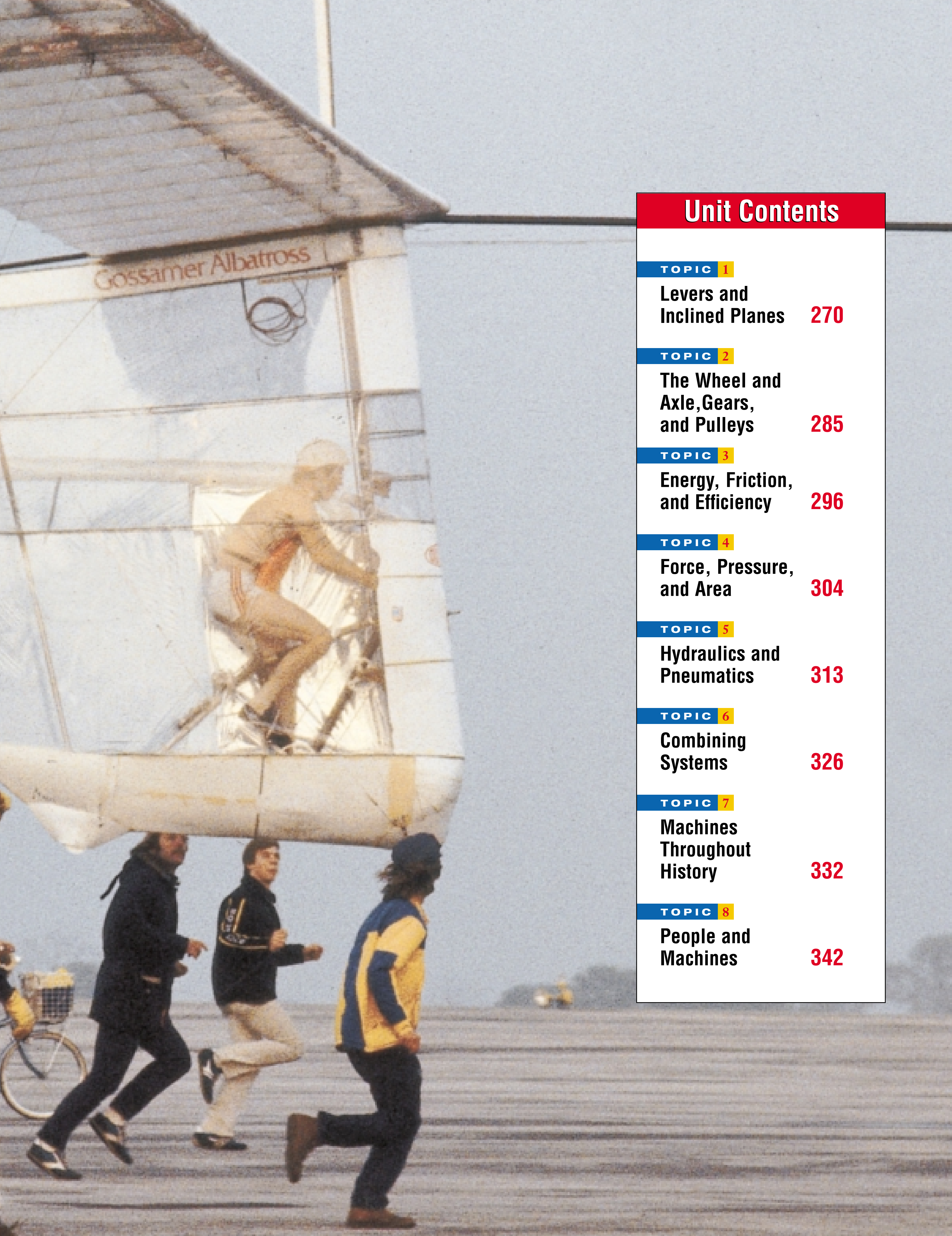
UNIT 4

Mechanical Systems

How many mechanical systems have you used today? You may not realize it, but you use mechanical systems all the time to do simple tasks. When you ride a bicycle, open a can, or sharpen a pencil, you have used a mechanical system to help you complete a task.

All mechanical systems have an energy source. The energy could come from electricity, gasoline, or solar energy, but often the energy comes from humans. (Remember that huge structures such as the pyramids were built solely using human power!) The energy needed to move this bicycle and this plane, for example, comes from a pedalling human. Can you see how machines help us perform tasks we might find difficult to do otherwise? Imagine opening a can without a can opener. Could you fly without a plane or other type of aircraft?

In this unit, you will learn how some small, human-powered mechanical devices work. You will see that tools as simple as a pair of scissors function on the same principles as massive equipment powered by fluid pressure and heat engines. You will discover the main factors in the efficient operation of mechanical systems. You will also design and build your own mechanical devices — including some powered by hydraulics and pneumatics — and investigate their efficiency. Finally, this unit examines how machines have changed as science and technology have changed.



Unit Contents

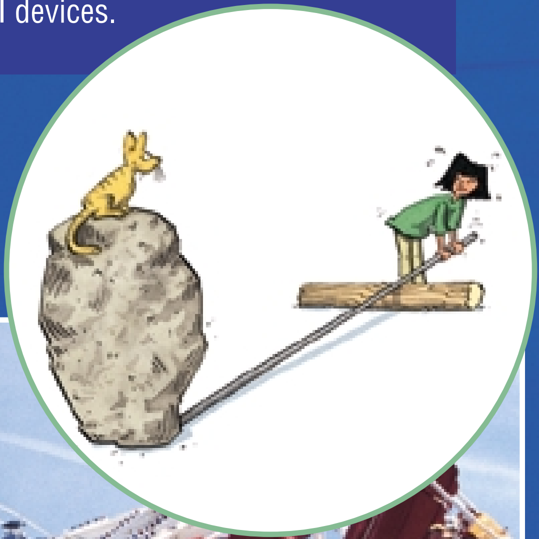
UNIT 4

Preview

Focussing Questions

- How do we use machines to do work and to transfer energy?
- How can we design and use machines efficiently and responsibly?
- How have machines changed over time?

How many machines have you used today? How do we use mechanical devices such as levers and pulleys to help us perform tasks? In Topics 1–3, you will learn about lots of mechanical devices.



How can the pressure of fluids be used to operate a machine such as this amusement park ride? In Topics 4–6, you will learn how fluids are used in mechanical systems, and how many systems — even your body — are a combination of several smaller systems working together.

How have mechanical devices changed over time? How do changes in society and the environment affect the mechanical devices we design? In Topics 7–8, you will explore how and why mechanical devices change over time.

Looking Ahead

Read pages 354–355, Unit 4 Project, "Adapting Tools." You will conduct this project after you have completed Topics 1–8.

- Carefully read the Challenge posed on page 354. Start thinking about items that you might like to adapt for an older person or a person with a physical injury or disability.
- Look in magazines, newspapers, or catalogues for examples of things you might want to adapt. Save your ideas in a "Project Planning File."
- Make simple sketches of how you might adapt an item, and keep them in your file.

TOPIC 1 Levers and Inclined Planes

Word CONNECT

In a dictionary, find the origin of the word "lever." Then look up the meaning of the word "leverage" and use it in a sentence.

Figure 4.1A and B How are the screwdriver and the teeter-totter alike?

Science Log

What is the largest object you have ever tried to lift? At the time, did you think that there must be an easier way to do this? Write your responses to these questions in your Science Log. As you study this unit, you will discover some "better ways" to lift large objects and move mechanical devices.

If you were to exert a force on a screwdriver, the screwdriver would exert a force on something else, as shown in Figure 4.1A. Both the screwdriver and the teeter-totter (shown in Figure 4.1B) act as levers.

As you learned in previous studies, a **lever** is a simple machine that changes the amount of force you must exert in order to move an object. It consists of a bar that is free to rotate around a fixed point. This fixed point, the **fulcrum**, supports the lever (see Figure 4.2). The fulcrum is the lever's point of rotation. The force that you exert on a lever to make it move is called the **effort force**. This term is used to describe the force supplied to any machine in order to produce an action. The **load** is the mass of an object that is moved or lifted by a machine such as a lever. In other words, the load is the resistance to movement that a machine must overcome. The distance between the fulcrum and the effort force is called the **effort arm**. The distance between the fulcrum and the load is called the **load arm**.

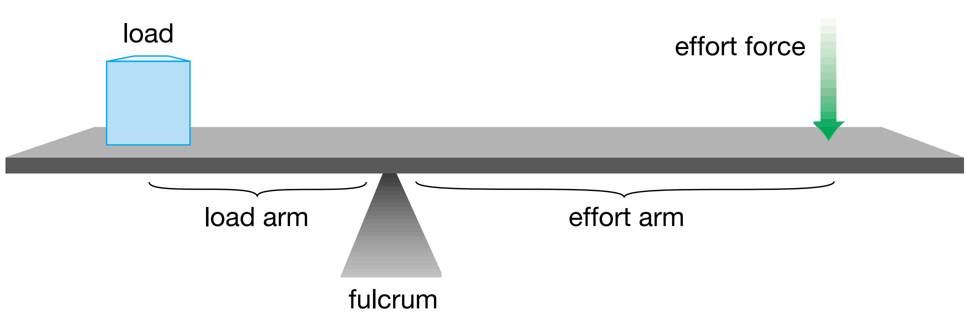


Figure 4.2 A lever is a simple machine consisting of a bar that rotates around a fixed point, the fulcrum.

Skill FOCUS

For tips on making a great Science Log, turn to Skill Focus 3.

You can discover levers in many different situations. Levers are sorted into three classes. The class a lever belongs to depends on the position of the effort force, the load, and the fulcrum, as shown in Figures 4.3A, B, and C. As the photographs show, different classes of levers are used for different purposes.

In a Class 1 lever, the fulcrum is between the effort and the load. A pair of scissors is an example of a Class 1 lever. This class of lever can be used either for power or for precision.

A **Class 2 lever**, such as a wheelbarrow, always exerts a greater force on the load than the effort force you exert on the lever. In this type of lever, the load is between the effort and the fulcrum.

In a **Class 3 lever** — a hockey stick, for example — the effort is exerted between the fulcrum and the load. When using a **Class 3 lever**, you must exert a greater force on the lever than the lever exerts on the load. However, the load can be moved very quickly.

DidYouKnow?

Have you ever rowed or sailed a boat? The oars in a rowboat and the rudder of a sailboat are both Class 1 levers. What class of lever do you think a canoe paddle is?

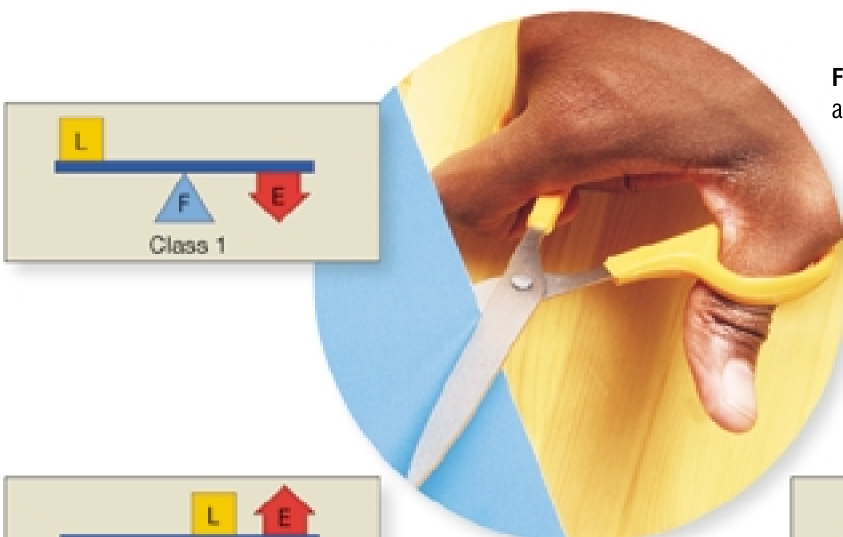


Figure 4.3A An example of a Class 1 lever

Figure 4.3B An example of a Class 2 lever

Figure 4.3C An example of a Class 3 lever

INQUIRY

INVESTIGATION 4-A

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

Levers in Action

How does the position of the fulcrum affect the effort force you must exert to lift a load? Do you have to exert a greater effort force on a Class 2 or a Class 3 lever to lift the same load? In this investigation you will contrast different types of levers.

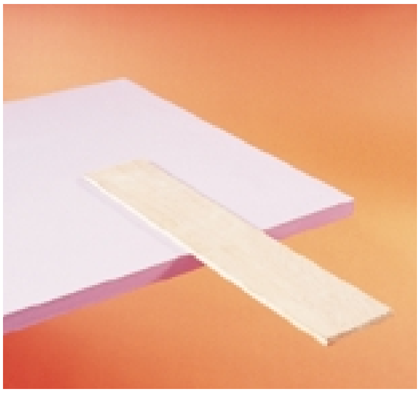
Hypothesis

Form a hypothesis about how the position of the fulcrum and the location of the load affect the amount of effort force you must exert to lift the load.

Apparatus

sturdy board
brick (or similar heavy mass)
strong string

Procedure



1. Place the board on a desk or work surface, with half its length extending over the edge.

2. Place the brick on the desk on top of the end of the board. This makes a Class 1 lever, with the edge of the desk acting as the fulcrum. **CAUTION** Handle the brick carefully so it does not fall on your foot.

3. Try to lift the brick by pushing down on the free end of the board.

4 Repeat step 3 with most of the board's length on the desk surface.

5 Repeat step 3 with most of the board extending over the edge of the desk.

6 **Compare** the amount of effort force you must exert in each position in steps 3 to 5. **Record** your observations.

7 Now tie the brick to the board so that the brick hangs underneath it. Put one end of the board on the desk and hold the other end. This makes a Class 2 lever. Try to lift the brick while it is hanging at two or three different places along the board.

8 Finally, tie the brick to the far end of the board. This makes a Class 3 lever. Try lifting it while holding the board in two or three different places. You will need to make sure the end of the board stays in place on the desk.

Analyze

1. **(a)** Which class or classes of lever exert(s) a load force greater than your effort force?

   (b) Which class or classes of lever exert(s) a load force less than your effort force?

2. Does a Class 1 lever always exert a load force that is greater than your effort force?

3. Which variable(s) was (were) the responding variable(s) in this investigation? Which variable was manipulated?

Conclude and Apply

4. Write a statement comparing the advantages of Class 1, Class 2, and Class 3 levers.

Bones and Muscles: Built-in Levers

Every time you move a finger, arm, or toe, you are using a lever. Your bones act as levers and each of your joints acts as a fulcrum. Tendons attach muscles to your bones. When a muscle contracts, the tendon exerts an effort force on the bone. The load might be something that you are lifting or pulling. The load could also be your own body; for example, when you do a knee bend.

Most of the levers in your body are Class 3, but you can find Class 1 and Class 2 levers as well (see Figure 4.4).

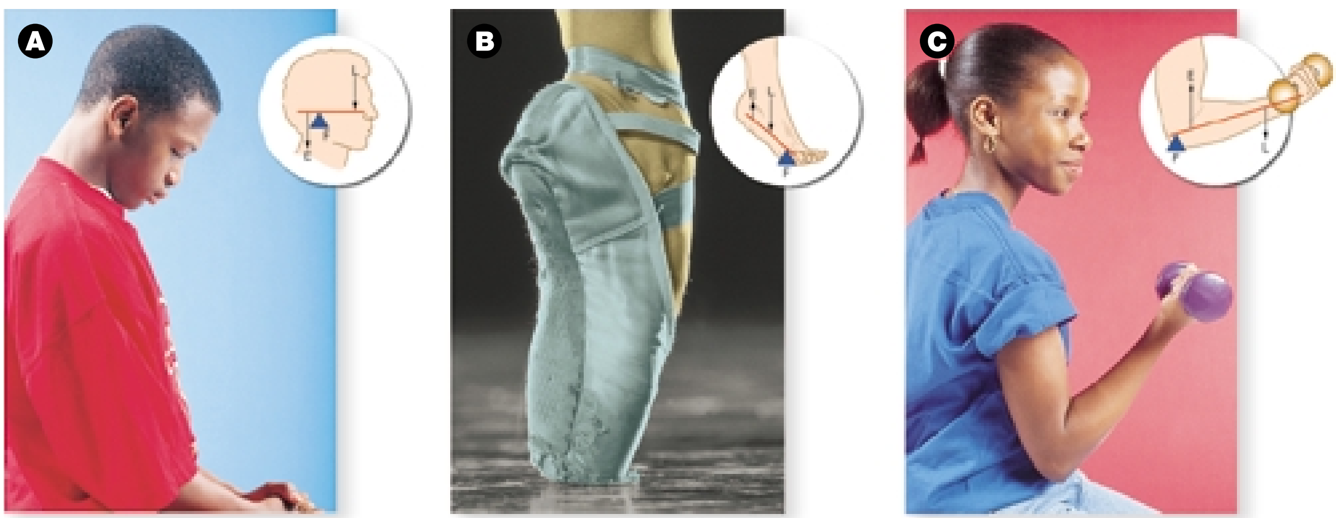


Figure 4.4 Your body's system of muscles and bones contains natural examples of levers, including Class 1 (A), Class 2 (B), and Class 3 (C).

Look at the body levers shown in Figures 4.5A, B, and C. Decide the class of each lever.

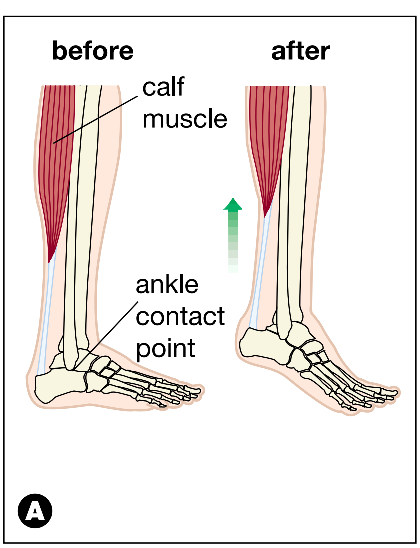


Figure 4.5A The calf muscle provides the effort force. Assume that a body weight of 600 N is the load.

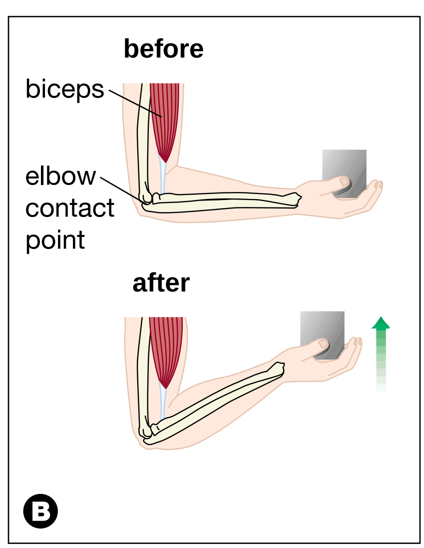


Figure 4.5B The biceps muscle provides the effort force. The hand is lifting a 15 N object.

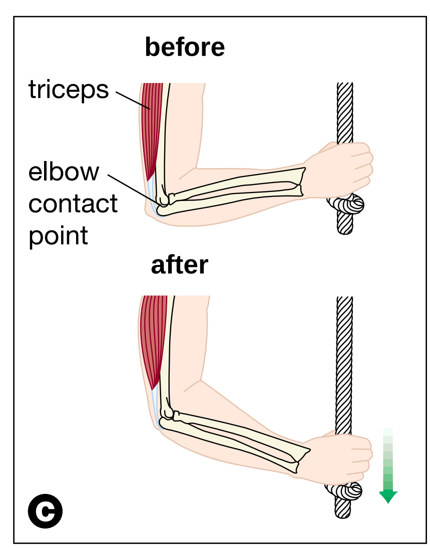


Figure 4.5C The triceps muscle provides the effort force. The hand is pulling the rope down with a force of 30 N.

An Arm in Space

One of the most exciting technological applications of levers is the Space Shuttle Remote Manipulator System, shown in Figure 4.6A. This system is usually called the Canadarm. It functions much like a human arm, and it was designed and built in Canada. The "joints" are moved by gears. As the gears turn, they move the "arms," which resemble levers.

Figure 4.6A The Canadarm is an amazing application of gears and levers in outer space.

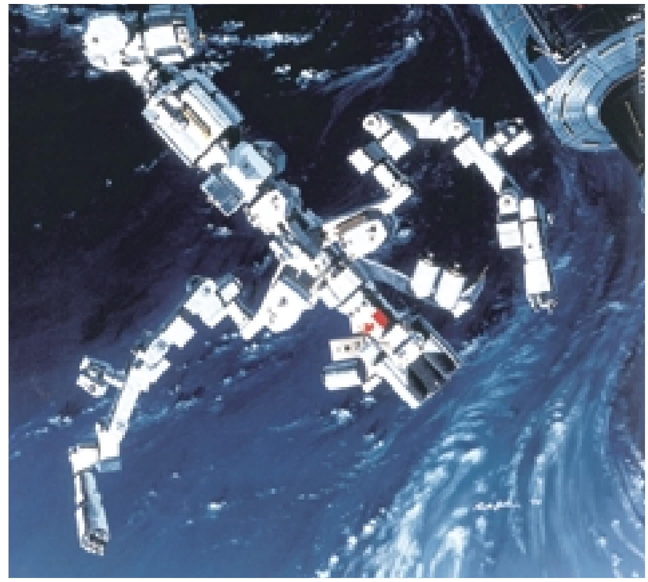


Figure 4.6B The Space Station Mobile Servicing System will be equipped with a smaller two-armed robot – the SPDM – to do complex repair jobs in space.

The Canadarm is a valuable addition to the space shuttle program because it helps launch and recover satellites from the shuttle's cargo bay. One of the Canadarm's most important missions was the repair of the Hubble Space Telescope. This orbiting telescope can see farther and more clearly than any ground-based optical telescope. (You may have learned about the Hubble Space Telescope in Unit 3.)

A more complex version of the Canadarm — the Space Station Mobile Servicing System — is shown in Figure 4.6B. This system will assist in assembling and maintaining the International Space Station. The base of the system will move along rails spanning the entire length of the space station. When stretched out straight, the arm will be more than 17 m long. It will be equipped with a smaller two-armed robot that can do delicate repair jobs that astronauts themselves have done on space walks until now.

Sixteen countries, including Canada, Russia, Japan, and the United States, are co-operating in the planning and assembling of the International Space Station.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

Learn more about the Canadarm and the International Space Station by going to the above web site. Go to **Science Resources**, then to **SCIENCEFOCUS 8** to find out where to go next.

Pause & Reflect

Do you remember the difference between mass and weight? Weight is a force, and it is measured in units called newtons (N). The mass of an object is the measure of the amount of material in it. Mass is measured in grams or kilograms. You measure weight with a spring scale, or a force meter. You measure mass with a balance.

What Is Work?

Does the title to this section sound like a silly question? Everyone knows what work is! When you study for two hours, you have done a lot of work. Cleaning your room always seems like a lot of work. Carrying your backpack full of books is work. Or is it?

In everyday language, work can mean many different things. However, in science, work has a special meaning. When you exert a force on an object and move that object some distance in the direction of the force, you do work on the object. For example, in Investigation 4-A, you exerted an effort force on the lever and moved it. You did work on the lever. In turn, the lever exerted a force on the load (the brick). The lever did work on the brick.

In science, work is defined as the product of the force exerted times the distance moved.

$$\text{Work} = \text{Force} \bullet \text{Distance}$$

Work is energy in action. Like energy, work is measured in units called **joules** (J). The joule is named after English scientist James Prescott Joule (1818–1889). In Unit 2, you learned that 1 N is approximately the weight of a 100 g mass. When you lift a 1 N weight a distance of 1 m, you do 1 J of work.

To practise using the formula, assume that you exerted a force of 2.0 N on the lever and moved it a distance of 0.6 m. Calculate the work.

$$W = F \bullet d$$
$$W = 2.0 \text{ N} \bullet 0.6 \text{ m}$$
$$W = 1.2 \text{ J}$$

You did 1.2 J of work on the lever. If the lever exerted a force of 6.0 N on the brick and moved it a distance of 0.20 m, how much work did the lever do on the brick?

Think once more about carrying your backpack full of books down the hall at school. Assume that your full backpack weighs 40 N. If you walk down the hall a distance of 16 m, how much work did you do on your books? According to the scientific definition, you did no work! Why? You were exerting a force upward on the backpack so it would not fall on the floor. However, you did not move upward. You moved it in a horizontal direction.

The Inclined Plane

An **inclined plane** is a ramp or a slope that reduces the force you need to exert to lift something. Inclined planes are also machines.

Look at the illustrations on the left. Olivia has the task of lifting a 50 kg box of camping gear into the back of the truck. The distance from the ground to the back of the truck is 1 m (see Figure 4.7A). Lifting the box straight up and carrying it to the truck would be difficult. However, if Olivia used a board to make a ramp, as she does in Figure 4.7B, she could probably push the box up.

Pause & Reflect

As you continue your studies in science, look for more words that have scientific meanings that are different from their everyday meanings. Can you think of any of these words that you have already learned in addition to work?

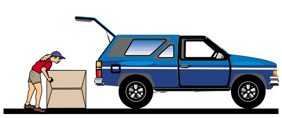


Figure 4.7A Somehow Olivia has to get a box into the back of this truck. Is lifting the box straight up and carrying it to the back of the truck the best option?

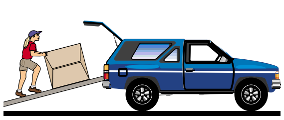


Figure 4.7B Olivia used an inclined plane to help her load the box of camping gear into the truck. The inclined plane decreased the effort force Olivia needed by increasing the distance through which her effort force was applied.

Find Out ACTIVITY

Easy Does It!

Why is it easier to climb a gentle hill than a steep mountain trail or a cliff face? How does the work you put into a machine (the work input) affect the work that the machine does (work output)? Try this activity to answer these questions.

Materials

spring scale

toy car or dynamics cart

string

tape (optional)

flat board at least 0.5 m long

metre stick

stack of books

Procedure ✷ Performing and Recording

1. Copy the data table shown here into your notebook.

2. Attach the spring scale to your car using the string. You may want to attach the string to the car with the tape.

3. Measure the weight of your car. Record this information in your data table.

4. Calculate the amount of work needed to lift the car for each height in the table without using a ramp. Record this information under the column "Work output (J)."

5. Using a thin book to prop up the board, make a ramp that has one end raised 5 cm (0.05 m). Use the spring scale to pull the car up the ramp. Pull at a slow, steady speed. Record the effort force needed to lift the car by pulling it up the ramp.

6. Measure the length of the ramp. Then calculate the amount of work required to pull the book up the ramp. This is the work input.

7. Repeat this procedure for ramp heights of 0.10 m, 0.15 m, 0.20 m, and 0.25 m. Use a stack of books to create the ramps.

Height of ramp (m)	Weight (N)	Work output (J) $W = N \times m$	Effort force (N)	Length of ramp (m)	Work input (J) $W = N \times m$
0.05					
0.10					
0.15					
0.20					
0.25					

What Did You Find Out? ✷ Analyzing and Interpreting

1. Which took more force, lifting the car straight up or using the ramp?

2. Write a statement explaining how the force needed to pull the car up the ramp relates to the length of the ramp.

3. Write a statement explaining how the force needed to pull the car up the ramp relates to the angle of the ramp.

4. Did it require less work to pull the car up the ramp than it did to lift the car to the same height directly? Explain your answer.

