and axles, and pulleys under the appropriate tab.



Preview this chapter's content and activities at blue.msscience.com



Work and Power

as you read

What You'll Learn

- **Recognize** when work is done.
- **Calculate** how much work is done.
- **Explain** the relation between work and power.

Why It's Important

If you understand work, you can make your work easier.

Review Vocabulary

force: a push or a pull

New Vocabulary

- work
- power

What is work?

What does the term *work* mean to you? You might think of household chores; a job at an office, a factory, a farm; or the homework you do after school. In science, the definition of work is more specific. **Work** is done when a force causes an object to move in the same direction that the force is applied.

Can you think of a way in which you did work today? Maybe it would help to know that you do work when you lift your books, turn a doorknob, raise window blinds, or write with a pen or pencil. You also do work when you walk up a flight of stairs or open and close your school locker. In what other ways do you do work every day?

Work and Motion Your teacher has asked you to move a box of books to the back of the classroom. Try as you might, though, you just can't budge the box because it is too heavy. Although you exerted a force on the box and you feel tired from it, you have not done any work. In order for you to do work, two things must occur. First, you must apply a force to an object. Second,

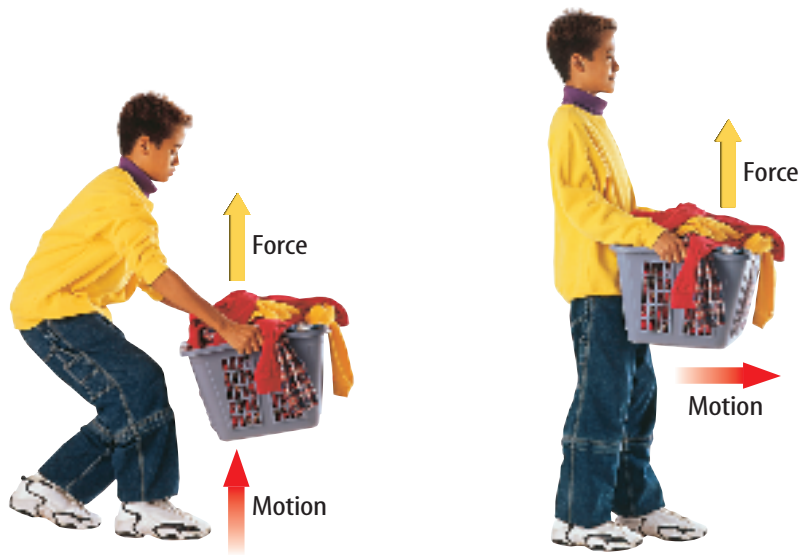
the object must move in the same direction as your applied force. You do work on an object only when the object moves as a result of the force you exert. The girl in **Figure 1** might think she is working by holding the bags of groceries. However, if she is not moving, she is not doing any work because she is not causing something to move.

✓ Reading Check

To do work, how must a force make an object move?



Figure 1 This girl is holding bags of groceries, yet she isn't doing any work. **Explain** what must happen for work to be done.



The boy's arms do work when they exert an upward force on the basket and the basket moves upward.

The boy's arms still exert an upward force on the basket. But when the boy walks forward, no work is done by his arms.

Figure 2 To do work, an object must move in the direction a force is applied.

Applying Force and Doing Work Picture yourself lifting the basket of clothes in **Figure 2**. You can feel your arms exerting a force upward as you lift the basket, and the basket moves upward in the direction of the force your arms applied. Therefore, your arms have done work. Now, suppose you carry the basket forward. You can still feel your arms applying an upward force on the basket to keep it from falling, but now the basket is moving forward instead of upward. Because the direction of motion is not in the same direction of the force applied by your arms, no work is done by your arms.

Force in Two Directions Sometimes only part of the force you exert moves an object. Think about what happens when you push a lawn mower. You push at an angle to the ground as shown in **Figure 3**. Part of the force is to the right and part of the force is downward. Only the part of the force that is in the same direction as the motion of the mower—to the right—does work.



Figure 3 When you exert a force at an angle, only part of your force does work—the part that is in the same direction as the motion of the object.



INTEGRATE History

James Prescott Joule This English physicist experimentally verified the law of conservation of energy. He showed that various forms of energy—mechanical, electrical, and thermal—are essentially the same and can be converted one into another. The SI unit of energy and work, the joule, is named after him. Research the work of Joule and write what you learn in your Science Journal.

Calculating Work

Work is done when a force makes an object move. More work is done when the force is increased or the object is moved a greater distance. Work can be calculated using the work equation below. In SI units, the unit for work is the joule, named for the nineteenth-century scientist James Prescott Joule.

Work Equation

work (in joules) = **force** (in newtons) \times **distance** (in meters)

$$W = Fd$$

Work and Distance Suppose you give a book a push and it slides across a table. To calculate the work you did, the distance in the above equation is not the distance the book moved. The distance in the work equation is the distance an object moves while the force is being applied. So the distance in the work equation is the distance the book moved while you were pushing.

Applying Math

Solve a One-Step Equation

CALCULATING WORK A painter lifts a can of paint that weighs 40 N a distance of 2 m. How much work does she do? *Hint: to lift a can weighing 40 N, the painter must exert a force of 40 N.*

Solution

1 This is what you know:

- force: $F = 40 \text{ N}$
- distance: $d = 2 \text{ m}$

2 This is what you need to find out:

work: $W = ? \text{ J}$

3 This is the procedure you need to use:

Substitute the known values $F = 40 \text{ N}$ and $d = 2 \text{ m}$ into the work equation:

$$W = Fd = (40 \text{ N})(2 \text{ m}) = 80 \text{ N}\cdot\text{m} = 80 \text{ J}$$

4 Check your answer:

Check your answer by dividing the work you calculated by the distance given in the problem. The result should be the force given in the problem.

Practice Problems

1. As you push a lawn mower, the horizontal force is 300 N. If you push the mower a distance of 500 m, how much work do you do?
2. A librarian lifts a box of books that weighs 93 N a distance of 1.5 m. How much work does he do?



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What is power?

What does it mean to be powerful? Imagine two weightlifters lifting the same amount of weight the same vertical distance. They both do the same amount of work. However, the amount of power they use depends on how long it took to do the work. **Power** is how quickly work is done. The weightlifter who lifted the weight in less time is more powerful.

Calculating Power Power can be calculated by dividing the amount of work done by the time needed to do the work.

Power Equation

$$\text{power (in watts)} = \frac{\text{work (in joules)}}{\text{time (in seconds)}}$$
$$P = \frac{W}{t}$$

In SI units, the unit of power is the watt, in honor of James Watt, a nineteenth-century British scientist who invented a practical version of the steam engine.

Mini LAB

Work and Power

Procedure

1. Weigh yourself on a scale.
2. Multiply your weight in pounds by 4.45 to convert your weight to newtons.
3. Measure the vertical height of a **stairway**.
WARNING: Make sure the stairway is clear of all objects.
4. Time yourself walking slowly and quickly up the stairway.

Analysis

Calculate and compare the work and power in each case.



Applying Math

Solve a One-Step Equation

CALCULATING POWER You do 200 J of work in 12 s. How much power did you use?

Solution

1 This is what you know:

- work: $W = 200 \text{ J}$
- time: $t = 12 \text{ s}$

2 This is what you need to find out:

- power: $P = ? \text{ watts}$

3 This is the procedure you need to use:

Substitute the known values $W = 200 \text{ J}$ and $t = 12 \text{ s}$ into the power equation:

$$P = \frac{W}{t} = \frac{200 \text{ J}}{12 \text{ s}} = 17 \text{ watts}$$

4 Check your answer:

Check your answer by multiplying the power you calculated by the time given in the problem. The result should be the work given in the problem.

Practice Problems

1. In the course of a short race, a car does 50,000 J of work in 7 s. What is the power of the car during the race?
2. A teacher does 140 J of work in 20 s. How much power did he use?



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Topic: James Watt

Visit blue.msscience.com for Web links to information about James Watt and his steam engine.

