

14.2

KEY CONCEPT

Six simple machines have many uses.



BEFORE, you learned

- Machines help you work by changing the size or direction of a force
- The number of times a machine multiplies the input force is the machine's mechanical advantage



NOW, you will learn

- How six simple machines change the size or direction of a force
- How to calculate mechanical advantage

VOCABULARY

simple machine p. 458
 lever p. 459
 fulcrum p. 459
 wheel and axle p. 460
 pulley p. 460
 inclined plane p. 462
 wedge p. 462
 screw p. 463

EXPLORE Changing Forces

How can you change a force?

PROCEDURE

- 1 Lay one pencil on a flat surface. Place the other pencil on top of the first pencil and perpendicular to it, as shown. Place the book on one end of the top pencil.
- 2 Push down on the free end of the top pencil to raise the book.
- 3 Change the position of the bottom pencil so that it is closer to the book and repeat step 2. Then move the bottom pencil closer to the end of the pencil you are pushing on and repeat step 2.

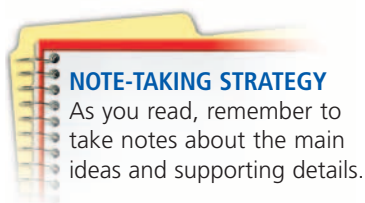
MATERIALS

- 2 pencils
- small book



WHAT DO YOU THINK?

- How did changing the position of the bottom pencil affect how much force you needed to lift the book?
- At which position is it easiest to lift the book? most difficult?



NOTE-TAKING STRATEGY

As you read, remember to take notes about the main ideas and supporting details.

There are six simple machines.

You have read about how a ramp and a shovel can help you do work. A ramp is a type of inclined plane, and a shovel is a type of lever. An inclined plane and a lever are both simple machines.

Simple machines are the six machines on which all other mechanical machines are based. In addition to the inclined plane and the lever, simple machines include the wheel and axle, pulley, wedge, and screw. As you will see, the wheel and axle and pulley are related to the lever, and the wedge and screw are related to the inclined plane. You will read about each of the six simple machines in detail in this section.

Lever

A **lever** is a solid bar that rotates, or turns, around a fixed point. The bar can be straight or curved. The fixed point is called the **fulcrum**. A lever can multiply the input force. It can also change the direction of the input force. If you apply a force downward on one end of a lever, the other end can lift a load.

The way in which a lever changes an input force depends on the positions of the fulcrum, the input force, and the output force in relation to one another. Levers with different arrangements have different uses. Sometimes a greater output force is needed, such as when you want to pry up a bottle cap. At other times you use a greater input force on one end to get a higher speed at the other end, such as when you swing a baseball bat. The three different arrangements, sometimes called the three classes of levers, are shown in the diagram below.



CHECK YOUR
READING

What two parts are needed to make a lever?

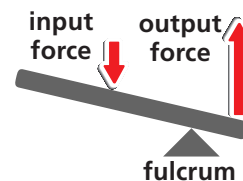
Levers

Levers can be classified according to where the fulcrum is.

First-Class Lever



The fulcrum is located between the input force and the output force. Use this type of lever to change the direction and size of a force.



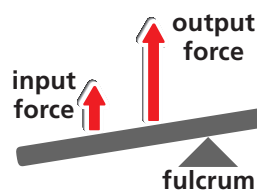
READING TIP

The lengths of the arrows in the diagram represent the size of the force.

Second-Class Lever



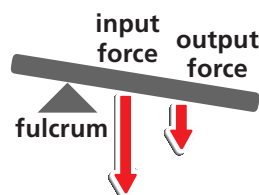
The output force is located between the input force and the fulcrum. Use this type of lever if you need a greater output force.



Third-Class Lever

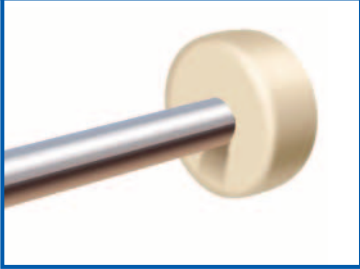


The input force is located between the output force and the fulcrum. Use this type of lever to reduce the distance over which you apply the input force or increase the speed of the end of the lever.



