

Part 2 Short Response/Grid In

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

- Explain why the law of conservation of energy also includes mass when applied to nuclear reactions.
- A student walks to school at a speed of 1.2 m/s. If the student's mass is 53 kg, what is the student's kinetic energy?
- A book sliding across a horizontal table slows down and comes to a stop. The book's kinetic energy was converted into what form of energy?
- Electrical energy was converted into which forms of energy by a hair dryer?

Use the figure below to answer questions 15 and 16.

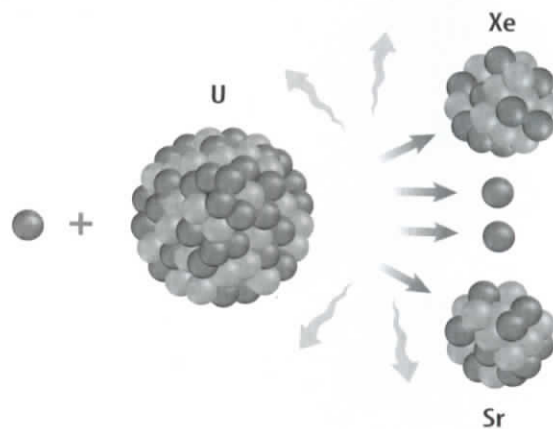


- At what point on the ball's path is the ball's kinetic energy lowest but its gravitational potential energy highest?
- How does the mechanical energy of the ball change from the moment just after the batter hits it to the moment just before it touches the ground?
- Explain whether it is possible for an object at rest to have energy.
- Find the speed of a 5.6-kg bowling ball that has a kinetic energy of 25.2 J.

Part 3 Open Ended

Record your answers on a sheet of paper.

Use the figure below to answer questions 19 and 20.



- Describe the process shown in the figure above, and explain how it obeys the law of conservation of energy.
- Describe how the total mass of the particles before the reaction occurs compares to the total mass of the particles produced by the reaction.
- Is the mechanical energy of a liter of water at the top of a waterfall greater than, the same as, or less than the mechanical energy of a liter of water just before it reaches the bottom of the waterfall? Explain.
- Name and describe some examples of how different forms of energy can be stored.
- Describe a process in which energy travels through the environment and changes from one form to another.

Test-Taking Tip

Show All your Work For constructed response questions, show all your work and any calculations on your answer sheet.

Question 19 On your answer sheet, list the energy changes that occur during each for each step of the process that you can think of.

Work and Machines

chapter preview

sections

- 1 Work
- 2 Using Machines
- 3 Simple Machines

Lab Levers

Lab Using Simple Machines



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

It Seemed Longer Going Up


Have you ever thought of a mountain bike as a machine? A mountain bike actually is a combination of simple machines. Like all machines, a bicycle makes doing work easier. A mountain bike, for example, gets you uphill and downhill faster than you can travel by walking or running.

Science Journal Diagram a bicycle and identify the parts you think are simple machines.

Start-Up Activities



Doing Work with a Simple Machine

Did you know you can lift several times your own weight with the help of a pulley? Before the hydraulic lift was invented, a car mechanic used pulleys to raise a car off the ground. In this lab you'll see how a pulley can increase a force. 

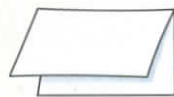


1. Tie a rope several meters in length to the center of a broom handle. Have one student hold both ends of the handle.
2. Have another student hold the ends of a second broom handle and face the first student as shown in the photo.
3. Have a third student loop the free end of the rope around the second handle, making six or seven loops.
4. The third student should stand to the side of one of the handles and pull on the free end of the rope. The two students holding the broom handles should prevent the handles from coming together.
5. **Think Critically** Describe how the applied force was changed. What would happen if the number of rope loops were increased?

FOLDABLES™ Study Organizer

Work and Machines Make the following Foldable to help you understand how machines make doing work easier.

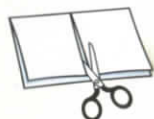
- STEP 1** Fold a vertical sheet of paper in half from top to bottom.



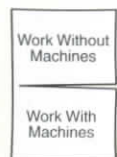
- STEP 2** Fold in half from side to side with the fold at the top.



- STEP 3** Unfold the paper once. Cut only the fold of the top flap to make two tabs.



- STEP 4** Turn the paper vertically and label the front tabs as shown.



List Before you read the chapter, list five examples of work you do without machines, and five examples of work you do with machines. Next to each example, rate the effort needed to do the work on a scale of 1 (little effort) to 3 (much effort).



Preview this chapter's content and activities at gpscience.com

Work

Reading Guide

What You'll Learn

- **Explain** the meaning of work.
- **Describe** how work and energy are related.
- **Calculate** work.
- **Calculate** power.

Why It's Important

Doing work is another way of transferring energy from one place to another.

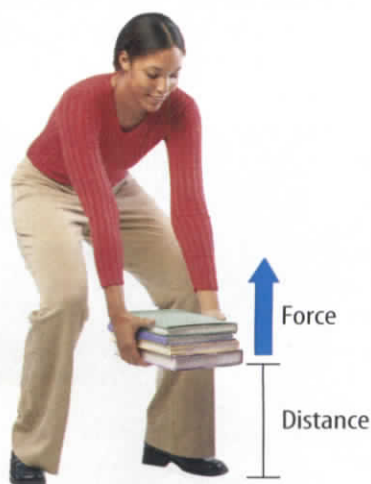
Review Vocabulary

energy: the ability to cause change

New Vocabulary

- work
- power

Figure 1 When you lift a stack of books, your arms apply a force upward and the books move upward. Because the force and distance are in the same direction, your arms have done work on the books.



What is work?


Have you done any work today? To many people, the word *work* means something they do to earn money. In that sense, work can be anything from filling fast-food orders or loading trucks to teaching or doing word processing on a computer. The word *work* also means exerting a force with your muscles. Someone might say they have done work when they push as hard as they can against a wall that doesn't move. However, in science the word *work* is used in a different way.

Work Makes Something Move Press your hand against the surface of your desk as hard as you can. Have you done any work? The answer is no, no matter how tired your effort makes you feel. Remember that a force is a push or a pull. In order for work to be done, a force must make something move. **Work** is the transfer of energy that occurs when a force makes an object move. If you push against the desk and nothing moves, then you haven't done any work.

Doing Work There are two conditions that have to be satisfied for work to be done on an object. One is that the applied force must make the object move, and the other is that the movement must be in the same direction as the applied force.

For example, if you pick up a pile of books from the floor as in **Figure 1**, you do work on the books. The books move upward, in the direction of the force you are applying. If you hold the books in your arms without moving the books, you are not doing work on the books. You're still applying an upward force to keep the books from falling, but no movement is taking place.

Force and Direction of Motion When you carry books while walking, like the student in **Figure 2**, you might think that your arms are doing work. After all, you are exerting a force on the books with your arms, and the books are moving. Your arms might even feel tired. However, in this case the force exerted by your arms does no work on the books. The force exerted by your arms on the books is upward, but the books are moving horizontally. The force you exert is at right angles to the direction the books are moving. As a result, your arms exert no force in the direction the books are moving.

 **Reading Check** *How are an applied force and an object's motion related when work is done?*

Work and Energy

How are work and energy related? When work is done, a transfer of energy always occurs. This is easy to understand when you think about how you feel after carrying a heavy box up a flight of stairs. Remember that when the height of an object above Earth's surface increases, the potential energy of the object increases. You transferred energy from your moving muscles to the box and increased its potential energy by increasing its height.

You may recall that energy is the ability to cause change. Another way to think of energy is that energy is the ability to do work. If something has energy, it can transfer energy to another object by doing work on that object. When you do work on an object, you increase its energy. The student carrying the box in **Figure 3** transfers chemical energy in his muscles to the box. Energy is always transferred from the object that is doing the work to the object on which the work is done.



Figure 3 By carrying a box up the stairs, you are doing work. You transfer energy to the box. **Explain** how the energy of the box changes as the student climbs the stairs.



Figure 2 If you hold a stack of books and walk forward, your arms are exerting a force upward. However, the distance the books move is horizontal. Therefore your arms are not doing work on the books.

Calculating Work The amount of work done depends on the amount of force exerted and the distance over which the force is applied. When a force is exerted and an object moves in the direction of the force, the amount of work done can be calculated as follows.

Work Equation

$$\text{work (in joules)} = \text{applied force (in newtons)} \times \text{distance (in meters)}$$
$$W = Fd$$

In this equation, force is measured in newtons and distance is measured in meters. Work, like energy, is measured in joules. One joule is about the amount of work required to lift a baseball a vertical distance of 0.7 m.

Applying Math Solve a Simple Equation

CALCULATING WORK You push a refrigerator with a force of 100 N. If you move the refrigerator a distance of 5 m, how much work do you do?

IDENTIFY known values and the unknown value

Identify the known values:

you push a refrigerator with a force of 100 N $\xrightarrow{\text{means}}$ $F = 100 \text{ N}$

you move the refrigerator a distance of 5 m $\xrightarrow{\text{means}}$ $d = 5 \text{ m}$

Identify the unknown value:

how much work do you do? $\xrightarrow{\text{means}}$ $W = ? \text{ J}$

SOLVE the problem

Substitute the known values $F = 100 \text{ N}$ and $d = 5 \text{ m}$ into the work equation.

$$W = Fd = (100 \text{ N})(5 \text{ m}) = 500 \text{ Nm} = 500 \text{ J}$$

CHECK your answer

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

Practice Problems

1. A force of 75 N is exerted on a 45-kg couch and the couch is moved 5 m. How much work is done in moving the couch?
2. A lawn mower is pushed with a force of 80 N. If 12,000 J of work are done in mowing a lawn, what is the total distance the lawn mower was pushed?
3. The brakes on a car do 240,000 J of work in stopping the car. If the car travels a distance of 50 m while the brakes are being applied, what is the total force the brakes exert on the car?