Activity Draw a diagram showing how his steam engine worked.

Work and Energy If you push a chair and make it move, you do work on the chair and change its energy. Recall that when something is moving it has energy of motion, or kinetic energy. By making the chair move, you increase its kinetic energy.

You also change the energy of an object when you do work and lift it higher. An object has potential energy that increases when it is higher above Earth's surface. By lifting an object, you do work and increase its potential energy.

Power and Energy When you do work on an object you increase the energy of the object. Because energy can never be created or destroyed, if the object gains energy then you must lose energy. When you do work on an object you transfer energy to the object, and your energy decreases. The amount of work done is the amount of energy transferred. So power is also equal to the amount of energy transferred in a certain amount of time.

Sometimes energy can be transferred even when no work is done, such as when heat flows from a warm to a cold object. In fact, there are many ways energy can be transferred even if no work is done. Power is always the rate at which energy is transferred, or the amount of energy transferred divided by the time needed.

section 1 review

Summary

What is work?

- Work is done when a force causes an object to move in the same direction that the force is applied.
- If the movement caused by a force is at an angle to the direction the force is applied, only the part of the force in the direction of motion does work.
- Work can be calculated by multiplying the force applied by the distance:

$$W = Fd$$

- The distance in the work equation is the distance an object moves while the force is being applied.

What is power?

- Power is how quickly work is done. Something is more powerful if it can do a given amount of work in less time.
- Power can be calculated by dividing the work done by the time needed to do the work:

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

Self Check

1. **Describe** a situation in which work is done on an object.
2. **Evaluate** which of the following situations involves more power: 200 J of work done in 20 s or 50 J of work done in 4 s? Explain your answer.
3. **Determine** two ways power can be increased.
4. **Calculate** how much power, in watts, is needed to cut a lawn in 50 min if the work involved is 100,000 J.
5. **Think Critically** Suppose you are pulling a wagon with the handle at an angle. How can you make your task easier?

Applying Math

6. **Calculate Work** How much work was done to lift a 1,000-kg block to the top of the Great Pyramid, 146 m above ground?
7. **Calculate Work Done by an Engine** An engine is used to lift a beam weighing 9,800 N up to 145 m. How much work must the engine do to lift this beam? How much work must be done to lift it 290 m?

Building the Pyramids

Imagine moving 2.3 million blocks of limestone, each weighing more than 1,000 kg. That is exactly what the builders of the Great Pyramid at Giza did. Although no one knows for sure exactly how they did it, they probably pulled the blocks most of the way.

Real-World Question

How is the force needed to lift a block related to the distance it travels?

Goals

- **Compare** the force needed to lift a block with the force needed to pull it up a ramp.

Materials

wood block	thin notebooks
tape	meterstick
spring scale	several books
ruler	

Safety Precautions

Procedure

1. Stack several books together on a tabletop to model a half-completed pyramid. Measure the height of the books in centimeters. Record the height on the first row of the data table under *Distance*.
2. Use the wood block as a model for a block of stone. Use tape to attach the block to the spring scale.
3. Place the block on the table and lift it straight up the side of the stack of books until the top of the block is even with the top of the books. Record the force shown on the scale in the data table under *Force*.

Work Done Using Different Ramps

Distance (cm)	Force (N)	Work (J)
Do not write in this book.		

4. **Arrange** a notebook so that one end is on the stack of books and the other end is on the table. Measure the length of the notebook and record this length as distance in the second row of the data table under *Distance*.
5. **Measure** the force needed to pull the block up the ramp. Record the force in the data table.
6. Repeat steps 4 and 5 using a longer notebook to make the ramp longer.
7. **Calculate** the work done in each row of the data table.

Conclude and Apply

1. **Evaluate** how much work you did in each instance.
2. **Determine** what happened to the force needed as the length of the ramp increased.
3. **Infer** How could the builders of the pyramids have designed their task to use less force than they would lifting the blocks straight up? Draw a diagram to support your answer.

Communicating Your Data

Add your data to that found by other groups. For more help, refer to the **Science Skill Handbook**.

Using Machines

as you read

What You'll Learn

- **Explain** how a machine makes work easier.
- **Calculate** the mechanical advantages and efficiency of a machine.
- **Explain** how friction reduces efficiency.

Why It's Important

Machines can't change the amount of work you need to do, but they can make doing work easier.

Review Vocabulary

friction: force that opposes motion between two touching surfaces

New Vocabulary

- input force
- output force
- mechanical advantage
- efficiency

What is a machine?

Did you use a machine today? When you think of a machine you might think of a device, such as a car, with many moving parts powered by an engine or an electric motor. But if you used a pair of scissors or a broom, or cut your food with a knife, you used a machine. A machine is simply a device that makes doing work easier. Even a sloping surface can be a machine.

Mechanical Advantage

Even though machines make work easier, they don't decrease the amount of work you need to do. Instead, a machine changes the way in which you do work. When you use a machine, you exert a force over some distance. For example, you exert a force to move a rake or lift the handles of a wheelbarrow. The force that you apply on a machine is the **input force**. The work you do on the machine is equal to the input force times the distance over which your force moves the machine. The work that you do on the machine is the input work.

The machine also does work by exerting a force to move an object over some distance. A rake, for example, exerts a force to move leaves. Sometimes this force is called the resistance force because the machine is trying to overcome some resistance. The force that the machine applies is the **output force**. The work that the machine does is the output work. **Figure 4** shows how a machine transforms input work to output work.

When you use a machine, the output work can never be greater than the input work. So what is the advantage of using a machine? A machine makes work easier by changing the amount of force you need to exert, the distance over which the force is exerted, or the direction in which you exert your force.

Figure 4 No matter what type of machine is used, the output work is never greater than the input work.





Changing Force Some machines make doing work easier by reducing the force you have to apply to do work. This type of machine increases the input force, so that the output force is greater than the input force. The number of times a machine increases the input force is the **mechanical advantage** of the machine. The mechanical advantage of a machine is the ratio of the output force to the input force and can be calculated from this equation:

Mechanical Advantage Equation

$$\text{mechanical advantage} = \frac{\text{output force (in newtons)}}{\text{input force (in newtons)}}$$

$$MA = \frac{F_{\text{out}}}{F_{\text{in}}}$$

Mechanical advantage does not have any units, because it is the ratio of two numbers with the same units.



Topic: Historical Tools

Visit blue.msscience.com for Web links to information about early types of tools and how they took advantage of simple machines.

Activity Write a paragraph describing how simple machines were used to design early tools.

Applying Math

Solve a One-Step Equation

CALCULATING MECHANICAL ADVANTAGE To pry the lid off a paint can, you apply a force of 50 N to the handle of the screwdriver. What is the mechanical advantage of the screwdriver if it applies a force of 500 N to the lid?

Solution

1 This is what you know:

- input force: $F_{\text{in}} = 50 \text{ N}$
- output force: $F_{\text{out}} = 500 \text{ N}$

2 This is what you need to find out:

mechanical advantage: $MA = ?$

3 This is the procedure you need to use:

Substitute the known values $F_{\text{in}} = 50 \text{ N}$ and $F_{\text{out}} = 500 \text{ N}$ into the mechanical advantage equation:

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

4 Check your answer:

Check your answer by multiplying the mechanical advantage you calculated by the input force given in the problem. The result should be the output force given in the problem.

Practice Problems

1. To open a bottle, you apply a force of 50 N to the bottle opener. The bottle opener applies a force of 775 N to the bottle cap. What is the mechanical advantage of the bottle opener?
2. To crack a pecan, you apply a force of 50 N to the nutcracker. The nutcracker applies a force of 750 N to the pecan. What is the mechanical advantage of the nutcracker?



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Figure 5 Changing the direction or the distance that a force is applied can make a task easier.

Sometimes it is easier to exert your force in a certain direction. This boy would rather pull down on the rope to lift the flag than to climb to the top of the pole and pull up.

