SECTION 3

Types of Machines

Imagine that it's a hot summer day. You have a whole ice-cold watermelon in front of you. It would taste cool and delicious—if only you had a machine that could cut it!

What You Will Learn

- Identify and give examples of the six types of simple machines.
- Analyze the mechanical advantage provided by each simple machine.
- Identify the simple machines that make up a compound machine.

Vocabulary

lever
pulley
wheel and axle
inclined plane
wedge
screw
compound machine

READING STRATEGY

Mnemonics As you read this section, create a mnemonic device to help you remember the different types of levers.

The machine you need is a knife. But how is a knife a machine? A knife is actually a very sharp wedge, which is one of the six simple machines. The six simple machines are the lever, the inclined plane, the wedge, the screw, the pulley, and the wheel and axle. All machines are made from one or more of these simple machines.

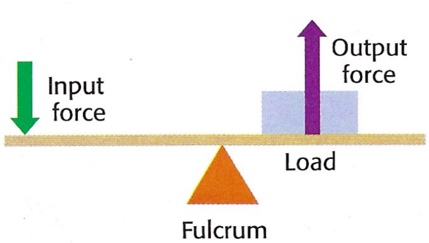
Levers

Have you ever used the claw end of a hammer to remove a nail from a piece of wood? If so, you were using the hammer as a lever. A **lever** is a simple machine that has a bar that pivots at a fixed point, called a *fulcrum*. Levers are used to apply a force to a load. There are three classes of levers, which are based on the placements of the fulcrum, the load, and the input force.

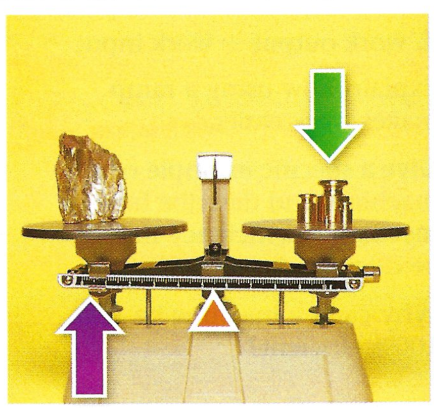
First-Class Levers

With a first-class lever, the fulcrum is between the input force and the load, as shown in **Figure 1.** First-class levers always change the direction of the input force. And depending on the location of the fulcrum, first-class levers can be used to increase force or to increase distance.

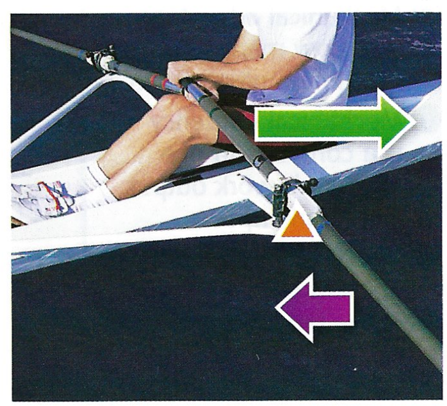
Figure 1 Examples of First-Class Levers



When the fulcrum is closer to the load than to the input force, the lever has a **mechanical advantage of greater than 1.** The output force is increased because it is exerted over a shorter distance.

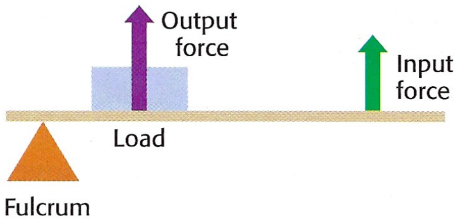


When the fulcrum is exactly in the middle, the lever has a **mechanical advantage of 1.** The output force is not increased because the input force's distance is not increased.