Work Input and Work Output

When you do work on a machine such as a lever, the machine does work on a load. The work you do on the machine is called **input work**. The work the machine does on the load is the **output work**. You may have noticed, when you did Investigation 4-A, that when your effort force was small, the distance you pushed on the lever was large. At the same time, the distance that the lever lifted the load was small. How do you think that the input work compares to the output work?

You probably discovered, in the Find Out Activity, that your input work on the ramp was nearly the same or larger than the output work. As you continue to study mechanical systems, you will discover that this is always true. A machine never does more work on the load than you do on the machine. Why, then, do we often say that machines make work easier? Machines make work easier because they change the size or the direction of the *force* exerted on the machine. Think about this. Could you lift a small, compact car a distance of one metre off the ground? Could you lift yourself (climb) up five flights of stairs? The two situations represent about the same amount of work.

What Is Mechanical Advantage?

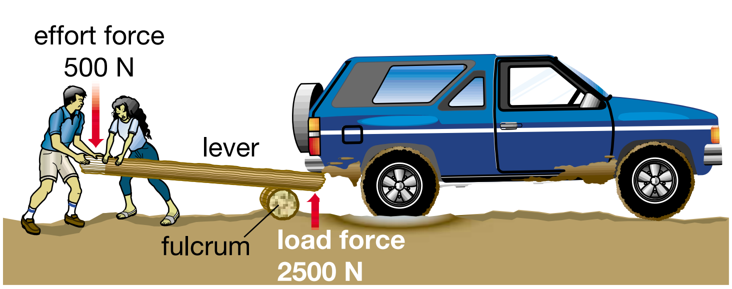
Mechanical advantage is the comparison of the force produced *by* a machine to the force applied *to* the machine. In other words, mechanical advantage is the comparison of the size of the load to the size of the effort force. The smaller the effort force compared to the load, the greater the mechanical advantage. You can use the following formula to calculate mechanical advantage:

$$\text{Mechanical Advantage } (MA) = \frac{\text{Load force } (F_L)}{\text{Effort force } (F_E)}$$

Suppose you are a passenger in a truck that gets stuck in mud. You and the driver use a tree branch as a lever to lift the truck out of the mud, as shown in Figure 4.8. If you apply an effort force of 500 N to the branch, and the back of the truck weighs 2500 N, then the mechanical advantage of the branch-lever is 5. Note that no units are used to express mechanical advantage because it is a ratio.

$$\begin{aligned}\text{Mechanical Advantage } (MA) &= \frac{\text{Load force } (F_L)}{\text{Effort force } (F_E)}\\ &= \frac{2500\text{ N}}{500\text{ N}}\\ &= 5\end{aligned}$$

Figure 4.8 The mechanical advantage of this branch-lever is 5.



The branch-lever has exerted a force 5 times greater than the force you exerted on it. This means the branch-lever made the job of lifting the truck 5 times easier. Any machine with a mechanical advantage greater than 1 allows the user to move a large load with a relatively small effort force.

A machine can also have a mechanical advantage that is less than 1. Imagine you are riding your bicycle. You exert an effort force of, say, 736 N downward as you push on the pedal. The resulting load force that causes the bicycle to move forward is 81 N. The mechanical advantage of the bicycle is calculated as follows:

$$\text{Mechanical Advantage } (MA) = \frac{\text{Load force } (F_L)}{\text{Effort force } (F_E)} = \frac{81\text{ N}}{736\text{ N}} = 0.11$$

Finally, a machine may have a mechanical advantage equal to 1. For example, suppose the effort force needed to raise a flag up a flagpole is 120 N. The load force — the flag plus the rope — is also 120 N. Therefore, the mechanical advantage of the pulley on the flagpole is 1:

$$\text{Mechanical Advantage } (MA) = \frac{\text{Load force } (F_L)}{\text{Effort force } (F_E)} = \frac{120\text{ N}}{120\text{ N}} = 1$$

Pause & Reflect

Some machines do not have any effect on the effort force that you exert. They simply change the direction of the effort force. For example, when you pull down on the cord of window blinds, the blinds go up. Only the direction of the force changes. The effort force and the load are equal, so the mechanical advantage is 1. Try to think of other mechanical devices that have a mechanical advantage of 1. Write your ideas in your Science Log.

Math Connect

A crafty coyote is trying to use a catapult to launch a heavy rock. The rock, with a mass of 1000 kg, sits on one end of a plank. The coyote figures that if he jumps on the other end of the plank, his 25 kg mass will be enough to launch the rock into the air. Calculate the mechanical advantage the catapult must have for the coyote's plan to work.

Pause & Reflect

What's the advantage of using a bicycle if it has a mechanical advantage that is less than 1? The advantage is that it causes the tire to turn faster than the pedals and the bicycle moves faster than your pedalling speed. You gain a speed advantage. What other devices have a mechanical advantage less than 1? Write your ideas in your Science Log.

Find Out ACTIVITY

Sharpen Up with Scissors

Is there a mechanical advantage to using scissors? Is one way of using scissors easier than another? Make a prediction about whether it takes less effort force to cut cardboard with the tip of the blades or with the base of the blades near the hinge.

Safety Precautions

Materials

scissors

piece of heavy cardboard or folded paper

Procedure ✷ Performing and Recording

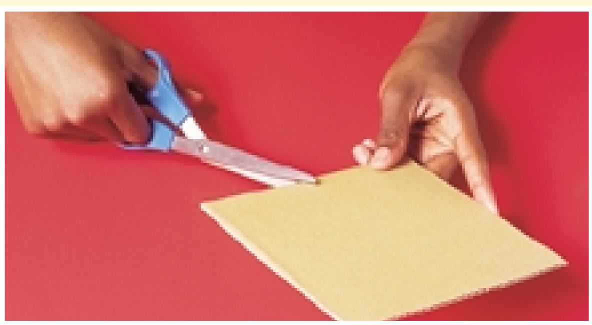
1. Test your prediction. Try to cut the cardboard with the tip of the scissors.

CAUTION When using scissors, always cut away from your body.

2. Open the scissors wide, put the cardboard close to the hinge of the scissors, and again make a cut.

What Did You Find Out? ✷ Analyzing and Interpretin

1. Does one method make cutting the cardboard easier than the other method?
2. Explain your observations based on what you have learned about levers, effort force, and mechanical advantage.
3. Describe how the effort arm relates to the load arm in these two photographs.



Computer CONNECT

You have been learning about different types of levers and how they give us a mechanical advantage. Create a web tutorial to teach other students about these machines and the ways they help us do work. In your tutorial, simulate the action of the three different types of levers. Your simulated levers can be simple machines, such as the ones shown here, or they can be parts of your body. Include a quiz and an answer key for self-checking.

Another Way to Calculate Mechanical Advantage

Levers can exert a force on a load that is either greater than or less than the effort force you exert. If the load is less than the effort force, the lever's mechanical advantage is less than 1. For example, a mechanical advantage of $\frac{1}{2}$ shows that your effort goes only half as far compared to a lever with a mechanical advantage of 1.

The concepts of mechanical advantage and work can be linked. Imagine that you are trying to lift a heavy boulder, as the coyote is on page 279. The closer you are to the fulcrum (the smaller rock), the harder it is to lift the boulder. The longer the effort arm (the distance between the fulcrum and the effort), the less effort it will take to lift the boulder. The longer effort arm gives you a mechanical advantage. Recall that Work = Force • Distance. You trade distance for force — you move the board farther, but moving it is easier. *However, the amount of work you do is the same.* This suggests another way to calculate the mechanical advantage of levers:

$$\text{Mechanical Advantage } (MA) = \frac{\text{Load force } (F_L)}{\text{Effort force } (F_E)} = \frac{\text{Effort arm}}{\text{Load arm}}$$

If the effort arm of the branch-lever mentioned on page 306 were 3 m, and the load arm were 0.3 m, then the mechanical advantage would be calculated as follows:

$$(MA) = \frac{\text{Effort arm}}{\text{Load arm}} = \frac{3\text{ m}}{0.3\text{ m}} = 10$$

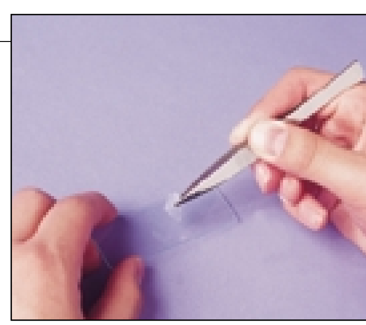
Using the branch as a Class 1 lever allows the effort force to be multiplied by 10.

Cool Tools

Surgeons use special tools in a type of microsurgery sometimes called "keyhole surgery" because only a small incision is needed. A long tube is pushed through the incision to the part of the patient's body requiring surgery. Fine wires running through the tube operate tiny levers to cut and sew as needed. The surgeon watches the operation on a television screen connected to a tiny camera at the end of the tube.

Did You Know?

Although it might seem strange, there are situations in which you might want to *increase* the force that you yourself exert. For example, you might need a machine to perform a delicate precision task. Think about how tweezers work as you study this photograph. Which class of lever do they use? Infer whether the mechanical advantage of tweezers will be greater than 1, equal to 1, or less than 1.



Speedy Levers

When you calculated mechanical advantage, you learned that you can use Class 1 levers to increase your effort force. You can exert only a little force to achieve an incredible result. (This is why you can use a simple Class 1 lever to lift very heavy objects.) Class 3 levers exert a force on the load that is smaller than the effort force, so why would you ever use such as lever? The advantage of a Class 3 lever is that the force will move the load a greater distance and at a faster speed. That is why you hit a hockey puck with the end of a metre-long stick. **Speed** is the rate of motion, or the rate at which an object changes position.

Look at the baseball pitcher and the pizza chef in Figures 4.9A and B. In both cases, the triceps muscle moves only a small amount to produce the effort force needed to make the hand move rapidly through a relatively large distance. The structure of the levers in the human body makes it possible to perform delicate tasks with precision, as well as major tasks requiring tremendous speed and flexibility.

Skill FOCUS

If you need tips on how to design an experiment, turn to Skill Focus 6.

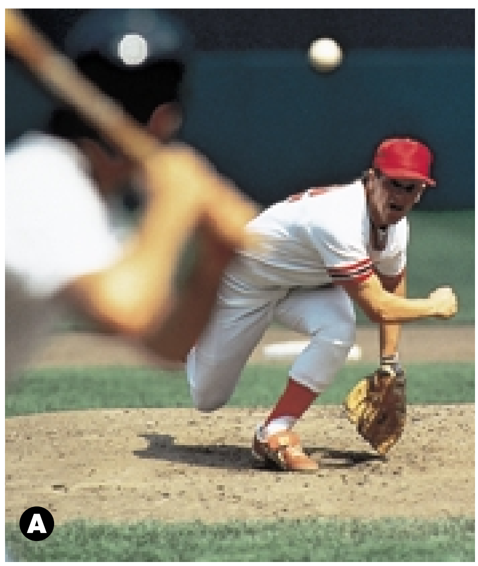


Figure 4.9A How can a small contraction (shortening) of the triceps muscle produce the long, fast movement of the pitcher's hand? Most of the levers inside your body have a mechanical advantage smaller than 1. Therefore, your muscles usually have to exert a greater force on the lever (bone) than the lever (bone) can exert on the load.

Figure 4.9B Why does the spinning pizza dough remain more or less in the same place?

Pause & Reflect

With a partner, design an experiment that tests what you have learned about the speed advantage of Class 3 levers. Use simple materials, such as marbles and a ruler. Write a hypothesis, and the steps that would test your hypothesis. What variable would you manipulate? How would you measure the speed and distance?

Machines Made to Measure

Industrial designers study the dimensions of the human body in great detail to make sure that every part of a machine or a product — such as the ones shown in Figure 4.10 — will fit the person using it. Body weight, height, size, age, and sometimes gender are factors taken into account when designing products. These products can range from cars to office furniture to light switches. The science of designing machines to suit people is called **ergonomics** (from the Greek words *ergon*, meaning "work," and *nomos*, meaning "natural laws").

Figure 4.10 This space suit, child's car seat, and assembly line in a factory have all been designed to ensure that they are easy, comfortable, and safe for people to use.

Ergonomics is especially important in the design of work environments where occupational safety is an issue. For example, a common workplace disorder known as **carpal tunnel syndrome** causes numbness and pain in the thumb and first three fingers. Carpal tunnel syndrome results from repetitive movements of the fingers, such as working at a computer keyboard. If the tendons that attach muscles to bones in the wrist become irritated, they swell and start to squeeze the nerve inside the carpal tunnel. If the condition is not treated soon after the symptoms appear, severe pain as far up as the shoulder can result. The damage could become permanent. The most common treatment for carpal tunnel syndrome is a brace that holds the wrist straight. This prevents irritation of the tissues near the carpal tunnel.

Pause & Reflect

Imagine you are an ergonomist (an ergonomics designer) working on the International Space Station program. What sorts of problems might you have to solve? Remember that the astronauts will be working in cramped positions as well as in weightlessness. Write your ideas in your Science Log.

Did You Know?

Another way to avoid carpal tunnel syndrome is to get rid of the keyboard altogether and to operate the computer using a special pen-like device, which keeps the wrist flat. "Palm pilots" (hand-held computers) are already pioneering this approach. Perhaps one day home computers will be able to "read" your handwriting — however messy it is! Voice-activated computer programs are also reducing the incidence of carpal tunnel syndrome.

Looking Ahead

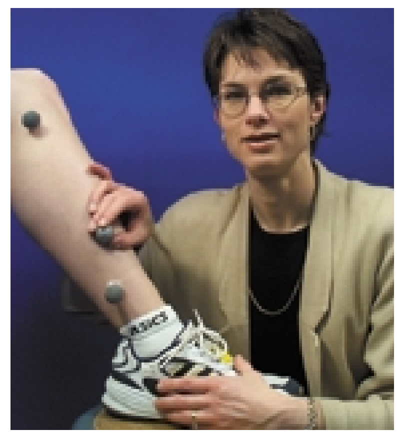
The simple machines you have learned about in this Topic are used to make work easier. Turn to "Adapting Tools" on page 354 to preview the project you will be undertaking at the end of this unit. Start thinking of a tool or utensil you might want to adapt using the knowledge you have gained so far.

Career CONNECT

Dr. Janet Ronsky knows the human knee like the back of her hand. She is a biomechanical engineer and an associate professor at the University of Calgary. Her research on the knee joint helps doctors and other researchers understand how the shape of a person's bones may contribute to degenerative joint diseases such as osteoarthritis. Many specialists believe that the bones of some people's joints press together in an unusual way as they walk. This may wear down the cartilage, the cushioning material between those bones, and result in joint problems.

Dr. Ronsky and her research team have found a way to analyze the surface of the joint bones while a person is walking. This is important because the contact between the bones changes over the course of the walking motion. The research team uses medical imaging along with high-speed camera and video systems that track the movement of the body parts. Other specialized equipment allows them to measure the force a person applies to different parts of the joint as they walk. By analyzing the three types of information, Dr. Ronsky can predict what is happening inside the patient's knee joint. And that information helps doctors decide how to treat the patient.

For Janet, working in bioengineering is the perfect career. "Once I discovered I could apply engineering to medical problems," she explains, "and possibly make a difference in people's everyday lives, I was hooked!" She takes her work very seriously, and she's not the only one who thinks it is important. In 1999, Dr. Ronsky was presented with the McCaig Program Development Award by the Calgary Regional Health Authority. She was also awarded a Natural Science and Engineering Research Council of Canada (NSERC) Women's Faculty Award in 1994.



TOPIC 1 Review

1. Classify the levers in the illustrations as Class 1, Class 2, or Class 3.
2. How much work, in joules, must you do to lift an elephant weighing 60 000 N up 1.5 m onto the back of a truck?
3. You have found a ramp to lead up to the back of the truck. Will you and your team need to exert more, less, or the same forces as in question 2?
4. If you exert a force of 100 N on a hockey stick, and the stick exerts a force of 20 N on the puck, what is the mechanical advantage of the stick?
5. If the "effort arm" distance for the hockey stick in question 4 (between your "fulcrum" hand and your pushing hand) is 25 cm, how long is the stick? (Use your answer to question 4.) If your hand is pushing at a speed of 20 km/h, how fast will the puck move?
6. **Thinking Critically** Think of a practical use for a lever with a mechanical advantage of 1. Draw a sketch of this lever in action.

TOPIC 2

The Wheel and Axle, Gears, and Pulleys

Earlier, you discovered that you can lift a heavy load as long as you can find a lever that is long enough and strong enough to do the job. Sometimes, however, levers are not practical, as shown in Figure 4.11. Fortunately, there are many other kinds of machines that can give you a mechanical advantage great enough to move a heavy load with a much smaller effort force. Think about this question: How could you modify a lever to make it shorter, but still able to move a load over a longer distance? Look for clues in Figure 4.12A, which shows a person loading a motor boat onto a boat-trailer.

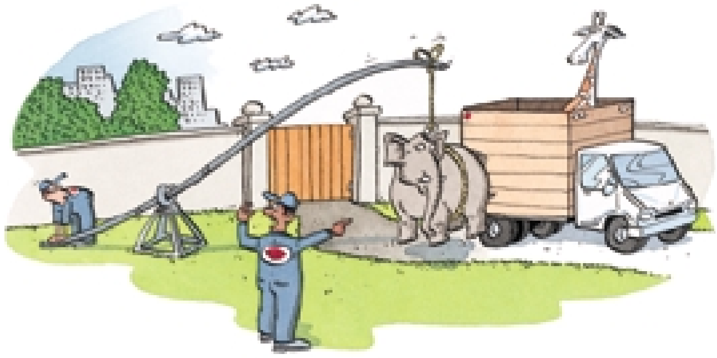


Figure 4.11 No one would ever try to lift an elephant like this!

A Lever That Keeps on Lifting

The device the person is using to move the boat is called a winch. A **winch** consists of a small cylinder and a crank or handle. Study Figure 4.12B to see how a winch works. Notice that the axle of the winch is held in place and acts like a fulcrum. The handle is like the effort arm of a lever. Exerting a force on the handle turns the wheel. This motion is much like the effort force on a lever. However, you do not reach "bottom" with the handle. You just keep turning.

DidYouKnow?

The handle of a manual pencil sharpener and the reel on a fishing rod are examples of winches.

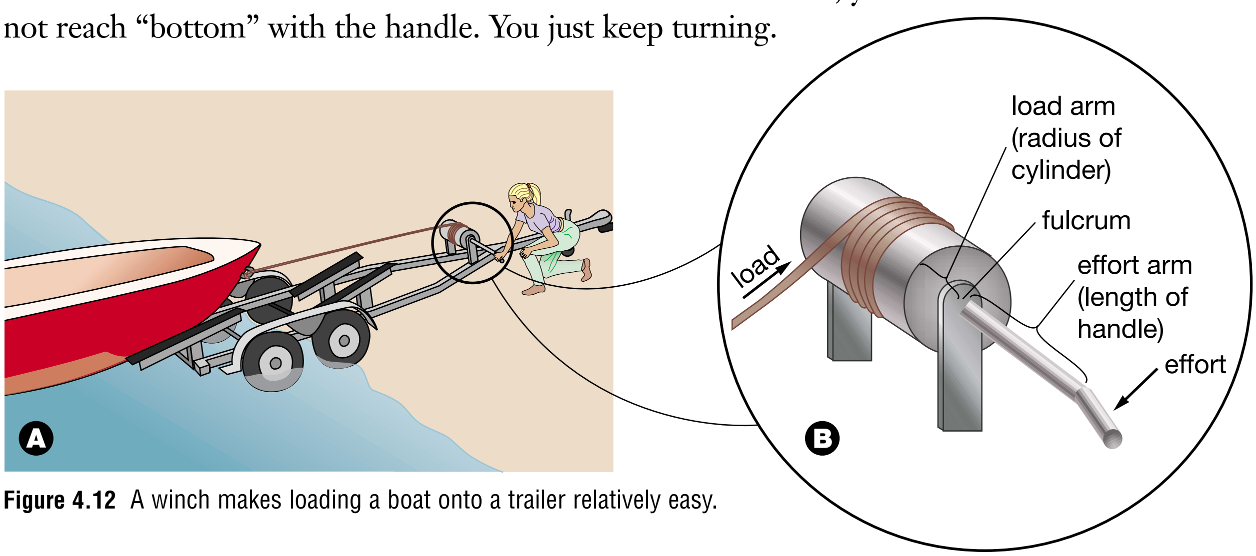


Figure 4.12 A winch makes loading a boat onto a trailer relatively easy.

Notice that the **radius** of the wheel — the distance from the centre of the wheel to the circumference — is like the load arm of a lever. The force that the cable exerts on the wheel is like the load on a lever. Since the handle is much longer than the radius of the wheel, the effort force is smaller than the load. Using a winch is like using a short lever over and over again.

The Wheel and Axle

A winch is just one example of a wheel-and-axle device. As you can see in Figure 4.13, wheel-and-axle combinations come in a variety of shapes and sizes. The "wheel" does not even have to be round. As long as two turning objects are attached to each other at their centres, and one causes the other to turn, you can call the device a **wheel and axle**.

You can hardly open your eyes without seeing a wheel-and-axle machine of some sort. Study Figure 4.13 and identify the wheel-and-axle devices. Remember that some instruments or machines have more than one wheel-and-axle combination. The wheel and axle is more convenient than a lever for some tasks, and, like a lever, it provides a mechanical advantage.

Figure 4.13 Each of these objects contains a wheel and axle.

Speed and Action

Gaining a mechanical advantage is one benefit of using a wheel-and-axle device. Just like a lever, a wheel-and-axle device can also generate speed, as shown in Figures 4.14A and B. In return, however, these machines require a large effort force and produce a smaller force on the load.

Figure 4.14A Look at the pedals and the front wheel on this tricycle. Is the effort force exerted on the wheel or the axle? What does the clown get in return for the effort put into the machine?

Figure 4.14B What are the possible benefits of the huge wheel on this old-fashioned bicycle?

Gearing Up

A wheel-and-axle device provides speed for a race car zooming around a track. However, the wheel and the axle are attached to each other, so each makes the same number of rotations every second. Suppose you wanted to make one wheel rotate faster than another wheel. For example, a clock has a second hand, a minute hand, and an hour hand, each rotating at different speeds from the same point.

A **gear** is a rotating wheel-like object with teeth around its rim. A group of two or more gears is called a **gear train**. Two different gear trains (A and B) are shown in Figure 4.15. The teeth of one gear fit into the teeth of another. When the first gear turns, its teeth push on the teeth of the second gear, causing the second gear to turn. The first gear, or **driving gear** (often called the **driver**), may turn because someone is turning a handle or because it is attached to a motor. The second gear is called the **driven gear** (often called the **follower**). Can you find a gear train in Figure 4.16? Figures 4.17 and 4.18 on page 288 illustrate two other applications of gears. Find out what gears can help you do in the next activity.

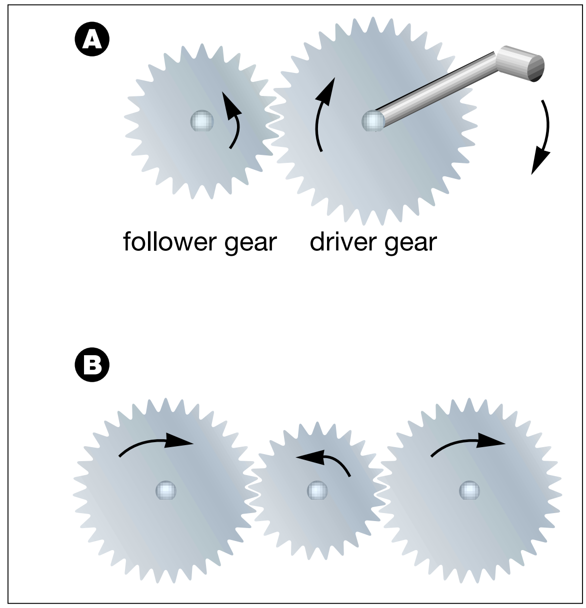


Figure 4.15 A gear train consists of two or more gears in contact with each other.

Figure 4.16 This combine features sprockets and belts, as well as a gear train.

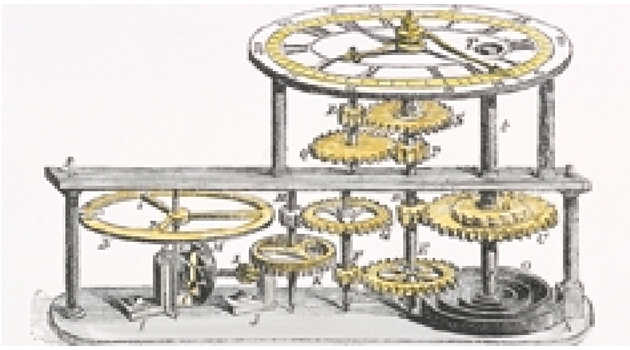


Figure 4.17 This diagram shows how the gears inside an old-fashioned clock ensure that the minute hand makes exactly 60 full rotations when the hour hand makes one full rotation.

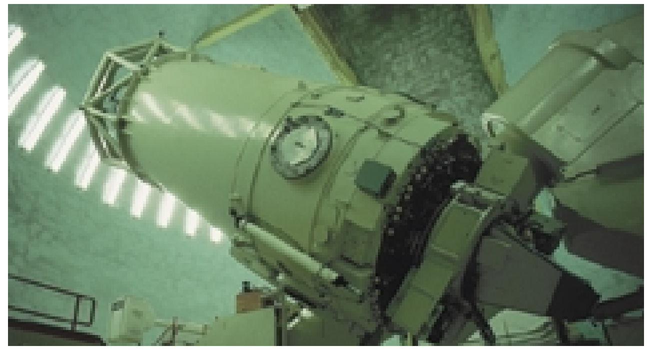


Figure 4.18 The gears inside a large telescope are designed so that the telescope can track the constant slow motion of stars across the sky with incredible precision.

Find Out ACTIVITY

Turnaround Time

How many times does the follower gear turn when the driver gear makes one full turn? Does the number of rotations depend on how much larger the driver gear is?

Materials

set of gears of different sizes — for example, from a Spirograph™ or Lego Technik™ set

felt tip pen and ruler

Procedure

Performing and Recording

1. With a felt tip pen, make a mark on one tooth of each of the two gears, at the spot where they touch.
2. Turn one gear and count the number of times the smaller gear turns when the larger gear makes one full turn. Record this number.
3. Measure and record the diameters of each of the gears.

4. Divide the diameter of the larger gear by the diameter of the smaller gear. Record your answer. Compare this number with the number you recorded in step 2.
5. Count the number of teeth on each gear. Divide the number of teeth on the larger gear by the number of teeth on the smaller gear. Record your answer. Compare this number with the numbers you calculated in steps 2 and 4.

What Did You Find Out?

Analyzing and Interpret

1. Why does the smaller gear complete one full rotation before the larger gear does? (Look at the felt tip marks as the gears go around.)
2. If the larger gear had three times as many teeth, how many rotations would the smaller gear make in one rotation of the larger gear? How much bigger would the larger gear be in this case?
3. Explain two different measurements that you could use to predict the numbers of turns a small gear will make every time the large gear makes one full turn. What would you predict about the mechanical advantage of this gear combination? Write a statement that summarizes your conclusion about gears.