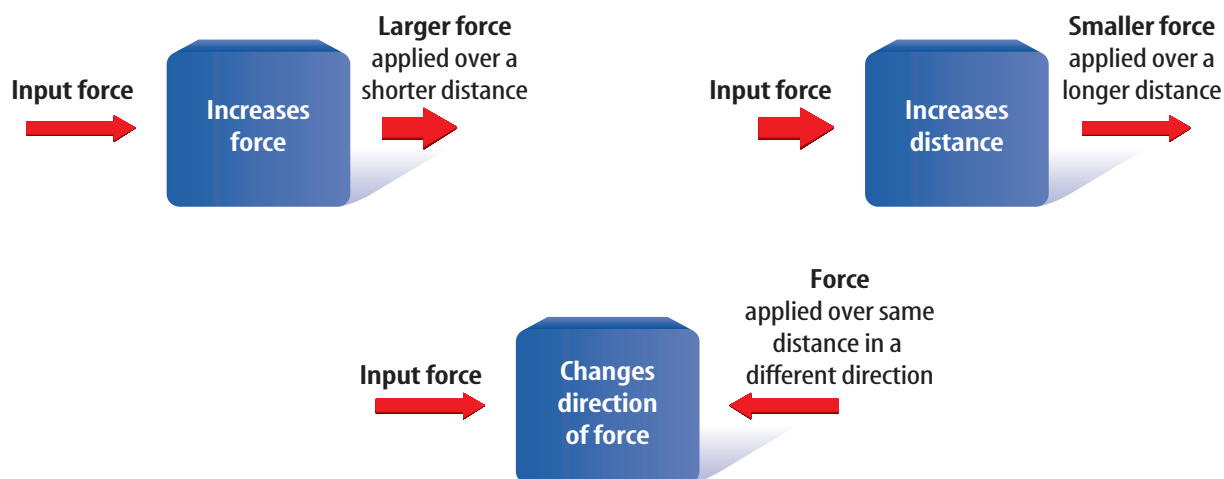


When you rake leaves, you move your hands a short distance, but the end of the rake moves over a longer distance.

Changing Distance Some machines allow you to exert your force over a shorter distance. In these machines, the output force is less than the input force. The rake in **Figure 5** is this type of machine. You move your hands a small distance at the top of the handle, but the bottom of the rake moves a greater distance as it moves the leaves. The mechanical advantage of this type of machine is less than one because the output force is less than the input force.

Changing Direction Sometimes it is easier to apply a force in a certain direction. For example, it is easier to pull down on the rope in **Figure 5** than to pull up on it. Some machines enable you to change the direction of the input force. In these machines neither the force nor the distance is changed. The mechanical advantage of this type of machine is equal to one because the output force is equal to the input force. The three ways machines make doing work easier are summarized in **Figure 6**.

Figure 6 Machines are useful because they can increase force, increase distance, or change the direction in which a force is applied.





Efficiency

A machine doesn't increase the input work. For a real machine, the output work done by the machine is always less than the input work that is done on the machine. In a real machine, there is friction as parts of the machine move. Friction converts some of the input work into heat, so that the output work is reduced. The **efficiency** of a machine is the ratio of the output work to the input work, and can be calculated from this equation:

Efficiency Equation

$$\text{efficiency (in percent)} = \frac{\text{output work (in joules)}}{\text{input work (in joules)}} \times 100\%$$

$$\text{eff} = \frac{W_{\text{out}}}{W_{\text{in}}} \times 100\%$$

If the amount of friction in the machine is reduced, the efficiency of the machine increases.



Body Temperature

Chemical reactions that enable your muscles to move also produce heat that helps maintain your body temperature. When you shiver, rapid contraction and relaxation of muscle fibers produces a large amount of heat that helps raise your body temperature. This causes the efficiency of your muscles to decrease as more energy is converted into heat.

Applying Math

Solve a One-Step Equation

CALCULATING EFFICIENCY Using a pulley system, a crew does 7,500 J of work to load a box that requires 4,500 J of work. What is the efficiency of the pulley system?

Solution

1 This is what you know:

- input work: $W_{\text{in}} = 7,500 \text{ J}$
- output work: $W_{\text{out}} = 4,500 \text{ J}$

2 This is what you need to find out:

efficiency: $\text{eff} = ? \%$

3 This is the procedure you need to use:

Substitute the known values $W_{\text{in}} = 7,500 \text{ J}$ and $W_{\text{out}} = 4,500 \text{ J}$ into the efficiency equation:

$$\text{eff} = \frac{W_{\text{out}}}{W_{\text{in}}} = \frac{4,500 \text{ J}}{7,500 \text{ J}} \times 100\% = 60\%$$

4 Check your answer:

Check your answer by dividing the efficiency by 100% and then multiplying your answer times the work input. The product should be the work output given in the problem.

Practice Problems

1. You do 100 J of work in pulling out a nail with a claw hammer. If the hammer does 70 J of work, what is the hammer's efficiency?
2. You do 150 J of work pushing a box up a ramp. If the ramp does 105 J of work, what is the efficiency of the ramp?



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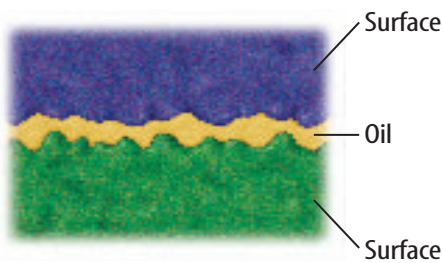


Figure 7 Lubrication can reduce the friction between two surfaces. Two surfaces in contact can stick together where the high spots on each surface come in contact. Adding oil or another lubricant separates the surface so that fewer high spots make contact.

Friction To help understand friction, imagine pushing a heavy box up a ramp. As the box begins to move, the bottom surface of the box slides across the top surface of the ramp. Neither surface is perfectly smooth—each has high spots and low spots, as shown in **Figure 7**.

As the two surfaces slide past each other, high spots on the two surfaces come in contact. At these contact points, shown in **Figure 7**, atoms and molecules can bond together. This makes the contact points stick together. The attractive forces between all the bonds in the contact points added together is the frictional force that tries to keep the two surfaces from sliding past each other.

To keep the box moving, a force must be applied to break the bonds between the contact points. Even after these bonds are broken and the box moves, new bonds form as different parts of the two surfaces come into contact.

Friction and Efficiency One way to reduce friction between two surfaces is to add oil. **Figure 7** shows how oil fills the gaps between the surfaces, and keeps many of the high spots from making contact. Because there are fewer contact points between the surfaces, the force of friction is reduced. More of the input work then is converted to output work by the machine.

section 2 review

Summary

What is a machine?

- A machine is a device that makes doing work easier.
- A machine can make doing work easier by reducing the force exerted, changing the distance over which the force is exerted, or changing the direction of the force.
- The output work done by a machine can never be greater than the input work done on the machine.

Mechanical Advantage and Efficiency

- The mechanical advantage of a machine is the number of times the machine increases the input force:

$$MA = \frac{F_{\text{out}}}{F_{\text{in}}}$$

- The efficiency of a machine is the ratio of the output work to the input work:

$$\text{eff} = \frac{W_{\text{out}}}{W_{\text{in}}} \times 100\%$$

Self Check

1. **Identify** three specific situations in which machines make work easier.
2. **Infer** why the output force exerted by a rake must be less than the input force.
3. **Explain** how the efficiency of an ideal machine compares with the efficiency of a real machine.
4. **Explain** how friction reduces the efficiency of machines.
5. **Think Critically** Can a machine be useful even if its mechanical advantage is less than one? Explain and give an example.

Applying Math

6. **Calculate Efficiency** Find the efficiency of a machine if the input work is 150 J and the output work is 90 J.
7. **Calculate Mechanical Advantage** To lift a crate, a pulley system exerts a force of 2,750 N. Find the mechanical advantage of the pulley system if the input force is 250 N.

Simple Machines

What is a simple machine?