Wheel and Axle

Wheel and Axle



A **wheel and axle** is a simple machine made of a wheel attached to a shaft, or axle. The wheels of most means of transportation—such as a bicycle and a car—are attached to an axle. The wheel and axle act like a rotating collection of levers. The axle at the wheel's center is like a fulcrum. Other examples of wheels and axles are screwdrivers, steering wheels, doorknobs, and electric fans.

Depending on your purpose for using a wheel and axle, you might apply a force to turn the wheel or the axle. If you turn the wheel, your input force is transferred to the axle. Because the axle is smaller than the wheel, the output force acts over a shorter distance than the input force. A driver applies less force to a steering wheel to get a greater turning force from the axle, or steering column. This makes it easier to steer the car.

If, instead, you turn the axle, your force is transferred to the wheel. Because the wheel is larger than the axle, the force acts over a longer distance. A car also contains this use of a wheel and axle. The engine turns the drive axles, which turn the wheels.



Compare the results of putting force on the axle with putting force on the wheel.

Pulley

A **pulley** is a wheel with a grooved rim and a rope or cable that rides in the groove. As you pull on the rope, the wheel turns.

A pulley that is attached to something that holds it steady is called a fixed pulley. An object attached to the rope on one side of the wheel rises as you pull down on the rope on the other side of the wheel. The fixed pulley makes work easier by changing the direction of the force. You must apply enough force to overcome the weight of the load and any friction in the pulley system.

Fixed Pulley



A fixed pulley allows you to take advantage of the downward pull of your weight to move a load upward. It does not, however, reduce the force you need to lift the load. Also, the distance you pull the rope through is the same distance that the object is lifted. To lift a load two meters using a fixed pulley, you must pull down two meters of rope.

In a movable pulley setup, one end of the rope is fixed, but the wheel can move. The load is attached to the wheel. The person pulling the rope provides the output force that lifts the load. A single movable pulley does not change the direction of the force. Instead, it multiplies the force. Because the load is supported by two sections of rope, you need only half the force you would use with a fixed pulley to lift it. However, you must pull the rope through twice the distance.

CHECK YOUR READING

How does a single fixed pulley differ from a single movable pulley?

Movable Pulley



A combination of fixed and movable pulleys is a pulley system called a block and tackle. A block and tackle is used to haul and lift very heavy objects. By combining fixed and movable pulleys, you can use more rope sections to support the weight of an object. This reduces the force you need to lift the object. The mechanical advantage of a single pulley can never be greater than 2. If engineers need a pulley system with a mechanical advantage greater than 2, they often use a block-and-tackle system.

INVESTIGATE Pulleys

What is the mechanical advantage of a pulley system?

PROCEDURE

- 1 Hang the mass on the spring scale to find its weight in newtons. Record this weight as your output force.
- 2 Tie the top of one pulley to the ring stand.
- 3 Attach the mass to the second pulley.
- 4 Attach one end of the second pulley's rope to the bottom of the first pulley. Then thread the free end of the rope through the second pulley. Loop the rope up and over the first pulley, as shown.
- 5 Attach the spring scale to the free end of the rope. Pull down to lift the mass. Record the force you used as your input force. Calculate the mechanical advantage of this pulley system.

Hint: The mechanical advantage can be calculated by dividing the output force by the input force.

WHAT DO YOU THINK?

- How did your input force compare with your output force?
- What caused the results you observed?

CHALLENGE Explain what the mechanical advantage would be for a pulley system that includes another movable pulley.

SKILL FOCUS Inferring

MATERIALS

- 100 g mass
- spring scale
- 2 pulleys with rope
- ring stand

TIME
20 minutes





Inclined Plane

Recall that it is difficult to lift a heavy object straight up because you must apply a force great enough to overcome the downward pull of the force of gravity. For this reason people often use ramps. A ramp is an **inclined plane**, a simple machine that is a sloping surface. The photograph at the left shows the interior of the Guggenheim Museum in New York City. The levels of the art museum are actually one continuous inclined plane.