For more practice problems go to page 834, and visit gpscience.com/extra_problems.



Figure 4 A pitcher exerts a force on the ball to throw it to the catcher. After the ball leaves her hand, she no longer is exerting any force on the ball. She does work on the ball only while it is in her hand.

When is work done? Suppose you give a book a push and it slides along a table for a distance of 1 m before it comes to a stop. The distance you use to calculate the work you did is how far the object moves while the force is being applied. Even though the book moved 1 m, you do work on the book only while your hand is in contact with it. The distance in the formula for work is the distance the book moved while your hand was pushing on the book. As **Figure 4** shows, work is done on an object only when a force is being applied to the object.

Power

Suppose you and another student are pushing boxes of books up a ramp to load them into a truck. To make the job more fun, you make a game of it, racing to see who can push a box up the ramp faster. The boxes weigh the same, but your friend is able to push a box a little faster than you can. She moves a box up the ramp in 30 s. It takes you 45 s. You both do the same amount of work on the books because the boxes weigh the same and are moved the same distance. The only difference is the time it takes to do the work.

In this game, your friend has more power than you do.

Power is the amount of work done in one second. It is a rate—the rate at which work is done.

 **Reading Check** How is power related to work?

Mini LAB

Calculating Your Work and Power

Procedure

1. Find a set of **stairs** that you can safely walk and run up. Measure the vertical height of the stairs in meters.
2. Record how many seconds it takes you to walk and run up the stairs.
3. Calculate the work you did in walking and running up the stairs using $W = Fd$. For force, use your weight in newtons (your weight in pounds times 4.5).
4. Use the formula $P = W/t$ to calculate the power you needed to walk and run up the stairs.

Analysis

1. Is the work you did walking and running the steps the same?
2. Which required more power—walking or running up the steps? Why?

Calculating Power Power is the rate at which work is done. To calculate power, divide the work done by the time that is required to do the work.

Power Equation

$$\text{Power (in watts)} = \frac{\text{work (in joules)}}{\text{time (in seconds)}}$$

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

The SI unit for power is the watt (W). One watt equals one joule of work done in one second. Because the watt is a small unit, power often is expressed in kilowatts. One kilowatt (kW) equals 1,000 W.

Applying Math Solve a Simple Equation

CALCULATING POWER You do 900 J of work in pushing a sofa. If it took 5 s to move the sofa, what was your power?

IDENTIFY known values and the unknown value

Identify the known values:

You do 900 J of work $\xrightarrow{\text{means}}$ $W = 900 \text{ J}$

it took 5 s to move the sofa $\xrightarrow{\text{means}}$ $t = 5 \text{ s}$

Identify the unknown value:

what was your power? $\xrightarrow{\text{means}}$ $P = ? \text{ W}$

SOLVE the problem

Substitute the known values $W = 900 \text{ J}$ and $t = 5 \text{ s}$ into the power equation.

$$P = \frac{W}{t} = \frac{900 \text{ J}}{5 \text{ s}} = 180 \text{ J/s} = 180 \text{ W}$$

CHECK your answer

Does your answer seem reasonable? 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

- To lift a baby from a crib 50 J of work are done. How much power is needed if the baby is lifted in 0.5 s?
- If a runner's power is 130 W, how much work is done by the runner in 10 minutes?
- The power produced by an electric motor is 500 W. How long will it take the motor to do 10,000 J of work?

For more practice problems go to page 834, and visit gpscience.com/extra_problems.

The symbol for work, W , is usually italicized. However, the abbreviation for watt, W , is not italicized.

Power and Energy Doing work is a way of transferring energy from object to another. Just as power is the rate at which work is done, power is also the rate at which energy is transferred. When energy is transferred, the power involved can be calculated by dividing the energy transferred by the time needed for the transfer to occur.

Power Equation for Energy Transfer

$$\text{power (in watts)} = \frac{\text{energy transferred (in joules)}}{\text{time (in seconds)}}$$

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

For example, when the lightbulb in **Figure 5** is connected to an electric circuit, energy is transferred from the circuit to the lightbulb filament. The filament converts the electrical energy supplied to the lightbulb into heat and light. The power used by the lightbulb is the amount of electrical energy transferred to the lightbulb each second.



Figure 5 This 100 W lightbulb converts electrical energy into light and heat at a rate of 100 J/s.

section 1 review

Summary

Work and Energy

- Work is done on an object when a force is exerted on the object and it moves in the direction of the force.
- If a force, F , is exerted on object while the object moves a distance, d , in the direction of the force, the work done is

$$W = Fd$$

- When work is done on an object, energy is transferred to the object.

Power

- Power is the rate at which work is done or energy is transferred.
- When work is done, power can be calculated from the equation

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

- When energy is transferred, power can be calculated from the equation

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

Self Check

1. **Explain** how the scientific definition of work is different from the everyday meaning.
2. **Describe** a situation in which a force is applied, but no work is done.
3. **Explain** how work and energy are related.
4. **Think Critically** In which of the following situations is work being done?
 - a. A person shovels snow off a sidewalk.
 - b. A worker lifts bricks, one at a time, from the ground to the back of a truck.
 - c. A roofer's assistant carries a bundle of shingles across a construction site.

Applying Math

5. **Calculate Force** Find the force a person exerts in pulling a wagon 20 m if 1,500 J of work are done.
6. **Calculate Work** A car's engine produces 100 kW of power. How much work does the engine do in 5 s?
7. **Calculate Energy** A color TV uses 120 W of power. How much energy does the TV use in 1 hour?

Using Machines

Reading Guide

What You'll Learn

- **Explain** how machines make doing work easier.
- **Calculate** the mechanical advantage of a machine.
- **Calculate** the efficiency of a machine.

Why It's Important

Cars, stairs, and teeth are all examples of machines that make your life easier.

Review Vocabulary

force: a push or a pull

New Vocabulary

- machine
- input force
- output force
- mechanical advantage
- efficiency

What is a machine?

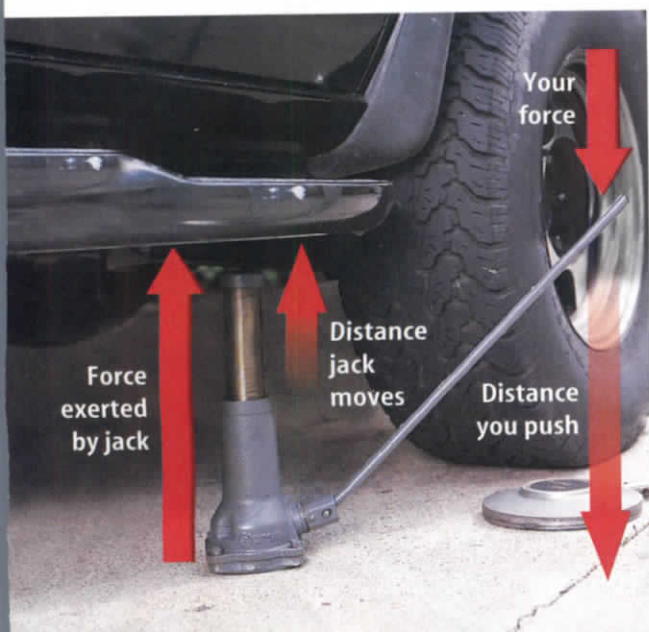
A **machine** is a device that makes doing work easier. When you think of a machine you may picture a device with an engine and many moving parts. However, machines can be simple. Some, like knives, scissors, and doorknobs, are used every day to make doing work easier.

Making Work Easier

Machines can make work easier by increasing the force that can be applied to an object. A screwdriver increases the force you apply to turn a screw. A second way that machines can make work easier is by increasing the distance over which a force can be applied. A leaf rake is an example of this type of machine.

Machines also can make work easier by changing the direction of an applied force. A simple pulley changes a downward force to an upward force.

Figure 6 A car jack is an example of a machine that increases an applied force.



Increasing Force A car jack, like the one in **Figure 6**, is an example of a machine that increases an applied force. The upward force exerted by the jack is greater than the downward force you exert on the handle. However, the distance you push the handle downward is greater than the distance the car is pushed upward. Because work is the product of force and distance, the work done by the jack is not greater than the work you do on the jack. The jack increases the applied force, but it doesn't increase the work done.



Figure 7 Whether the mover slides the chair up the ramp or lifts it directly into the truck, she will do the same amount of work. Doing the work over a longer distance allows her to use less force.

Force and Distance Why does the mover in **Figure 7** push the heavy furniture up the ramp instead of lifting it directly into the truck? It is easier for her because less force is needed to move the furniture.

The work done in lifting an object depends on the change in height of the object. The same amount of work is done whether the mover pushes the furniture up the long ramp or lifts it straight up. If she uses a ramp to lift the furniture, she moves the furniture a longer distance than if she just raised it straight up. If work stays the same and the distance is increased, then less force will be needed to do the work.

Reading Check How does a ramp make lifting an object easier?

Changing Direction Some machines change the direction of the force you apply. When you use the car jack, you are exerting a force downward on the jack handle. The force exerted by the jack on the car is upward. The direction of the force you applied is changed from downward to upward. Some machines change the direction of the force that is applied to them in another way. The wedge-shaped blade of an ax is one example. When you use an ax to split wood, you exert a downward force as you swing the ax toward the wood. As **Figure 8** shows, the blade changes the downward force into a horizontal force that splits the wood apart.

Figure 8 An ax blade changes the direction of the force from vertical to horizontal.