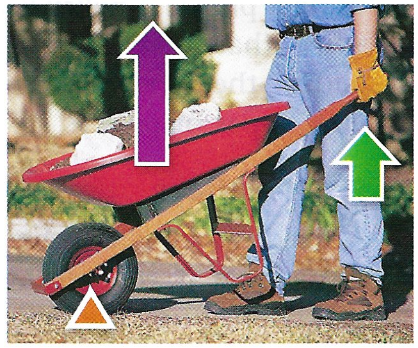


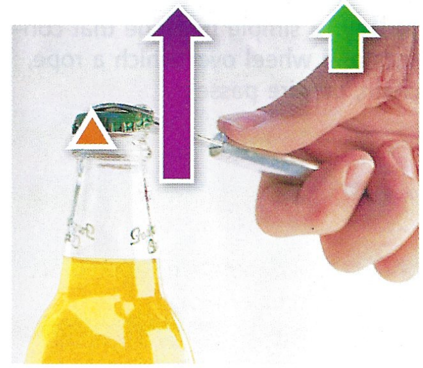
When the fulcrum is closer to the input force than to the load, the lever has a **mechanical advantage of less than 1.** Although the output force is less than the input force, distance increases.

Figure 2 **Examples of Second-Class Levers**



In a **second-class lever,** the output force, or load, is between the input force and the fulcrum.





Using a second-class lever results in a **mechanical advantage of greater than 1.** The closer the load is to the fulcrum, the more the force is increased and the greater the mechanical advantage is.

Second-Class Levers

The load of a second-class lever is between the fulcrum and the input force, as shown in **Figure 2.** Second-class levers do not change the direction of the input force. But they allow you to apply less force than the force exerted by the load. Because the output force is greater than the input force, you must exert the input force over a greater distance.

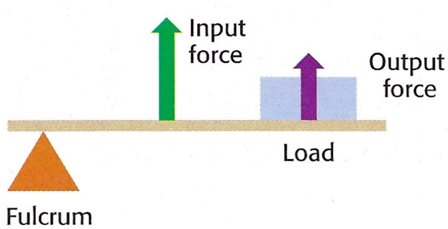
lever a simple machine that consists of a bar that pivots at a fixed point called a *fulcrum*

Third-Class Levers

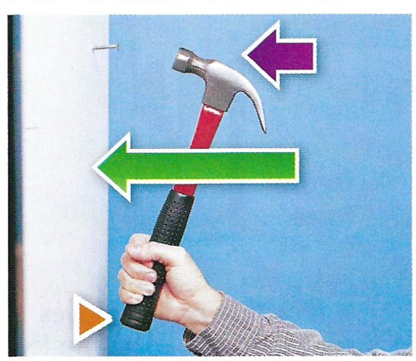
The input force in a third-class lever is between the fulcrum and the load, as shown in **Figure 3.** Third-class levers do not change the direction of the input force. In addition, they do not increase the input force. Therefore, the output force is always less than the input force.

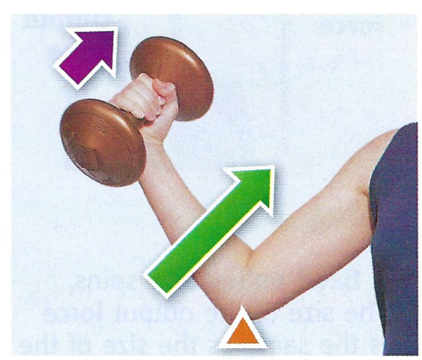
Reading Check **How do the three types of levers differ from one another?** (*See the Appendix for answers to Reading Checks.*)

Figure 3 **Examples of Third-Class Levers**



In a **third-class lever,** the input force is between the fulcrum and the load.





Using a third-class lever results in a **mechanical advantage of less than 1** because force is decreased. But third-class levers increase the distance through which the output force is exerted.

Pulleys

pulley a simple machine that consists of a wheel over which a rope, chain, or wire passes

When you open window blinds by pulling on a cord, you're using a pulley. A **pulley** is a simple machine that has a grooved wheel that holds a rope or a cable. A load is attached to one end of the rope, and an input force is applied to the other end. Types of pulleys are shown in **Figure 4.**

Fixed Pulleys

A fixed pulley is attached to something that does not move. By using a fixed pulley, you can pull down on the rope to lift the load up. The pulley changes the direction of the force. Elevators make use of fixed pulleys.