Going the Distance

Can one gear turn another gear without touching it? Does this sound impossible? Think about the gears on your bicycle. One set of gears is attached to the pedals and another to the rear wheel. A chain connecting the gears allows the front gear to turn the gear on the rear wheel, some distance away. A gear with teeth that fit into the links of a chain is called a **sprocket**. Figure 4.19 compares gears in contact with each other and gears in a sprocket.

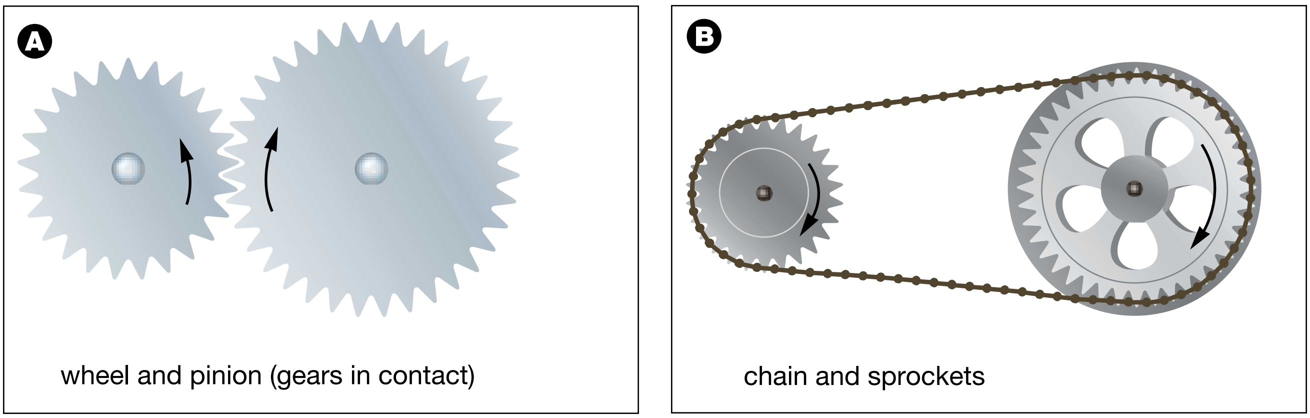


Figure 4.19 Take a look at this comparison of gears in contact (A) and gears, or sprockets, connected by a chain (B). While the gears in contact turn in opposite directions, the gears connected by a chain turn in the same direction.

Each link of a bicycle chain moves the same distance in the same period of time. Thus, if the front sprocket moves the chain a distance equal to 45 teeth, the back sprocket will also move through a distance of 45 teeth. However, the back sprocket may have only 15 teeth and the front sprocket may have 45 teeth. As a result, the back sprocket would make three full turns for every one complete turn of the front sprocket. The relationship between the speed of rotations of a smaller gear and a larger gear is called the **speed ratio**. In this example, the bicycle has a speed ratio of 3. Here is the formula for calculating speed ratio:

$$\text{Speed ratio} = \frac{\text{Number of driver gear teeth}}{\text{Number of follower gear teeth}}$$

In the next investigation, examine the speed ratio of gears in a bicycle.

Figure 4.20 This enormous conveyor belt is used at Syncrude Oil Sands in Fort McMurray, Alberta. The belt acts like a chain. Can you see the sprockets?

INQUIRY

INVESTIGATION 4-B

SKILLCHECK

- Initiating and Planning
- ✸ Performing and Recording
- ✸ Analyzing and Interpreting
- Communication and Teamwork

Gear Up for Speed!

How do bicycle gears help your bicycle go faster, or help you pedal up a hill? What is the difference between high gear and low gear? Why would you want more than one gear on your bicycle anyway? This investigation will demonstrate how gears on a bicycle can give you a mechanical advantage.

Question

How does the speed ratio change as you switch between different gears on a bicycle, and how does this affect the force you need to pedal the bicycle?

Apparatus

bicycle with double set of racing gears

Procedure

1. **Make a data table** like the one shown below. Give your table a suitable title. You may have to change the number of rows and columns, depending on the number of sprockets on the bicycle you are using.

2. Count the number of teeth on each of the front sprockets. **Record** these numbers in the row of your table to the right of the heading, "Number of teeth." Make sprocket number 1 the largest sprocket.

3. Count the number of teeth on each of the back sprockets. **Record** these numbers in the column below the heading, "Number of teeth." Again, make sprocket number 1 the largest sprocket.

		Front sprockets		
	Number of teeth	1	2	3
Back sprockets	1			
	2			
	3			
	4			
	5			
	6			

Skill FOCUS

For tips on creating data tables, turn to Skill Focus 10.

4 For each box in the rest of the table, divide the number of teeth in the front sprocket (at the top of the column) by the number of teeth in the back sprocket (in the first column of the table). This gives you the speed ratio of each gear combination.

Analyze

1. What do the data indicate about the number of times the back sprocket and the wheels turn when the front sprocket and the pedals make one full turn?
2. Explain what you think "high gear" and "low gear" mean.
3. If the speed ratio increases when you change gear, will the mechanical advantage of the bicycle increase or decrease? (Hint: Remember what you learned about trading force for distance or speed.)

Conclude and Apply

4. Why do you need to pedal faster to go at the same speed when your bicycle is in a lower gear?
5. Which gear helps you go faster on level ground? Why?
6. Why do you use low gear when going up hills?

Pulleys

Figure 4.21 How does this weight machine allow the woman to lift weights safely and comfortably?

You learned in previous studies that a **pulley** is a grooved wheel with a rope or a chain running along the groove. You can see an example of pulleys in action in Figure 4.21. A pulley is similar to a Class 1 lever. Instead of a bar, a pulley has a rope. The axle of the pulley acts like a fulcrum. The two sides of the pulley are the effort arm and the load arm.

Pulleys can be fixed or movable, as shown in Figure 4.22. A **fixed pulley** is attached to something that does not move, such as a ceiling, a wall, or a tree. A fixed pulley, such as the one used at the top of a flagpole, can change the direction of an effort force. When you pull down on the effort arm with the rope, the pulley raises the object attached to the load arm. Thus, a single fixed pulley simply changes the direction of the motion and makes certain movements more convenient. Once the flagpole pulley is attached, you can raise and lower the flag without ever climbing to the top of the flagpole!

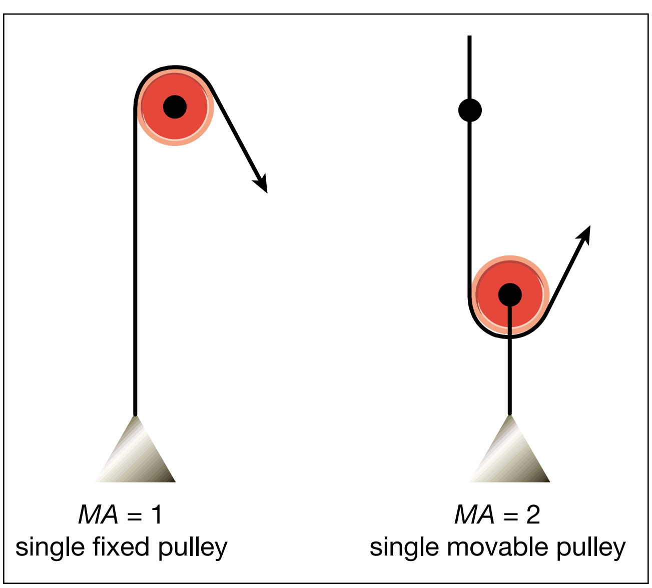


Figure 4.22 Pulleys can be fixed or movable.

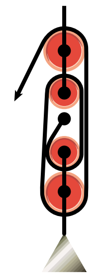
A **movable pulley** is attached to something else, often by a rope that goes around the pulley itself. If a rope is fixed to the ceiling and then comes down around the pulley and back up, you can lift and lower the pulley itself by pulling on the rope. The load may be attached to the centre of the pulley.

Supercharging Pulleys

You saw that a wheel-and-axle combination can be compared to a lever. It would seem logical to analyze a pulley in the same way. However, if you imagine a pulley as a lever, you will discover that the "effort" arm and the "load" arm are the same. So how do pulleys help you lift heavy loads?

You have seen that a single pulley can make lifting a load more convenient. Combinations of pulleys are required to lift very heavy or awkward loads (see Figure 4.23). The very complex pulley system shown in Figure 4.24 is a combination of fixed and movable pulleys, called a **block and tackle**. Depending on the number of pulleys used, a block and tackle can have a large mechanical advantage. You have probably noticed that pulley systems designed to lift very heavy loads have long cables running around several pulleys. How can you determine the mechanical advantage of a **compound pulley** — one made up of several pulleys working together? To find out, perform the investigation on the next page. As a warm-up, you can also do the activity below.

Figure 4.23 This oil pump uses several pulleys and a lever to raise and lower the pump valves to bring the oil to the surface.



MA = 4

Figure 4.24 A block and tackle

Find Out ACTIVITY

Tug of War

How can you increase the mechanical advantage of a pulley?

Safety Precaution

Always wear gloves to protect your hands from rope burn.

Materials

2 broom handles or similar smooth poles
rope or twine (about 4 m)

Procedure Communication and Teamwork

1. Two students hold the upright broom handles between them, side by side.
2. Tie one end of the rope to one broom handle, and pass it once around the other handle.
3. A third student should try to pull the handles together using the rope, while the other two try to hold them apart.
4. Now wind the rope a couple more times around the handles, and try again.

Experiment with different numbers of rope windings.

What Did You Find Out? Analyzing and Interpr

1. Does increasing the number of rope windings make it easier for the student pulling the rope to move the handles together?
2. What forces do the two students holding the handles experience?

Extension

3. Is there any change in how far the student has to pull the rope as the number of windings increases?

PROBLEM-SOLVING

INVESTIGATION 4-C

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Pick It Up

Imagine you and your group are a team of engineers working for the Ace Crane Company. You are in the process of developing a new crane to be used in the construction industry.

Challenge

Use your knowledge of simple machines to design and build a prototype of a crane. The crane must feature a wheel-and-axle system that can lift weights of up to 12 000 N. The motor that must be used to turn the crane's wheel-and-axle system can generate a force of 4000 N on the rim of the axle.

Safety Precautions

Materials

wood, cardboard, dowelling, Lego™ parts (or similar construction kit parts), string, glue gun, 12 N weight

Design Specifications

Build a model (a prototype) that can lift a load of 12 N (to represent the 12 000 N weight) with an effort of 4 N (to represent the 4000 N force).

Plan and Construct

1. As a group, discuss potential designs. Make technical drawings and discuss possible problems with each design until you have decided on a design that you think will work.
2. Select the materials for the prototype.
3. Show your plan to your teacher for approval.
4. Collect your materials and draw a blueprint. Assign the tasks among your team members.
5. Construct your prototype. You should have some members of your team working on the wheel-and-axle system and others working on the body of the crane.
6. Test your crane using a 12 N load.

Evaluate

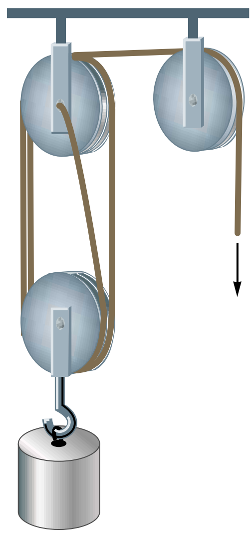
1. Does your mechanical device satisfy all the conditions in the Challenge? If not, how could you modify the design to make it work? If you have the opportunity, make and test your modifications.
2. Write a report that describes your device. Include your blueprint and clearly label each part. Discuss any problems your team had with the device and present possible solutions.

TOPIC 2 Review

1. Draw a sketch of a single pulley in an arrangement that gives a mechanical advantage of 1. Then draw a sketch of a single pulley in an arrangement that gives a mechanical advantage of 2.

2. If you wanted a winch to have a mechanical advantage of 4 and the radius of the axle was 5 cm, how long would the handle have to be?

3. Find the overall mechanical advantage of the pulley system shown in the diagram below.



4. **Thinking Critically** If a bicycle has two sprockets on the front and four sprockets on the back, how many different gear combinations should it have?

5. **Design Your Own** Design an experiment that would test the advantage of using a mechanical system to lift a bucket of cement to a height of 1 m. Use the mechanical system of your choice (e.g., inclined plane, pulley, etc.). Be sure to identify responding and manipulated variables, and to specify a control. After you have performed your investigation, list criteria for assessing your solution to the problem.

TOPIC 3

Energy, Friction, and Efficiency


Figure 4.25 (A) The source of energy for this machine is the person. (B) This combine gets its energy from fuel. (C) Electricity is the source of energy for the compressor on this refrigerator.

Work and Energy

You have learned about many different kinds of simple machines in the last two Topics. In every case — levers, pulleys, gears, and sprockets — when someone did work on the machine, the machine did work on a load. You have learned that, in science, work has a specific meaning. Have you figured out just what work really is? Work is a transfer of energy. You use energy when you push on the pedals of a bicycle and make them move (see Figure 4.25A). Now the pedals have the energy of motion called **kinetic energy**. The pedals are attached to the sprocket. This combination forms a wheel-and-axle machine. This machine does work on the sprocket and chain machine, transferring energy to it. Trace the energy transfers throughout the entire bicycle. What is the final form of energy?

You may already know that energy cannot be created or destroyed. It has to come from somewhere. When you do work on a machine, where did you get the energy? Your energy came from the chemical energy stored in the food you eat.

Most of today's machines are not "people powered." Two of the most common sources of energy for machines are illustrated in Figure 4.25 B and C. Most vehicles such as this large combine obtain energy from fuels such as gasoline. The refrigerator runs on electrical energy.

Stored Energy

Energy must be transferred to a machine to make the machine work. However, we want to control when the machines work and when they do not. So, we need to store the energy in some way, then use it when we need it. Stored energy is also called **potential energy**. Much of the energy for machines, including your body, is stored as chemical energy. You could call this chemical potential energy.

In the next activity, you are going to transfer energy to a machine made of a tube and small ball. This activity will help you to understand another form of potential energy, gravitational potential energy. You will do work on the ball by lifting it to a high level.

When you lift it to a higher level, what is the form of the energy that you have transferred to the ball? It is not moving so it has no kinetic energy. However, if you released it, the force of gravity would make it fall and give it kinetic energy. This type of stored energy is called gravitational potential energy. What practical systems store energy in the form of gravitational potential energy? Hint: Look at Figure 4.26.

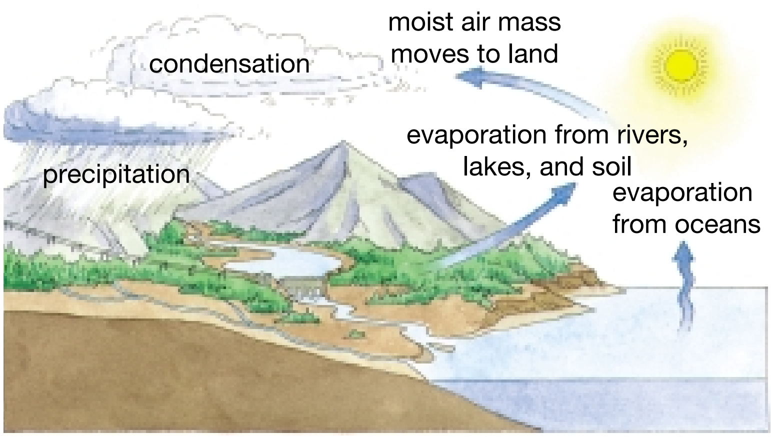


Figure 4.26 How is gravitational potential energy being stored here? Into what form of energy will this stored energy be converted?

DidYouKnow?

The ultimate source of energy for Earth is the Sun. The Sun causes winds to blow, drives the water cycle, and can be captured as solar energy. As well, some fuels, such as oil and gas, are made of the remains of plants that grew million of years ago using the Sun's energy. Can you think of other forms of energy and how the Sun affects them?

Find Out ACTIVITY

A Rubber Roller Coaster

What is the best design for a roller coaster? Your challenge is to work in a team to design a roller coaster with two hills. A small ball must be able to travel the entire length of the tube.

Materials

4 m of 5 mm diameter vinyl or rubber tubing

tape

small ball that will fit inside tubing (for example, ball bearing)

metre stick

Procedure

Performing and Recording
Communication and Teamwork

1. Tape one end of the tube to the wall. Have one person in your team hold the other end of the tube at chest height.
2. Use the rest of the tubing to make two hills. Determine the maximum height that the hills can be so that the ball still makes it to the end of the tube.
3. Examine the photograph. Will the students' design work? Explain. Experiment with other designs. How do different designs affect the movement of the ball? Sketch some of your designs and describe how well they worked.

What Did You Find Out?

Analyzing and Interpre

Sketch your roller coaster and show where the ball has potential energy and where it has kinetic energy.

Energy Transmitters

Earlier you learned how energy can be *converted* from one form into another. Energy, or power, can also be transmitted. In energy **transmission**, the energy is transferred from one place to another, and no energy is changed or converted. For example, the chain on your bicycle links the two sprockets. Electrical wires transmit the power from the generating station to your home. The chain and the electrical wires are both energy transmitters.

Figure 4.27 The fan belt transmits power from a car's crankshaft to a fan that cools the radiator and to a pulley that turns an alternator. The alternator produces electricity for use in the car or storage in the battery.

No Machine Is 100 Percent Efficient

An ideal machine would transfer all of the energy it received to a load or to another machine. However, real machines do not work this efficiently. Some of the energy is always lost. The work output of a machine is always less than the work input.

No machine is perfect, but some machines come closer than others. The **efficiency** of a machine tells you how much of the energy you gave to the machine was transferred to the load by the machine. Efficiency is a comparison of the useful work provided *by* a machine or a system with the work supplied *to* the machine or system. Efficiency is usually stated as a percentage. If we use a lever as an example, you can calculate the efficiency of the lever by using this formula:

$$\text{Efficiency} = \frac{\text{Work done by lever on load}}{\text{Work done on lever by effort force}} \times 100\%$$

The higher the efficiency, the better the lever is at transferring energy. A "perfect" machine would transfer all the work done by the effort and would be 100 percent efficient. However, the efficiency of real machines is always less than 100 percent. Why? Every time a machine does work, some energy is lost because of friction. Think about a pair of hedge trimmers. As you close the handles, the blades rub against each other. If the blades are rusty, they will tend to stick even more. You could summarize this situation by means of the following word equation:

Work done *on* a machine = Work done *by* the machine
+ energy lost as heat due to friction

STRETCH Your Mind

Many car engines are only about 20 percent efficient. Where does all the "lost" energy go?

Many machines can be made more efficient by reducing friction. You can usually do this by adding a lubricant (such as oil or grease) to surfaces that rub together, as shown in Figure 4.28. After a time, dirt will build up on the grease or oil, and the lubricant will lose its effectiveness. The dirty lubricant should be wiped off and replaced with clean grease or oil.

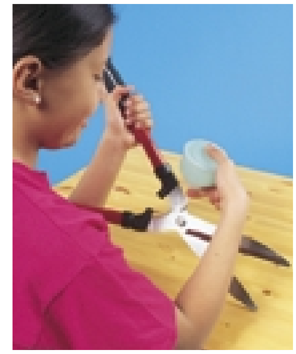


Figure 4.28 You can improve a machine's efficiency by oiling parts of it to reduce friction.

Boosting Efficiency

You have seen that gears are modified wheel-and-axle machines. A gear is simply a wheel with teeth along its circumference. Effort exerted on one gear causes another gear to turn. The mechanical advantage of a pair of gears is found by dividing the radius of the effort gear by the radius of the load gear.

As you have learned, some of the effort force put into any machine must overcome friction. For example, some of the effort force you exert when you pedal a bike must overcome the friction of the pedal gear rubbing against the bicycle chain. This reduces the efficiency of the bicycle. Low-efficiency machines lose much of the work put into them because of friction; high-efficiency machines do not.

You can boost the efficiency of a machine such as a bicycle. You have seen that you can increase efficiency by adding a lubricant such as oil or grease to the surfaces that rub together. If a bicycle's chain, gears, and other moving parts are cleaned and lubricated periodically, the bike will operate more efficiently. Also, keeping the tires properly inflated will reduce friction between the road and the tires. Similarly, keeping car tires properly inflated and changing the engine oil to keep it clean will increase the efficiency of a car. A more efficiently running car gives better gas mileage and saves both money and energy.

Useful Friction

Often we need friction for machines to work properly. If you did not have any friction between bike tires and the ground, your bike would slip. You would also slip if there were no friction between your running shoes and the ground. Many sports and outdoor activities use friction in a useful way. Baseball players and gymnasts rub a powder called rosin on their hands to increase friction and improve their grip. Curlers "sweep" the ice in front of their rock to decrease the friction, so that the rock goes farther and straighter. Can you think of other places where friction is useful? (Here's a hint: What happens when you rub your hands together?) Explore efficiency and friction further in the next investigation.

Pause & Reflect

If you have ever ridden a bike that is poorly maintained you will know that it is hard work fighting friction. Inflating the tires and oiling the moving parts helps reduce friction. In your Science Log, list some other ways you could reduce friction for a bicycle rider.

INQUIRY

INVESTIGATION 4-D

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

Easy Lifting

Industrial pulley systems are usually made up of many pulleys working together. As you know, a combination of pulleys is called a compound pulley. Do compound pulleys make lifting more efficient?

Questions

How can you calculate the mechanical advantage of a compound pulley? How can you test the efficiency of a pulley system?

Hypothesis

Form a hypothesis about how using compound pulleys affects the ability to lift an object.

Safety Precautions

- Be very careful not to drop any heavy weights.
- Have your teacher check your apparatus before you make any measurements.

Apparatus

10 N spring scale
1 kg mass
support stand, held firmly in place
2 single pulleys
2 double pulleys
1 triple pulley

Materials

rope (at least 6 m)

Procedure

1. **Make a data table** like this one. Give your table a title.

Trial	Load	Effort	Number of ropes
A			
B			
C			
D			
E			

2. Suspend the mass on the spring scale and **observe** the weight. **Record** this value in every row of your table, in the column labelled "Load."

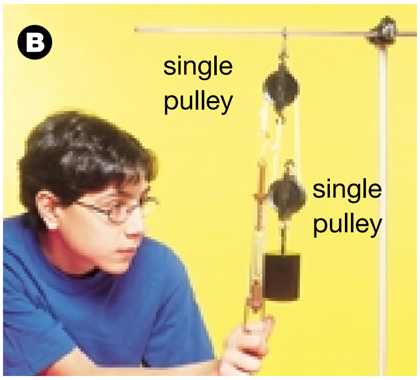
3. Assemble the apparatus as shown for Trial A above. While supporting the load with the spring scale, read the amount of force shown on the scale. **Record** this number in the column of your table labelled "Effort."

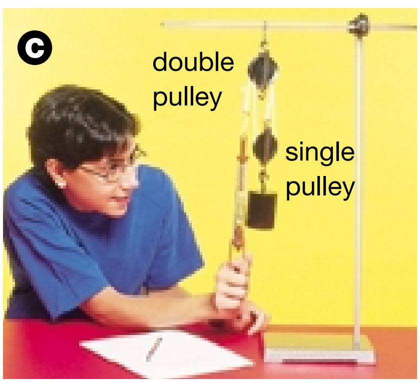
4. Count the number of ropes that are supporting the load and **record** the number in the column labelled "Number of ropes."

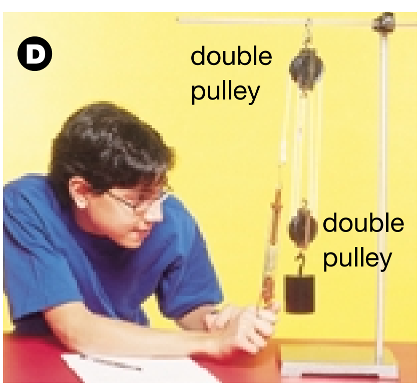
Skill FOCUS

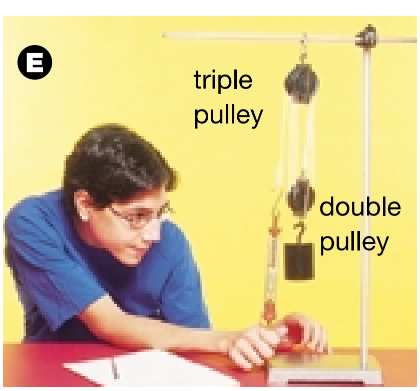
For tips on using a spreadsheet program, turn to Skill Focus 9.

5 Repeat steps 3 and 4 for trials B through E, shown below.









Analyze

1. Make an analysis table with the following headings to record the results of your calculations. Give your table a title.

Trial	Number of ropes	Mechanical advantage
A		
B		
C		
D		
E		

2. For each trial, divide the weight of the load by the effort force. Record this number in your table in the column labelled "Mechanical advantage."

3. For each trial, copy "Number of ropes" from your data table to your analysis table.

4. What were the manipulating and responding variables in this investigation?

Conclude and Apply

5. Compare the mechanical advantage with the number of ropes for every trial. What conclusion can you draw from this comparison?

Extension

6. Determine the efficiency of the compound pulley in Trial E. You can calculate efficiency using the same formula you used previously for levers:

$$\text{Efficiency} = \frac{\text{Work done on load}}{\text{Work done by effort force}} \times 100\%$$

Remember that work equals force multiplied by distance. Thus, you will need to repeat Trial E to measure how far the effort and the load move. What is the efficiency of your pulley system? Why is it less than 100 percent?

Computer CONNECT

If you have access to a computer spreadsheet program, you may want to use it for your data tables.

TOPIC 3 Review

1. Identify two places where energy was converted and two places where energy has been transmitted in the following scene. Your clock radio wakes you up at 7:00 a.m. and you turn on the bedside lamp. After a quick shower, you eat a breakfast of cereal and toast, hop on your bike, and ride to school.

2. (a) Define efficiency.
   (b) What is the formula for calculating the efficiency of a mechanical system?

3. Describe how a conveyor belt uses friction in a useful way. Give one more example of a situation in which friction is applied in a useful way.

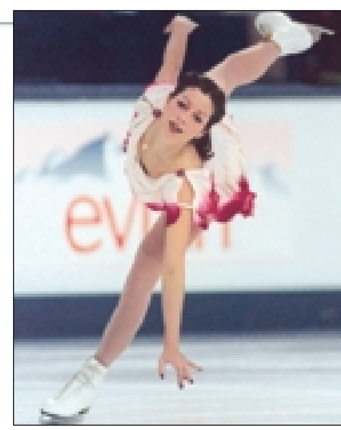
4. **Design Your Own** Write your own question about the efficient operation of mechanical systems and design your own investigation to explore possible answers. Be sure to identify responding and manipulated variables, and to specify a control.

Skill FOCUS

For tips on designing your own experiment, turn to Skill Focus 6.

Pause & Reflect

A good ice skater can glide quickly across the ice with only a little effort, because the small area and smooth surface of the blades mean there is very little friction between the ice and the skates. The pressure of the blades on the ice melts the ice a bit. When the ice melts, it leaves a thin film of water between the skate blades and the ice. The water layer acts as a lubricant and helps the blades slide smoothly across the ice without sticking. Think of other ways in which friction can be reduced in machines. Write your ideas in your Science Log.



Pause & Reflect

Does a lever always do as much work on the load as you do on the lever? Suppose you have a summer job trimming hedges. Someone leaves the hedge-trimming shears out in the rain, causing the bolt at the joint to get rusty. The next time you trim the hedge, you discover that you have to exert a much greater force on the handles than you did before. You are doing more work on the shears, but the shears are doing the same amount of work on the hedge that they did before the joint rusted. In your Science Log, explain why this happens.