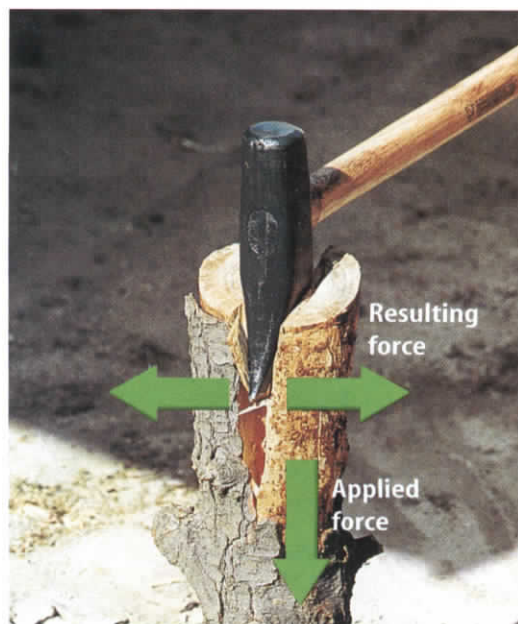
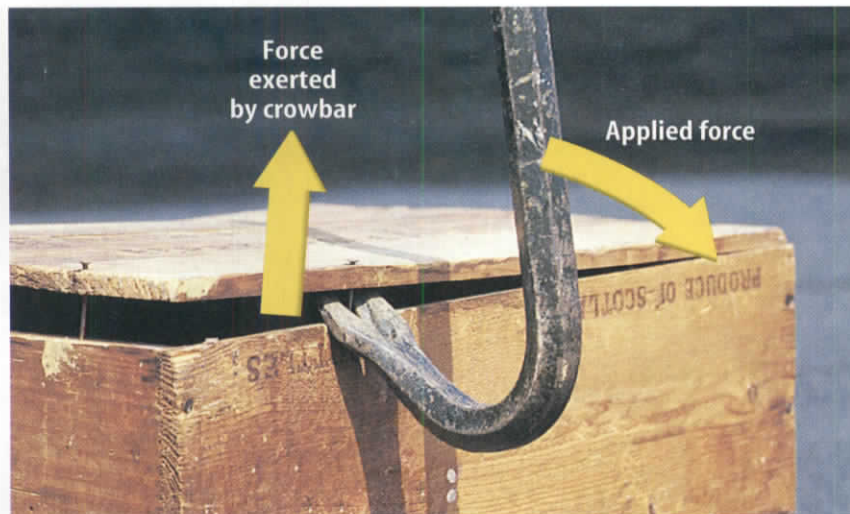


Figure 9 A crowbar increases the force you apply and changes its direction.



Mini LAB

Machines Multiplying Force

Procedure

1. Open a can of food using a manual can opener.
WARNING: Do not touch can opener's cutting blades or cut edges of the can's lid.
2. Use a metric ruler to measure the diameter of the cutting blade of the can opener.
3. Measure the length of the handle you turn.

Analysis

1. Compare how difficult it is to open the can using the can opener with how difficult it would have been to open the can by turning the cutting blade with a smaller handle.
2. Compare the diameter of the cutting blade with the diameter of the circle formed by turning the can opener's handle.
3. Infer why a can opener makes it easier to open a metal can.



The Work Done by Machines

To pry the lid off a wooden crate with a crowbar, you'd slip the end of the crowbar under the edge of the crate lid and push down on the handle. By moving the handle downward, you do work on the crowbar. As the crowbar moves, it does work on the lid, lifting it up. **Figure 9** shows how the crowbar increases the amount of force being applied and changes the direction of the force.

When you use a machine such as a crowbar, you are trying to move something that resists being moved. For example, if you use a crowbar to pry the lid off a crate, you are working against the friction between the nails in the lid and the crate. You also could use a crowbar to move a large rock. In this case, you would be working against gravity—the weight of the rock.

Input and Output Forces Two forces are involved when a machine is used to do work. You exert a force on the machine, such as a bottle opener, and the machine then exerts a force on the object you are trying to move, such as the bottle cap. The force that is applied to the machine is called the **input force**. F_{in} stands for the input force. The force applied by the machine is called the **output force**, symbolized by F_{out} . When you try to pull a nail out with a hammer as in **Figure 10**, you apply the input force on the handle. The output force is the force the claw applies to the nail.

Two kinds of work need to be considered when you use a machine—the work done by you on the machine and the work done by the machine. When you use a crowbar, you do work when you apply force to the crowbar handle and make it move. The work done by you on a machine is called the input work and is symbolized by W_{in} . The work done by the machine is called the output work and is abbreviated W_{out} .

Conserving Energy Remember that energy is always conserved. When you do work on the machine, you transfer energy to the machine. When the machine does work on an object, energy is transferred from the machine to the object. Because energy cannot be created or destroyed, the amount of energy the machine transfers to the object cannot be greater than the amount of energy you transfer to the machine. A machine cannot create energy, so W_{out} is never greater than W_{in} .

However, the machine does not transfer all of the energy it receives to the object. In fact, when a machine is used, some of the energy transferred changes to heat due to friction. The energy that changes to heat cannot be used to do work, so W_{out} is always smaller than W_{in} .

Ideal Machines Remember that work is calculated by multiplying force by distance. The input work is the product of the input force and the distance over which the input force is exerted. The output work is the product of the output force and the distance over which that force is exerted.

Suppose a perfect machine could be built in which there was no friction. None of the input work or output work would be converted to heat. For such an ideal machine, the input work equals the output work. So for an ideal machine,

$$W_{\text{in}} = W_{\text{out}}$$

Suppose the ideal machine increases the force applied to it. This means that the output force, F_{out} , is greater than the input force, F_{in} . Recall that work is equal to force times distance. If F_{out} is greater than F_{in} , then W_{in} and W_{out} can be equal only if the input force is applied over a greater distance than the output force is exerted over.

For example, suppose the hammer claw in **Figure 10** moves a distance of 1 cm to remove a nail. If an output force of 1,500 N is exerted by the claw of the hammer, and you move the handle of the hammer 5 cm, you can find the input force as follows.

$$\begin{aligned} W_{\text{in}} &= W_{\text{out}} \\ F_{\text{in}} d_{\text{in}} &= F_{\text{out}} d_{\text{out}} \\ F_{\text{in}} (0.05 \text{ m}) &= (1,500 \text{ N}) (0.01 \text{ m}) \\ F_{\text{in}} (0.05 \text{ m}) &= 15 \text{ N}\cdot\text{m} \\ F_{\text{in}} &= 300 \text{ N} \end{aligned}$$

Because the distance you move the hammer is longer than the distance the hammer moves the nail, the input force is less than the output force.



Figure 10 When prying a nail out of a piece of wood with a claw hammer, you exert the input force on the handle of the hammer, and the claw exerts the output force.

Describe how the hammer changes the input force.

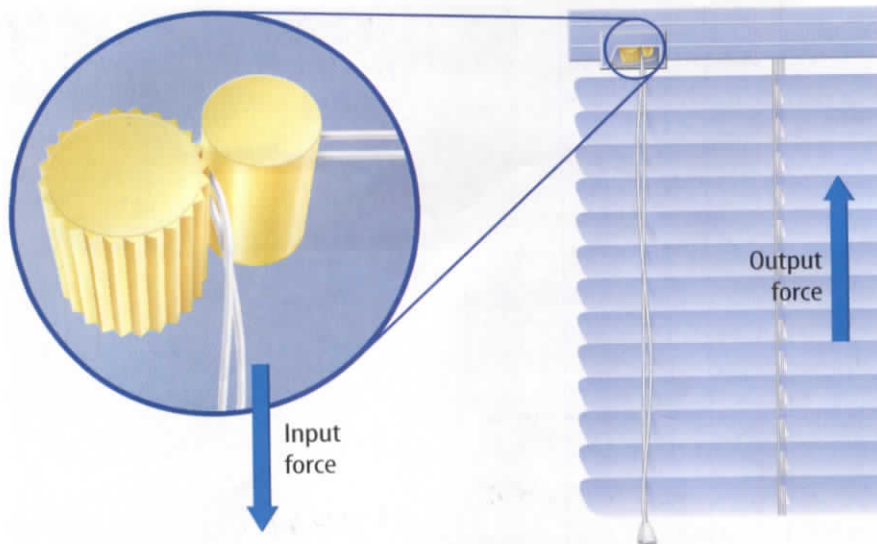


Figure 11 Window blinds use a machine that changes the direction of an input force. A downward pull on the cord is changed to an upward force on the blinds. The input and output forces are equal, so the MA is 1.

Mechanical Advantage

Machines like the car jack, the ramp, the crow bar, and the claw hammer make work easier by making the output force greater than the input force. The ratio of the output force to the input force is the **mechanical advantage** of a machine. The mechanical advantage of a machine can be calculated from the following equation.

Mechanical Advantage Equation

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

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

Figure 11 shows that the mechanical advantage equals one when only the direction of the input force changes.



INTEGRATE Chemistry

Graphite Lubricant

Graphite is a solid that sometimes is used as a lubricant to increase the efficiency of machines. Find out what element graphite is made of and why graphite is a good lubricant.

Ideal Mechanical Advantage The mechanical advantage of an a machine without friction is called the ideal mechanical advantage, or IMA. The IMA can be calculated by dividing the input distance by the output distance. For a real machine, the IMA would be the mechanical advantage of the machine if there were no friction.

Efficiency

For real machines, some of the energy put into a machine is always converted into heat by frictional forces. For that reason, the output work of a machine is always less than the work put into the machine.

Efficiency is a measure of how much of the work put into a machine is changed into useful output work by the machine. A machine with high efficiency produces less heat from friction so more of the input work is changed to useful output work.