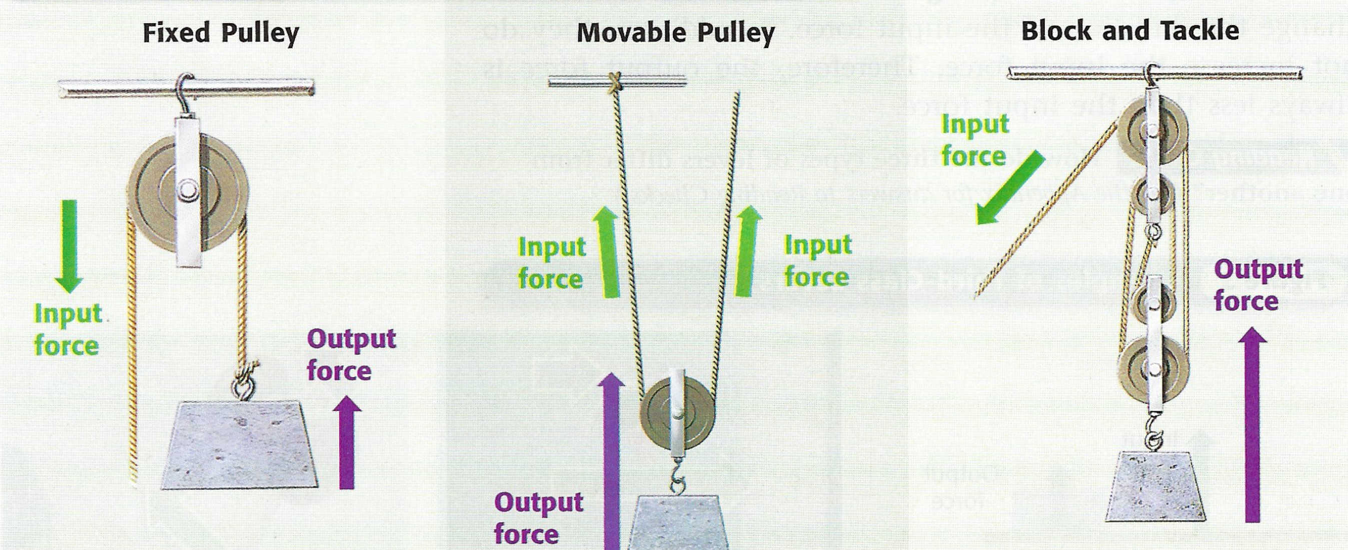
Movable Pulleys

Unlike fixed pulleys, movable pulleys are attached to the object being moved. A movable pulley does not change a force's direction. Movable pulleys do increase force, but they also increase the distance over which the input force must be exerted.

Block and Tackles

When a fixed pulley and a movable pulley are used together, the pulley system is called a *block and tackle*. The mechanical advantage of a block and tackle depends on the number of rope segments.

Figure 4 Types of Pulleys

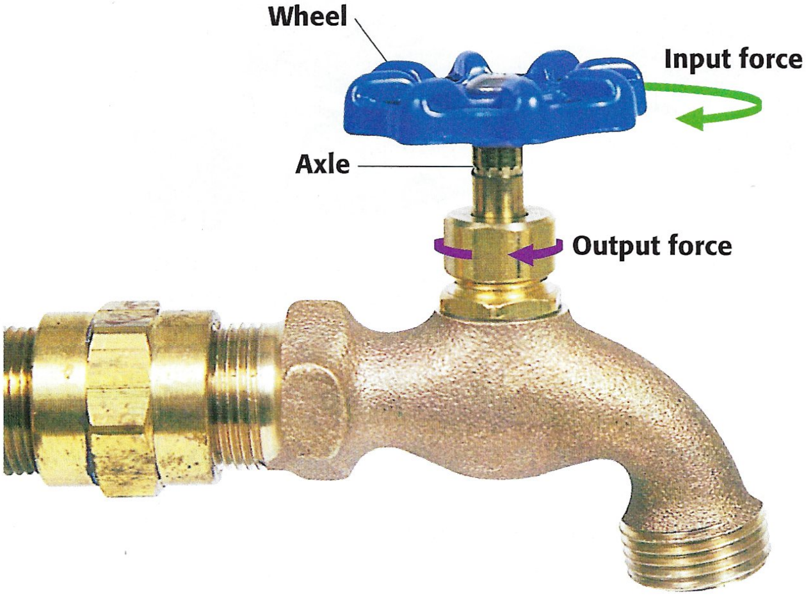


A **fixed pulley** only spins. The size of the output force is the same as the size of the input force. Therefore, a fixed pulley provides a mechanical advantage of 1.