What do you think of when you hear the word *machine*? Many people think of machines as complicated devices such as cars, elevators, or computers. However, some machines are as simple as a hammer, shovel, or ramp. A **simple machine** is a machine that does work with only one movement. The six simple machines are the inclined plane, lever, wheel and axle, screw, wedge, and pulley. A machine made up of a combination of simple machines is called a **compound machine**. A can opener is a compound machine. The bicycle in **Figure 8** is a familiar example of another compound machine.

Inclined Plane

Ramps might have enabled the ancient Egyptians to build their pyramids. To move limestone blocks weighing more than 1,000 kg each, archaeologists hypothesize that the Egyptians built enormous ramps. A ramp is a simple machine known as an inclined plane. An **inclined plane** is a flat, sloped surface. Less force is needed to move an object from one height to another using an inclined plane than is needed to lift the object. As the inclined plane becomes longer, the force needed to move the object becomes smaller.



as you read

What You'll Learn

- **Distinguish** among the different simple machines.
- **Describe** how to find the mechanical advantage of each simple machine.

Why It's Important

All machines, no matter how complicated, are made of simple machines.

Review Vocabulary

compound: made of separate pieces or parts

New Vocabulary

- simple machine
- compound machine
- inclined plane
- wedge
- screw
- lever
- wheel and axle
- pulley

Figure 8 Devices that use combinations of simple machines, such as this bicycle, are called compound machines.

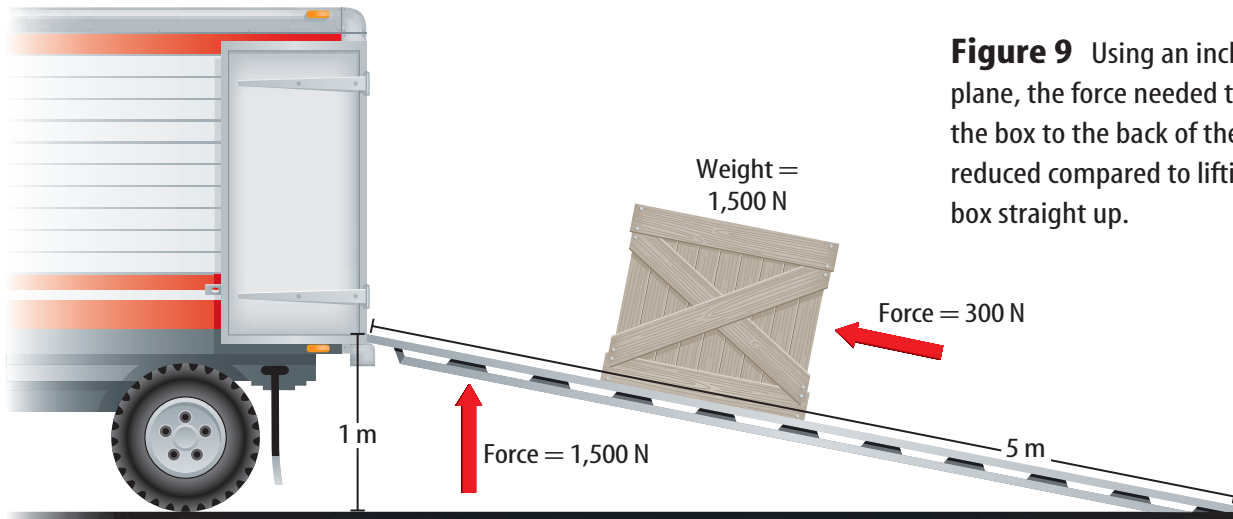


Figure 9 Using an incline plane, the force needed to move the box to the back of the truck is reduced compared to lifting the box straight up.

Using Inclined Planes Imagine having to lift a box weighing 1,500 N to the back of a truck that is 1 m off the ground. You would have to exert a force of 1,500 N, the weight of the box, over a distance of 1 m, which equals 1,500 J of work. Now suppose that instead you use a 5-m-long ramp, as shown in **Figure 9**. The amount of work you need to do does not change. You still need to do 1,500 J of work. However, the distance over which you exert your force becomes 5 m. You can calculate the force you need to exert by dividing both sides of the equation for work by distance.

$$\text{Force} = \frac{\text{work}}{\text{distance}}$$

Figure 10 This chef's knife is a wedge that slices through food.



If you do 1,500 J of work by exerting a force over 5 m, the force is only 300 N. Because you exert the input force over a distance that is five times as long, you can exert a force that is five times less.

The mechanical advantage of an inclined plane is the length of the inclined plane divided by its height. In this example, the ramp has a mechanical advantage of 5.

Wedge An inclined plane that moves is called a **wedge**. A wedge can have one or two sloping sides. The knife shown in **Figure 10** is an example of a wedge. An axe and certain types of doorstops are also wedges. Just as for an inclined plane, the mechanical advantage of a wedge increases as it becomes longer and thinner.



Figure 11 Wedge-shaped teeth help tear food.



Your front teeth help tear an apple apart.

The wedge-shaped teeth of this *Tyrannosaurus rex* show that it was a carnivore.



Wedges in Your Body You have wedges in your body. The bite marks on the apple in **Figure 11** show how your front teeth are wedge shaped. A wedge changes the direction of the applied effort force. As you push your front teeth into the apple, the downward effort force is changed by your teeth into a sideways force that pushes the skin of the apple apart.

The teeth of meat eaters, or carnivores, are more wedge shaped than the teeth of plant eaters, or herbivores. The teeth of carnivores are used to cut and rip meat, while herbivores' teeth are used for grinding plant material. By examining the teeth of ancient animals, such as the dinosaur in **Figure 11**, scientists can determine what the animal ate when it was living.

The Screw Another form of the inclined plane is a screw. A **screw** is an inclined plane wrapped around a cylinder or post. The inclined plane on a screw forms the screw threads. Just like a wedge changes the direction of the effort force applied to it, a screw also changes the direction of the applied force. When you turn a screw, the force applied is changed by the threads to a force that pulls the screw into the material. Friction between the threads and the material holds the screw tightly in place. The mechanical advantage of the screw is the length of the inclined plane wrapped around the screw divided by the length of the screw. The more tightly wrapped the threads are, the easier it is to turn the screw. Examples of screws are shown in **Figure 12**.

Figure 12 The thread around a screw is an inclined plane. Many familiar devices use screws to make work easier.



How are screws related to the inclined plane?



Figure 13 The mechanical advantage of a lever changes as the position of the fulcrum changes. The mechanical advantage increases as the fulcrum is moved closer to the output force.

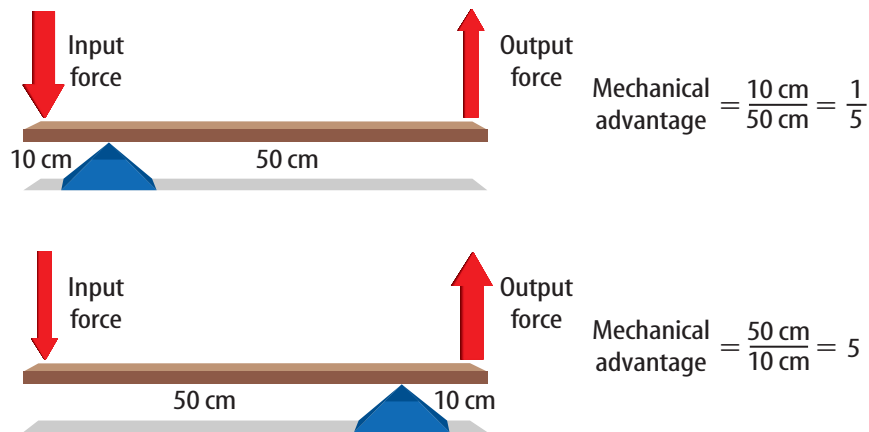


Figure 14 A faucet handle is a wheel and axle. A wheel and axle is similar to a circular lever. The center is the fulcrum, and the wheel and axle turn around it. **Explain** how you can increase the mechanical advantage of a wheel and axle.