Reading Check

Why is the output work always less than the input work for a real machine?

Calculating Efficiency To calculate the efficiency of a machine, the output work is divided by the input work. Efficiency is usually expressed as a percentage by this equation:

Efficiency Equation

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

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

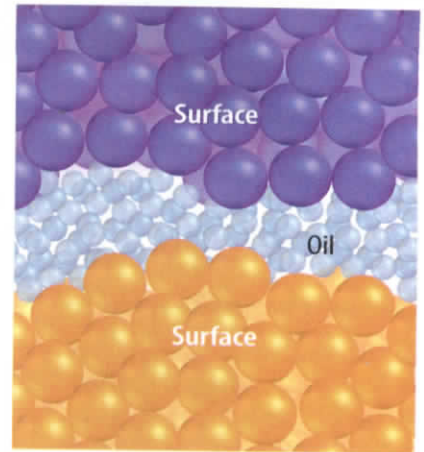


Figure 12 Oil reduces the friction between two surfaces. Oil fills the space between the surfaces so high spots don't rub against each other.

In an ideal machine there is no friction and the output work equals the input work. So the efficiency of an ideal machine is 100 percent. In a real machine, friction causes the output work to always be less than the input work. So the efficiency of a real machine is always less than 100 percent.

Increasing Efficiency Machines can be made more efficient by reducing friction. This usually is done by adding a lubricant, such as oil or grease, to surfaces that rub together, as shown in **Figure 12**. A lubricant fills in the gaps between the surfaces, enabling the surfaces to slide past each other more easily.

section 2 review

Summary

Work and Machines

- Machines make doing work easier by changing the applied force, changing the distance over which the force is applied, or changing the direction of the applied force.
- Because energy cannot be created or destroyed, the output work cannot be greater than the input work.
- In a real machine, some of the input work is converted into heat by friction.

Mechanical Advantage and Efficiency

- The mechanical advantage of a machine is the output force divided by the input force:

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

- The efficiency of a machine is the output work divided by the input work times 100%:

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

Self Check

1. **Describe** the circumstances for which the output work would equal the input work in a machine.
2. **Infer** how lubricating a machine affects the output force exerted by the machine.
3. **Explain** why in a real machine the output work is always less than the input work.
4. **Think Critically** The mechanical advantage of a machine is less than one. Compare the distances over which the input and output forces are applied.

Applying Math

5. **Calculate** the mechanical advantage of a hammer if the input force is 125 N and the output force is 2,000 N.
6. **Calculate Efficiency** Find the efficiency of a machine that does 800 J of work if the input work is 2,400 J.
7. **Calculate Force** Find the force needed to lift a 2,000-N weight using a machine with a mechanical advantage of 15.

Simple Machines

Reading Guide

What You'll Learn

- **Describe** the six types of simple machines.
- **Explain** how the different types of simple machines make doing work easier.
- **Calculate** the ideal mechanical advantage of the different types of simple machines.

Why It's Important

All complex machines, such as cars, are made of simple machines. Even your body contains simple machines.

Review Vocabulary

compound: composed of separate elements or parts

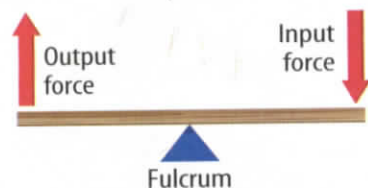
New Vocabulary

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

Figure 13 There are three classes of levers.

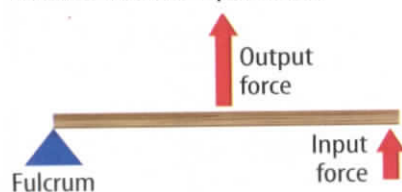
First-class Lever

The fulcrum is between the input force and the output force.



Second-class Lever

The output force is between the fulcrum and the input force.



Third-class Lever

The input force is between the fulcrum and the output force.



Types of Simple Machines

If you cut your food with a knife, or use a screwdriver, or even chew your food, you are using a simple machine. A **simple machine** is a machine that does work with only one movement of the machine. There are six types of simple machines: lever, pulley, wheel and axle, inclined plane, screw, and wedge. The pulley and the wheel and axle are modified levers, and the screw and the wedge are modified inclined planes.

Levers

You've used a lever if you've used a wheelbarrow, or a lawn rake, or swung a baseball bat. A **lever** is a bar that is free to pivot or turn around a fixed point. The fixed point the lever pivots on is called the fulcrum. The input arm of the lever is the distance from the fulcrum to the point where the input force is applied. The output arm is the distance from the fulcrum to the point where the output force is exerted by the lever.

The output force produced by a lever depends on the lengths of the input arm and the output arm. If the output arm is longer than the input arm, the law of conservation of energy requires that the output force be less than the input force. If the output arm is shorter than the input arm, then the output force is greater than the input force.

There are three classes of levers, as shown in **Figure 13**. The differences among the three classes of levers depend on the locations of the fulcrum, the input force, and the output force.

Figure 14 Levers are classified by the location of the input force, output force, and the fulcrum.

A The screwdriver is being used as a first-class lever. The fulcrum is the paint can rim.



B A wheelbarrow is a second-class lever. The fulcrum is the wheel.



First-Class Lever The screwdriver used to open the paint can in **Figure 14A** is an example of a first-class lever. For a first-class lever, the fulcrum is located between the input and output forces. The output force is always in the opposite direction to the input force in a first-class lever.

Second-Class Lever For a second-class lever, the output force is located between the input force and the fulcrum. Look at the wheelbarrow in **Figure 14B**. You apply an upward input force on the handles, and the wheel is the fulcrum. The output force is exerted between the input force and fulcrum. For a second-class lever, the output force is always greater than the input force.

Third-Class Lever Many pieces of sports equipment, such as a baseball bat, are third-class levers. For a third-class lever, the input force is applied between the output force and the fulcrum. The right-handed batter in **Figure 14C**, applies the input force with the right hand and the left hand is the fulcrum. The output force is exerted by the bat above the right hand. The output force is always less than the input force in a third-class lever. Instead, the distance over which the output force is applied is increased.

Every lever can be placed into one of these classes. Each class can be found in your body, as shown in **Figure 15** on the next page.



C A baseball bat is a third-class lever. The fulcrum here is this batter's left hand.

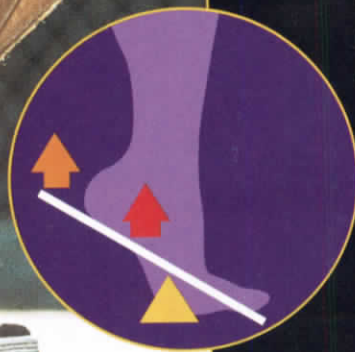
Figure 15

All three types of levers—first-class, second-class, and third-class—are found in the human body. The forces exerted by muscles in your body can be increased by first-class and second-class levers, while third-class levers increase the range of movement of a body part. Examples of how the body uses levers to help it move are shown here.

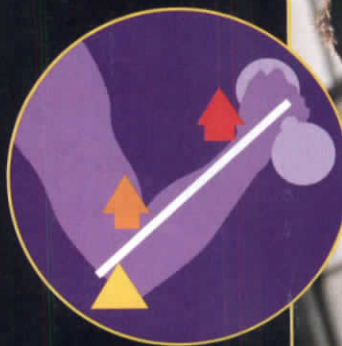
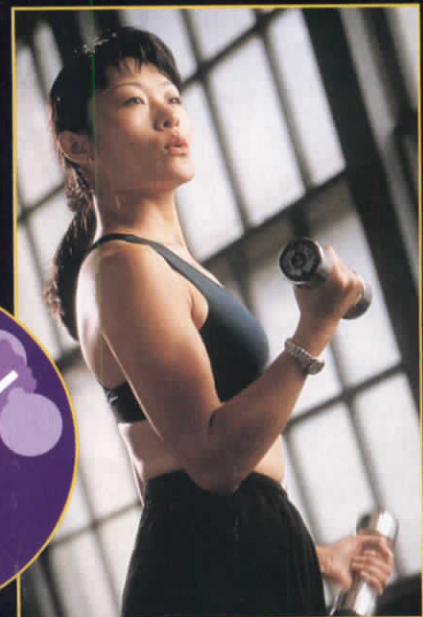
- ▲ Fulcrum
- ▼ Input force
- ▲ Output force



▲ **FIRST-CLASS LEVER** The fulcrum lies between the input force and the output force. Your head acts like a first-class lever. Your neck muscles provide the input force to support the weight of your head.



◀ **SECOND-CLASS LEVER** The output force is between the fulcrum and the input force. Your foot becomes a second-class lever when you stand on your toes.



▶ **THIRD-CLASS LEVER** The input force is between the fulcrum and the output force. A third-class lever increases the range of motion of the output force. When you do a curl with a dumbbell, your forearm is a third-class lever.