A **movable pulley** moves up with the load as the load is lifted. The mechanical advantage of this movable pulley is 2.

The mechanical advantage of this **block and tackle** is 4 because there are four rope segments. It multiplies your input force by 4, but you have to pull the rope 4 m just to lift the load 1 m.

Figure 5 **How a Wheel and Axle Works**



a When a small input force is applied to the wheel, the wheel rotates through a circular distance.

b As the wheel turns, so does the axle. But because the axle is smaller than the wheel, it rotates through a smaller distance, which makes the output force larger than the input force

Wheel and Axle

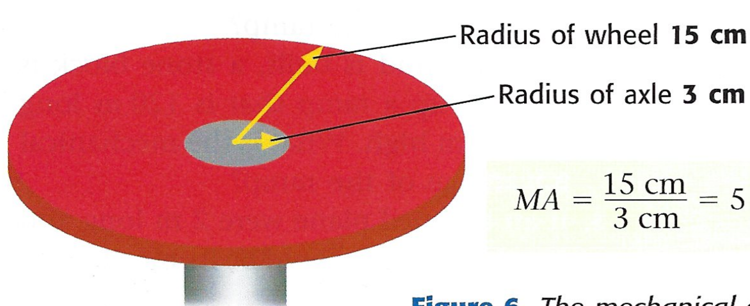
Did you know that a faucet is a machine? The faucet shown in **Figure 5** is an example of a **wheel and axle,** a simple machine consisting of two circular objects of different sizes. Doorknobs, wrenches, and steering wheels all use a wheel and axle. **Figure 5** shows how a wheel and axle works.

wheel and axle a simple machine consisting of two circular objects of different sizes; the wheel is the larger of the two circular objects

Mechanical Advantage of a Wheel and Axle

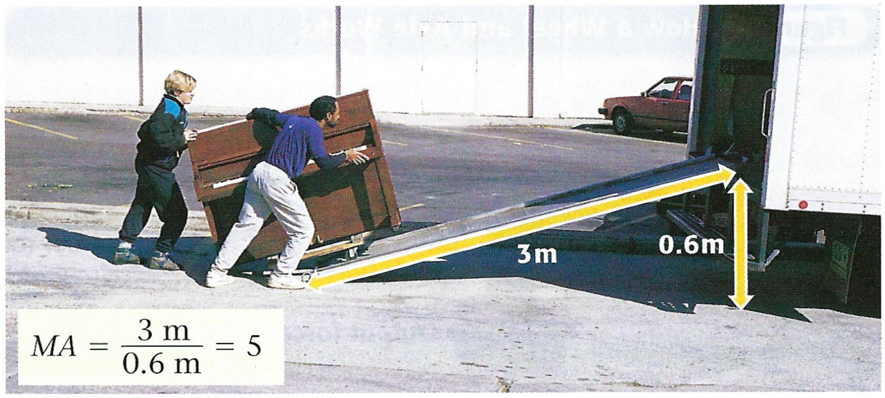
The mechanical advantage of a wheel and axle can be found by dividing the *radius* (the distance from the center to the edge) of the wheel by the radius of the axle, as shown in **Figure 6.** Turning the wheel results in a mechanical advantage of greater than 1 because the radius of the wheel is larger than the radius of the axle.

Reading Check **How is the mechanical advantage of a wheel and axle calculated?**



$$MA = \frac{15 \text{ cm}}{3 \text{ cm}} = 5$$

Figure 6 *The mechanical advantage of a wheel and axle is the radius of the wheel divided by the radius of the axle.*



$$MA = \frac{3\text{ m}}{0.6\text{ m}} = 5$$

Figure 7 *The work you do on the piano to roll it up the ramp is the same as the work you would do to lift it straight up. An inclined plane simply allows you to apply a smaller force over a greater distance.*

Inclined Planes

inclined plane a simple machine that is a straight, slanted surface, which facilitates the raising of loads; a ramp

Do you remember the story about how the Egyptians built the Great Pyramid? One of the machines they used was the **inclined plane.** An *inclined plane* is a simple machine that is a straight, slanted surface. A ramp is an inclined plane.