Lever

You step up to the plate. The pitcher throws the ball and you swing your lever to hit the ball? That's right! A baseball bat is a type of simple machine called a lever. A **lever** is any rigid rod or plank that pivots, or rotates, about a point. The point about which the lever pivots is called a fulcrum.

The mechanical advantage of a lever is found by dividing the distance from the fulcrum to the input force by the distance from the fulcrum to the output force, as shown in **Figure 13**. When the fulcrum is closer to the output force than the input force, the mechanical advantage is greater than one.

Levers are divided into three classes according to the position of the fulcrum with respect to the input force and output force. **Figure 15** shows examples of three classes of levers.

Wheel and Axle

Do you think you could turn a doorknob easily if it were a narrow rod the size of a pencil? It might be possible, but it would be difficult. A doorknob makes it easier for you to open a door because it is a simple machine called a wheel and axle. A **wheel and axle** consists of two circular objects of different sizes that are attached in such a way that they rotate together. As you can see in **Figure 14**, the larger object is the wheel and the smaller object is the axle.

The mechanical advantage of a wheel and axle is usually greater than one. It is found by dividing the radius of the wheel by the radius of the axle. For example, if the radius of the wheel is 12 cm and the radius of the axle is 4 cm, the mechanical advantage is 3.

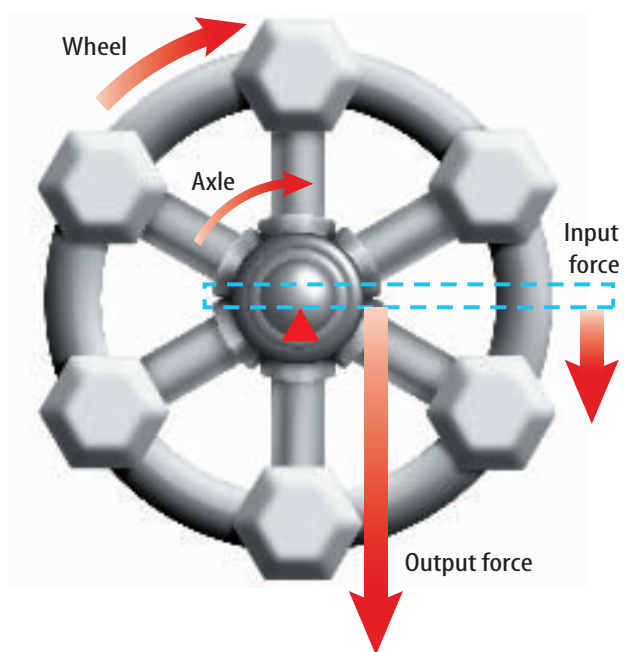



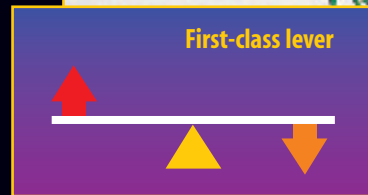


Figure 15

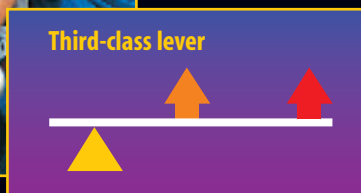
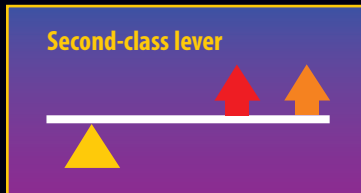
Lever are among the simplest of machines, and you probably use them often in everyday life without even realizing it. A lever is a bar that pivots around a fixed point called a fulcrum. As shown here, there are three types of levers—first class, second class, and third class. They differ in where two forces—an input force and an output force—are located in relation to the fulcrum.

-  **Fulcrum**
-  **Input force**
-  **Output force**

In a first-class lever, the fulcrum is between the input force and the output force. First-class levers, such as scissors and pliers, multiply force or distance depending on where the fulcrum is placed. They always change the direction of the input force, too.



In a second-class lever, such as a wheelbarrow, the output force is between the input force and the fulcrum. Second-class levers always multiply the input force but don't change its direction.



In a third-class lever, such as a baseball bat, the input force is between the output force and the fulcrum. For a third-class lever, the output force is less than the input force, but is in the same direction.

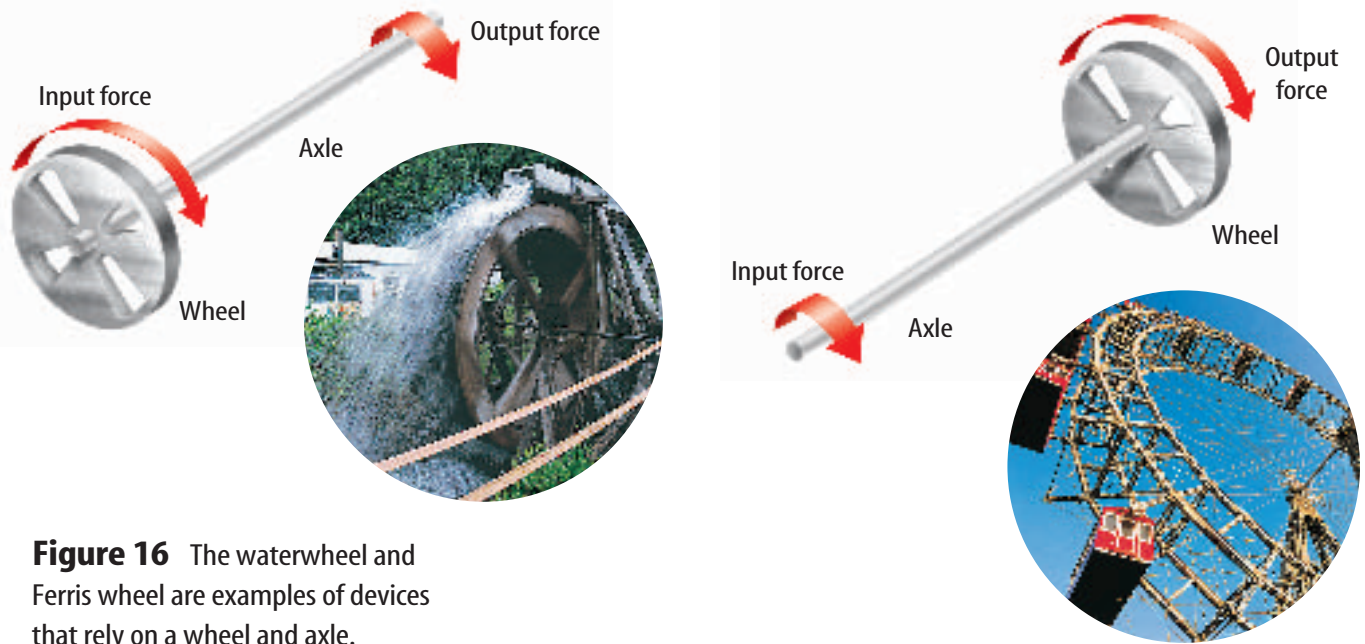


Figure 16 The waterwheel and Ferris wheel are examples of devices that rely on a wheel and axle.

Compare and contrast *waterwheels and Ferris wheels in terms of wheels and axles.*

Using Wheels and Axles In some devices, the input force is used to turn the wheel and the output force is exerted by the axle. Because the wheel is larger than the axle, the mechanical advantage is greater than one. So the output force is greater than the input force. A doorknob, a steering wheel, and a screwdriver are examples of this type of wheel and axle.

In other devices, the input force is applied to turn the axle and the output force is exerted by the wheel. Then the mechanical advantage is less than one and the output force is less than the input force. A fan and a ferris wheel are examples of this type of wheel and axle. **Figure 16** shows an example of each type of wheel and axle.

Mini LAB

Observing Pulleys

Procedure

1. Obtain two broomsticks. Tie a 3-m-long rope to the middle of one stick. Wrap the rope around both sticks four times.
2. Have two students pull the broomsticks apart while a third pulls on the rope.
3. Repeat with two wraps of rope.