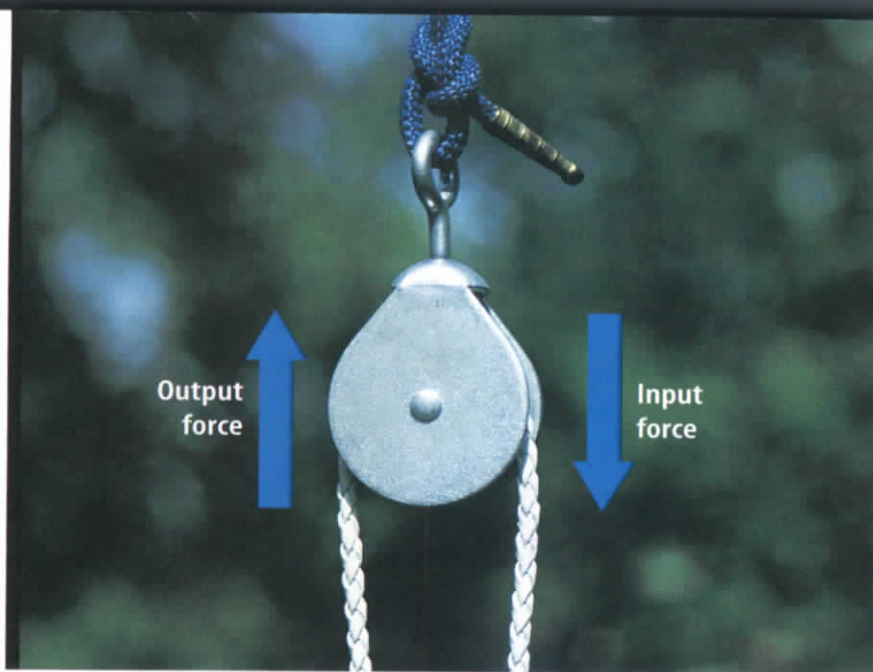


Figure 16 A fixed pulley is another form of the lever.
Infer the lengths of the input arm and output arm in a pulley.

Ideal Mechanical Advantage of a Lever The ideal mechanical advantage, or IMA, can be calculated for any machine by dividing the input distance by the output distance. For a lever, the input distance is the length of the input arm and the output distance is the length of the output arm. The IMA of a lever can be calculated from this equation:

Ideal Mechanical Advantage of a Lever

$$\text{ideal mechanical advantage} = \frac{\text{length of input arm (m)}}{\text{length of output arm (m)}}$$

$$\text{IMA} = \frac{L_{\text{in}}}{L_{\text{out}}}$$

Pulleys

A **pulley** is a grooved wheel with a rope, chain, or cable running along the groove. A fixed pulley is a modified first-class lever, as shown in **Figure 16**. The axle of the pulley acts as the fulcrum. The two sides of the pulley are the input arm and output arm. A pulley can change the direction of the input force or increase input force, depending on whether the pulley is fixed or movable. A system of pulleys can change the direction of the input force and make it larger.

Fixed Pulleys The cable attached to an elevator passes over a fixed pulley at the top of the elevator shaft. A fixed pulley, such as the one in **Figure 17**, is attached to something that doesn't move, such as a ceiling or wall. Because a fixed pulley changes only the direction of force, the IMA is 1.

Figure 17 A fixed pulley changes only the direction of your force. You need to apply an input force of 4 N to lift the 4-N weight.

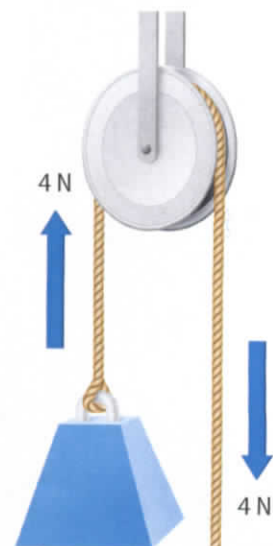
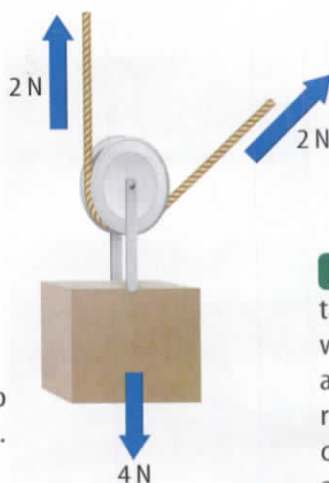
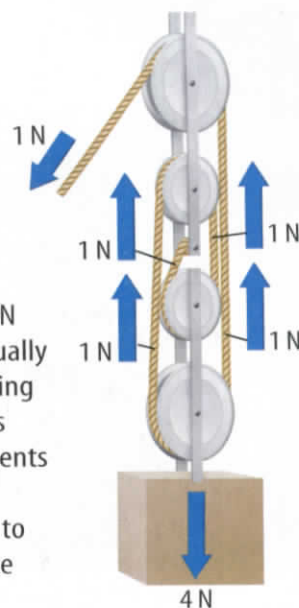


Figure 18 A movable pulley and a pulley system called a block and tackle reduce the force needed to lift a weight.

A With a movable pulley, the attached side of the rope supports half of the 4-N weight. You have to apply a 2-N force to lift the weight.




B In a block-and-tackle system, the 4-N weight is divided equally among each supporting rope segment. In this case, four rope segments are supporting the weight. So you have to apply only a 1-N force to lift the weight.



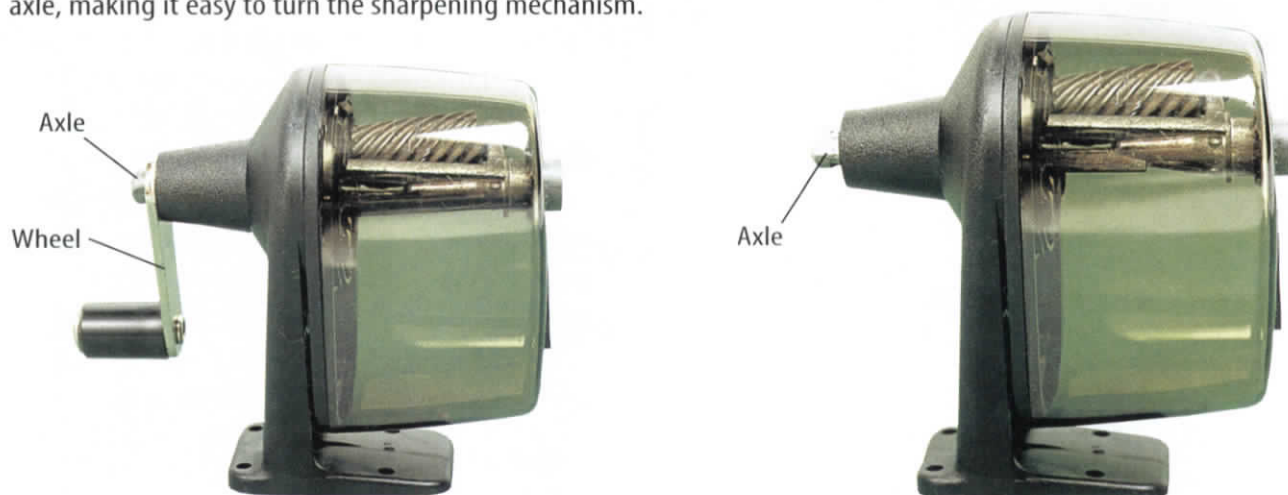
Movable Pulleys A pulley in which one end of the rope is fixed and the wheel is free to move is called a movable pulley. Unlike a fixed pulley, a movable pulley does multiply force. Suppose a 4-N weight is hung from the movable pulley in **Figure 18A**. The ceiling acts like someone helping you to lift the weight. The rope attached to the ceiling will support half of the weight—2 N. You need to exert only the other half of the weight—2 N—in order to support and lift the weight. The output force exerted on the weight is 4 N, and the applied input force is 2 N. Therefore the IMA of the movable pulley is 2.

For a fixed pulley, the distance you pull the rope downward equals the distance the weight moves upward. For a movable pulley, the distance you pull the rope upward is twice the distance the weight moves upward.

 **Reading Check** *How does a movable pulley reduce the input force needed to lift a weight?*

The Block and Tackle A system of pulleys consisting of fixed and movable pulleys is called a block and tackle. **Figure 18B** shows a block and tackle made up of two fixed pulleys and two movable pulleys. If a 4-N weight is suspended from the movable pulley, each rope segment supports one fourth of the weight, reducing the input force to 1 N. The IMA of a pulley system is equal to the number of rope segments that support the weight. The block and tackle shown in **Figure 18B** has a IMA of 4. The IMA of a block and tackle can be increased by increasing the number of pulleys in the pulley system.

Figure 19 The handle on a pencil sharpener is part of a wheel and axle. You apply a force to the handle. This force is made larger by the wheel and axle, making it easy to turn the sharpening mechanism.



Wheel and Axle

Could you use the pencil sharpener in **Figure 19** if the handle weren't attached? The handle on the pencil sharpener is part of a wheel and axle. A **wheel and axle** is a simple machine consisting of a shaft or axle attached to the center of a larger wheel, so that the wheel and axle rotate together. Doorknobs, screwdrivers, and faucet handles are examples of wheel and axles. Usually the input force is applied to the wheel, and the output force is exerted by the axle.

Mechanical Advantage of the Wheel and Axle A wheel and axle is another modified lever. The center of the axle is the fulcrum. The input force is applied at the rim of the wheel. So the length of the input arm is the radius of the wheel. The output force is exerted at the rim of the axle. So the length of the output arm is the radius of the axle. The ideal mechanical advantage of a lever is the length of the input arm divided by the length of the output arm. So the IMA of a wheel and axle is given by this equation:

Ideal Mechanical Advantage of Wheel and Axle

$$\text{ideal mechanical advantage} = \frac{\text{radius of wheel (m)}}{\text{radius of axle (m)}}$$

$$\text{IMA} = \frac{r_w}{r_a}$$

According to this equation, the IMA of a wheel and axle can be increased by increasing the radius of the wheel.



Figure 20 If an input force is applied to the larger gear, and it rotates clockwise, the smaller gear rotates counterclockwise. The output force exerted by the smaller gear is less than the input force applied to the larger gear.

Gears A gear is a wheel and axle with the wheel having teeth around its rim. When the teeth of two gears interlock, turning one gear causes the other gear to turn.