Using an inclined plane to load a piano into a truck, as **Figure 7** shows, is easier than lifting the piano into the truck. Rolling the piano along an inclined plane requires a smaller input force than is needed to lift the piano into the truck. The same work is done on the piano, just over a longer distance.

Reading Check What is an inclined plane?

Mechanical Advantage of Inclined Planes

The greater the ratio of an inclined plane's length to its height is, the greater the mechanical advantage is. The mechanical advantage (*MA*) of an inclined plane can be calculated by dividing the *length* of the inclined plane by the *height* to which the load is lifted. The inclined plane in **Figure 7** has a mechanical advantage of 3 m/0.6 m = 5.

Math Focus

Mechanical Advantage of an Inclined Plane A heavy box is pushed up a ramp that has an incline of 4.8 m long and 1.2 m high. What is the mechanical advantage of the ramp?

Step 1: Write the equation for the mechanical advantage of an inclined plane.

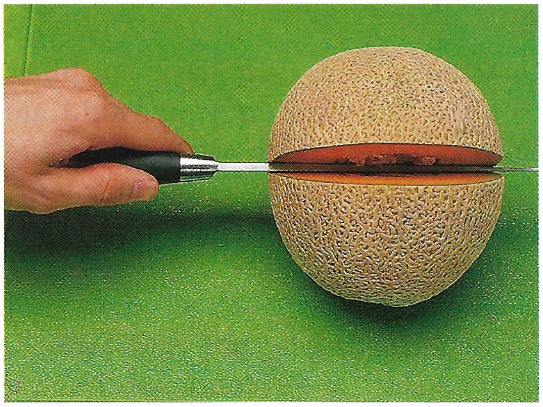
$$MA = \frac{l}{h}$$

Step 2: Replace l and h with length and height.

$$MA = \frac{4.8\text{ m}}{1.2\text{ m}} = 4$$

Now It's Your Turn

1. A wheelchair ramp is 9 m long and 1.5 m high. What is the mechanical advantage of the ramp?
2. As a pyramid is built, a stone block is dragged up a ramp that is 120 m long and 20 m high. What is the mechanical advantage of the ramp?
3. If an inclined plane were 2 m long and 8 m high, what would be its mechanical advantage?



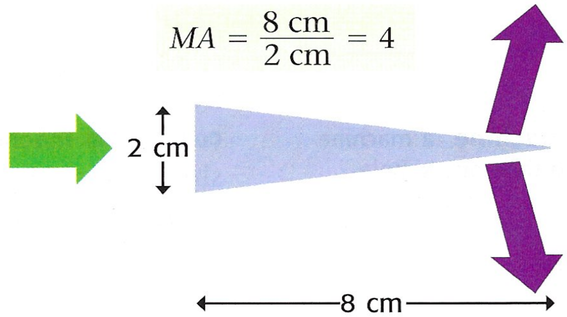


Figure 8 *A knife is a common example of a wedge, a simple machine consisting of two inclined planes back to back.*

Wedges

Imagine trying to cut a melon in half with a spoon. It wouldn't be easy, would it? A knife is much more useful for cutting because it is a **wedge.** A *wedge* is a pair of inclined planes that move. A wedge applies an output force that is greater than your input force, but you apply the input force over a greater distance. For example, a knife is a common wedge that can easily cut into a melon and push apart its two halves, as shown in **Figure 8.** Other useful wedges include doorstops, plows, ax heads, and chisels.

wedge a simple machine that is made up of two inclined planes and that moves; often used for cutting

screw a simple machine that consists of an inclined plane wrapped around a cylinder

Mechanical Advantage of Wedges

The longer and thinner the wedge is, the greater its mechanical advantage is. That's why axes and knives cut better when you sharpen them—you are making the wedge thinner. Therefore, less input force is required. The mechanical advantage of a wedge can be found by dividing the length of the wedge by its greatest thickness, as shown in **Figure 8.**

Screws

A **screw** is an inclined plane that is wrapped in a spiral around a cylinder, as you can see in **Figure 9.** When a screw is turned, a small force is applied over the long distance along the inclined plane of the screw. Meanwhile, the screw applies a large force through the short distance it is pushed. Screws are used most commonly as fasteners.