Wrap-up TOPICS 1–3

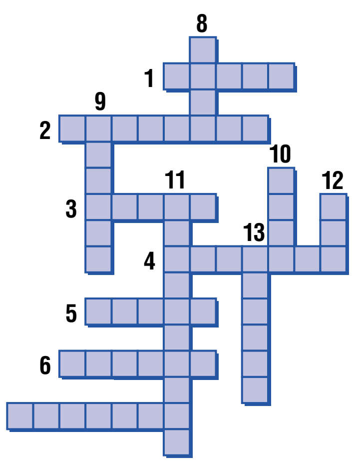
If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

lever	Class 3 lever	ergonomics	driving gear (driver)	compound pulley
fulcrum	inclined plane	carpal tunnel	driven gear (follower)	potential energy
effort force	work	syndrome	sprocket	kinetic energy
load	joules	winch	speed ratio	transmission
effort arm	work input	radius	pulley	efficiency
load arm	work output	wheel and axle	fixed pulley	
Class 1 lever	mechanical advantage	gear	movable pulley	
Class 2 lever	speed	gear train	block and tackle	

Reviewing Key Terms

Copy the crossword puzzle into your notebook and complete it using some key terms listed above.



Across

1. The unit for work. (1)

2. Its teeth fit into the links of a chain. (2)

3. A bottle opener is this kind of tool. (1)

4. The point where a lever does not move. (1)

5. Turn the handle of this machine and it will pull on a cable and wrap it around a cylinder. (2)

6. This gear turns another gear. (2)

7. Energy that causes something to move. (3)

Down

8. The transfer of energy through motion. (3)

9. A wheel that turns and allows a rope to move over it easily. (2)

10. A wheel with teeth. (2)

11. The percentage of work done on a machine that the machine then does on the load. (3)

12. The distance from the fulcrum to the load is the load ____________. (1)

13. A hockey stick is this kind of lever. (1)

Understanding Key Concepts

14. Which class of lever always has a mechanical advantage that is less than 1? Give an example of this type of lever. (1)

15. State at least three situations in which it would be more practical to use a wheel and axle rather than to use a lever. (2)

16. Explain how a winch is like a lever. (2)

17. Sketch a diagram showing how you could use one single pulley and one double pulley to gain a mechanical advantage of 3. (2)

18. Which of these does *not* describe what a machine does? (1, 3)

(a) changes the effort force

(b) transforms energy

(c) changes the direction of a force

(d) does work

19. Describe as many ways as you can in which a simple machine can make work easier. (1, 2, 3)

20. Many machines, including levers, wheel-and-axle devices, and pulleys, exert a greater force on a load than you exert on the machine. What do you have to do in return for a mechanical advantage that is greater than 1? (1, 2, 3)

TOPIC 4 Force, Pressure, and Area

Pause& Reflect

Use your understanding of pressure, force, and area to describe why the head and point of a nail are shaped as they are. Why is it easier to slice food using a sharp knife, rather than a dull one? Write your answers in your Science Log.

As you learned in Unit 1, the **force** (F) acting over a certain **area** (A) is called **pressure** (p). When you change the area and keep the force constant, the pressure changes. This happens when you strap on snowshoes, for example. The force (your body's weight) remains the same with or without snowshoes. However, snowshoes increase the area over which the force is spread. This reduces the pressure, so you stay on top of the snow instead of sinking through it.

Calculating Pressure

The equation for pressure is written as: Pressure = $\frac{\text{Force}}{\text{Area}}$ or $p = \frac{F}{A}$

Recall that force is measured in newtons (N) and area is measured in square metres (m^2). The unit for pressure, therefore, is newtons per square metres (N/m^2). This unit is also called a pascal (Pa). A kilopascal (kPa) is equal to 1000 Pa. How does popping a balloon with a pin demonstrate this equation? Try the next activity to find out.

Find Out ACTIVITY

Pop 'em Quick!

Suppose you were in a contest to see who could pop the greatest number of balloons in 1 min. What could you do to pop the balloons as quickly as possible?

Materials

3 balloons straight pin pencil

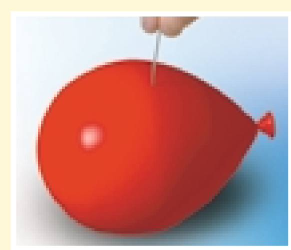
Safety Precautions

Be careful when using sharp objects such as straight pins.

Wear goggles to protect your eyes from pieces of flying balloon.

Procedure ✷ Performing and Recording

1. Blow up the balloons to approximately the same size. Knot the end of each one.
2. Set one balloon on a table. Push your index finger into the balloon until it pops. (You may need to steady the balloon with your other hand.)
3. Repeat step 2 using a pencil instead of your finger.
4. Repeat step 2 using the straight pin instead of your finger.



What Did You Find Out? ✷ Analyzing and Interpreting

1. Which method required less force to pop the balloon? Which method was faster?
2. Which "popping tool" had the smaller surface area: your finger, the pencil, or the straight pin?
3. Which popping method required more pressure?

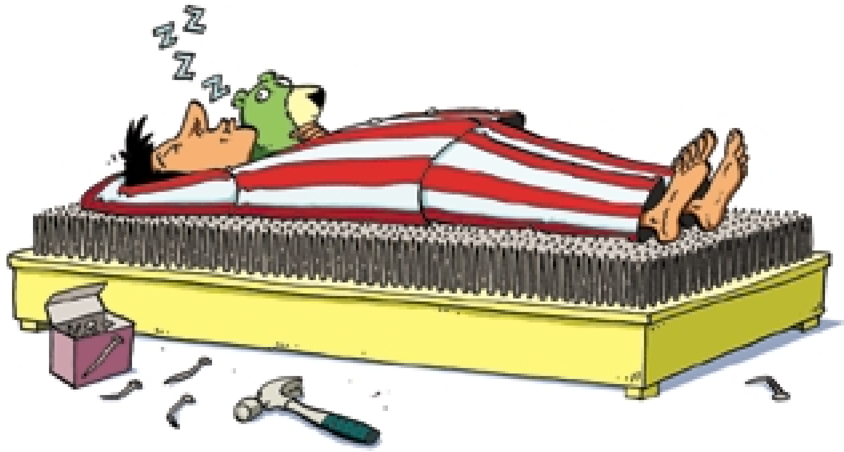


Figure 4.29 How can the man lie on this bed of nails and not injure himself? While lying on a bed of nails may sound painful, can you imagine lying on a single nail? Which would hurt more? On the bed of nails, the force of the man's weight is spread over a larger area. Thus, although the nails may poke a bit, the man's feat isn't life-threatening.

Equipped Against Pressure

Before a game, football players spend a lot of time strapping on protective equipment. Helmets, chest protectors, and shoulder pads all help spread any force — such as a powerful tackle — over a larger area. This equipment helps lessen the force of a blow and therefore the potential for injury. You wear safety equipment when you in-line skate for the same reason.

Figure 4.30 Each of these safety objects protects people based on concepts you have learned in this section. Describe how each item works.

Math CONNECT

Calculate the difference in the pressure placed on snow if you were standing in the snow on one snowshoe compared to standing in the snow in one boot. Assume that the area of a snowshoe is 0.20 m^2 and the area of a boot is 0.05 m^2.

Math CONNECT

If your head weighs about 50 N and you are travelling at 30 km/h, your head will exert about 150 N of force in a collision. Using mathematical calculations, show if it is better to hit an air bag rather than to hit the dashboard. Assume that your face has an area of 300 cm^2. If you do not use an air bag, assume that the area of your forehead that might hit the dashboard is 3 cm^2.

PROBLEM-SOLVING

INVESTIGATION 4-E

SKILLCHECK
Initiating and Planning
Performing and Recording
Analyzing and Interpreting
Communication and Teamwork

Egg Drop!

You have seen how safety equipment has been designed to spread a force over a large area. Now, design and build your own structure that will protect a raw egg when it is dropped.

Challenge

Design and build a structure that will protect a raw egg and prevent it from breaking when you drop it from a height of 2 m.

Safety Precaution

Materials

50 drinking straws
scissors
raw egg
masking tape
metre-stick

Design Specifications

A. You cannot use more than 50 straws and 1 m of masking tape.

B. Drop your egg and its protective structure from a height of 2 m.

C. Your structure must prevent the egg from breaking.

Plan and Construct

1. With your group, **predict** what arrangement of straws might protect your egg and prevent it from breaking. Use your knowledge of pressure, force, and area.
2. **Build** and **test** your design.
3. Clean up the equipment and your work area after you have completed this investigation.

Evaluate

1. Use your knowledge of force, pressure, and area to write an explanation of why your design worked, or why it failed.

2. How could you modify and improve your design?

Extend Your Skills

1. How could you **calculate** the force exerted by the egg on your straw structure?

2. **Compare** how your structure works to the way a car bumper works.

Skill FOCUS

For tips on conducting fair tests and experiments, turn to Skill Focus 6.

Did You Know?

Scientists in the Antarctic often receive supplies by having them dropped out of passing aircraft. One plane dropped 100 dozen individually bubble-wrapped eggs and no eggs broke!

Pascal's Law

Figure 4.31 Pascal's vases show that a container's shape has no effect on pressure.

Have you ever squeezed a water-filled balloon? Did you notice how the walls of the balloon bulged out in all directions? Squeezing a water-filled balloon demonstrates Pascal's law. **Pascal's law** states that pressure exerted on a contained fluid is transmitted undiminished in all directions throughout the fluid and perpendicular to the walls of the container. French physician and scientist Blaise Pascal (1623–1662) first observed that the shape of a container has no effect on the pressure at any given depth (see Figure 4.31).

Many mechanical systems use Pascal's law. Figure 4.32 shows one such system: the hydraulic lift. A **hydraulic lift** is a mechanical system that raises heavy objects, such as a vehicle on a service station lift. A hydraulic lift uses a fluid under pressure in a closed system. A **closed system** is a self-contained collection of parts. Your body's circulatory system is an example of a closed hydraulic system. Your heart pumps blood to all the cells of the body and back to the heart through a continuous network of blood vessels that are directly connected to one another.

As the illustration in Figure 4.32A shows, a hydraulic lift consists of a small cylinder and a large cylinder. The cylinders are connected by a pipe. Each cylinder is filled with a hydraulic fluid, usually oil. (Water is not used in a hydraulic lift for two reasons — it is not a good lubricant, and it can cause parts of a system to rust.) Note that each cylinder also has a type of platform, or piston, that rests on the surface of the oil. Figure 4.32B shows a forklift that uses hydraulic pressure.

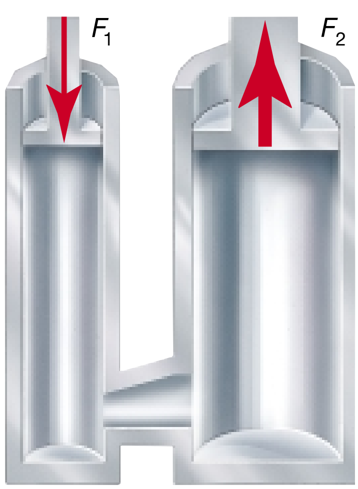
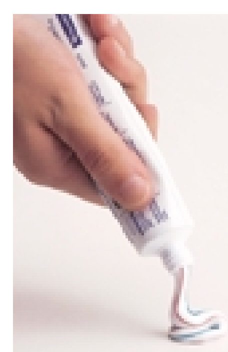


Figure 4.32A In this hydraulic lift, pressure applied to a small piston is transmitted to a large piston by means of a hydraulic fluid.

Figure 4.32B Powered hydraulically, this forklift can move very large containers.

Off the Wall

Every time you squeeze out some toothpaste, you are applying Pascal's law! You can squeeze anywhere on the tube and get the same result.



Suppose you apply 500 N of force to the small piston with an area of 5cm². The pressure on the small piston is expressed in the following equation. Recall that pressure (p) is force (F) divided by the area (A) over which the force is acting.

$$p = \frac{F}{A}$$

$$= \frac{500\ \text{N}}{5\ \text{cm}^2}$$

$$= 100\ \text{N/cm}^2$$

Pascal's law states that this pressure is transmitted unchanged throughout the liquid. Therefore, the large piston will also have a pressure of 100 N/cm^2 applied to it. However, the total area of the large piston is greater than the area of the small piston. The large piston's area is 50 cm^2. Thus, the total force on the large piston is 100 N/cm^2 × 50 cm^2 = 5000 N. This is *ten times* the force applied to the small piston. Using this hydraulic machine, you could use your own weight to lift something ten times as heavy as you are!

In Unit 2, you learned that the pascal (Pa) is the standard unit of pressure. One pascal of pressure is a force of one newton per square metre. This is a small pressure unit, so most pressures are given in kilopascals (kPa).

To sum up, a hydraulic lift uses a liquid to produce a large force on a load when a small effort force is exerted on the liquid. Because a small effort force produces a large force on a load, a hydraulic lift provides a mechanical advantage.

Pascal's Law and Mechanical Advantage

Study Figure 4.33. Note that the area of the small piston of the hydraulic lift is 1 unit. If you push down on the piston with a force of 10 N, you will generate a pressure in the fluid by 10 N per unit of area. Now examine the area of the large piston. There are nine squares. Each square has the same area as the small piston. According to Pascal's law, the pressure on every unit of area on that piston will be 10 N. Since there are 9 units of area, the total force on the large piston will be:

$$\frac{10\ \text{N}}{\text{unit area}} \times 9\ \text{unit areas} = 90\ \text{N}$$

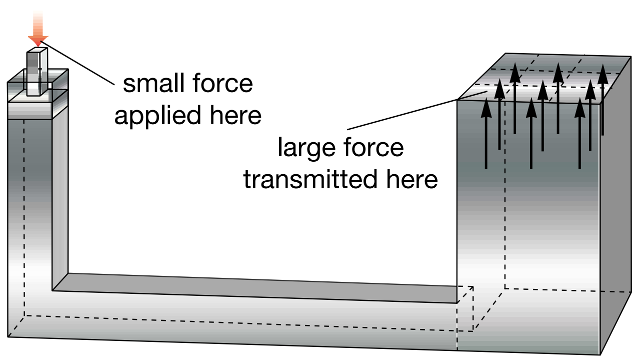


Figure 4.33 This simplified diagram of a hydraulic lift shows how a small effort force can produce a large force on a load.

By exerting 10 N of effort force, you could cause the large piston to exert 90 N of force on a load. Thus, the hydraulic lift provides a mechanical advantage. As you learned in Topic 1, mechanical advantage is the load divided by the effort force:

$$MA = \frac{\text{Load force}}{\text{Effort force}}$$
$$= \frac{90\ \text{N}}{10\ \text{N}}$$
$$= 9$$

This hydraulic lift has a mechanical advantage of 9. However, remember that you would have to push the piston nine times farther than the distance you could lift the load. You would have to increase the effort distance because the work done on the small piston must be at least as great as the work done on the load. (Recall that work equals force multiplied by distance.)

For example, suppose you wanted to lift a 90 N load a distance of 2 m using the hydraulic lift in Figure 4.33. Approximately how far would you have to push the piston as you exert your effort force? You could find out by doing the following calculations (note the formula for work):

$$W = F \bullet d$$
$$W(\text{effort}) = 10\ \text{N} \bullet d\ (\text{effort})$$
$$W(\text{load}) = 90\ \text{N} \bullet 2\ \text{m}$$
$$W(\text{effort}) = W(\text{load})$$

Therefore,

$$10\ \text{N} \bullet d\ (\text{effort}) = 180\ \text{J}$$
$$d\ (\text{effort}) = \frac{180\ \text{J}}{10\ \text{N}}$$
$$= 18\ \text{m}$$

To lift a 90 N load a distance of 2 m using the hydraulic lift, you would have to push the piston 18 m. This effort distance is nine times the load distance.

Pause & Reflect

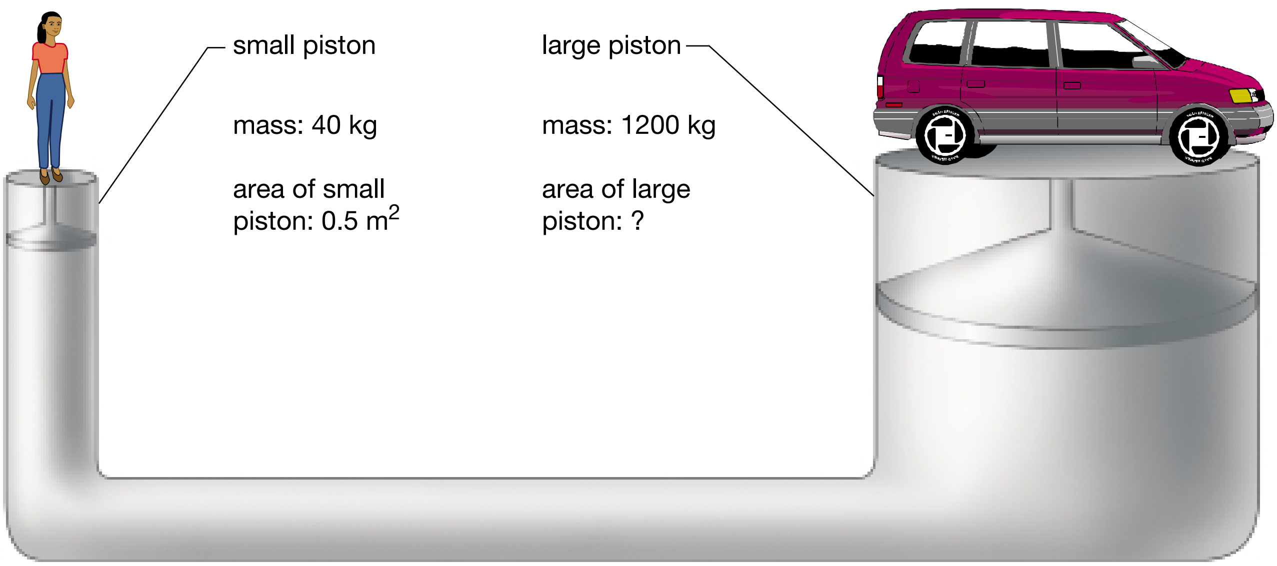
When you squeeze mustard out of a plastic container, the mustard comes out of a small opening, but spreads out over a larger area so that it coats a hamburger. Explain why this happens using your understanding of Pascal's law. Write your explanation in your Science Log.

Figure 4.34 This "cherry picker" uses hydraulic pistons combined with levers to move the "bucket" over large distances. Examine the picture and see if you can explain how this is possible.

INVESTIGATION 4-F

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

What a Lift!



Think About It

In a hydraulic lift, how large a piston would you need to lift a minivan? Imagine you are standing on one piston of a hydraulic lift and a minivan is on the other piston. The area of your piston is 0.5 m^2. Suppose you have a mass of 40 kg and the minivan has a mass of 1200 kg. How large must the other piston be to lift the minivan?

Recall that mass is measured in grams (g) and kilograms (kg). Weight, which is a force, is measured in newtons (N). A kilogram of mass on Earth's surface weighs 10 N.

What to Do

1. Estimate the size of the large piston in the hydraulic lift. Think of an area that is about the same size as the large piston. What is the area of your kitchen table? Of your bedroom floor? Of your living room? Of your classroom? Which area do you estimate is closest to the area of the large piston in the hydraulic lift?

2. Study the diagram, then calculate the area of the large piston. (Hint: Remember that the ratio of the two masses is the same as the ratio of the two areas of the pistons.)

Analyze

1. What result did you get when you calculated the area of the piston supporting the minivan? How close was your estimate to this result?

2. Do you think that this design for a hydraulic lift is practical? Explain your answer.

Skill FOCUS

To review estimating, turn to Skill Focus 5.

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Build Your Own Hydraulic Lift

Now that you understand how a hydraulic lift operates, design and build your own working model of one. Use your knowledge of Pascal's law and mechanical advantage to help you with your design.

Challenge

Design and build a model of a hydraulic lift that will exert a large force on a load when you exert a small force on the lift.

Safety Precautions

Materials

10 mL modified syringe
50 mL modified syringe (the plungers of both syringes must slide freely)
narrow plastic tubing
1 kg mass
250 g mass
variety of smaller masses
2 wood squares (5 cm x 5 cm)
2 support stands
4 stopcocks or clamps
glue gun
water

Design Specifications

A. Your model hydraulic lift must exert a force in one place when you exert a force in a different place.

B. There must be no air bubbles in the tubing and in the syringes.

C. Your model hydraulic lift must provide an observable mechanical advantage.

Plan and Construct

1. With your group, predict what arrangement might allow you to balance the 250 g and 1 kg masses on the two modified syringes. Test your prediction. **CAUTION** Place the masses carefully on the wood platform each time, so that they do not fall off the work surface onto your foot. Also, the glue gun is hot and the glue remains hot for several minutes.
2. Predict what arrangement might allow you to raise the 1 kg mass using the least amount of force. Test this prediction as well.
3. Wipe up any spilled water after this investigation.

Evaluate

1. Did your model hydraulic lift produce a mechanical advantage? How could you tell?
2. Suppose you need to raise a 1 kg mass using an even smaller force. How could you modify your model hydraulic lift to achieve this?

Extend Your Skills

1. How could you calculate the work done by your effort force?
2. How could you find out the pressure exerted by the water in the modified syringes?

TOPIC 4 Review

1. Explain the difference between force and pressure.

2. Pressure is measured in pascals (Pa). What combination of units is the same as a pascal?

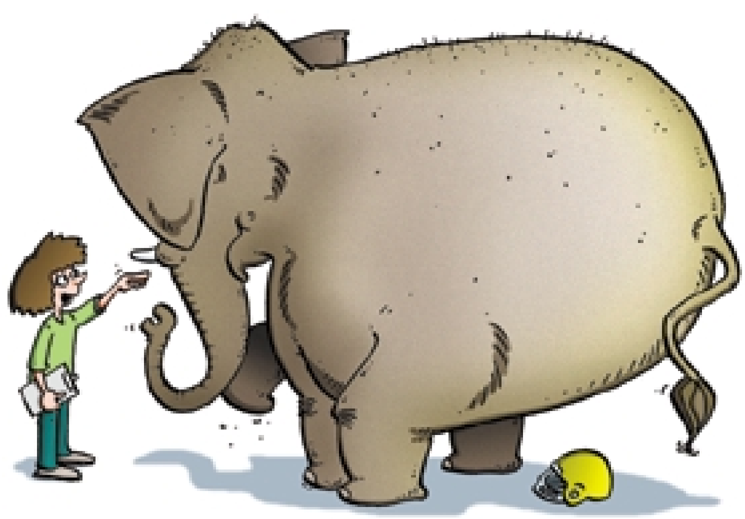
3. When you exert force on a fluid in a closed container, does the pressure increase, decrease, or remain constant?

4. State Pascal's law.

5. In a drawing, show how to set up a model hydraulic system with a mechanical advantage of 4.

6. Explain how a thumbtack is designed so that you do not have to use a lot of force to push it through paper or the surface of a bulletin board.

7. **Design Your Own** You have been given the task of testing the effectiveness of a new style of football helmet. What characteristics might affect the strength of the helmet? Make a hypothesis related to one of these characteristics and design an experiment to test your hypothesis. Identify which variable(s) will change for your experiment, and which will remain constant. List criteria for assessing your solution.



TOPIC 5 Hydraulics and Pneumatics

When you squeeze a water bottle, you apply a force that pushes water out of the bottle. There is air and water in a water bottle and when you squeeze it, hydraulic and pneumatic systems are at work.

Hydraulic systems use the force of a liquid in a confined space, such as an oil pipeline. Hydraulic systems apply two essential characteristics of fluids — their incompressibility and their ability to transmit pressure. The hydraulic lift you built in Topic 4 is an example of hydraulic systems.

Pneumatic systems do not seal the gas — usually air — in a mechanical system in the same way that hydraulic machines seal in hydraulic fluid. Usually the air passes through the pneumatic device under high pressure and then escapes outside the device. The high-pressure air may come from a machine that draws in outside air and compresses it. Hoses then carry the high-pressure air to the pneumatic device. Do the gases in pneumatic systems and the liquids in hydraulic systems behave differently when you exert pressure on them? Find out in the next investigation.

Ask an Expert

To meet firefighter Randy Segboer, who uses hydraulics and pneumatics at work, turn to page 352.

Figure 4.35 Firefighters are using the hydraulically powered Jaws of Life to rescue an accident victim from a crushed car. Above the photo are three types of tools used in the Jaws of Life (from left to right): spreaders, rams, and cutters.

Figure 4.36 Inflatable walkways are examples of pneumatic systems. Inflatable walkways help workers reach accident victims and carry them to safety.

INQUIRY

INVESTIGATION 4-H

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

Comparing Pressure Exerted on a Gas and on a Liquid

You know that some mechanical devices use pneumatic systems and others use hydraulic systems. How do engineers decide which system to use?

Question

What happens when you exert the same amount of pressure on a gas and on a liquid?

Prediction

Will the results be the same or different if you exert the same amount of pressure on a gas and on a liquid? Make a prediction and test it in this investigation.

Safety Precautions

Apparatus

2 modified syringes (the plungers of both syringes must slide freely)
2 wood squares (5 cm x 5 cm)
2 masses (500 g each)
stopcocks
plastic dishpan
stopwatch or watch with a second hand
support stand
felt tip pen
glue gun

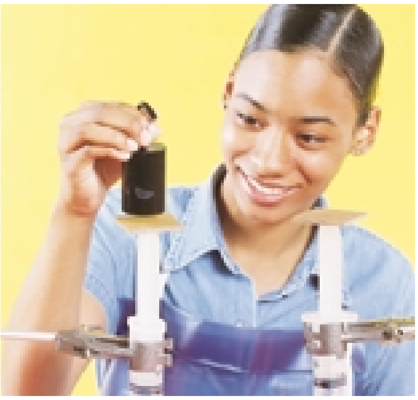
Materials

water

Procedure

Note: Your teacher will glue the wood squares to the plungers ahead of time so the glue will have time to dry.

1. Fill one syringe with water. Turn it upside down over the dishpan and press the plunger until all of the air is gone.
2. Close the stopcock.



3 **Assemble** the apparatus as shown. Leave air in the second syringe. Adjust the plunger so that it is at the same position as the plunger in the water-filled syringe.

(a) Close the stopcock, making sure that all the connections are airtight.

(b) Wipe up any spilled water.

4 **Observe** the positions of the two plungers. Mark the positions of the plungers with a felt tip pen.

5 Place a 500 g mass on top of each syringe. **Observe** the new positions of the plungers. **CAUTION** Place the masses carefully on the wood platforms so that they do not fall off the work surface onto your foot.

6 Before you open the stopcocks, **make a prediction**. Will the time it takes for each of the plungers to reach the bottom of the syringes be the same or different? Open the stopcocks one at a time and **record** the time it takes for each of the plungers to reach the bottom of the syringe. Wipe up any spilled water after this investigation.

Analyze

1. What happened when you put the mass on top of the water-filled syringe?
2. Was the result the same or different when you put the mass on the air-filled syringe?
3. Did one modified syringe empty faster than the other when you opened the stopcock? If so, which one emptied faster?
4. What were the manipulated and responding variables in this investigation? Which variables were controlled?

Conclude and Apply

5. What property of liquids did you demonstrate in this investigation? What property of gases did you demonstrate? Use the term "viscosity," which you learned in Unit 2, to explain your observation in question 3.
6. Write a statement that summarizes and compares how gases and liquids respond to pressure.