When two gears of different sizes are interlocked, they rotate at different rates. Each rotation of the larger gear causes the smaller gear to make more than one rotation. If the input force is applied to the larger gear, the output force exerted by smaller gear is less than the input force.

Gears also may change the direction of the force as shown in **Figure 20**. When

the larger gear is rotated clockwise, the smaller gear rotates counterclockwise.

Inclined Planes

Why do the roads and paths on mountains zigzag? Would it be easier to climb directly up a steep incline or walk a longer path gently sloped around the mountain? A sloping surface, such as a ramp that reduces the amount of force required to do work, is an **inclined plane**.

Mechanical Advantage of an Inclined Plane You do the same work by lifting a box straight up or pushing it up an inclined plane. But by pushing the box up an inclined plane, the input force is exerted over a longer distance compared to lifting the box straight up. As a result the input force is less than the force needed to lift the box straight upward. The IMA of an inclined plane can be calculated from this equation.

Ideal Mechanical Advantage of Inclined Plane

$$\text{ideal mechanical advantage} = \frac{\text{length of slope (m)}}{\text{height of slope (m)}}$$

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

The IMA of an inclined plane for a given height is increased by making the plane longer.

When you think of an inclined plane, you normally think of moving an object up a ramp—you move and the inclined plane remains stationary. The screw and the wedge, however, are variations of the inclined plane in which the inclined plane moves and the object remains stationary.

Science online

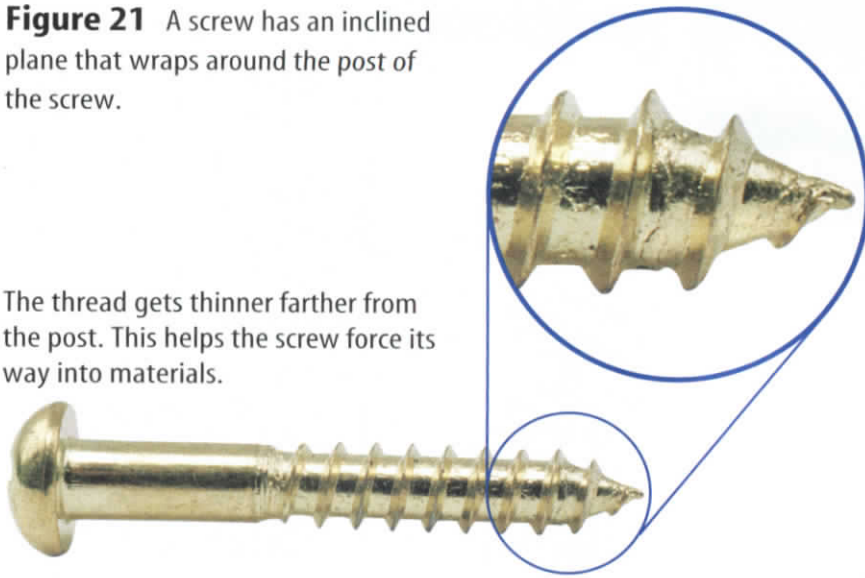
Topic: Nanorobots

Visit gpscience.com for Web links to information about how tiny robots called nanorobots might be used as microsurgical instruments.

Activity Use the information you find to make a diagram of a nanorobot that might be used to perform surgery.

Figure 21 A screw has an inclined plane that wraps around the post of the screw.

The thread gets thinner farther from the post. This helps the screw force its way into materials.



The Screw

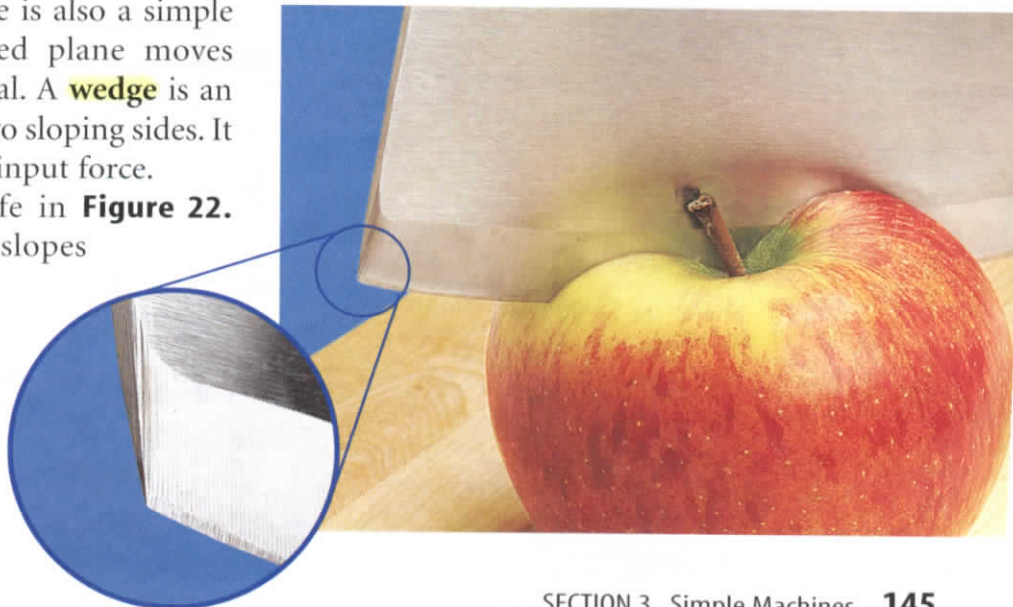
A **screw** is an inclined plane wrapped in a spiral around a cylindrical post. If you look closely at the screw in **Figure 21**, you'll see that the threads form a tiny ramp that runs upward from its tip. You apply the input force by turning the screw. The output force is exerted along the threads of the screw. The IMA of a screw is related to the spacing of the threads. The IMA is larger if the threads are closer together. However, if the IMA is larger, more turns of the screw are needed to drive it into some material.

How do you remove the lid off a jar of peanut butter, like in **Figure 22**? If you look closely, you see threads similar to the ones on the screw in **Figure 21**. Where else can you find examples of a screw?

The Wedge

Like the screw, the wedge is also a simple machine where the inclined plane moves through an object or material. A **wedge** is an inclined plane with one or two sloping sides. It changes the direction of the input force.

Look closely at the knife in **Figure 22**. One edge is sharp, and it slopes outward at both sides, forming an inclined plane. As it moves through the apple, the downward input force is changed to a horizontal force, forcing the apple apart.



Many lids, such as those on peanut butter jars, also contain threads.

Figure 22 A knife blade is a wedge. As you cut through the apple, it pushes the halves of the apple apart.

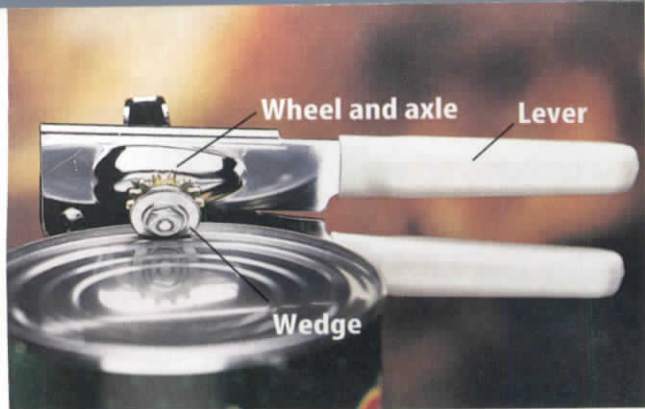


Figure 23 A compound machine, such as a can opener, is made up of simple machines.

Compound Machines

Some of the machines you use every day are made up of several simple machines. Two or more simple machines that operate together form a **compound machine**.

Look at the can opener in **Figure 23**. To open the can you first squeeze the handles together. The handles act as a lever and increase the force applied on a wedge, which then pierces the can.

You then turn the handle, a wheel and axle, to open the can.

A car is also a compound machine. Burning fuel in the cylinders of the engine causes the pistons to move up and down. This up-and-down motion makes the crankshaft rotate. The force exerted by the rotating crankshaft is transmitted to the wheels through other parts of the car, such as the transmission and the differential. Both of these parts contain gears, that can change the rate at which the wheels rotate, the force exerted by the wheels, and even reverse the direction of rotation.

section 3 review

Summary

The Lever Family

- A lever is a bar that is free to pivot about a fixed point called the fulcrum.
- There are three classes of levers based on the relative locations of the input force, output force, and the fulcrum.
- A pulley is a grooved wheel with a rope, chain, or cable placed in the groove and is a modified form of a lever.
- The IMA of a lever is the input arm divided by the output arm.
- A wheel and axle consists of a shaft or axle attached to the center of a larger wheel.

The Inclined Plane Family

- An inclined plane is a ramp or sloping surface that reduces the force needed to do work.
- The IMA of an inclined plane is the length of the plane divided by the height of the plane.
- A screw consists of an inclined plane wrapped around a shaft.
- A wedge is an inclined plane that moves and can have one or two sloping surfaces.

Self Check

1. **Classify** a screwdriver as one of the six types of simple machine. Explain how the IMA of screw driver could be increased.
2. **Determine** for which class of lever the output force is always greater than the input force. For which class is the output force always less than the input force?
3. **Make a diagram** of a bicycle and label the parts of a bicycle that are simple machines.
4. **Think Critically** Use the law of conservation of energy to explain why in a second-class lever the distance over which the input force is applied is always greater than the distance over which the output force is applied.