Analysis

1. Compare the results.
2. Predict whether it will be easier to pull the broomsticks together with ten wraps of rope.

Pulley

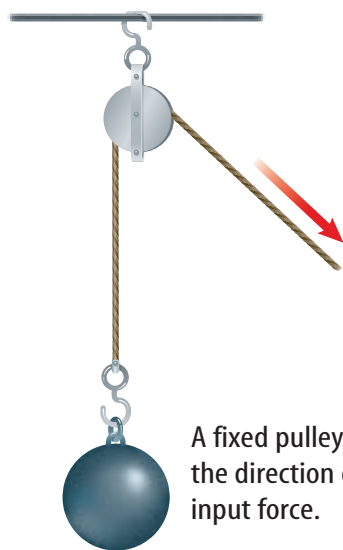
To raise a sail, a sailor pulls down on a rope. The rope uses a simple machine called a pulley to change the direction of the force needed. A **pulley** consists of a grooved wheel with a rope or cable wrapped over it.

Fixed Pulleys Some pulleys, such as the one on a sail, a window blind, or a flagpole, are attached to a structure above your head. When you pull down on the rope, you pull something up. This type of pulley, called a fixed pulley, does not change the force you exert or the distance over which you exert it. Instead, it changes the direction in which you exert your force, as shown in **Figure 17**. The mechanical advantage of a fixed pulley is 1.



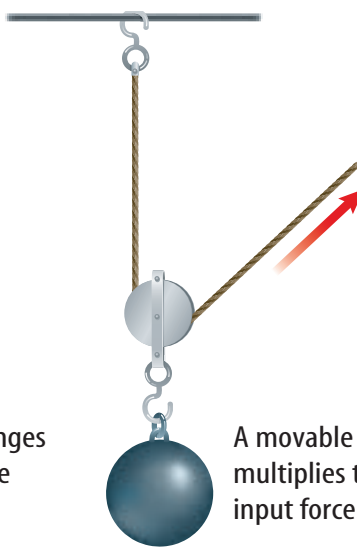
Reading Check

How does a fixed pulley affect the input force?



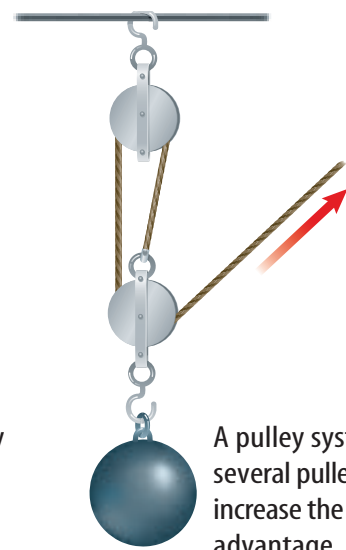
Fixed pulley

A fixed pulley changes the direction of the input force.



Movable pulley

A movable pulley multiplies the input force.



Pulley system

A pulley system uses several pulleys to increase the mechanical advantage.

Movable Pulleys Another way to use a pulley is to attach it to the object you are lifting, as shown in **Figure 17**. This type of pulley, called a movable pulley, allows you to exert a smaller force to lift the object. The mechanical advantage of a movable pulley is always 2.

More often you will see combinations of fixed and movable pulleys. Such a combination is called a pulley system. The mechanical advantage of a pulley system is equal to the number of sections of rope pulling up on the object. For the pulley system shown in **Figure 17** the mechanical advantage is 3.

Figure 17 Pulleys can change force and direction.

section 3 review

Summary

Simple and Compound Machines

- A simple machine is a machine that does work with only one movement.
- A compound machine is made from a combination of simple machines.

Types of Simple Machines

- An inclined plane is a flat, sloped surface.
- A wedge is an inclined plane that moves.
- A screw is an inclined plane that is wrapped around a cylinder or post.
- A lever is a rigid rod that pivots around a fixed point called the fulcrum.
- A wheel and axle consists of two circular objects of different sizes that rotate together.
- A pulley is a grooved wheel with a rope or cable wrapped over it.

Self Check

1. **Determine** how the mechanical advantage of a ramp changes as the ramp becomes longer.
2. **Explain** how a wedge changes an input force.
3. **Identify** the class of lever for which the fulcrum is between the input force and the output force.
4. **Explain** how the mechanical advantage of a wheel and axle change as the size of the wheel increases.
5. **Think Critically** How are a lever and a wheel and axle similar?

Applying Math

6. **Calculate Length** The Great Pyramid is 146 m high. How long is a ramp from the top of the pyramid to the ground that has a mechanical advantage of 4?
7. **Calculate Force** Find the output force exerted by a moveable pulley if the input force is 50 N.

Pulley Power

Goals

- **Design** a pulley system.
- **Measure** the mechanical advantage and efficiency of the pulley system.

Possible Materials

single- and multiple-pulley systems
 nylon rope
 steel bar to support the pulley system
 meterstick
**metric tape measure*
 variety of weights to test pulleys
 force spring scale
 brick
**heavy book*
 balance
**scale*
**Alternate materials*

Safety Precautions



WARNING: *The brick could be dangerous if it falls. Keep your hands and feet clear of it.*

Real-World Question

Imagine how long it might have taken to build the Sears Tower in Chicago without the aid of a pulley system attached to a crane. Hoisting the 1-ton I beams to a maximum height of 110 stories required large lifting forces and precise control of the beam's movement.

Construction workers also use smaller pulleys that are not attached to cranes to lift supplies to where they are needed. Pulleys are not limited to construction sites. They also are used to lift automobile engines out of cars, to help load and unload heavy objects on ships, and to lift heavy appliances and furniture. How can you use a pulley system to reduce the force needed to lift a load?



Form a Hypothesis

Write a hypothesis about how pulleys can be combined to make a system of pulleys to lift a heavy load, such as a brick. Consider the efficiency of your system.

Test Your Hypothesis

Make a Plan

1. Decide how you are going to support your pulley system. What materials will you use?
2. How will you measure the effort force and the resistance force? How will you determine the mechanical advantage? How will you measure efficiency?
3. **Experiment** by lifting small weights with a single pulley, double pulley, and so on. How efficient are the pulleys? In what ways can you increase the efficiency of your setup?

Using Scientific Methods

4. Use the results of step 3 to design a pulley system to lift the brick. Draw a diagram of your design. Label the different parts of the pulley system and use arrows to indicate the direction of movement for each section of rope.

Follow Your Plan

1. Make sure your teacher approves your plan before you start.
2. Assemble the pulley system you designed. You might want to test it with a smaller weight before attaching the brick.
3. **Measure** the force needed to lift the brick. How much rope must you pull to raise the brick 10 cm?

Analyze Your Data

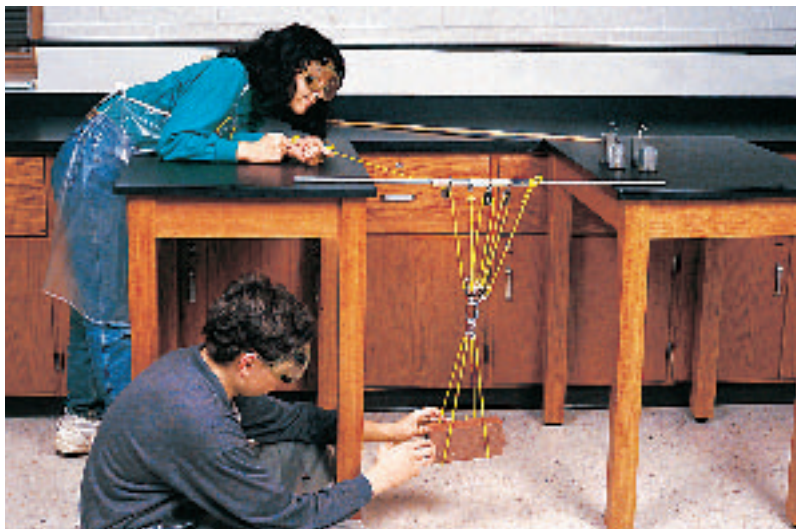
1. **Calculate** the ideal mechanical advantage of your design.
2. **Calculate** the actual mechanical advantage of the pulley system you built.
3. **Calculate** the efficiency of your pulley system.
4. How did the mechanical advantage of your pulley system compare with those of your classmates?