Inclined Plane



Inclined planes make the work of raising an object easier because they support part of the weight of the object while it is being moved from one level to another. The surface of an inclined plane applies a reaction force on the object resting on it. This extra force on the object helps to act against gravity. If you are pushing an object up a ramp, you have to push with only enough force to overcome the smaller net force that pulls the object down parallel to the incline.

The less steep an inclined plane is, the less force you need to push or pull an object on the plane. This is because a less steep plane supports more of an object's weight than a steeper plane. However, the less steep an inclined plane is, the farther you must go to reach a certain height. While you use less force, you must apply that force over a greater distance.

CHECK YOUR READING

How do inclined planes help people do work?
Your answer should mention force.

Wedge



Wedge

A **wedge** is a simple machine that has a thick end and a thin end. Wedges are used to cut, split, or pierce objects—or to hold objects together. A wedge is a type of inclined plane, but inclined planes are stationary, while wedges often move to do work.

Some wedges are single, movable inclined planes, such as a doorstop, a chisel, or an ice scraper. Another kind of wedge is made of two back-to-back inclined planes. Examples include the blade of an axe or a knife. In the photograph at the left, a sculptor is using a chisel to shape stone. The sculptor applies an input force on the chisel by tapping its thicker end with a mallet. That force pushes the thinner end of the chisel into the stone. As a result, the sides of the thinner end exert an output force that separates the stone.

The angle of the cutting edge determines how easily a wedge can cut through an object. Thin wedges have small angles and need less input force to cut than do thick wedges with large angles. That is why a sharp knife blade cuts more easily than a dull one.

You also can think of a wedge that cuts objects in terms of how it changes the pressure on a surface. The thin edges of a wedge provide a smaller surface area for the input force to act on. This greater pressure makes it easier to break through the surface of an object. A sharp knife can cut through an apple skin, and a sharp chisel can apply enough pressure to chip stone.

A doorstop is a wedge that is used to hold objects together. To do its job, a doorstop is pressed tip-first under a door. As the doorstop is moved into position, it lifts the door slightly and applies a force to the bottom of the door. In return, the door applies pressure to the doorstop and causes the doorstop to press against the floor with enough force to keep the doorstop—and the door—from moving.

Screw

A **screw** is an inclined plane wrapped around a cylinder or cone to form a spiral. A screw is a simple machine that can be used to raise and lower weights as well as to fasten objects. Examples of screws include drills, jar lids, screw clamps, and nuts and bolts. The spiraling inclined plane that sticks out from the body of the screw forms the threads of the screw.

In the photograph at right, a person is using a screwdriver, which is a wheel and axle, to drive a screw into a piece of wood. Each turn of the screwdriver pushes the screw farther into the wood. As the screw is turned, the threads act like wedges, exerting an output force on the wood. If the threads are very close together, the force must be applied over a greater distance—that is, the screw must be turned many times—but less force is needed.

The advantage of using a screw instead of a nail to hold things together is the large amount of friction that keeps the screw from turning and becoming loose. Think of pulling a nail out of a piece of wood compared with pulling a screw from the same piece of wood. The nail can be pulled straight out. The screw must be turned through a greater distance to remove it from the wood.

Notice that the interior of the Guggenheim Museum shown on page 462 is not only an inclined plane. It is also an example of a screw. The inclined plane is wrapped around the museum's atrium, which is an open area in the center.



Screw



Explain how a screw moves deeper into the wood as it is turned.

The mechanical advantage of a machine can be calculated.

Recall that the number of times a machine multiplies the input force is the machine's mechanical advantage. You can calculate a machine's mechanical advantage using this formula:

$$\text{Mechanical Advantage} = \frac{\text{Output Force}}{\text{Input Force}}$$

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

This formula works for all machines, regardless of whether they are simple machines or more complicated machines.

If a machine decreases the force you use to do work, the distance over which you have to apply that force increases. It is possible to use this idea to calculate the mechanical advantage of a simple machine without knowing what the input and output forces are. To make this calculation, however, you must assume that your machine is not losing any work to friction. In other words, you must assume that your machine is 100 percent efficient. The mechanical advantage that you calculate when making this assumption is called the ideal mechanical advantage.