Applying Math

5. **Calculate IMA** What is the IMA of a car's steering wheel if the wheel has a diameter of 40 cm and the shaft it's attached to has a diameter of 4 cm?
6. **Calculate Output Arm Length** A lever has an IMA of 4. If the length of the input arm is 1.0 m, what is the length of the output arm?
7. **Calculate IMA** A 6.0 m ramp runs from a sidewalk to a porch that is 2.0 m above the sidewalk. What is the ideal mechanical advantage of this ramp?

Levers

Have you ever tried to balance a friend on a seesaw? If your friend was lighter, you had to move toward the fulcrum. In this lab, you will use the same method to measure the mass of a coin.

Real-World Question

How can a lever be used to measure mass?

Goals

- **Measure** the lengths of the input arm and output arm of a lever.
- **Calculate** the ideal mechanical advantage of a lever.
- **Determine** the mass of a coin.

Materials

stiff cardboard, 3 cm by 30 cm
 coins (one quarter, one dime, one nickel)
 balance
 metric ruler

Safety Precautions



Procedure

1. **Measure** the mass of each coin.
2. Mark a line 2 cm from one end of the cardboard strip. Label this line *Output*.
3. Slide the other end of the cardboard strip over the edge of a table until the strip begins to tip. Mark a line across the strip at the table edge and label this line *Input*.
4. **Measure** the mass of the strip to the nearest 0.1 g. Write this mass on the input line.
5. Center a dime on the output line. Slide the cardboard strip until it begins to tip. Mark the balance line. Label it *Fulcrum 1*.



6. **Measure** the lengths of the output and input arms to the nearest 0.1 cm.
7. Calculate the IMA of the lever. Multiply the IMA by the mass of the lever to find the approximate mass of the coin.
8. Repeat steps 5 through 7 with the nickel and the quarter. Mark the fulcrum line *Fulcrum 2* for the nickel and *Fulcrum 3* for the quarter.

Conclude and Apply

1. **Explain** why there might be a difference between the mass of each coin measured by the balance and the mass measured using the lever.
2. **Explain** what provides the input and output force for the lever.
3. **Explain** why the IMA of the lever changes as the mass of the coin changes.

Communicating Your Data

Compare your results with those of other students in your class. **For more help, refer to the Science Skill Handbook.**

Using Simple Machines

Goals

- **Model** lifting devices based on a block and tackle and on an inclined plane.
- **Calculate** the output work that will be accomplished.
- **Measure** the force needed by each machine to lift a weight.
- **Calculate** the input work and efficiency for each model machine.
- **Select** the best machine for your job based on the force required.

Possible Materials

spring scale, 0–10 N range
 9.8-N weight (1 kg mass)
 two double pulleys
 string for pulleys
 stand or support for the pulleys
 wooden board, 40 cm long
 support for board, 10 cm high

Safety Precautions



Real-World Question

You are the contractor on a one-story building with a large air-conditioner. How can you get the air conditioner to the roof? How can you minimize the force needed to lift an object? What machines could you use? Consider a fixed pulley with ideal mechanical advantage (IMA) = 1, a movable pulley with IMA = 2, a block and tackle with one fixed double pulley and one movable double pulley with IMA = 4, and an inclined plane with IMA = slope / height = 4. How can you find the efficiency of machines?

Make the Model

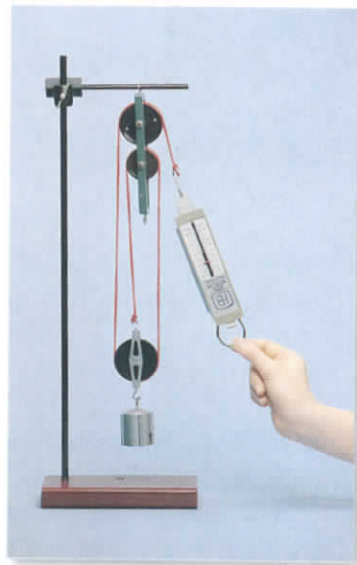
1. Work in teams of at least two. **Collect** all the needed equipment.
2. Sketch a model for each lifting machine. **Model** the inclined plane with a board 40-cm long and raised 10 cm at one end. Include a control in which the weight is lifted while being suspended directly from the spring scale.
3. Make a table for data.
4. Is the pulley support high enough that the block and tackle can lift a weight 10 cm?
5. Obtain your teacher's approval of your sketches and data table before proceeding.

Problem Data			
	Control	Inclined Plane	Block and Tackle
Ideal Mechanical Advantage, IMA	1	4	4
Input force, F_{in} , N			
Input distance, d_{in} , m	0.10		
Output force, F_{out} , N	9.8	9.8	9.8
Output distance, d_{out} , m	0.10	0.10	0.10
$Work_{in} = F_{in} d_{in}$, Joules			
$Work_{out} = F_{out} d_{out}$, Joules	0.98	0.98	0.98
$Efficiency = (Work_{out} / Work_{in}) \times 100\%$			

Using Scientific Methods

▶ Test the Model

1. Tie the weight to the spring scale and measure the force required to lift it. Record the input force in your data table under *Control*, along with the 10-cm input distance.
2. Assemble the inclined plane so that the weight can be pulled up the ramp at a constant rate. The 40-cm board should be supported so that one end is 10 cm higher.
3. Tie the string to the spring scale and measure the force required to move the weight up the ramp at a constant speed. Record this input force under *Inclined Plane* in your data table. Record 40 cm as the input distance for the inclined plane.
4. Assemble the block and tackle using one fixed double pulley and one movable single pulley.
5. Tie the weight to the single pulley and tie the spring scale to the string at the top of the upper double pulley.
6. **Measure** the force required to lift the weight with the block and tackle. Record this input force.
7. **Measure** the length of string that must be pulled to raise the weight 10 cm. Record this input distance.



▶ Analyze Your Data

1. **Calculate** the output work for all three methods of lifting the 9.8-N weight a distance of 10 cm.
2. **Calculate** the input work and the efficiency for the control, the inclined plane, and the block and tackle.
3. **Compare** the efficiencies of each of the three methods of lifting.

▶ Conclude and Apply

1. **Explain** how you might improve the efficiency of the machine in each case.
2. **Infer** what types of situations would require use of a ramp over a pulley to help lift something.
3. **Infer** which machines would be most likely to be affected by friction.

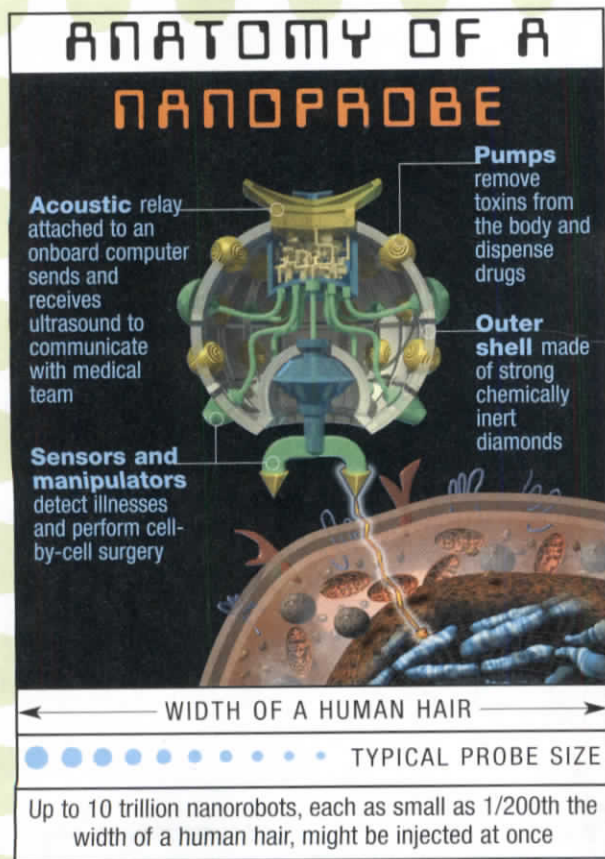
Communicating Your Data

Make a poster showing how the best machine would be used to lift the air conditioner to the roof of your building.

The
Science of very, very small

Imagine an army of tiny robots, each no bigger than a bacterium swimming through your bloodstream.

Welcome to the world of nanotechnology—the science of creating molecular-sized machines. These machines are called nanobots.



This is the smallest guitar in the world. It is about as big as a human white blood cell. Each of its six silicon strings is 100 atoms wide. You can see the guitar only with an electron microscope.

The smallest of these machines are only billionths of a meter in size. They are so tiny that they can do work on the molecular scale.

Small, Smaller, Smallest

Nanotechnologists are predicting that within a few decades they will be creating nanobots that can do just about anything, as long as it's small. Already, nanotechnologists have built gears 10,000 times thinner than a human hair. They've also built tiny molecular "motors" only 50 atoms long. At Cornell University, nanotechnologists created the world's smallest guitar. It is approximately the size of a white blood cell and it even has six strings.

In the future, they might transmit your internal vital signs to a nanocomputer, which might be implanted under your skin. There the data could be analyzed for signs of disease. Other nanomachines then could be sent to scrub your arteries clean of dangerous blockages, or mop up cancer cells, or even vaporize blood clots with tiny lasers. These are just some of the possibilities in the imaginations of those studying the new science of nanotechnology.

Design Think up a very small simple or complex machine that could go inside the body and do something. What would the machine do? Where would it go? Share your diagram or design with your classmates.

Science  online

For more information, visit
gpscience.com/time

Reviewing Main Ideas

Section 1 Work

1. Work is the transfer of energy when a force makes an object move.
2. Work is done only when force produces motion in the direction of the force.
3. Power is the amount of work, or the amount of energy transferred, in a certain amount of time.



Section 2 Using Machines

1. A machine makes work easier by changing the size of the force applied, by increasing the distance an object is moved, or by changing the direction of the applied force.
2. The number of times a machine multiplies the force applied to it is the mechanical advantage of the machine. The actual mechanical advantage is always less than the ideal mechanical advantage.