Conclude and Apply

1. **Explain** how increasing the number of pulleys increases the mechanical advantage.
2. **Infer** How could you modify the pulley system to lift a weight twice as heavy with the same effort force used here?
3. **Compare** this real machine with an ideal machine.

Communicating Your Data

Show your design diagram to the class. Review the design and point out good and bad characteristics of your pulley system. For more help, refer to the **Science Skill Handbook**.



Bionic People

Artificial limbs can help people lead normal lives

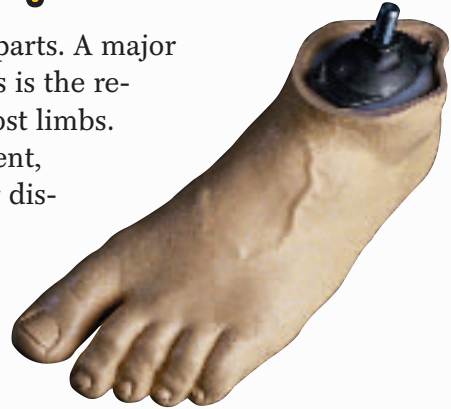
People in need of transplants usually receive human organs. But many people's medical problems can only be solved by receiving artificial body parts. These synthetic devices, called prostheses, are used to replace anything from a heart valve to a knee joint. Bionics is the science of creating

artificial body parts. A major focus of bionics is the replacement of lost limbs. Through accident, birth defect, or disease, people sometimes lack hands or feet, or even whole arms or legs.

For centuries, people have used prostheses to replace limbs. In the past, physically challenged people used devices like peg legs or artificial arms that ended in a pair of hooks. These prostheses didn't do much to replace lost functions of arms and legs.

The knowledge that muscles respond to electricity has helped create more effective prostheses. One such prostheses is the myoelectric arm. This battery-powered device connects muscle nerves in an amputated arm to a sensor.

The sensor detects when the arm tenses, then transmits the signal to an artificial hand, which opens or closes. New prosthetic hands even give a sense of touch, as well as cold and heat.



Myoelectric arms make life easier for people who have them.

Research Use your school's media center to find other aspects of robotics such as walking machines or robots that perform planetary exploration. What are they used for? How do they work? You could take it one step further and learn about cyborgs. Report to the class.

Science  **online**

For more information, visit blue.msscience.com/time

Reviewing Main Ideas

Section 1 Work and Power

1. Work is done when a force exerted on an object causes the object to move.
2. A force can do work only when it is exerted in the same direction as the object moves.
3. Work is equal to force times distance, and the unit of work is the joule.
4. Power is the rate at which work is done, and the unit of power is the watt.

Section 2 Using Machines

1. A machine can change the size or direction of an input force or the distance over which it is exerted.

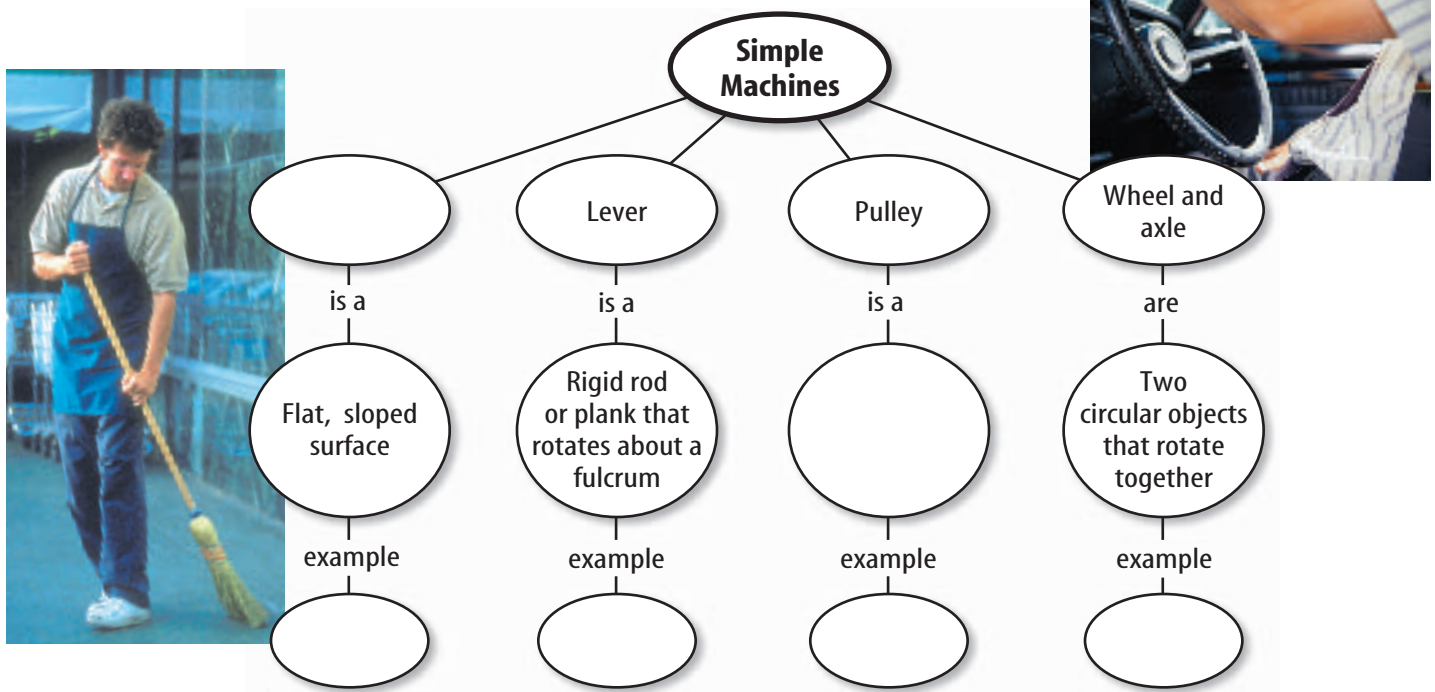
2. The mechanical advantage of a machine is its output force divided by its input force.

Section 3 Simple Machines

1. A machine that does work with only one movement is a simple machine. A compound machine is a combination of simple machines.
2. Simple machines include the inclined plane, lever, wheel and axle, screw, wedge, and pulley.
3. Wedges and screws are inclined planes.
4. Pulleys can be used to multiply force and change direction.

Visualizing Main Ideas

Copy and complete the following concept map on simple machines.



Using Vocabulary

compound machine p. 591	output force p. 586
efficiency p. 589	power p. 583
inclined plane p. 591	pulley p. 596
input force p. 586	screw p. 593
lever p. 594	simple machine p. 591
mechanical advantage p. 587	wedge p. 592
	wheel and axle p. 594
	work p. 580

Each phrase below describes a vocabulary word. Write the vocabulary word that matches the phrase describing it.

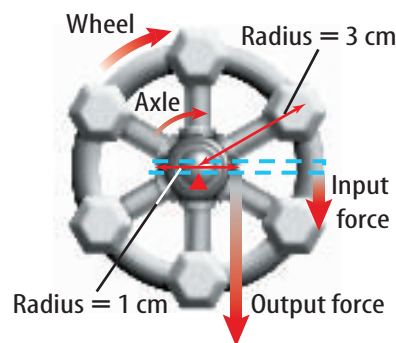
- percentage of work in to work out
- force put into a machine
- force exerted by a machine
- two rigidly attached wheels
- input force divided by output force
- a machine with only one movement
- an inclined plane that moves
- a rigid rod that rotates about a fulcrum
- a flat, sloped surface
- amount of work divided by time

Checking Concepts

Choose the word or phrase that best answers the question.