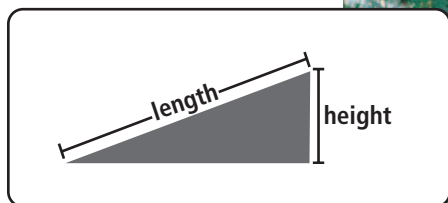
Inclined Plane You can calculate the ideal mechanical advantage of an inclined plane by dividing its length by its height.

$$\text{Ideal Mechanical Advantage} = \frac{\text{length of incline}}{\text{height of incline}}$$

$$IMA = \frac{l}{h}$$

READING TIP

Scientists often consider the way in which an object will behave under ideal conditions, such as when there is no friction.



Be sure to use the length of the incline in your calculation, as shown in the diagram, and not the length of the base. If the mover in the photograph on page 464 increased the length of the ramp, he would increase the ramp's mechanical advantage. However, he would also increase the distance over which he had to carry the box.

Wheel and Axle To calculate the ideal mechanical advantage of a wheel and axle, use the following formula:

$$\text{Ideal Mechanical Advantage} = \frac{\text{Radius of input}}{\text{Radius of output}}$$

$$IMA = \frac{R_{in}}{R_{out}}$$

The Ferris wheel below is a giant wheel and axle. A motor applies an input force to the Ferris wheel's axle, which turns the wheel. In this example, the input force is applied to the axle, so the radius of the axle is the input radius in the formula above. The output force is applied by the wheel, so the radius of the wheel is the output radius.

For a Ferris wheel, the input force is greater than the output force. The axle turns through a shorter distance than the wheel does. The ideal mechanical advantage of this type of wheel and axle is less than 1.

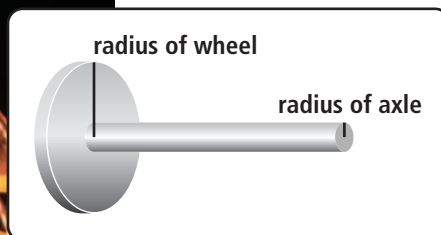
Sometimes, as with a steering wheel, the input force is applied to turn the wheel instead of the axle. Then the input radius is the wheel's radius, and the output radius is the axle's radius. In this case, the input force on the wheel is less than the output force applied by the axle. The ideal mechanical advantage of this type of wheel and axle is greater than 1.

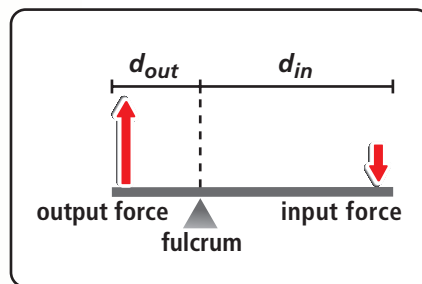


Explore the mechanical advantage of an inclined plane.

REMINDER

The radius is the distance from the center of the wheel or axle to any point on its circumference.





Lever The beam balance above is a lever. The beam is the solid bar that turns on a fixed point, or fulcrum. The fulcrum is the beam's balance point. When you slide the weight across the beam, you are changing the distance between the input force and the fulcrum. The mechanical advantage depends on the distances of the input force and output force from the fulcrum. The output force is applied to balance the beaker.

To calculate the ideal mechanical advantage of a lever, use the following formula:

$$\text{Ideal Mechanical Advantage} = \frac{\text{distance from input force to fulcrum}}{\text{distance from output force to fulcrum}}$$

$$IMA = \frac{d_{in}}{d_{out}}$$

This formula applies to all three arrangements of levers. If the distance from the input force to the fulcrum is greater than the distance from the output force to the fulcrum, the ideal mechanical advantage is greater than 1. The beam balance is an example of this type of lever.

14.2 Review

KEY CONCEPTS

1. Name the six simple machines and give an example of each.
2. Explain how a screw changes the size of the force needed to push it into wood.
3. To calculate mechanical advantage, what two things do you need to know?

CRITICAL THINKING

4. **Synthesize** How is a pulley similar to a wheel and axle?
5. **Calculate** What is the ideal mechanical advantage of a wheel with a diameter of 30 cm fixed to an axle with a diameter of 4 cm if the axle is turned?

CHALLENGE

6. **Infer** How can you increase a wedge's mechanical advantage? Draw a diagram to show your idea.