3. The efficiency of a machine equals the output work divided by the input work.
4. Friction always causes the output work to be less than the input work, so no real machine can be 100 percent efficient.

Section 3 Simple Machines

1. A simple machine is a machine that can do work with a single movement.
2. A simple machine can increase an applied force, change its direction, or both.
3. A lever is a bar that is free to pivot about a fixed point called a fulcrum. A pulley is a grooved wheel with a rope running along the groove. A wheel and axle consists of two different-sized wheels that rotate together. An inclined plane is a sloping surface used to raise objects. The screw and wedge are special types of inclined planes.
4. A combination of two or more simple machines is called a compound machine.



FOLDABLES Use the Foldable that you made at the beginning of this chapter to help you review how machines make doing work easier.

Using Vocabulary

compound machine p. 146	output force p. 134
efficiency p. 136	power p. 129
inclined plane p. 144	pulley p. 141
input force p. 134	screw p. 145
lever p. 138	simple machine p. 138
machine p. 132	wedge p. 145
mechanical advantage p. 136	wheel and axle p. 143
	work p. 126

Complete each statement using a word(s) from the vocabulary list above.

- A combination of two or more simple machines is a(n) _____.
 - A wedge is another form of a(n) _____.
 - The ratio of the output force to the input force is the _____ of a machine.
 - A(n) _____ is a grooved wheel with a rope, chain, or cable in the groove.
 - The force exerted by a machine is the _____.
 - Energy is transferred when _____ is done.
 - _____ is the rate at which work is done or energy is transferred.
- In an ideal machine, which of the following is true?
 - Work input is equal to work output.
 - Work input is greater than work output.
 - Work input is less than work output.
 - The IMA is always equal to one.
 - Which of these is not done by a machine?
 - multiply force
 - multiply energy
 - change direction of a force
 - work
 - What term indicates the number of times a machine multiplies the input force?
 - efficiency
 - power
 - mechanical advantage
 - resistance
 - How could you increase the IMA of an inclined plane?
 - increase its length
 - increase its height
 - decrease its length
 - make its surface smoother
 - In a wheel and axle, which of the following usually exerts the output force?
 - the axle
 - the wheel
 - the fulcrum
 - the input arm

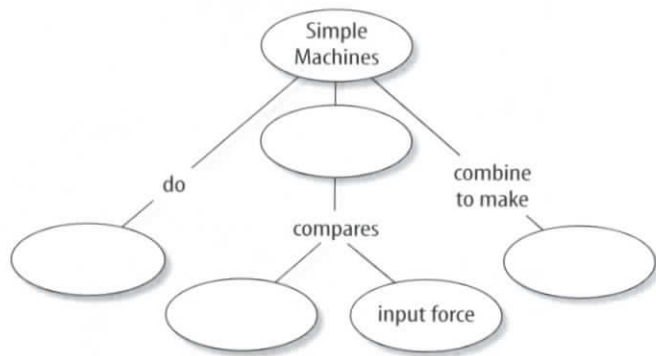
Checking Concepts

Choose the word or phrase that best answers the question.

- Using the scientific definition, which of the following is true of work?
 - It is difficult.
 - It involves levers.
 - It involves a transfer of energy.
 - It is done with a machine.
- How many types of simple machines exist?
 - three
 - six
 - eight
 - ten
- What is the IMA of screwdriver with a shaft radius of 3 mm and a handle radius of 10 mm?
 - 0.3
 - 3.3
 - 30
 - 13
- What is the IMA of an inclined plane that is 2.1 m long and 0.7 m high?
 - 0.3
 - 2.8
 - 1.5
 - 3.0
- Which of the following increases as the efficiency of a machine increases?
 - work input
 - work output
 - friction
 - IMA

Interpreting Graphics

18. Copy and complete the concept map of simple machines using the following terms: *compound machines*, *mechanical advantage*, *output force*, *work*.



Use the table below to answer questions 19 and 20.

Lever Input and Output Arms		
Lever	Input arm (cm)	Output arm (cm)
A	25	75
B	53	42
C	36	36
D	32	99
E	10.	30

19. Determine which of the levers listed in the table above has the largest IMA.
20. An input force of 50 N is applied to lever B. If the lever is 100 percent efficient, what is the output force?

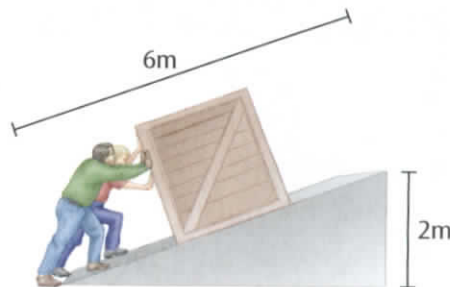
Thinking Critically

21. **Describe** how the effort force, resistance force and fulcrum should be arranged so that a child can lift an adult using his own body weight on a see saw.

22. **Determine** what arrangement of movable and fixed pulleys would give a mechanical advantage of 3.
23. **Explain** which would give the best mechanical advantage for driving a screw down into a board: a screwdriver with a long, thin handle, or a screwdriver with a short, fat handle.

Applying Math

24. **Calculate Work** Find the work needed to lift a book weighing 20.0 N 2.0 m.
25. **Calculate Axle Radius** A doorknob has an IMA equal to 8.5. If the diameter of the doorknob is 8.0 cm, what is the radius of the shaft the doorknob is connected to?
26. **Calculate Input Work** A machine has an efficiency of 61 percent. Find the input work if the output work is 140 J.
27. **Calculate Efficiency** Using a ramp 6 m long, workers apply an input force of 1,250 N to move a 2,000-N crate onto a platform 2 m high. What is the efficiency of the ramp?



28. **Calculate Power** A person weighing 500 N climbs 3 m. How much power is needed to make the climb in 5 s?

Part 1 Multiple Choice

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

Use the figure below to answer questions 1 and 2



- The figure above shows a doorknob with a radius of 4.8 cm and a mechanical advantage of 4.0. What is the radius of the inner rod that connects the knob to the door?
 - 0.6 cm
 - 1.2 cm
 - 1.8 cm
 - 2.4 cm
- What would happen to the mechanical advantage if the radius of the doorknob were doubled?
 - It would be multiplied by 4.
 - It would be multiplied by 2.
 - It would be divided by 4.
 - It would be divided by 2.
- A ramp is 2.8 m long and 1.2 m high. How much power is needed to push a box up the ramp in 4.6 s with a force of 96 N?
 - 21 W
 - 25 W
 - 58 W
 - 270 W
- How much work is done in lifting a 9.10-kg box onto a shelf 1.80 m high?
 - 5.06 J
 - 16.4 J
 - 49.5 J
 - 161 J
- What type of simple machine is your foot when you stand on your toes?
 - first-class lever
 - second-class lever
 - third-class lever
 - inclined plane
- An input force of 80 N is used to lift an object weighing 240 N with a system of pulleys. How far down must the rope around the pulleys be pulled in order to lift the object a distance of 1.4 m?
 - 0.47 m
 - 1.4 m
 - 2.8 m
 - 4.2 m

Use the figure below to answer questions 7 and 8.



- If the distance between the lever's input force and the fulcrum is 8 cm, and the distance between the fulcrum and the output force is 24 cm, what is the ideal mechanical advantage of the lever?
 - 4
 - 3
 - 0.33
 - 0.25
- Which device uses the same class of lever as that shown in the figure?
 - baseball bat
 - scissors
 - shovel
 - wheelbarrow
- How much more work is done to push a box 2.5 m with a force of 30 N than to push a box 2.0 m with a force of 26 N?
 - 28 J
 - 23 J
 - 4 J
 - 56 J

Test-Taking Tip

Don't Panic Stay calm during the test. If you feel yourself getting nervous, close your eyes and take five slow, deep, breaths.

Part 2 Short Response/Grid In

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

10. As you throw a ball, you exert a force on ball of 4.2 N. You exert this force on the ball while the ball moves a distance of 0.45 m. The ball leaves your hand and travels a horizontal distance of 8.5 m to your friend. How much work have you done on the ball?

Use the illustration below to answer questions 11–13.

11. What is the ideal mechanical advantage of the pulley system shown in the figure to the right?



12. If the block supported by the pulley system shown above has a weight of 20 N, what is the input force on the rope?
13. If an additional pulley were included in the system shown in the illustration, what would the input force be?
14. A machine does 760 J of work in 32 s. What is the machine's power?
15. Write an equation for the efficiency of a lever if you know the lever's input force and distance as well as the output force and distance.
16. A centripetal force is exerted in a direction perpendicular to the motion of an object in circular motion. Is work done by a centripetal force? Why or why not?

Part 3 Open Ended

Record your answers on a sheet of paper.

17. Is the following statement true? If so, give an example that supports it. If not, explain why.
When work is done, a transfer of energy always occurs, but a transfer of energy does not always mean that work has been done.
18. What are three ways that simple machines can make work easier? For each one, give an example of a machine that makes work easier in that way.
19. Explain what causes friction in a machine and how a lubricant reduces a machine's friction. Describe the change a lubricant would make in the efficiency of a machine.
20. Use the law of conservation of energy to explain why it is impossible for the output work of a machine to be greater than the machine's input work.

Use the illustration below to answer questions 21 and 22.

21. The boy in the photograph to the right is carrying a box to the top of the stairs. Describe how the work that the boy does on the box is related to the energy transfer that occurs. How does the energy of the box change form as the boy carries the box up the stairs?



22. Explain how the work, power, and energy would change if the boy walked faster. How would the work, power, and energy change if the steps were the same height but steeper?