Pneumatics at Work

DidYouKnow?

Using air pressure of about 620 000 Pa, more than 5.5 m^3 of air flow through a jackhammer every minute.

Pneumatic devices are used all around us. A common example is the jackhammer (see Figures 4.37 and 4.38). You have probably heard the extremely loud noise of a jackhammer breaking up concrete when a sidewalk or a road is being repaired. Jackhammers are also used in the mining of coal, nickel, and gold. Bursts of air, under very high pressure, drive a part called a "chuck" in and out of the jackhammer at high speeds. Resembling a very large screwdriver, the chuck pounds the rocks or concrete into fragments.

Word CONNECT

In a dictionary, look up the origin of the word "pneumonia."

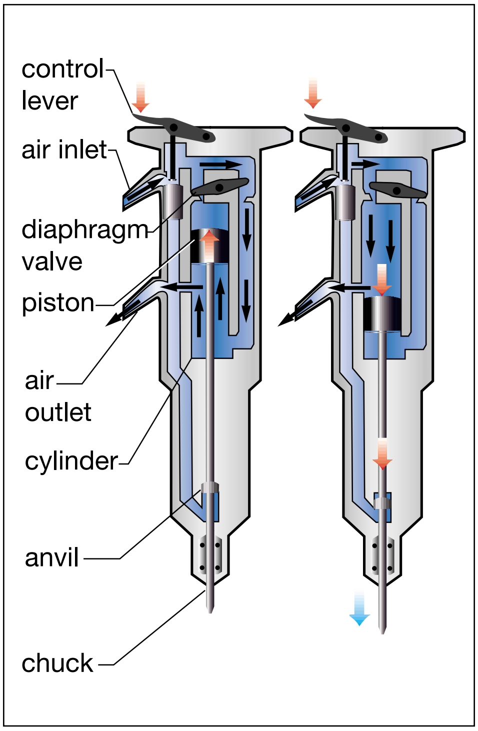


Figure 4.37 Cross section of a jackhammer

Figure 4.38 Every time you hear the ear-splitting sound produced by a jackhammer, you are hearing compressed air at work.

Cool Tools

The high-speed drill that dentists currently use is a pneumatic instrument that relies on pressurized air. The cutaway diagram on the right shows how a dentist's drill works. This technology has led to almost pain-free dentistry.

What does the future hold? A newly invented machine that drills teeth with a high-powered jet of water will make life easier for dentists — and for patients. The device, called the Millennium, works by pumping a jet of water at the teeth. The droplets of water are split by a laser into tiny particles. As these hit the enamel, they exert enough force to grind the tooth. This technology means there is no noise from a drill and no heat.

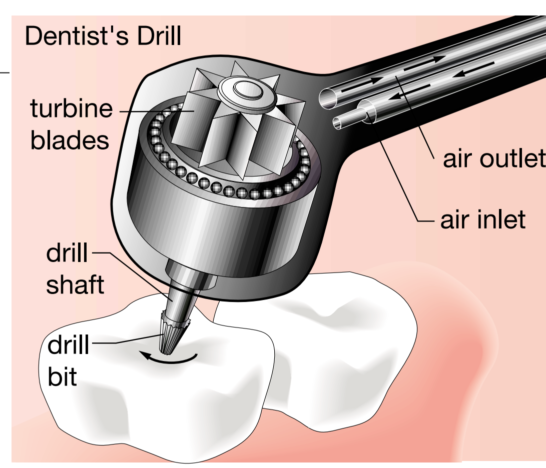


Figure 4.39 Air pressure makes this staple gun work.

Figure 4.40A Before sandblasting

Figure 4.40B After sandblasting

Staple guns and pneumatic nailers use pulses of air pressure to drive staples or nails into solid objects. Staple guns are used in making furniture, woodworking, upholstering, and many other applications. Pneumatic nailers can even nail wood to concrete. A staple gun is shown in Figure 4.39.

Sandblasters do exactly what the name implies. High-pressure air blasts tiny sand particles out of a nozzle. Sandblasting is an excellent way to remove dirt and paint from stone or brick. Old, dirty buildings or statues can be made to look new, as shown in Figures 4.40A and B. Can you imagine sanding a large stone building with sandpaper?

Besides improving appearances, sandblasting is also used for practical applications. For example, slippery granite or marble stairs can be made safer by being sandblasted. Sandblasting roughens the edges of the stairs to increase friction. The friction, in turn, prevents people from slipping on a step.

Figure 4.41 This "air cast" is used for both sprains and fractures.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

Continue to search the Internet for information about mechanical systems, but start adding pneumatic devices to your list. Visit the above web site. Go to **Science Resources**, then to **SCIENCEFOCUS 8** to find out where to go next. Each class member can look for at least one type of pneumatic equipment (other than the ones presented in this textbook) and present an oral or written report to the class. See what unusual devices you can find!

The photograph above shows another application of pneumatics. Medical engineers have developed a type of cast filled with pressurized air. A solid frame with a balloonlike lining is fitted to the injured leg. High-pressure air is pumped into the lining through a hose. Because the air pressure can be controlled precisely, the cast can be made to fit snugly and securely.

Pause & Reflect

In your Science Log, describe how some modern sports shoes are similar to an air cast.

Riding on Air

Figure 4.42 shows a Canadian Coast Guard hovercraft used primarily for rescue operations. Hovercraft also transport people, cars, and equipment long distances over land or water.

Figure 4.42 Hovercraft are used not only for rescue operations but also for routine travel.

In a hovercraft, powerful pumps draw in outside air and pump it out through holes in the bottom of the hovercraft (see Figure 4.43). A "skirt" around the bottom holds in enough air to support the weight of the craft above water or land. Given enough air pressure, a hovercraft can support extremely heavy loads. Propellers drive the hovercraft forward, and rudders are used to steer it.

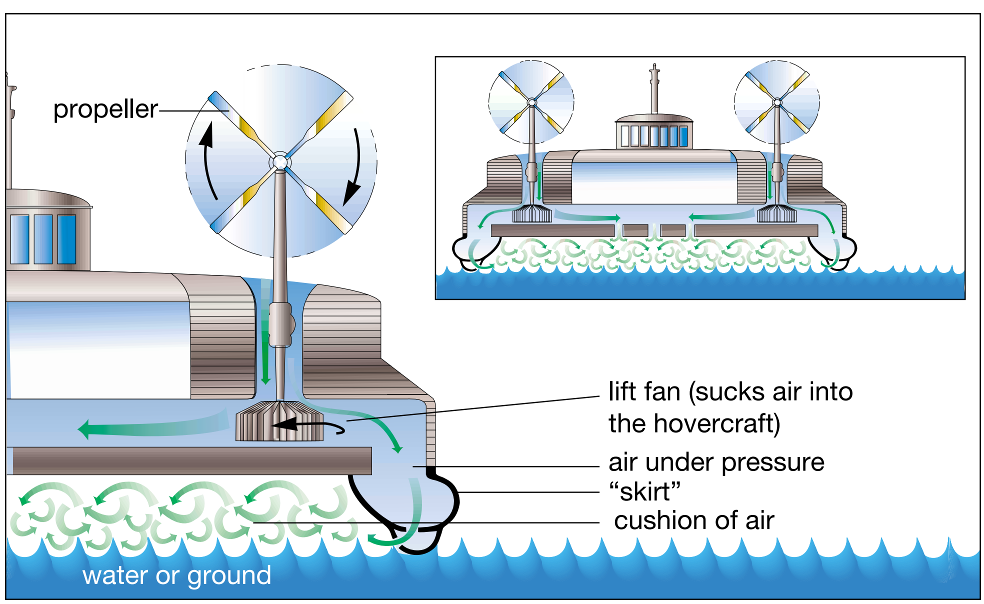


Figure 4.43 A hovercraft rides on a cushion of air.

Find Out ACTIVITY

Build a Model Hovercraft

See if you can send a miniature hovercraft skimming across a table.

Safety Precautions

Materials

cardboard	pencil
empty thread spool	glue gun
paper	balloon
scissors	

Procedure

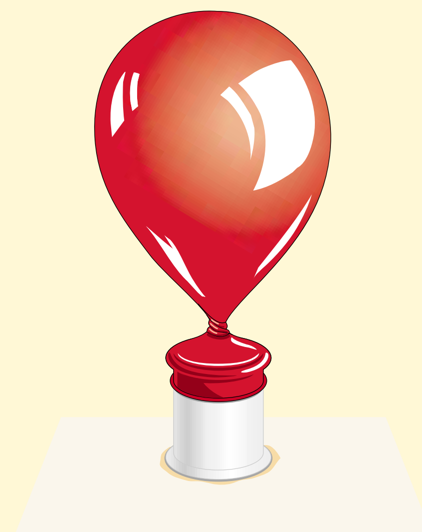
Performing and Recording

1. Cut out a 10 cm square from the cardboard and use a pencil to punch a hole in the centre of the square. The hole should be the same size as the hole in the empty thread spool. **CAUTION** Be careful when using sharp objects such as scissors and when punching the cardboard with a pencil. Also, the glue gun is hot and the glue remains hot for several minutes.
2. Glue the empty spool on top of the hole in the cardboard so that the holes line up.
3. Using the glue gun, seal the base of the thread spool so that no air can escape.
4. Cut out a circle of paper and glue it onto the top of the thread spool.
5. Using a pencil, punch a hole in the middle of the paper circle to line up with the hole of the spool.
6. Blow up the balloon and twist the neck. Stretch the mouth of the balloon over the top of the spool. Let the balloon go and give your hovercraft a nudge.

What Did You Find Out?

Analyzing and Interpretin

What are some ways that you could change your hovercraft design to make it go farther?



www.school.mcgrawhill.ca/resources/

There are many types of hovercrafts, or air-cushion vehicles. These machines are used for many different purposes. Create a database with information about at least three different hovercrafts. Include data on how large they are, how much weight they can carry, where they are designed to run, and how fast they can go. As well, include information about any special features each hovercraft may have. What features do all of these hovercrafts have in common? What features are different? Do different types of hovercrafts have different overall designs? Visit the above web site and go to **Science Resources**. Then go to **SCIENCEFOCUS 8** to find out where to go next.

Skill FOCUS

For tips on creating a database, turn to Skill Focus 9.

Hydraulics at Work

Have you ever seen a bulldozer clearing an area to build new homes? You may have seen a backhoe digging a trench for a new water line or a sewer pipe. Have you ever watched a "cherry picker" in action? Perhaps you've seen a farmer driving a tractor in a field. In all these cases, you were watching hydraulic equipment at work.

Figure 4.44A This student is training to become a heavy equipment operator. Here, she is learning how to operate an earth mover.

Figure 4.44B Why do you think this farm equipment is called a "bi-directional tractor"?

Figure 4.44C This backhoe is digging up a lawn to install a gas pipe. (To see a diagram showing how a backhoe works, turn to page 327.)

Skill FOCUS

For tips on doing Internet research, turn to Skill Focus 9.

Unlike the simple hydraulic systems you have explored so far, the huge machines shown in Figure 4.44 A, B, and C are not operated by plungers that workers push manually! Instead, the machines contain tanks filled with hydraulic fluid and pumps that generate pressure. In most hydraulic equipment, the energy for pumping is supplied by a gasoline engine or by an electric motor. Valves direct the high-pressure fluid through steel pipes to the parts of the machine where the pressure of the fluid is needed to generate large forces to lift or to dig. Often the steering and braking systems in large machines are powered by the high-pressure hydraulic fluid as well.

www.school.mcgrawhill.ca/resources/

As a class project, start an Internet search for as many types of hydraulic equipment as you can find. Visit the above web site. Go to **Science Resources**, then to **SCIENCEFOCUS 8** to find out where to go next. Decide how you want to keep track of all the machines and instruments that you find. You could create a bulletin board display, a poster, or a trade magazine entitled *Popular Hydraulics*. (Use a library if you do not have access to the Internet.)

Hydraulics in Flight

When an airplane such as the one shown in Figure 4.45A taxis along a runway, the pilot steers the plane using the nose wheel. During takeoff, the pilot may lower the flaps. To make a turn while airborne, the pilot moves the ailerons up or down and adjusts the rudder. To keep the plane level, the pilot adjusts the elevators. Landing a plane is a multi-system process. The pilot uses hydraulics to lower the flaps and slats to slow the aircraft during the approach before landing. The pilot then uses hydraulics to raise the spoilers when the aircraft touches down. The spoilers prevent the wing from lifting the aircraft again.

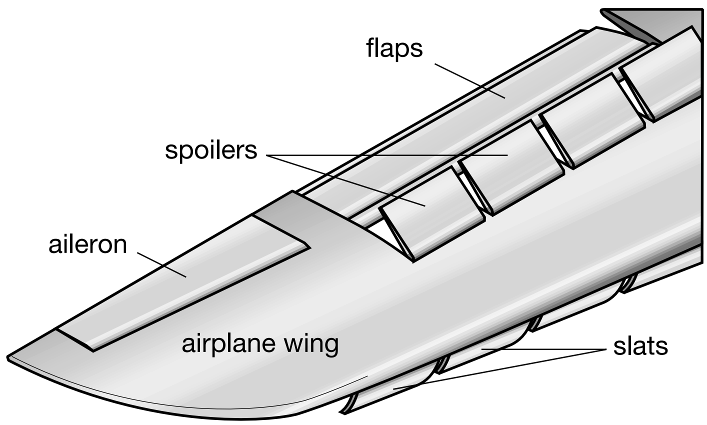


Figure 4.45A The various parts of an airplane wing are raised and lowered hydraulically when the pilot lands the plane.

Figure 4.46 These aircraft have three separate hydraulic systems, as well as an emergency backup system.

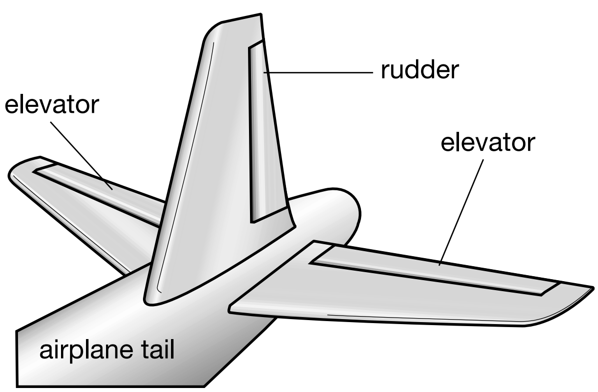


Figure 4.45B Hydraulics are responsible for tail adjustments that enable the pilot to turn the plane while airborne.

Every mechanical system mentioned in the paragraph above is powered by hydraulics (see Figures 4.45A and B). The precise designs of the hydraulic systems are different for different models of aircraft, but the basic principles are the same.

Each airplane in Figure 4.46 is an Airbus A340. The Airbus A340 has three separate hydraulic systems: the green system, the blue system, and the yellow system. If one system malfunctions, there are one or two other systems to back it up. For example, the green and yellow systems both control the flaps. The green and blue systems control the slats. All three systems control the ailerons.

The green system relies on fluid pressure generated by engines 1 and 4. The blue system relies on fluid pressure generated by engine 2, and the yellow system relies on pressure from engine 3. If an engine fails, additional backup motors provide pressure for the hydraulic systems. What happens if all the systems fail? Could the pilot still control the guidance systems? The answer is yes. An emergency air-driven generator drops out from a door in the bottom of the plane. As shown in Figure 4.47, this generator resembles a fan. It has a propeller that spins when outside air strikes it. Since jets travel at tremendous speeds, the air turns the propeller extremely rapidly. This rapid turning motion generates alternative power to supply the hydraulic systems.

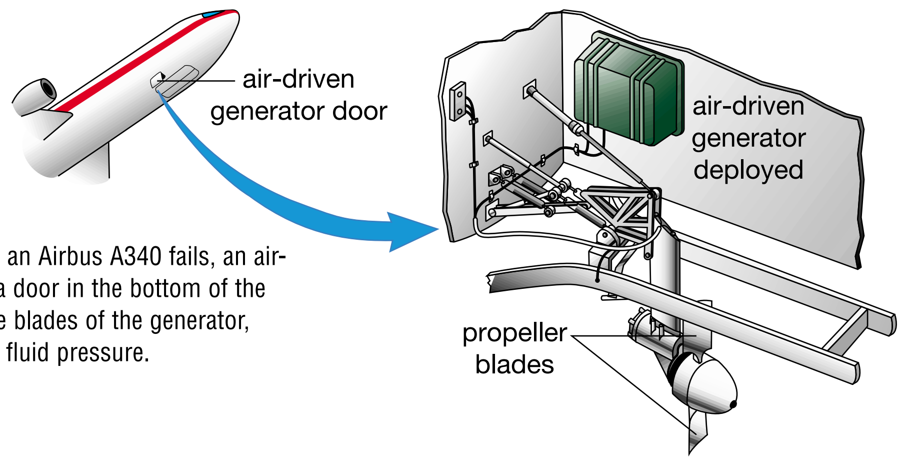


Figure 4.47 If hydraulic pressure in an Airbus A340 fails, an air-driven generator drops down from a door in the bottom of the plane. The air rushing past turns the blades of the generator, which produces both electricity and fluid pressure.

Career CONNECT

Heavy-Duty Work

Merritt Shilling is a heavy equipment operator. He knows how to operate everything from a huge excavator to a small bulldozer safely and efficiently. These specialized vehicles often have a separate control for each hand and as many as three foot pedals. Learning how to control several mechanical systems at once takes special training. Merritt got his training on the job and temporarily moved to a larger community for the experience he wanted. His career path looks something like this:

- completed high school
- cleared snow using a truck with an attached plow
- worked for a landscaper driving tractors and bulldozers
- worked for a large metal company driving huge forklifts and other equipment
- returned to his Native community and now works for local contractors driving whatever equipment each job requires

To become a heavy equipment operator, you could attend a privately run heavy equipment school. You could also complete a college course in truck driving or in heavy equipment mechanics, or work with an experienced operator as an apprentice.

Locate someone in your community who works as a heavy equipment operator, or contact a spokesperson for your province's workers' compensation board (check the provincial government pages in the telephone book). Ask about the safety issues related to this type of work. What safety gear must be worn on the job? For example, is ear protection necessary? What are the most common risk situations that could arise, and how can these risks be reduced? How can an operator prevent accidents from occurring? Present answers to these or other questions in a brief oral or written in-class report.

Hydraulics and Pneumatics in Your Body

Did you know that your life depends on a pneumatic system? The respiratory system in your body is more complex than any pneumatic machinery. As you learned in Unit 1, this system is made up of lungs; tubes that allow air to enter and leave the lungs; and muscles that cause your lungs to expand and contract. Breathing depends on changes in air pressure. When you are breathing normally, your muscles make your lungs expand and draw in about 500 mL of air. Simply relaxing will push the air back out. You breathe in and out about 12 times per minute. When you are active, like the girls in Figure 4.48, you breathe more quickly and more deeply.

Your body also depends on a complex hydraulic system. In Unit 1, you learned that blood must be kept under pressure so that it can be pumped to all parts of your body. Your heart is the pump that moves blood through the blood vessels with pressure that rises and falls. Like the rhythmic squeezing of the water bottle, each time your heart beats, it exerts a force on your blood and pushes it along. In Unit 2, you learned that blood pressure is exerted by blood against the inner walls of arteries and, to a lesser extent, capillaries.

Your heart is an amazing hydraulic device. Over the course of a lifetime, it can pump nearly 4 billion times without stopping, and it can circulate a total of nearly 500 million litres of fluid. Throughout your lifetime, your heart will pump enough blood to fill 13 supertankers, each holding one million barrels!

When blood leaves the left ventricle, it travels first through arteries, then capillaries, and finally veins, before it returns to your heart. Figure 4.49 shows how the arteries become smaller and smaller until they are tiny, thin-walled capillaries through which oxygen and waste products pass easily.

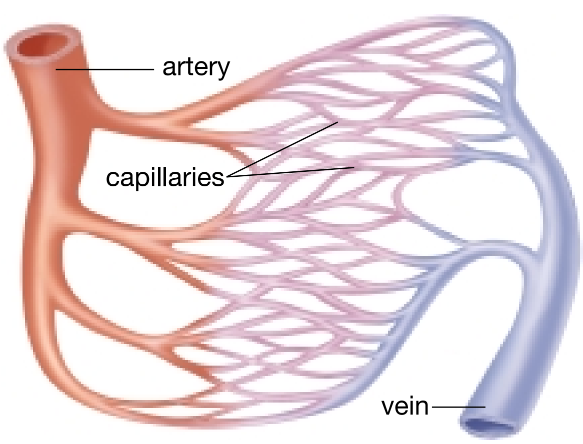


Figure 4.49 The aorta, the largest artery, branches into smaller and smaller arteries that lead to capillaries, which are tiny vessels that carry blood to every part of the body.

The diameter of the largest blood vessel in your body is just under 2 cm. The smallest vessels, the capillaries, are less than 0.0001 cm in diameter. It takes a great deal of pressure to push a fluid through tubes with small diameters, such as capillaries.

STRETCH Your Mind

If you lived for 85 years and breathed normally, how much air would you breathe in and out of your lungs?

DidYouKnow?

If the blood vessels in your body were connected end to end, they would extend almost 100 000 km. That is two and a half times around the planet Earth!

Figure 4.48 During strenuous activity, your breathing quickens and deepens.

Valves and Pumps

Recall that pressure is transmitted equally throughout a fluid. What happens when the pressure is reduced in one area? If you are holding an inflated balloon closed, the pressure inside is equal throughout the balloon. When you release your fingers, the pressure in the neck of the balloon is reduced and the fluid (air) comes rushing out.

Something similar happens when you turn on a tap. The pressure on one side of the tap is greater than the pressure on the other side. The fluid (water) moves from the side of high pressure to the side of low pressure.

In both of these situations a **valve** is used to control the fluid. A valve is a movable part that controls the flow of a fluid by opening or closing. Your fingers are the valve when you hold the balloon closed. The tap is the valve in the water pipe. These are both manually operated valves.

In other situations, valves can be made to operate automatically using the pressure that the valve is controlling. Many **pumps** use automatic valves controlled by pressure to move fluids in a specific direction. The valve is pushed open by pressure on one side and will close if the pressure becomes greater on the other side of the valve. Did you know you have valves in the large veins in your body that operate in this way?

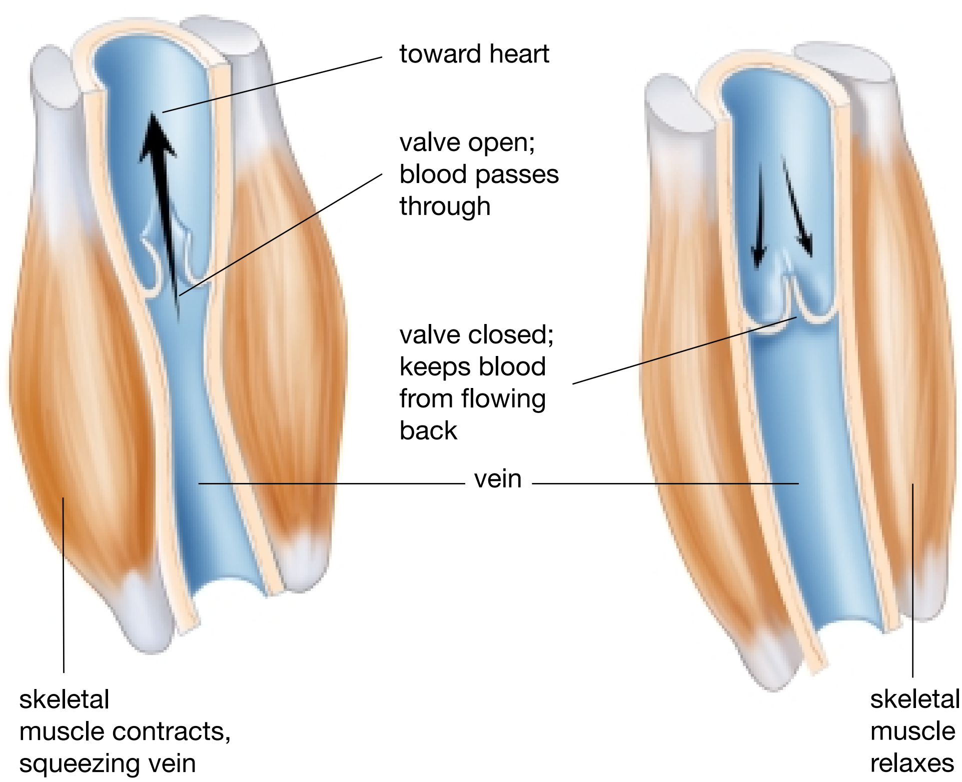


Figure 4.50 When muscles surrounding veins contract, they squeeze the veins. This forces the blood within the veins to move forward under pressure.

Your heart is actually two pumps, which circulate your blood throughout the arteries and capillaries in your body. The heart uses four automatic valves to circulate the blood. Blood pressure increases and decreases between heartbeats. Immediately after the heart contracts, a surge of blood causes high pressure in the arteries. Then, before the next heartbeat, the pressure falls, only to increase again at the next contraction.

Math CONNECT

An average human heart beats about 72 times each minute. If you live to be 85 years old, how many times would your heart beat in your lifetime?

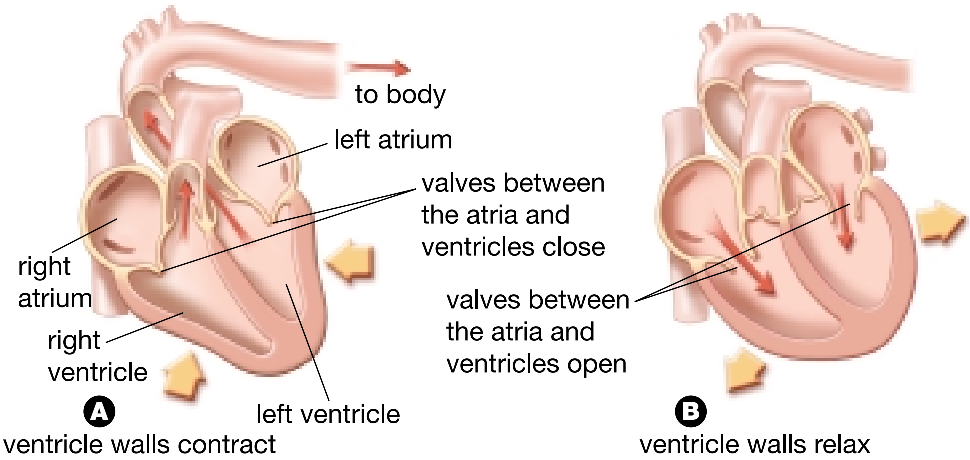


Figure 4.51 The heart uses four automatic valves to circulate the blood. **A**. When the ventricles contract, the valves to the arteries are opened, and the valves between the atria and the ventricles are closed. This forces blood into the arteries. **B**. When the ventricles relax and the atria contract, the valves to the arteries are closed, and the valves between the atria and the ventricles are opened.

TOPIC 5 Review

1. Contrast the responses of gases and liquids to pressure.
2. List four instruments or machines that use hydraulics.
3. Describe one important difference between the use of gases in pneumatic systems and the use of liquids in hydraulic systems.
4. Give four examples of pneumatic devices.
5. Use sketches and labels to show (a) how a hovercraft uses pneumatic systems, and (b) how an airplane uses hydraulic systems.
6. **Apply** Rescue workers often use inflatable airbags to free people trapped under heavy objects. Use simple, readily available materials to design a model that shows how an inflatable airbag could be used to lift a heavy object.