Mechanical Advantage of Screws

If you could unwind the inclined plane of a screw, you would see that the plane is very long and has a gentle slope. Recall that the longer an inclined plane is compared with its height, the greater its mechanical advantage. Similarly, the longer the spiral on a screw is and the closer together the threads are, the greater the screw's mechanical advantage is. A jar lid is a screw that has a large mechanical advantage.

Figure 9 *If you could unwind a screw, you would see that it is actually a very long inclined plane.*

Compound Machines

compound machine a machine made of more than one simple machine

You are surrounded by machines. You even have machines in your body! But most of the machines in your world are **compound machines,** machines that are made of two or more simple machines. You have already seen one example of a compound machine: a block and tackle. A block and tackle consists of two or more pulleys.

Figure 10 shows a common example of a compound machine. A can opener may seem simple, but it is actually three machines combined. It consists of a second-class lever, a wheel and axle, and a wedge. When you squeeze the handle, you are making use of a second-class lever. The blade of the can opener acts as a wedge as it cuts into the can's top. The knob that you turn to open the can is a wheel and axle.

SCHOOL to HOME

Everyday Machines

With an adult, think of five simple or compound machines that you encounter each day. List them in your **science journal,** and indicate what type of machine each is. Include at least one compound machine and one machine that is part of your body.

ACTIVITY

Mechanical Efficiency of Compound Machines

The mechanical efficiency of most compound machines is low. The efficiency is low because compound machines have more moving parts than simple machines do, thus there is more friction to overcome. Compound machines, such as automobiles and airplanes, can involve many simple machines. It is very important to reduce friction as much as possible, because too much friction can damage the simple machines that make up the compound machine. Friction can be lowered by using lubrication and other techniques.

✓ Reading Check **What special disadvantage do compound machines have?**

Figure 10 *A can opener is a compound machine. The handle is a second-class lever, the knob is a wheel and axle, and a wedge is used to open the can.*

SECTION Review

Summary

- In a first-class lever, the fulcrum is between the force and the load. In a second-class lever, the load is between the force and the fulcrum. In a third-class lever, the force is between the fulcrum and the load.
- The mechanical advantage of an inclined plane is length divided by height. Wedges and screws are types of inclined planes.
- A wedge is a type of inclined plane. Its mechanical advantage is its length divided by its greatest thickness.
- The mechanical advantage of a wheel and axle is the radius of the wheel divided by the radius of the axle.
- Types of pulleys include fixed pulleys, movable pulleys, and block and tackles.
- Compound machines consist of two or more simple machines.
- Compound machines have low mechanical efficiencies because they have more moving parts and therefore more friction to overcome.

Using Key Terms

1. In your own words, write a definition for the term *lever.*

2. Use the following terms in the same sentence: *inclined plane, wedge,* and *screw.*

Understanding Key Ideas

3. Which class of lever always has a mechanical advantage of greater than 1?

a. first-class
b. second-class
c. third-class
d. None of the above

4. Give an example of each of the following simple machines: first-class lever, second-class lever, third-class lever, inclined plane, wedge, and screw.

Math Skills

5. A ramp is 0.5 m high and has a slope that is 4 m long. What is its mechanical advantage?

6. The radius of the wheel of a wheel and axle is 4 times the radius of the axle. What is the mechanical advantage of the wheel and axle?

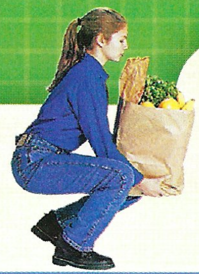
Critical Thinking

7. Applying Concepts A third-class lever has a mechanical advantage of less than 1. Explain why it is useful for some tasks.

8. Making Inferences Which compound machine would you expect to have the lowest mechanical efficiency: a can opener or a pair of scissors? Explain your answer.