- Which of the following is a requirement for work to be done?
 - Force is exerted.
 - Object is carried.
 - Force moves an object.
 - Machine is used.
- How much work is done when a force of 30 N moves an object a distance of 3 m?
 - 3 J
 - 10 J
 - 30 J
 - 90 J
- How much power is used when 600 J of work are done in 10 s?
 - 6 W
 - 60 W
 - 600 W
 - 610 W
- Which is a simple machine?
 - baseball bat
 - bicycle
 - can opener
 - car
- Mechanical advantage can be calculated by which of the following expressions?
 - input force/output force
 - output force/input force
 - input work/output work
 - output work/input work
- What is the ideal mechanical advantage of a machine that changes only the direction of the input force?
 - less than 1
 - zero
 - 1
 - greater than 1

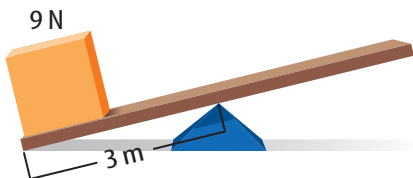
Use the illustration below to answer question 17.



- What is the output force if the input force on the wheel is 100 N?
 - 5 N
 - 200 N
 - 500 N
 - 2,000 N
- Which of the following is a form of the inclined plane?
 - pulley
 - screw
 - wheel and axle
 - lever
- For a given input force, a ramp increases which of the following?
 - height
 - output force
 - output work
 - efficiency

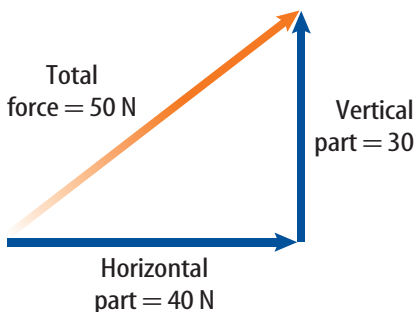
Thinking Critically

Use the illustration below to answer question 20.



- 20. **Evaluate** Would a 9-N force applied 2 m from the fulcrum lift the weight? Explain.
- 21. **Explain** why the output work for any machine can't be greater than the input work.
- 22. **Explain** A doorknob is an example of a wheel and axle. Explain why turning the knob is easier than turning the axle.
- 23. **Infer** On the Moon, the force of gravity is less than on Earth. Infer how the mechanical advantage of an inclined plane would change if it were on the Moon, instead of on Earth.
- 24. **Make and Use Graphs** A pulley system has a mechanical advantage of 5. Make a graph with the input force on the x -axis and the output force on the y -axis. Choose five different values of the input force, and plot the resulting output force on your graph.

Use the diagram below to answer question 25.



- 25. **Work** The diagram above shows a force exerted at an angle to pull a sled. How much work is done if the sled moves 10 m horizontally?

Performance Activities

- 26. **Identify** You have levers in your body. Your muscles and tendons provide the input force. Your joints act as fulcrums. The output force is used to move everything from your head to your hands. Describe and draw any human levers you can identify.
- 27. **Display** Make a display of everyday devices that are simple and compound machines. For devices that are simple machines, identify which simple machine it is. For compound machines, identify the simple machines that compose it.

Applying Math

- 28. **Mechanical Advantage** What is the mechanical advantage of a 6-m long ramp that extends from a ground-level sidewalk to a 2-m high porch?
- 29. **Input Force** How much input force is required to lift an 11,000-N beam using a pulley system with a mechanical advantage of 20?
- 30. **Efficiency** The input work done on a pulley system is 450 J. What is the efficiency of the pulley system if the output work is 375 J?

Use the table below to answer question 31.

Output Force Exerted by Machines

Machine	Input Force (N)	Output Force (N)
A	500	750
B	300	200
C	225	225
D	800	1,100
E	75	110

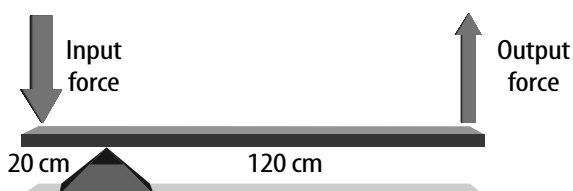
- 31. **Mechanical Advantage** According to the table above, which of the machines listed has the largest mechanical advantage?

Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

1. The work done by a boy pulling a snow sled up a hill is 425 J. What is the power expended by the boy if he pulls on the sled for 10.5 s?
- A. 24.7 W C. 247 W
B. 40.5 W D. 4460 W

Use the illustration below to answer questions 2 and 3.

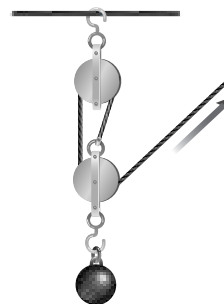


2. What is the mechanical advantage of the lever shown above?
- A. $\frac{1}{6}$ C. 2
B. $\frac{1}{2}$ D. 6
3. What would the mechanical advantage of the lever be if the triangular block were moved to a position 40 cm from the edge of the output force side of the plank?
- A. $\frac{1}{4}$ C. 2
B. $\frac{1}{2}$ D. 4
4. Which of the following causes the efficiency of a machine to be less than 100%?
- A. work
B. power
C. mechanical advantage
D. friction

Test-Taking Tip

Simplify Diagrams Write directly on complex charts, such as a Punnett square.

Use the illustration below to answer questions 5 and 6.



5. The pulley system in the illustration above uses several pulleys to increase the mechanical advantage. What is the mechanical advantage of this system?
- A. 1 C. 3
B. 2 D. 4
6. Suppose the lower pulley was removed so that the object was supported only by the upper pulley. What would the mechanical advantage be?
- A. 0 C. 2
B. 1 D. 3
7. You push a shopping cart with a force of 12 N for a distance of 1.5 m. You stop pushing the cart, but it continues to roll for 1.1 m. How much work did you do?
- A. 8.0 J C. 18 J
B. 13 J D. 31 J
8. What is the mechanical advantage of a wheel with a radius of 8.0 cm connected to an axle with a radius of 2.5 cm?
- A. 0.31 C. 3.2
B. 2.5 D. 20
9. You push a 5-kg box across the floor with a force of 25 N. How far do you have to push the box to do 63 J of work?
- A. 0.40 m C. 2.5 m
B. 1.6 m D. 13 m

Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

10. What is the name of the point about which a lever rotates?
11. Describe how you can determine the mechanical advantage of a pulley or a pulley system.

Use the figure below to answer questions 12 and 13.



12. What type of simple machine is the tip of the dart in the photo above?
13. Would the mechanical advantage of the dart tip change if the tip were longer and thinner? Explain.
14. How much energy is used by a 75-W lightbulb in 15 s?
15. The input and output forces are applied at the ends of the lever. If the lever is 3 m long and the output force is applied 1 m from the fulcrum, what is the mechanical advantage?
16. Your body contains simple machines. Name one part that is a wedge and one part that is a lever.
17. Explain why applying a lubricant, such as oil, to the surfaces of a machine causes the efficiency of the machine to increase.
18. Apply the law of conservation of energy to explain why the output work done by a real machine is always less than the input work done on the machine.

Part 3 Open Ended

Record your answers on a sheet of paper.

19. The output work of a machine can never be greater than the input work. However, the advantage of using a machine is that it makes work easier. Describe and give an example of the three ways a machine can make work easier.
20. A wheel and axle may have a mechanical advantage that is either greater than 1 or less than 1. Describe both types and give some examples of each.
21. Draw a sketch showing the cause of friction as two surfaces slide past each other. Explain your sketch, and describe how lubrication can reduce the friction between the two surfaces.
22. Draw the two types of simple pulleys and an example of a combination pulley. Draw arrows to show the direction of force on your sketches.

Use the figure below to answer question 23.



23. Identify two simple machines in the photo above and describe how they make riding a bicycle easier.
24. Explain why the mechanical advantage of an inclined plane can never be less than 1.