Skill FOCUS

For tips on using models in science, turn to Skill Focus 12.

TOPIC 6 Combining Systems

Pause& Reflect

Flip through some old magazines or catalogues and find two machines that use three or more subsystems. Cut out the pictures and paste them in your Science Log. Label the various subsystems.

When you look under the hood of a car, such as the one shown in Figure 4.52A, do you say to yourself, "Now there is a simple machine!"? Most likely, you would not. What is a simple machine? A single lever, a pulley, or a wheel and axle is a simple machine. However, when you put simple machines together, you do not call them simple. Most modern machines are combinations of dozens or even hundreds of simple machines working together to carry out a precise function. When a simple machine is part of a large system, we call it a **subsystem**. When you look at a large machine, it is often hard to see, or even imagine, how all of the subsystems work. However, when you concentrate only on a small part of the whole system, the workings of the machine become clearer. The braking system in a car is a good example of a system that you can analyze easily.

The braking system shown in Figure 4.52B is known as "disc brakes." The brake pedal subsystem is a Class 2 lever. The force of the driver's foot on the brake pedal is the effort force. The load is the force on a piston that applies pressure on the brake fluid in the master cylinder. As the driver pushes down harder on the brake pedal, the effort force increases the pressure transmitted in the brake fluid. From the master cylinder, brake fluid flows through tubes that branch out to every wheel. The illustration shows the final action at each wheel. The brake fluid exerts pressure on brake pads that press on a disc. The friction between the brake pads and the disc slows and eventually stops the car.

Figure 4.52A How many different simple machines can you see under this hood? How many more simple machines are in other parts of the car? Would you say there are hundreds of simple machines making up this car?

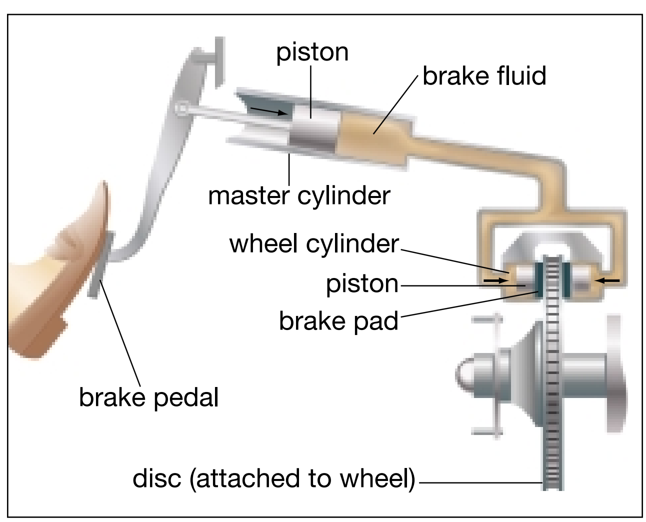


Figure 4.52B The pressure of the driver's foot on a brake pedal is transmitted by fluid pressure to the wheels of the car.

Figure 4.53 shows another example of a highly efficient combination of levers and hydraulics, the backhoe. Also known as an excavator, a backhoe is a rotating combination of three levers. These three levers are called the boom, the dipper, and the bucket. As the diagram shows, this rotating assembly of levers is mounted on caterpillar tracks. The assembly swings around on a gear-like part called a slew ring. Powered by hydraulics, the three levers combine to place the bucket in any position. The boom is a Class 3 lever that raises or lowers the dipper. The dipper is a Class 1 lever that moves the bucket in and out. The bucket itself is a Class 1 lever that tilts to dig a hole and then empty its load of dirt or other material.

Looking Ahead

Hang on to the magazines and catalogues you looked through for the Pause & Reflect on page 326. Look for pictures of a tool you might want to adapt for the Project, "Adapting Tools" on page 354.

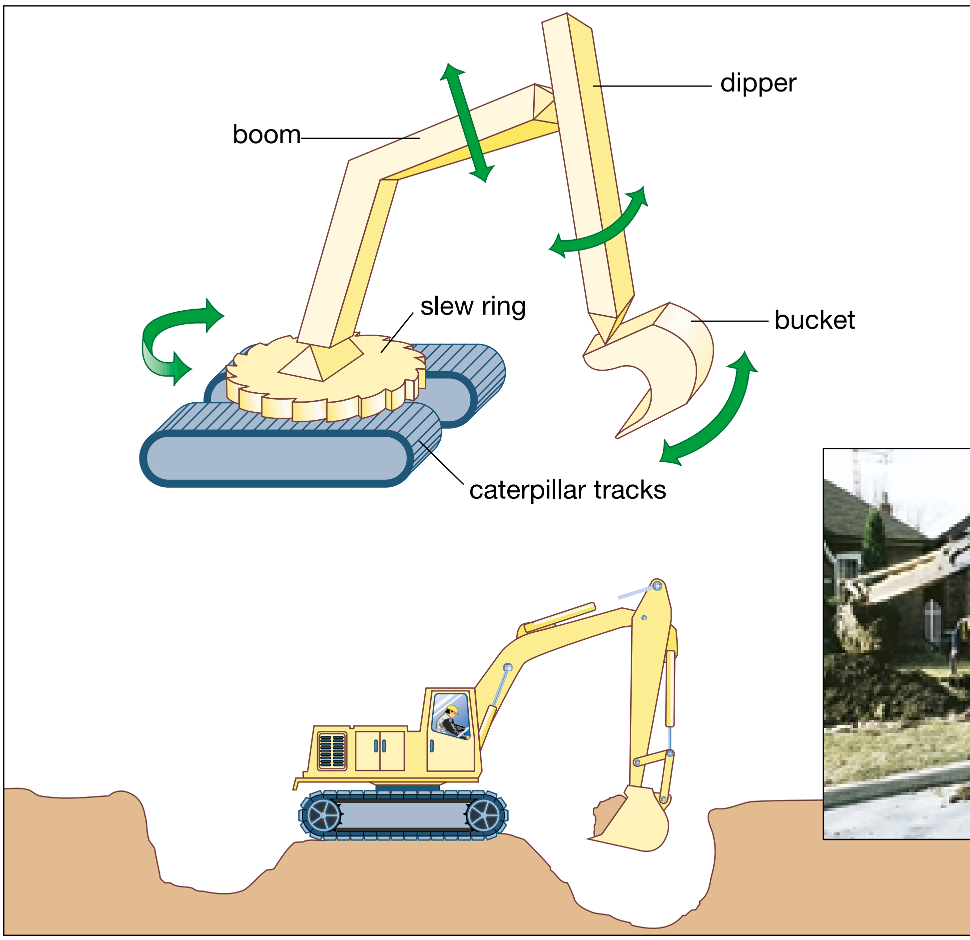


Figure 4.53A A backhoe is a rotating assembly of three levers combined with a hydraulic system.

Figure 4.53B Can you see two hydraulic devices on this backhoe?

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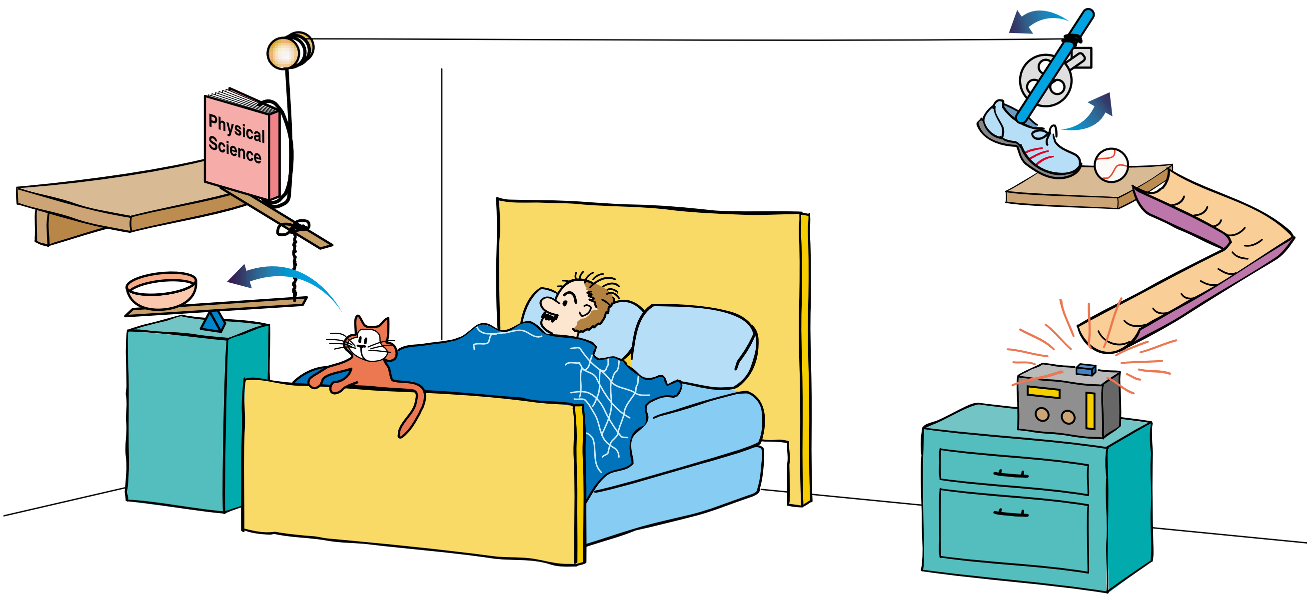
Search the Internet for machines that combine two or more subsystems. Visit the above web site, and go to **Science Resources**. Then go to **SCIENCEFOCUS 8** to find out where to go next. What machine combines a wheel and axle with a hydraulic system? Some pneumatic systems work in combination with levers. See how many combined subsystems you can find.

INVESTIGATION 4-I

How Silly Can It Be?



Think About It

Are machines always practical? Sometimes mechanical systems are designed just for the fun of it. In the twentieth century, the cartoonist Rube Goldberg drew many pictures of ridiculously elaborate machines for doing everyday tasks, often with unexpected parts like old boots or broomsticks. His cartoons became so popular that "overdesigned" and accident-prone machines in real life are still called "Rube Goldberg™ devices."

Look at the Rube Goldberg™-type device in this picture. Could a machine like this work if you built it?

What to Do

1. Try to figure out, step by step, how the device in the picture works. Which step do you think is the most likely not to work?

2. Now design your own Rube Goldberg™-type device on paper. It might open a door when someone rings the bell, stir a cooking pot, dress someone in a hat and scarf, or even do several tasks at once. Make sure your design has at least four distinct steps, and try to use as many different types of machines — levers, winches, pulleys, ramps, wheels and axles, pneumatic or hydraulic systems — as you can.

Analyze

1. List the different kinds of machines in your device, in order of use.

2. Describe in writing how your device works, step by step.

3. Exchange your written description with a partner, and see if your partner can follow the operation of your device.

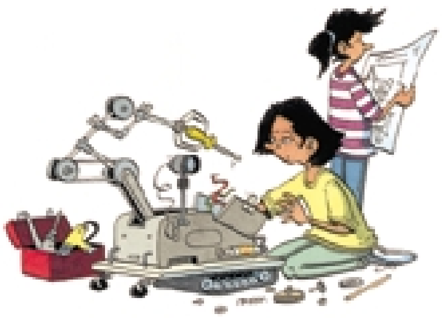
4. **Apply** After receiving your teacher's approval, try to build a simple version of your device, and see if you can get it to work.

PROBLEM-SOLVING
INVESTIGATION 4-J

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

New, Improved Robots Required!

You are an engineer for a company specializing in the research and design field of robotics. Robots are made using a combination of simple machines. Your company has been approached to design new and improved robotic devices to handle hazardous wastes.



Challenge

Use the scientific knowledge you have gained in Topics 1–6 to design and build a robotic arm that can transport hazardous waste in containers to a loading area.

Safety Precautions

- A glue gun is hot and the glue remains hot for several minutes.
- Be careful when using tools such as saws and hand drills.

Materials

jinx wood (1 cm × 1 cm)
dowelling (3 different diameters)
plywood platform (12 cm × 15 cm)
assorted wood screws, nuts and bolts, handles, gears, pulleys, winches, wheels, tubes, modified syringes, glue gun, saws, mitre box, small tools (e.g., a hand drill)

Design Specifications

A. You provide the power for the robotic arm.

B. Your robotic arm must be able to pick up a container and move it a minimum of 10 cm to the drop-off location.

C. The movement of the robotic arm described in A above must be completed in 1 min.

D. The robotic arm must be able to move up and down as well as side to side.

E. The robotic arm must have an operational jaw mechanism.

F. Three different mechanisms must be combined in the working prototype (model). These mechanisms must be chosen from the following list: gears, pulleys, cranks, wheels, hydraulics, and pneumatics.

G. Students may not touch the mechanism or the load directly at any time during the pickup, transport, and unloading.

Plan and Construct

1. Plan and sketch your team's solution on paper before beginning construction, and show it to your teacher.
2. How will the robotic arm manoeuvre and stop?
3. How will the simulated hazardous waste be picked up, transported, and unloaded?
4. Does the mechanism balance with and without the load?

Evaluate

1. How well did your team co-operate in arriving at the best solution using the design specifications?
2. How did sketches, planning, and experimentation lead to a successful design?
3. Did your team make efficient use of materials and time, and follow safe, tidy work practices?
4. How well did your prototype demonstrate good design principles?

Across Canada

Inna Sharf

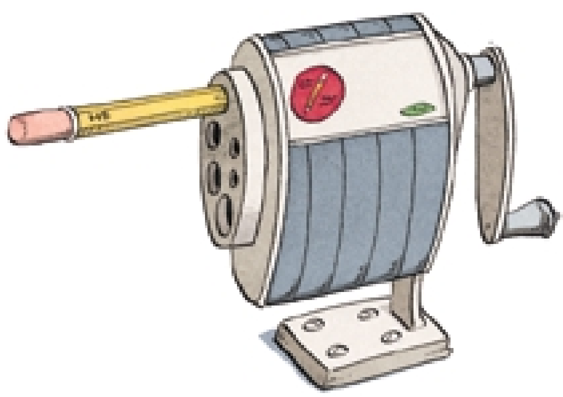
"My work involves simulation, modelling, and control of robotic systems for space applications, such as the Canadarm," explains Inna Sharf, professor of mechanical engineering at the University of Victoria in British Columbia. "The conditions in space are very different from those on Earth. With no gravity and a great deal of friction in a space environment, it is important to simulate the conditions of space when testing new machines and specialized equipment. Anyone who is developing new space technology depends on simulation tools to test whether a particular technological device will work effectively in space.

"I develop computer models to predict the motion of robotic systems in a space environment," Dr. Sharf adds. "We develop methods to ensure more precise control and manipulation of robotic arms in space," she says, describing the work of her research group at the Space & Subsea Robotics Lab. The focus of this group's research is primarily the needs of the Space Shuttle and International Space Station programs now underway. Many of Dr. Sharf's projects have been developed co-operatively with a Canadian aerospace company that makes advanced technology systems, including robotic machines for use in space.

Dr. Sharf says she enjoys "thinking about challenging problems and generating new results." She also enjoys interacting with her students.

TOPIC 6 Review

1. Describe the subsystems in the pencil sharpener shown here.



2. Apply Explain how brakes in an automobile work. Use a diagram in your answer.

3. Apply Design and sketch a mechanical system that uses a pulley or a lever in combination with a hydraulic or pneumatic device. Label the subsystems in the device.

4. Thinking Critically Formulate your own question related to how subsystems function in a mechanical device and explore possible answers.

Wrap-up TOPICS 4-6

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

force
area
pressure
Pascal's law
hydraulic lift
closed system
hydraulic systems
pneumatic systems
valve
pump
subsystems

Reviewing Key Terms

1. Which of the key terms best matches each of the following words or phrases?
   (a) force per unit area (4)
   (b) change of pressure is transmitted evenly throughout a fluid (4)
   (c) circulatory system (5)
   (d) unit of pressure (4)
   (e) provides a mechanical advantage (4)
   (f) brakes in a vehicle (6)

Understanding Key Concepts

2. What hydraulic pump generates the pressure to force hydraulic fluid through 100 000 km of tubes? (5)
3. What is the main function of your body's pneumatic system? (5)
4. Restate Pascal's law in your own words. (4)
5. When you squeeze some toothpaste onto your toothbrush, you are applying Pascal's law. Give some other everyday applications of Pascal's law. (4)
6. List four parts of an airplane that are controlled by hydraulic systems. (5)
7. List two differences between hydraulic and pneumatic systems. (5)
8. Describe four machines or instruments that use pneumatic systems. (4, 5, 6)
9. Explain how a hovercraft works. (5)
10. Name several careers in which fluid pressure plays a role. (4, 5, 6)

TOPIC 7
Machines Throughout History

Figure 4.54 If you had taken a trip in Canada in the 1800s and early 1900s, you might have travelled on a steam locomotive similar to the one pictured here.

Off the Wall

Many people feared the first steam-powered trains. In England in 1829, a locomotive called the *Rocket* won a race at a speed of 47 km/h — unbelievably fast for that time! In the nineteenth century, some people believed it was dangerous for humans to travel faster than 20 km/h.

To power this train, a railway worker called a "stoker" shovelled coal into the furnace to keep the train moving. In a locomotive, burning coal heats water in the boiler. The water in the boiler turns to steam, which turns the gears, which move the wheels. Without the power of steam — the gas into which water is changed by boiling — the train could not move. You rarely see locomotives like this anymore, except perhaps in museums or on display. However, the motion of cars, trucks, ocean liners, and many other vehicles is based on the same scientific principles as the motion of a locomotive.

The invention of the steam engine in the late eighteenth century was an important milestone in the history of science and technology. In a **steam engine**, fuel such as coal or wood is burned to heat water in a boiler outside the engine. The water changes to steam and drives the engine. The invention of the steam engine led to many changes in transportation technology and also in the way that we manufacture goods. For example, people used to weave cloth on looms in their own homes. When large, steam-powered engines became available, these workers moved to large factories in cities.

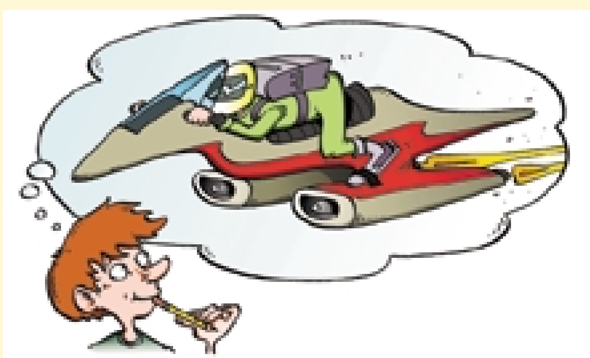
We don't use steam locomotives anymore, but we do use other types of engines in our cars, planes, and trains. In the Find Out Activity on the next page, you will look at how transportation has changed over time in response to changes in our understanding of science and technology.

Figure 4.55 How have modes of transportation changed as our understanding of science and technology have changed? What has replaced the vehicles shown here in the modern world? What changes in scientific understanding, in knowledge of materials, and in society might have prompted these changes?

Find Out ACTIVITY

Travelling Time

How have the methods of travel changed in the area where you live? How have our lives changed as means of transportation have changed?



Materials

large sheet of paper (poster size)

coloured felt markers

Procedure ✷ Performing and Recording

1. Use a coloured marker to divide your sheet of paper into nine sections (three rows and three columns).
2. In the first box in the left-hand column, describe how you got to school today. In the next two boxes in this column, describe something that you did recently that meant that you had to use a form of transportation. For example, *Drove to the mountains to hike* or *Went to a movie on the subway* or *Flew to Vancouver for a vacation*. Indicate how long it took you to get to your destination.
3. In the three boxes in the middle of your page, describe how these activities would have been done 100 years ago. You can ask your grandparents or older friends and relatives for help.
4. In the three boxes on the right side of your page, predict how these activities will be done 100 years from now.

What Did You Find Out? ✷ Analyzing and Interpreting

1. How did the options for transportation affect work and recreation in the past? For example, would people have travelled great distances for their entertainment or work, or would they have worked and relaxed closer to home?
2. How does the way you get to school differ from the way your parents and grandparents got to school?
3. How do technological inventions such as the Internet affect how you might attend school in the future?

Putting Steam to Work

This hot-air balloon works using a basic scientific principle — warm air rises. From this simple understanding, people began to develop many mechanical devices and even experimented with flying machines. When Thomas Savery developed the first practical steam engine in 1699, he expanded on this basic understanding. He heated water to a very high temperature to make steam. The steam was then used to perform tasks such as moving a piston. As you can see in Figure 4.56, a **piston** is a movable disk or platform that fits inside a closed cylinder. When this piston moves, it causes an attached rod to move. The rod, in turn, is attached to another part of the machine such as a crankshaft in an engine.

Why do you think the inventors of early steam engines used steam rather than liquid water to drive their engines?

If you poured 100 mL of water at 4°C into a measuring cup, then heated the water to 100°C, the volume of water would expand to 104 mL. An increase from 100 mL to 104 mL is quite small. What would happen if you continued to add heat to the water until it boiled? When water boils, it changes from a liquid to a gas.

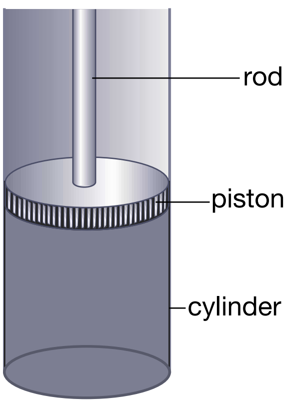


Figure 4.56 This simple diagram shows how a piston works.

If the entire 100 mL of water boiled into steam at 100°C at atmospheric pressure, it would expand to about 170 000 mL. In other words, when you convert liquid water into a gas, the volume increases to 1700 times its original volume! If you then heat the steam to 200°C, the volume would continue to increase to more than 200 000 mL, or 2000 times its original volume.

The expansion of a liquid to such extreme temperatures that it turns to a gas can be used to do work and to drive machines such as the steam engine.

Steam engines were not the first mechanical devices to run on steam. Heat-operated mechanical devices have existed for a long time. About 150 B.C.E., for example, Hero of Alexandria in Egypt wrote a book describing many mechanical devices. These devices used gears, wheels and axles, pulleys, hydraulics, and pneumatics.

Off the Wall

One of Hero's devices is shown here. The machine combines pneumatic and hydraulic systems. In this device, the pedestal and the altar were sealed and connected only by a tube. Observers could not see the connecting tube, nor could they see the tubes running from the pedestal up through the statues to the bowls they are holding. The pedestal was filled from the back with water and then sealed as well. A fire lit on the altar heated the air sealed inside. As the heat increased the air pressure in the altar, the air moved through the connecting tube into the pedestal. What would this increased pressure do to the water in the pedestal? What would happen to the fire? Imagine what it would be like to witness Hero's altar in action if you didn't understand hydraulics and pneumatics.

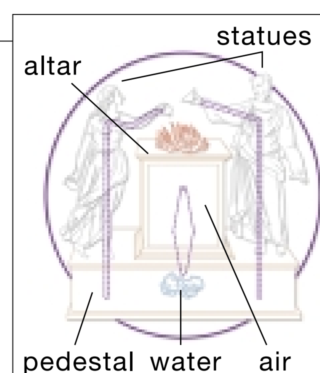


Figure 4.57 This photograph shows a replica of a paddle-wheeled steamboat docked in Edmonton.

The invention of steam engines led to innovations in transportation. At one time, steamboats were an important means of transportation in Canada. For example, from 1836–1957, more than 3000 steamboats travelled along the rivers and coasts of British Columbia and the Yukon, carrying gold seekers between the two regions. Incredible as it may seem, for a time, a fleet of steamboats supplied the Canadian West (see Figure 4.57). These steamships became a common sight in what many people assumed was a landlocked prairie. By 1879, seventeen ships travelled regularly on the North Saskatchewan, the South Saskatchewan, the Assiniboine, and the Red rivers. These steamboats transported the materials of the fur trade, as well as pioneers and farming equipment for the new society springing up on the Prairies.

Exactly how does steam cause a paddle wheel to turn? Under high pressure, steam flows into the right side of the cylinder, as shown in Figure 4.58. The steam expands and pushes the piston to the left. At the same time, an **exhaust valve** on the left side opens to allow old, cooled steam to escape. Then the exhaust valve switches to the right side and steam enters the left side, pushing the piston to the right in the cylinder. As the process repeats itself again and again, the piston moves back and forth. The rod of the piston is attached to gears and levers that do work. In a steamboat, the gears turn a paddle wheel that pushes against the water and propels the boat forward.

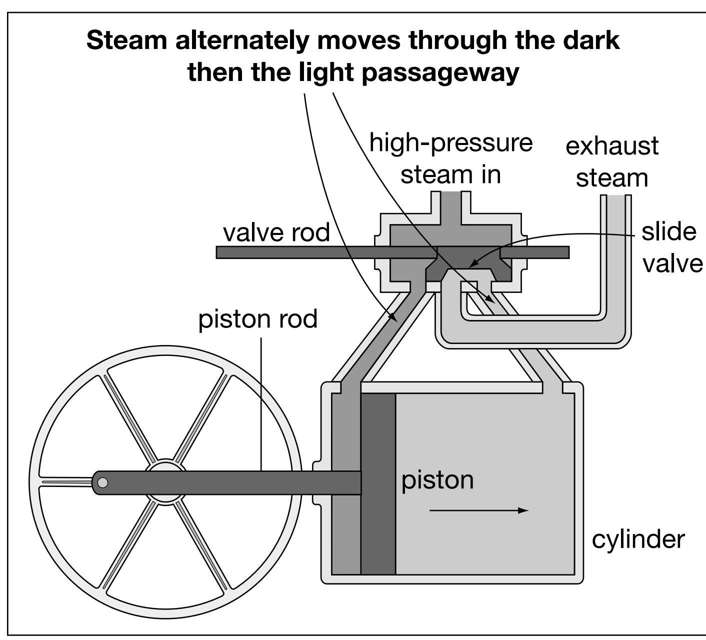
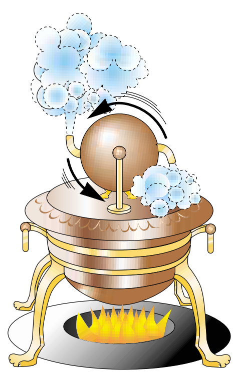


Figure 4.58 Steam under high pressure operates pistons to turn a paddle wheel.

DidYouKnow?

The first record in history of a wheel turned by steam is found in the writings of Hero of Alexandria. Hero described what appeared to be a toy. The toy had a pot filled with water that was closed with a lid. A pipe ran from the lid to the inside of a hollow wheel. Bent pipes were attached to the edge of the wheel. When placed over a fire, the water in the pot began to boil. Steam was driven up the pipe into the hollow wheel. As the steam escaped through the bent pipes, the pressure of the steam caused the wheel to rotate.



Turning Wheels

Figure 4.59 Steam powers huge ocean liners that can carry thousands of passengers at a time. This cruise ship is entering Burrard Inlet in British Columbia.

Paddle-wheeled riverboats are rarely seen today, but steam still propels most ocean liners, such as the one shown in Figure 4.59. In these huge ships, steam does not drive pistons up and down. Instead, the steam turns large turbines. A turbine is a rotary engine used to convert the motion of a fluid into mechanical energy. It consists of a number of fan blades attached to a central hub (see Figure 4.60). The blades rotate when steam moves past them at a high speed. The spinning turbine is attached to an axle that turns giant propellers. These propellers drive the ocean liner through the water.