Interpreting Graphics

9. Indicate two simple machines being used in the picture below.



Chapter Review

USING KEY TERMS

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

1. *work* and *power*
2. *lever* and *inclined plane*
3. *wheel and axle* and *pulley*

UNDERSTANDING KEY IDEAS

Multiple Choice

4. Work is being done when
   a. you apply a force to an object.
   b. an object is moving after you applied a force to it.
   c. you exert a force that moves an object in the direction of the force.
   d. you do something that is difficult.

5. What is the unit for work?
   a. joule
   b. joule per second
   c. newton
   d. watt

6. Which of the following is a simple machine?
   a. a bicycle
   b. a jar lid
   c. a pair of scissors
   d. a can opener

7. A machine can increase
   a. distance by decreasing force.
   b. force by decreasing distance.
   c. neither distance nor force.
   d. Either (a) or (b)

8. What is power?
   a. the strength of someone or something
   b. the force that is used
   c. the work that is done
   d. the rate at which work is done

9. What is the unit for power?
   a. newton
   b. kilogram
   c. watt
   d. joule

Short Answer

10. Identify the two simple machines that make up a pair of scissors.

11. Explain why you do work on a bag of groceries when you pick it up but not when you carry it.

12. Why is the work output of a machine always less than the work input?

13. What does the mechanical advantage of a first-class lever depend upon? Describe how it can be changed.

Math Skills

14. You and a friend together apply a force of 1,000 N to a car, which makes the car roll 10 m in 1 min and 40 s.
    a. How much work did you and your friend do together?
    b. What was the power output?

15. A lever allows a 35 N load to be lifted with a force of 7 N. What is the mechanical advantage of the lever?

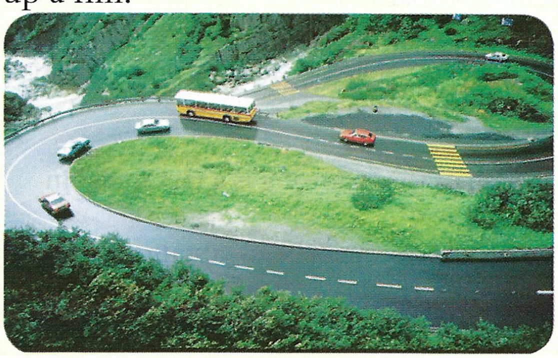
CRITICAL THINKING

16 **Concept Mapping** Use the following terms to create a concept map: *work, force, distance, machine,* and *mechanical advantage.*

17 **Analyzing Ideas** Explain why levers usually have a greater mechanical efficiency than other simple machines do.

18 **Making Inferences** The amount of work done on a machine is 300 J, and the machine does 50 J of work. What can you say about the amount of friction that the machine has while operating?

19 **Applying Concepts** The winding road shown below is a series of inclined planes. Describe how a winding road makes it easier for vehicles to travel up a hill.



20 **Predicting Consequences** Why wouldn't you want to reduce the friction involved in using a winding road?

21 **Making Comparisons** How does the way that a wedge's mechanical advantage is determined differ from the way that a screw's mechanical advantage is determined?

22 **Identifying Relationships** If the mechanical advantage of a certain machine is greater than 1, what does that tell you about the relationship between the input force and distance and output force and distance?

INTERPRETING GRAPHICS

For each of the images below, identify the class of lever used and calculate the mechanical advantage of the lever.

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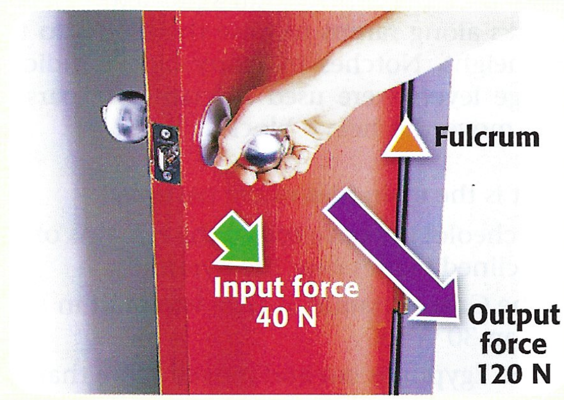

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