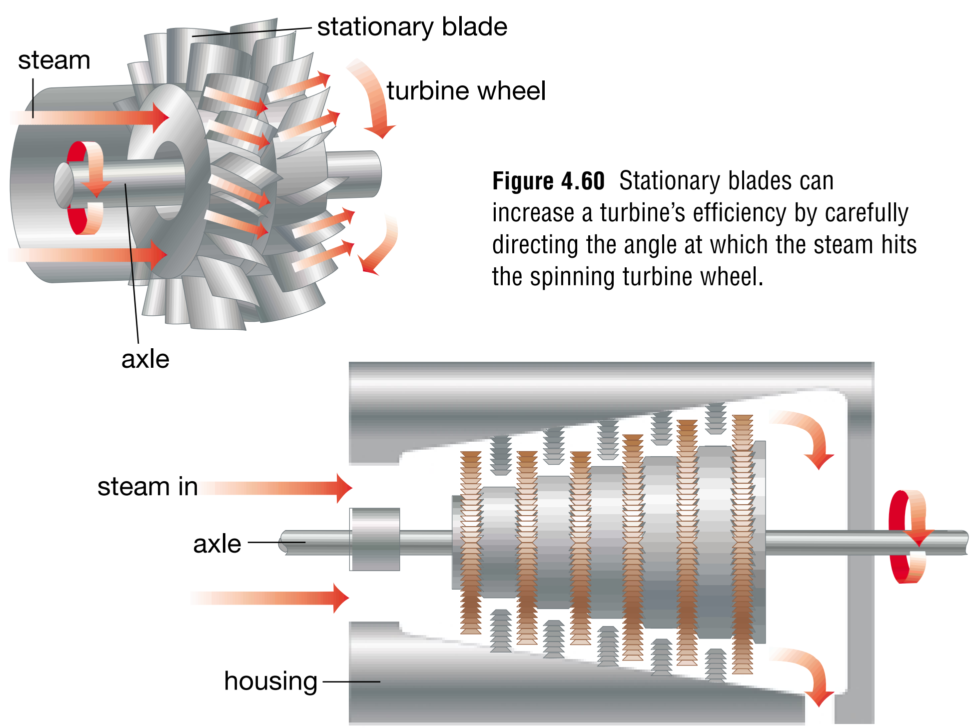


Figure 4.60 Stationary blades can increase a turbine's efficiency by carefully directing the angle at which the steam hits the spinning turbine wheel.

Turbines turn more than toys or propellers on ships. They are used in jet engines, and they turn shafts that operate many machines. Turbines also provide electricity. In thermo-electric generating stations, burning coal is used to heat water to steam. In other cases, nuclear reactors heat the water. In still other cases, turbines are powered by moving water to generate hydro-electric power.

Find Out ACTIVITY

Build a Model Steam Turbine

Watch the power of steam in action!

Safety Precautions

Use care when pushing the wire through the bleach bottle.

Materials

3.6 L plastic bleach bottle

coat hanger wire

scissors

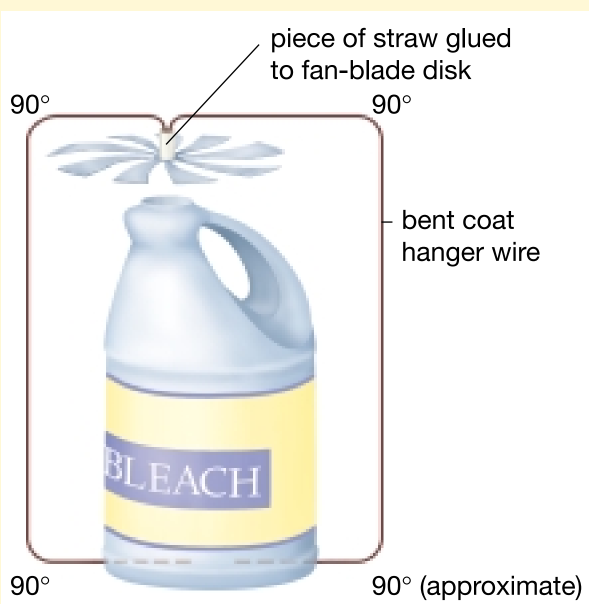
kettle with boiling water

drinking straw

glue gun or tape

Procedure ✷ Performing and Recording

1. Remove the top from the bleach bottle. **CAUTION** Make sure the bottle is very clean.



2. Cut out the bottom of the bottle. **CAUTION** Be careful when using the scissors. Cut this bottom piece into fan-shaped blades, like a windmill, as shown.

3. Bend two pieces of coat hanger wire into a square-shaped frame. The frame should be large enough to allow the fan blades to turn within it.

4. Poke the end of each length of wire through the bottom of the bleach bottle. Then insert a piece of a drinking straw over the two top ends of the wire, as shown.

5. Glue or tape the fan-blade disk to the piece of straw (not to the wire), so the blades will not flop back and forth.

6. Using the handle of the bleach bottle, hold your turbine over a steaming kettle. **CAUTION** Wear heat-resistant safety gloves and do this only under your teacher's supervision to avoid a severe burn. Alternatively, your teacher can hold the bottle carefully over the steam.

What Did You Find Out? ✷ Analyzing and Interpreting

1. What did you observe when you held the bleach-bottle turbine over the steam?

2. **Apply** The water in the kettle was heated by means of a coil that conducts heat. What is the source of the heat that converts water into steam to turn the turbine in a thermo-electric generating station?

Pause & Reflect

In your Science Log, draw an illustrated time-line showing the development of the use of fluid pressure, including:

- an early example from ancient literature, where steam pressure was used to operate a device
- first useful steam engine
- improvements in steam engines
- use of steam turbines
- first use of internal combustion engines

Burning Inside

Think for a moment about the size and the weight of the parts of a steam engine. A steam engine requires a furnace, coal or wood for fuel, a large boiler with a lot of water, and, finally, the actual engine and its pistons. If you could eliminate the furnace and the boiler, the engine would be much smaller and lighter. The desire to improve the steam engine's efficiency led to the development of the **internal combustion engine** in Germany in 1876. The term "internal combustion" describes the way the engine works. The combustion, or burning, of fuel occurs internally, that is, *inside* the engine. No external furnace, boiler, or water is needed. The fuel, gasoline, is burned right inside the cylinders.

Internal combustion engines usually have four, six, or eight pistons and cylinders. Each piston goes through the steps shown in Figure 4.61, but each piston does not carry out the same step at the same time. The diagram follows one piston through a cycle. The entire cycle is repeated many times each minute.

Most automobile engines have pistons that move either up and down or back and forth. A part called a **crankshaft** changes this up-and-down or back-and-forth motion to rotary motion, which turns the automobile's wheels. The power to move the pistons comes from the energy released by burning gasoline.

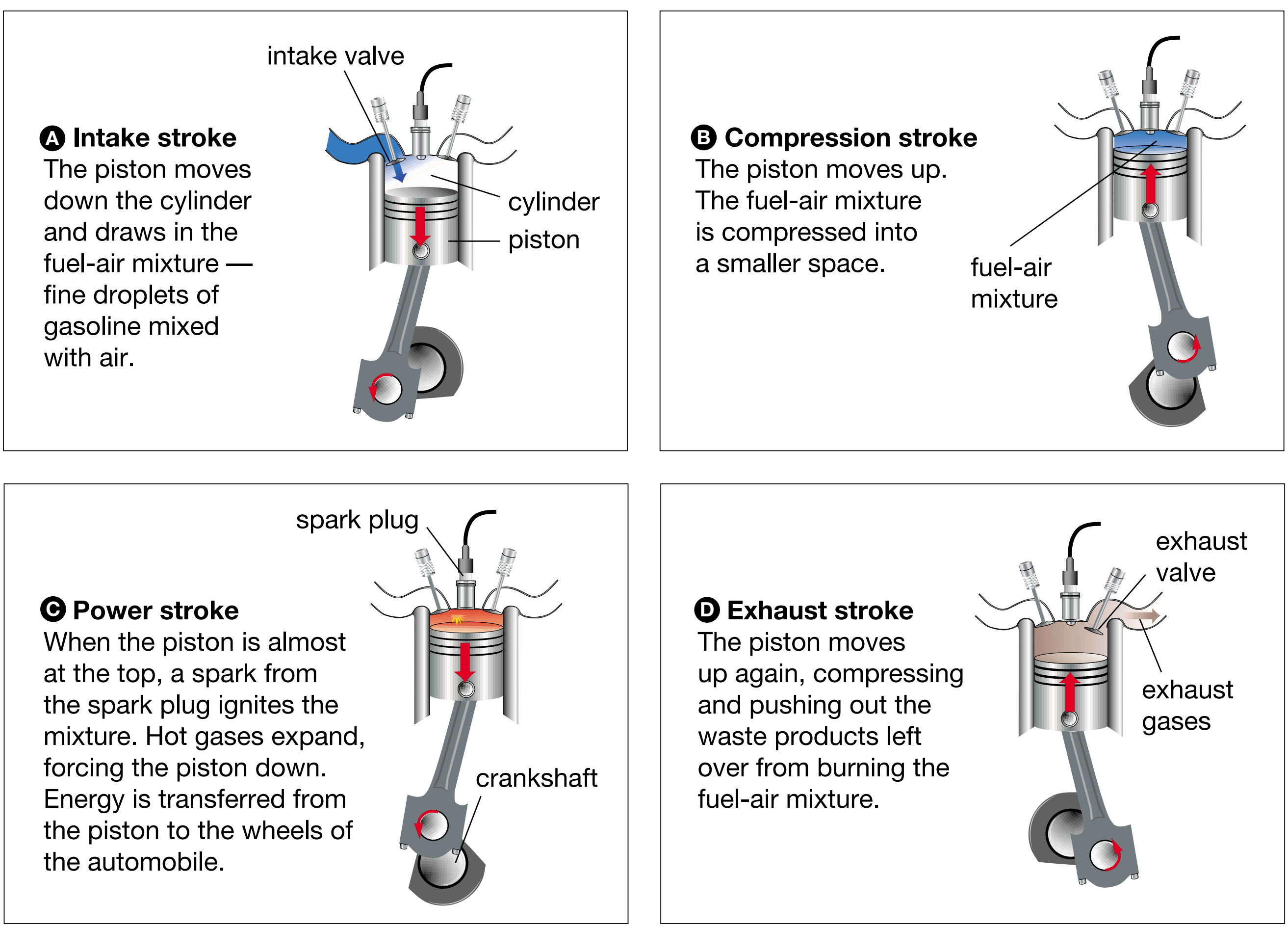


Figure 4.61 Automobiles move as a result of the transfer of thermal energy in their engines.

Taking Flight

Some of the earliest internal combustion engines were developed for use in aircraft. Steam engines were used in early cars, but they were too heavy and cumbersome for aircraft. The lighter, smaller internal combustion engine was ideal for a machine designed to fly. Although they have been around for more than 100 years, internal combustion engines continue to be tested and improved.

Examine the two aircraft in Figures 4.62A and B. Although they were built more than 70 years apart, they both use similar technology and shorten the travel time and distance between two places. The Silver Dart had a maximum speed of about 80 km/h, while the Space Shuttle can travel at 10 000 km/h. The Space Shuttle can orbit at altitudes of 1500 km, while the Silver Dart never flew above 100 m. These aircraft were both incredible inventions when they were designed. What do you think the aircraft of the future will look like?

People have always needed to travel. In ancient times, if their water supply dried up, a whole village would have to move to a distant location. Today we travel for many reasons. Science and technology have not changed our need to travel. They have simply provided more and faster ways to travel.

Figure 4.62B The Space Shuttle is a spacecraft that consists of a winged orbiter and booster rockets that propel the craft into space. About two minutes after lift off, the boosters use up their fuel, separate from the spacecraft and re-enter the atmosphere, where they are retrieved. After completion of the space mission, the orbiter reduces its speed, descends through the atmosphere, and lands like an airplane.

Figure 4.62A The Silver Dart was the first powered airplane flown in Canada. It was designed in 1909 by Canadian J.A.D. McCurdy, a member of Alexander Graham Bell's Aerial Experiment Association. To launch the plane, a horse-drawn sleigh pulled it over the ice of Baddeck Bay in Cape Breton. The plane rose after being pulled about 30 m, and flew at an elevation of 3 to 9 m and a speed of 65 km/h for 0.8 km.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

Industrialization and the internal combustion engine have created a threat to the environment — smog. Use the Internet to do research on smog and the internal combustion engine. How does smog affect trees and other plants? What health problems are caused by smog? What can be done to reduce smog? Visit the above web site. Go to **Science Resources.** Then go to **SCIENCEFOCUS 8** to find out where to go next. (Use your library if you do not have access to the Internet.) Work with a partner to produce a poster about smog and how to reduce it.

Find Out ACTIVITY

Against the Wind

How does air pressure affect flight? Try this activity to find out.

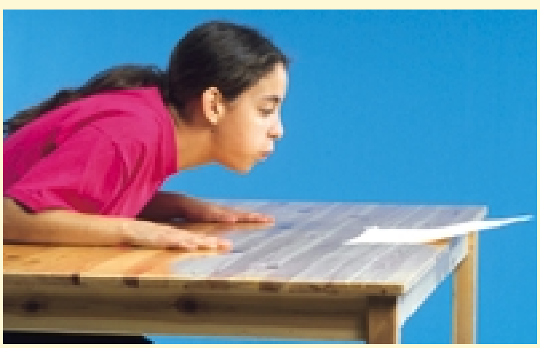
Materials

sheet of paper

tape

Procedure ✱ Performing and Recording

1. Tape a sheet of paper to the top of a desk so that the sheet hangs over the edge.
2. From across the desk, blow over the sheet of paper. Blow gently at first. Then increase the force of the air blowing over the paper. Observe what happens to the sheet of paper as you blow over it.



3. Remove the sheet of paper from the desk and hold it up in front of you. Blow into the middle of the page.

4. Observe what happens to the sheet of paper as you blow into the middle of it.

What Did You Find Out? ✱ Analyzing and Interpreting

1. Where was the air pressure greatest in each of these tests?
2. Which test was similar to flying a kite? Explain your answer.
3. Which test showed how an aircraft wing works?

Pause & Reflect

This timeline shows a few systems in which water has been collected throughout history. Do some research to find other methods that were once used. Ideas include aqueducts, water towers, waterwheels, and windmills.

Technology Timelines

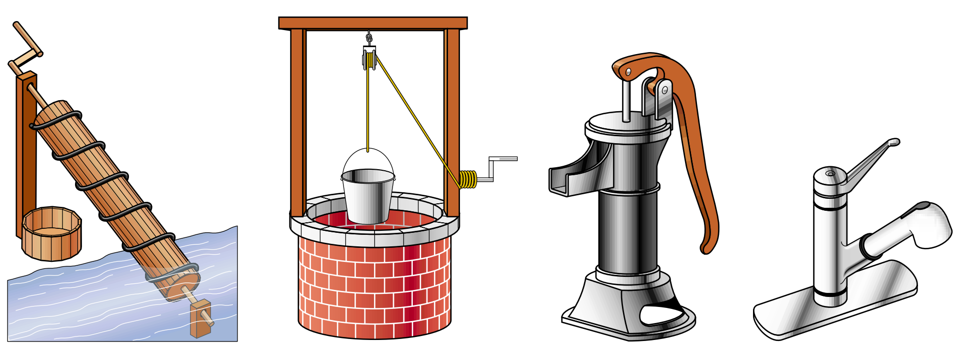


Figure 4.63 The ways in which we collect water have changed over time. Estimate when each of these methods came into popular use. Do research to find out how accurate your estimate is.

Humans, as well as all other forms of life, have always needed water to survive. Technology has made it much easier for us to meet that need. The timeline shown in Figure 4.63 shows how the technology for collecting water has changed over time. Similar timelines can be drawn for many of the mechanical devices we use today, from a can opener to a computer. Draw your own timeline for a mechanical device in the next activity.

Find Out ACTIVITY

Time for a Change?

How did people cut wheat or drill for oil 100 years ago? Choose one of these tasks, or one of your own and create your own technology timeline.

Materials

long sheets of paper

coloured felt markers

Procedure ✷ Performing and Recording

Choose a machine or mechanical system and draw a timeline showing how the machine or mechanical system has changed over time.

You could also choose a particular task such as washing clothes, and illustrate how this task has changed as science and technology have changed. Your timeline should include the approximate dates at which various changes occurred.

What Did You Find Out? ✷ Analyzing and Interpreting

Why do you think the technology you chose changed over time? In addition to scientific or technological reasons, decide whether any changes were made for societal or environmental reasons.

TOPIC 7 Review

1. Use a labelled drawing to explain how a piston in a steam engine works.
2. How does a steam turbine differ from a steam engine?
3. **Apply** Sometimes steam engines are called "external combustion engines." Explain what this term means by comparing it to "internal combustion engines."
4. **Thinking Critically** People have always needed to travel. Give two or three different reasons why.
5. **Thinking Critically** Explain how science and technology have changed human travel.

Skill FOCUS

For tips on how to design an experiment, turn to Skill Focus 6.

TOPIC 8 People and Machines

Science and technology have given us a variety of amazing machines that have made many of our daily tasks easier. Imagine the excitement of seeing the first "horseless carriage," the very first car. Not long after its introduction a large percentage of people owned cars and were able to travel farther and faster. Soon cars became larger and fuels became more efficient. The automobile seemed like an ideal machine until scientists discovered that the gasoline additive, lead tetraethyl, was polluting the atmosphere. The lead helped the gasoline to burn more efficiently but it caused health problems. The search was on for other ways to make gasoline burn efficiently. In Canada today, all vehicles use lead-free gasoline. However, other gasoline products pollute the air.

Automobile emissions are just one of many problems that our advanced machines bring with them. As you read this Topic, think about how the development of machines throughout history has brought pleasure and comfort to societies. Think also of the negative side. What kinds of problems and challenges do these technologies bring as well? How are we trying to meet these challenges? What types of choices must we make? What do we need to learn from past experience in order to make the future better?

Figure 4.64A The chemical Freon 12 was once the most common coolant used in refrigerators and car air conditioners. However, scientists discovered that Freon 12 contributed to the gases destroying Earth's ozone layer. Now, alternative coolants are used in refrigerators and air conditioners.

Figure 4.64B As cities grew larger and more people moved to suburbs far from their workplace, mass-transit systems such as this "Sky Train" were developed.

Pause& Reflect

In your Science Log, list and describe two other machines or mechanical systems that you think have changed as a result of changes in society or the environment.

The Industrial Revolution

The invention of the steam engine transformed society. No one can say for certain when the Industrial Revolution began. Simple machinery had been taking the place of hand labour since 1700. The water-driven spinning machine introduced in 1769, for example, could do the work of twelve workers. A combination of events in the late 1700s, however, transformed England and the world. First came James Watt's invention of an efficient steam engine in 1769 (see Figure 4.65A). A year later, Henry Cort developed a method of making iron using coal for fuel instead of wood. The iron to build machines and the engines to drive them led to the rapid development of mass-production industry. (**Mass production** is the manufacturing of large quantities of a standardized item by standardized mechanical processes. Modern examples include the manufacture of home appliances in a factory, the canning of foods in a food-processing plant, and the production of automobiles in an assembly plant.)

Within a few years, small towns such as Manchester and Birmingham in England became industrialized cities teeming with factories (see Figure 4.65B). Industrialization led to great social change. Unable to compete with the new factories, the spinners, weavers, and craftspeople from the villages flocked to the cities to find work. The transformation from a rural to an urban society had begun.

Pause & Reflect

Imagine that you are living in England in the late 1700s. Your family once spun and wove cloth in their home in a small rural village. Now you cannot sell your cloth because it is being made less expensively in large factories in the city. You and your parents must go to the city to work in these factories. Write a paragraph or draw a picture in your Science Log. Explain or show the ways in which you think the introduction of a new technology (the steam engine) and its use in factories might change the society and the environment around you.

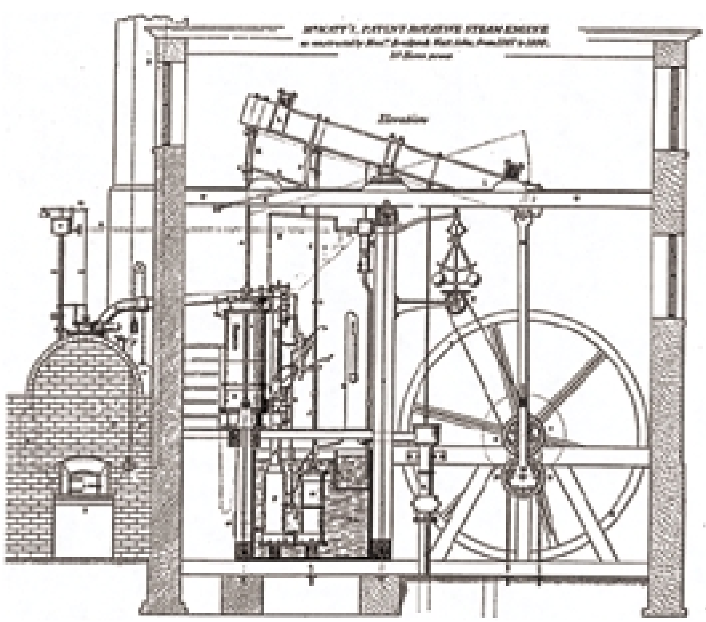


Figure 4.65A The plans for James Watt's steam engine. Watt's invention was one of the technological advances that gave rise to the Industrial Revolution in England.

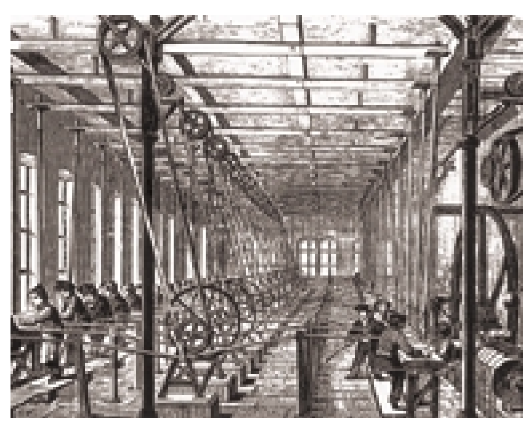


Figure 4.65B In the late eighteenth and early nineteenth centuries, factories were built in Europe to mass-produce goods, and people moved from farms to cities to find work. Children as well as adults worked long, hard hours in these factories.

Figure 4.66 Do you think we would have such large, sprawling cities surrounded by suburbs if we did not use our automobiles so much?

Which Came First?

The question of whether the needs or wants of society results in new technology, or whether new technology changes society, continues to challenge us. It is sometimes said, for example, that the oil industry is so large because of the demand for fuel to run automobiles. However, some people also say that the reason we have so many cars and use them so often is because of the low price and abundance of gasoline. We can build large cities because it is possible to get around in them so easily using automobiles. Even in our largest cities, people travel from one end to the other to get to work and back home again. One hundred years ago it would have taken half a day to make the trip one way. Do you think cities are so large because we have vehicles, or do you think we have vehicles because our cities are so large?

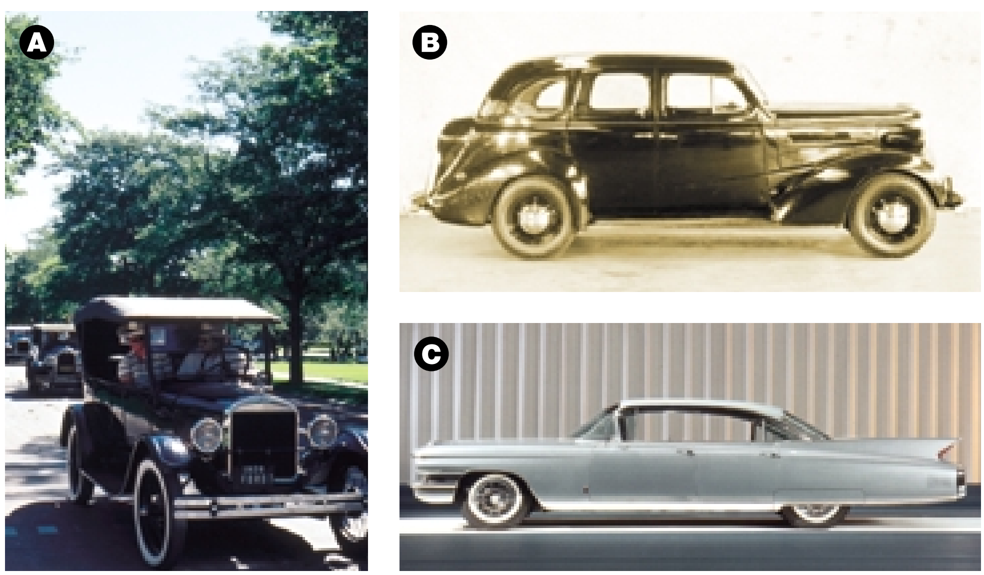


Figure 4.67 These cars were built before there was concern over the effect of air pollution from vehicle exhaust.

All the vehicles in Figure 4.67 were popular at a time when people thought fuel was unlimited and that the atmosphere could absorb all of the pollutants entering it from industry and car exhausts. In the 1970s, scientists began to inform people about a shortage of fuel and the negative environmental effects of fuel combustion. As a result, many people's attitudes changed, and so did their choice of vehicles. Look at the newer models of vehicles in Figure 4.68. What are the obvious differences between the older models in Figure 4.67 and these newer models?

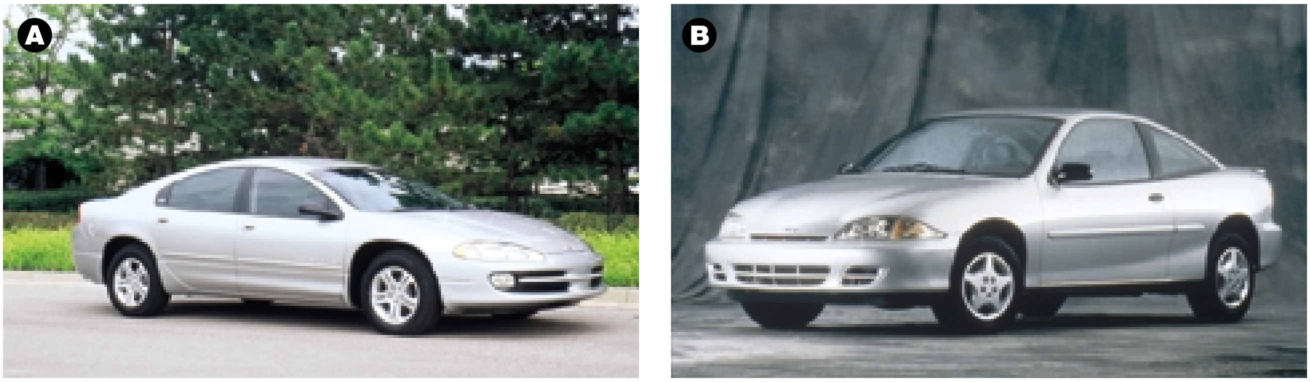


Figure 4.68 In the last thirty years, car motors have become smaller and cars have become more aerodynamic. Inventions such as fuel injection and catalytic converters have become more widely used. These cars are more fuel-efficient and get better gas mileage.

Like the aircraft that you studied in Topic 7 and the cars you have examined here, vehicles are constantly being improved as experimental designs are tested. The vehicles in Figure 4.69 are alternatives to gasoline-powered vehicles. The racing car in Figure 4.69A uses solar panels to capture the energy of the Sun. Solar energy is stored in a battery in the car. The van in Figure 4.69B is powered by electricity. Most electrically powered vehicles can travel about 80 km before the battery needs recharging. The bus in Figure 4.69C is fuelled by a **hydrogen fuel cell**. This cell fuels a chemical reaction that uses hydrogen and oxygen from the atmosphere to make electricity. The only exhaust from this bus is water that is clean enough to drink! Why do you think these vehicles are not widely used?

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

A Canadian company, Ballard Power Systems, developed the hydrogen fuel cell. To learn more about this company and the hydrogen fuel cell it produces, visit the above web site. Go to **Science Resources**, then to **SCIENCEFOCUS 8** to find out where to go next. In your notebook, draw and label a hydrogen fuel cell.

Figure 4.69A A solar-powered racing car

Figure 4.69B Electricity powers this van.

Figure 4.69C This bus is fuelled by a hydrogen fuel cell.

What Is It For?

When you set out to design a new technology or improve an existing one, you must start with a clear understanding of what it is you want the technology to do. This means that you must be very specific about the task you wish to accomplish. For example, at one time, all rail cars were either flat decks, or boxcars. These types of cars had limited uses. Today, rail cars are specifically designed for different tasks. Examine the rail cars in Figure 4.70 and try to determine the specific use of each one.

Each type of rail car is constantly evaluated by the people who use and design them to ensure that they are performing the tasks they were designed to do. Scientists and technicians must always ask questions, evaluate their work, and decide if changes need to be made.

Sometimes scientists have to ask themselves difficult questions. They often have to weigh the positive and negative effects of a technology or a new discovery. We may have the scientific understanding and the technological know-how to design something, but should we do it? For example, many people feel that we should not use nuclear power to generate electricity even though we know how to make and use this form of energy. While this technology is actually quite clean and causes little pollution when it is working properly, accidents at nuclear power-generating plants can have devastating effects on both society and the environment.

There are times when you need to answer questions responsibly and consider how your choices might affect society or the environment. You often do this when you purchase something. Do you own an item that features much more technology than you will ever need? Do you ever consider the energy required to make something that you own? What kinds of materials were used to make this product? Where did these materials come from? Does the product generate any waste? In the next activity, you will evaluate a mechanical device to determine whether its production and operation had any environmental or social costs.

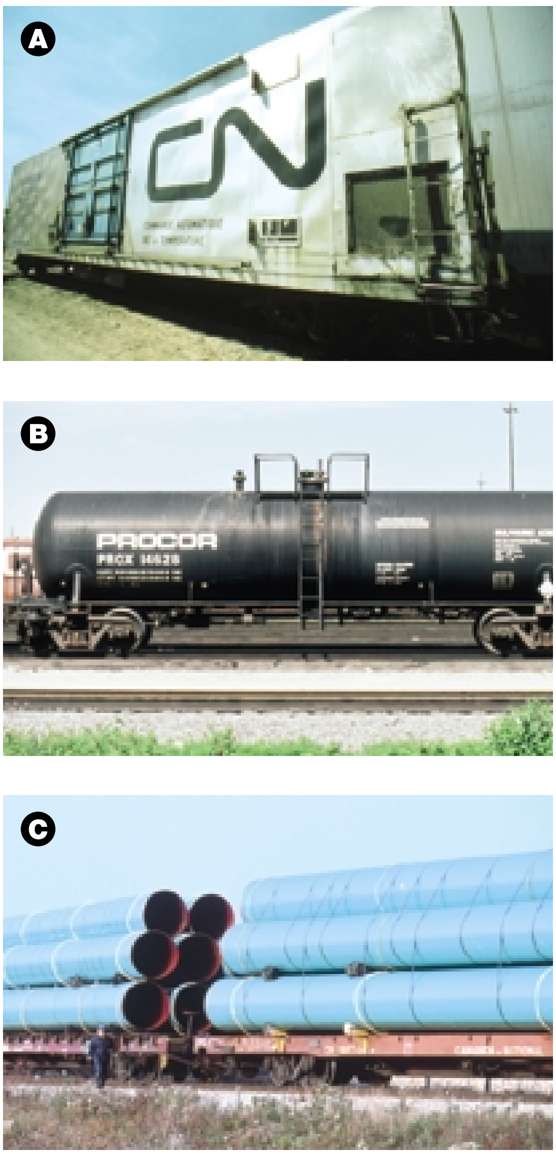


Figure 4.70 Rail cars are designed for specific uses.

Skill FOCUS

For tips on scientific decision making, turn to Skill Focus 8.

INVESTIGATION 4-K

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

The Real Costs

Think About It

When you consider the cost of an item, you usually think of its price tag. Costs can also apply to other things, such as the cost to society or the environment. Think of the bicycles that we use today. Do we need bicyles that have so many gears and special features, or do we own something that has much more technology than most of us will ever use? We usually think of bicycles as being good for the environment since they don't produce pollution when they are being used. Of course this is true. We should also consider, however, how a product is made and what happens to it when it is no longer needed.

What to Do

1. In a group, create an evaluation form that you can use to compare two different bicycles. You will need to include:
   - the purpose of the bicycle (e.g., commuting to school, racing, trail riding, etc.),
   - where the bicycle is ridden,
   - any important design and safety features (e.g., number of gears, modifications to seat, handlebars, etc.), and
   - other questions that you think are important to ask.

   You must also include questions and criteria to evaluate whether the device is meeting the purpose for which it was purchased. Devise some questions to determine how the bicycles might affect society and the environment in both positive and negative ways. (Hints: Consider whether mountain bikes are ridden on trails; if people spend more money on bicycles than they can afford; if people are riding their bikes instead of driving or taking a bus; if they own a bike that can do more than they actually need it to do; or, if they own a new bike when their last bike was perfectly adequate.)

2. Use your form to evaluate two different bicycles. Try to examine two bicycles that are quite different, such as a mountain bike and a road bike. Revise your evaluation form if necessary.

Analyze

1. Explain how the two bicycles you evaluated affect society and the environment, either positively or negatively.

2. Why is determining the purpose of a mechanical device so important when you evaluate the device?

Designed for Comfort

One of the features you might have evaluated in the previous investigation was the comfort of each bicycle's seat. If you have ever attended a sporting event or a concert, you will know how uncomfortable some seats can be.

The fans in the cartoon have found a way to make watching a sports event more comfortable. What do the cushions do to make sitting easier? How do inventors use their understanding of scientific concepts to design a more comfortable seat? The answer lies in the relationship between force, area, and pressure that you learned about in Topic 4. Think about the difference between sleeping on the ground and sleeping on an air mattress. Why is an air mattress more comfortable? The activity below gives you a chance to test your answer.

Find Out ACTIVITY

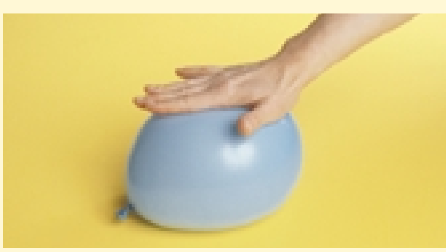
Flat Out

Materials

balloon

Procedure ✸ Performing and Recording

1. Inflate the balloon until it is about half full. It should be soft enough so that you won't pop it when you poke it with your finger.
2. Press on the balloon with the palm of your hand. Observe what happens to the balloon.



3. Using the same force, press on the balloon with the side of your hand. Observe what happens to the balloon.

4. Using the same force, press on the balloon with one of your fingers. Observe what happens to the balloon.

What Did You Find Out? ✸ Analyzing and Interpreting

1. Which method of pressing on the balloon could you do for the longest time without feeling tired or uncomfortable?
2. Explain why an air mattress can support you off the ground when you lie on it, but it won't support you off the ground if you are on your knees or are standing on it.
3. Why do you usually change positions often when you sit in class or when you are sleeping? What would happen if you didn't move frequently?

The Science of Comfort

Topic 1 introduced the science of ergonomics. When ergonomic researchers discover something that increases the comfort or efficiency of a particular item, technicians are quick to build, test, and market the changes.

Figure 4.71A A "pregnant" crash-test dummy is being used to test seat belts.

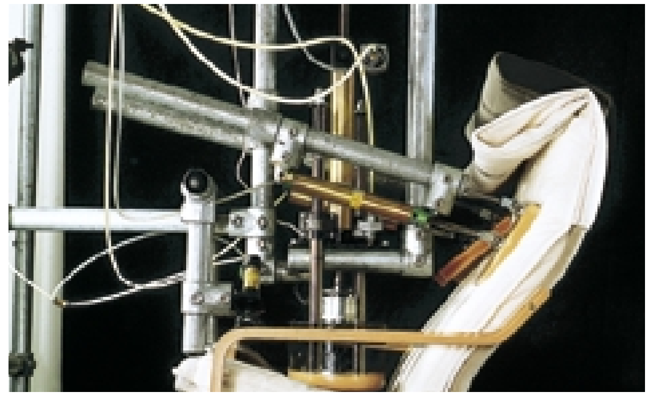


Figure 4.71B This chair is being product-tested to determine its strength and durability.

The testing systems shown above are designed to provide scientific information to researchers. This allows them to decide what type of safety belt or chair is the best for its designed purpose. Comfort is often something that is evaluated when a device is tested. Sometimes people must spend long periods of time in one position. Look at the wheelchairs on the right. How have the wheelchairs changed over time? Do earlier models look comfortable? Recent improvements in wheelchair design were made as a result of ergonomic research. Today, there are also many types of specialized wheelchairs. Thanks to advances in the design and comfort of wheelchairs, people who use wheelchairs are able to take part in sports such as basketball and track and field.

Modifications in wheelchair design reflect how changes in society can produce changes in science and technology. Not long ago, for instance, people who use wheelchairs had limited access to many buildings and activities. Today, because people with disabilities have spoken out, and because society is much more concerned about the rights of people with disabilities, there have been many technological advances. Now, we see wheelchair ramps, specially designed washrooms, doors that open automatically, hand-operated vehicles and bicycles, and many other technologies that give people in wheelchairs greater freedom.

In this Topic, you have learned how machines and mechanical systems have changed over time and how changes in society and the environment have prompted changes in science and technology. Not so long ago people had never heard of compact discs, or personal computers, or cellular phones. What changes might lie in the future?

Figure 4.72 Ergonomic research has improved wheelchair comfort.

Looking Ahead

Designers adapt wheelchairs to suit different needs and different activities. Now you have the chance to adapt or redesign a tool to help people with different needs. Turn to the Unit 4 Project on page 354.

Career CONNECT

Putting the Wheels in Motion

A number of companies in North America manufacture wheelchairs. No one design is suitable for every person and every use, so they build many types. Most of the wheelchairs are designed by mechanical or manufacturing engineers. These people have the specialized knowledge for the job. They know how to position the parts so the chair won't tip. They know what size and type of motor can provide appropriate speed, and so on.

Not all wheelchairs were developed by these manufacturing professionals, though. Some chairs have been designed by teams of students in universities or colleges. Some were designed by experts in rehabilitation medicine. A few universities and learning institutes offer courses and programs in rehabilitation engineering that teach about wheelchair design. Some wheelchairs have been designed by people who use them. Two paraplegic men who love basketball decided to build a good, economical sports wheelchair. A quadraplegic man wanted to travel down the bumpy hill to the river beside his house, so he designed a specialized chair that could take him there. These people needed products that no manufacturer had developed, so they developed them themselves.

Do some research to find out about courses in rehabilitation medicine or rehabilitation engineering that are offered at Canadian colleges, universities, and other learning institutes.

TOPIC 8 Review

1. Explain how science has been used to improve the vehicles that we drive today.
2. What is the first step you must take when designing a new machine or redesigning an existing machine? In other words, what is the first question you must ask yourself about the machine you want to build?
3. Describe how people's understanding of the environment and the potential environmental impacts of emissions such as lead, as well as scientific knowledge, have caused changes in the vehicles that we drive.
4. Describe how changes in society's attitude toward people in wheelchairs may have led to changes in the wheelchairs available to people who need them. Were these changes made using science or technology or both?
5. **Thinking Critically** The relationship between science and technology is often called a "chicken and egg argument." (Which came first, the chicken or the egg?) Explain how science and technology are like the chicken and the egg.
6. **Thinking Critically** Give some examples showing how technology has improved our ability to study science.

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

steam engine
piston
exhaust valve
internal combustion engine
crankshaft
mass production
hydrogen fuel cell

Reviewing Key Terms

1. How does a steam turbine differ from a steam engine? (7)
2. What makes a piston move? (7)
3. Where would you find pistons? (7)
4. Explain the meaning of the words "internal" and "combustion" as they are used in the term "internal combustion engine." (7)
5. Describe how the Industrial Revolution made mass production possible. (8)
6. Describe the different types of exhaust that come from a steam engine, an internal combustion engine, and a hydrogen fuel cell. (7, 8)

Understanding Key Concepts

7. Steam engines and internal combustion engines both have pistons that go through an up-and-down cycle. State two ways in which the cycles for steam engines and internal combustion engines are different. (7)
8. Explain the relationship between air pressure and flight. How do aircraft take advantage of changes in air pressure? (7)
9. Explain how science and technology relate to one another. (7, 8)
10. Describe three differences between a mountain bike and a road bike. Explain why these differences exist. (8)
11. List three questions you would ask if you were given the task of improving the design of a shopping cart. (8)
12. Testing an idea using a computer model or a simulation is often better than actual testing. Look at Figure 4.71A on page 349 of your textbook. A crash-test dummy is one example of a test simulation. Describe when a simulation or model would be useful. Describe when a simulation or model would not be useful. (8)

13. Give three examples of how science and technology have helped to improve life for people with disabilities. (8)
14. Explain whether science or technology is responsible for most of the improvements in the mechanical devices that we use. (7, 8)
15. List two mechanical devices that have changed because of environmental concerns. (7, 8)
16. List two mechanical devices that have changed because of societal concerns. (7, 8)

Ask an Expert

If you had to get someone out of an upside-down car that has been crushed in a collision, what tool would you use? Randy Segboer will tell you there is no simple answer to that question. As a firefighting instructor at the Alberta Fire Training School (AFTS), Randy trains firefighters and rescue workers in just about every skill they need to know. His specialty is rescue extrication — getting people out of dangerous situations.

Q How did you become a firefighting instructor?

A I was a mechanic for many years before I joined the fire service. I came to AFTS for specialized training as a firefighter, and later I became an instructor. I've been teaching here for three years now.

Q What do you teach students about rescue extrication?

A We teach them the proper use of tools at a rescue scene and give them hands-on experience in judging when to use each tool. We stage many kinds of rescue scenarios here at the school, and the students respond as though each scenario were the real thing.

Q Can you describe one of those scenarios?

A Let's say we have a car accident, a single-vehicle rollover, with an injured victim pinned inside the car. First, we have to stabilize the scene — make sure the car isn't going to roll farther, slide down a hill, or burst into flames. Next, we assess the victim's health and determine what's trapping the victim inside the car.

Q How do you decide which tools you will use to get the victim out?

A Unless a car door will open, we will have to force or cut some part of the car in order to get inside. It's important to use as little force as possible so that we don't make the situation worse, by causing the car to collapse, for example. So, we first try hand tools because they don't require any set-up time.

We may try to force open a jammed door using a leverage tool called a Halligan™. While one firefighter is prying with the Halligan™, others are setting up the next type of equipment in case the Halligan™ doesn't do the job. For many jammed doors, simple hand tools alone would take too long.

In this rescue simulation, Richelle Johnson, who is training to become an emergency services technician, uses a Halligan™ to pry a small opening in a jammed car door.

Randy shows Richelle how to use a heavy hydraulic spreader to force open a car door.

Q What type of equipment do the rescue workers try next?

A The next option is to use hand hydraulic tools. These are similar to a hydraulic car jack. We pump these tools by hand and the hydraulic action pulls or pushes apart two sections of the car. Hydraulic tools apply more force than a simple hand tool, but it takes two people to operate them. One person pumps to supply power while the other person manipulates the tool.

If the car door remains jammed, we move on to heavy hydraulic tools, which are powered by an engine or compressed air. Simple hand tools, hand hydraulic tools, and heavy hydraulic tools all do the same thing: push, pull, or cut. The advantage of the heavy hydraulic tools is their power and strength. In most situations, these tools get the job done.

Q If that is so, why not just use heavy hydraulic tools in every situation?

A Heavy hydraulic tools take time to set up. During that time, other workers might as well be trying the faster tools. Noise is another factor. The sound of the loud, heavy hydraulic tools can raise the victim's anxiety and blood pressure. Also, heavy hydraulic tools are extremely powerful. They apply a lot of force and when something finally gives, it gives in a big way. If you haven't correctly anticipated the point that will give, you may have made the situation worse.

Q Do you use any other kinds of rescue equipment?

A Rescue trucks and fire-pump trucks usually carry some pneumatic equipment as well, such as pneumatic wrenches, chisels, and jack-hammers. We also have airbags, which we place between the ground and a solid part of the vehicle. Then we inflate the airbag to raise the vehicle.

Our goal is to get the victim out as quickly as possible to improve chances of survival. Basically, we'll use anything that helps us achieve that goal.

EXPLORING Further

Tools of the Trade

Reread the information about the specific tools mentioned in this interview. For each tool, list as much information as you can, including

- the energy source
- any simple machine(s) involved
- advantages and disadvantages of using the tool in a rescue situation

Can you suggest other jobs that might use these same tools? List the jobs and compare your list with a classmate's.

Adapting Tools

Have you ever broken your arm and had it set in a cast? If so, you probably had trouble doing simple, everyday tasks. Opening a jar of peanut butter or styling your hair would be awkward with your arm in a cast.

Some people are born with conditions that make it hard to perform delicate hand and finger movements. Also, many older people do not have the strength to open a jar or a can. People with arthritis find it difficult to open bottles or jars with childproof lids. Common household utensils and tools are not usually designed for people with such physical challenges.

With the help of an occupational therapist, this woman is relearning how to use a knife after a hand injury.

A person who has arthritis is using a specially designed manual aid to open a jar of honey.

One of the jobs of an occupational therapist is to find or adapt tools and gadgets for use by people who have been injured or disabled. The photograph on the right above shows a special tool designed for use by people who have conditions such as arthritis. (Arthritis is an inflammation of the joints characterized by pain, swelling, and stiffness.)

Challenge

Adapt or redesign tools, utensils, personal-care items, or craft or hobby items for use by an older person who has lost strength or another person with a physical injury or disability.

Materials

tools (e.g., pliers, wrench, hammer, screwdriver, putty knife)

utensils (e.g., table knife, fork, spoon, tongs, funnel, measuring spoons, spatula)

personal-care items (e.g., comb, hairbrush, toothbrush, soap, mirror, empty childproof prescription bottle), or other common household items of your choice

cardboard

scissors

dowels

tape

wood

Styrofoam™

glue or glue gun

Safety Precautions

- Be careful when using sharp objects such as scissors, knives, and screwdrivers.
- A glue gun is hot and the glue remains hot for several minutes.

Design Criteria

A. Choose two items from the tools, utensils, and personal-care items listed above. Adapt or redesign the devices for use by a person who is physically challenged in some way.

B. Each adaptation must include at least one type of simple machine that you have studied in this unit.

C. Your adaptation must be completed and ready to demonstrate to the class during the time allotted by your teacher.

D. Your adaptation may be either an actual device or a working model.

E. You must submit a summary of each team member's contribution to the design, development, and demonstration of your adapted device.

Plan and Construct

1. In your group, brainstorm a variety of tools or utensils that you could adapt to meet the Challenge outlined above. Decide what specific task each adapted device would allow the person using it to perform. Discuss why a person with a specific physical disability would be unable to perform the task without your device.

2. Of the items that you discussed, select two that the majority of the group members would like to adapt or redesign. If you wish, select one optional device in case one of your choices does not function as planned.

3. Make a list of the materials you will need for each device or model.

4. Assign tasks to each member of your group, such as the collection of materials, the assembly of the device or model, and the testing of the device or model. Set deadlines for each stage of the project.

5. As a group, draft an illustrated plan that clearly shows the materials and the design of the adapted device. Submit your plan to your teacher for approval.

6. Subdivide the group into two smaller groups and assign one of the two devices to each group. Assemble your device, testing it at each stage of assembly. When each group has accomplished as much as possible, the two groups will confer with each other. If one group has ideas that can help the other group improve its device, implement that idea. If either group finds that its device cannot be made to function properly, the group should start to work on the alternative.

7. When the devices or models are completed, the whole group will prepare a written and oral presentation describing and demonstrating the devices for the class.

Evaluate

1. As a group, discuss the effectiveness of your devices. Did they perform as well as you had intended? Why or why not?

2. Did you encounter problems in developing your devices? If so, how well did you solve the problems?

3. How practical would your devices be for use by a person who has a physical challenge?

4. What would you change about your design if you were to begin again?

5. Write a summary of your group's evaluation of the two devices.

MORE PROJECT IDEAS

Working in a group, design an original tool or device for use by a person who has a physical disability. If time permits, construct a model of your new device and give it a name.

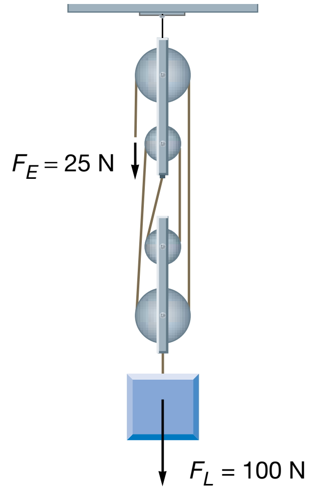
Review

Unit at a Glance

- Simple machines, such as levers, inclined planes, and pulleys, help people perform tasks that would otherwise be difficult to do.
- There are three kinds of levers: Class 1, Class 2, and Class 3.
- Work is done only when force produces motion in the direction of the force.
- Machines make work easier because they change the size or the direction of the force put into a machine.
- Mechanical advantage is the comparison of the force produced by a machine to the force applied to the machine.
- Machines and other products can be designed and adapted to suit the specific needs of people.
- Pulleys can be fixed or movable. Pulleys change the direction of the motion when objects are lifted.
- Objects have stored or potential energy, and kinetic energy.
- Machines such as a chain and sprocket are used to transfer energy.
- Friction reduces the efficiency of mechanical systems.
- When you change the area over which a force acts, the pressure changes.
- Equipment such as seatbelts and football helmets spread force over a larger area.
- Pascal's law states that pressure exerted on a contained fluid is transmitted unchanged throughout the fluid.
- Pressure exerted on a gas and on a liquid results in different outcomes.
- Hydraulic systems are closed systems. They confine a fluid in an enclosed space.
- Pneumatic systems are open systems. Fluid — usually air — passes through pneumatic devices under high pressure and then escapes outside the device.
- Hydraulic and pneumatic systems are all around us, even in our bodies.
- Many mechanical devices are a combination of smaller subsystems.
- Mechanical devices have changed as science and technology have changed.
- Changes in society and the environment sometimes result in changes to science and technology.

Understanding Key Concepts

1. Define the terms "work" and "mechanical advantage" and express them as mathematical formulas.
2. Explain why machines, including levers, are not 100 percent efficient. Use the definition of efficiency in your answer.
3. Explain the difference between energy conversion and power transmission.
4. Describe a situation in which friction is useful.
5. Describe how valves work. Use a drawing if you wish.
6. Determine the mechanical advantage of the compound pulley shown here.



7. Describe how a change in area affects pressure.

8. Explain how a hydraulic lift works.

9. State Pascal's law and describe some applications of this principle in hydraulic and pneumatic systems.

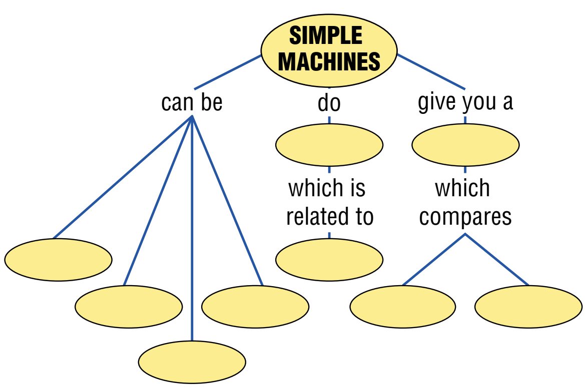
10. Using diagrams, explain how (a) a steam engine works, and (b) how an internal combustion engine works.

11. Imagine picking up a bowling ball and carrying it across the room. Explain the steps in which you are doing work in the scientific sense.

12. Give an example of a situation in which you would want to reduce the force exerted by a simple machine.

Developing Skills

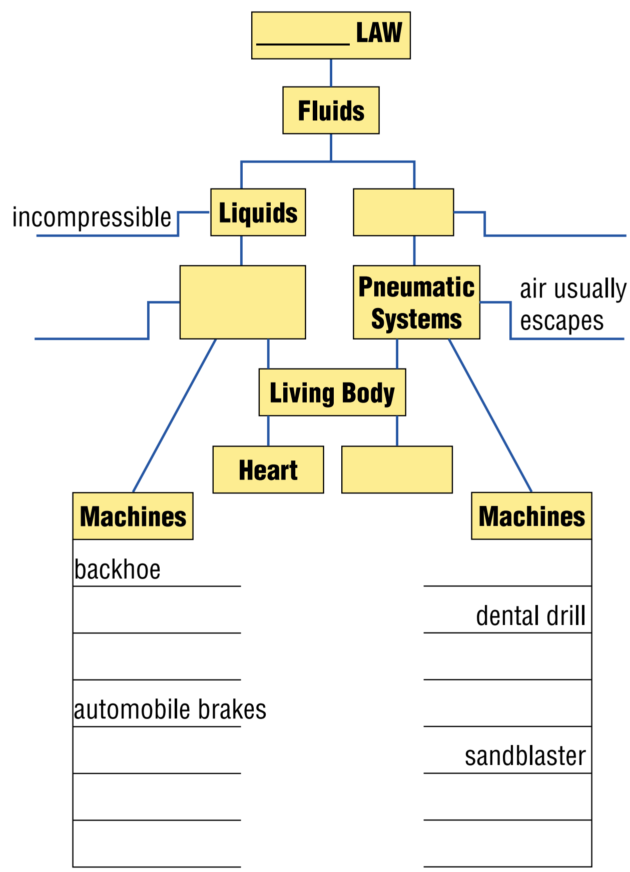
13. Complete the following concept map of simple machines, using these words and phrases: lever, inclined plane, wheel and axle, effort force, work, pulley, mechanical advantage, load, and efficiency.



14. Look at the photograph above of the man chopping wood with an axe. If the man exerts an effort force of 80 N and the load force of the wood is 320 N, what is the mechanical advantage of the axe?

15. Choose a mechanical device and make a timeline showing how this device has changed over time. Write a statement predicting how this device might change in the future. Use diagrams if you wish.

16. Copy the following flow chart into your notebook and fill in the blanks.



17. A typical high school student weighs 725 N and wears shoes that touch the ground over an area of 412 cm^2.
   (a) What is the average pressure the student's shoes exert on the ground?
   (b) How does the answer to (a) change if the student stands on one foot?

18. Choose an object found in nature and speculate about which qualities of the object scientists might investigate and learn from.

19. Redesign a pen so that it can be used by a person with severe arthritis in the hands.

Problem Solving/Applying

20. Design a pulley system that is similar to the platform of a window washer. You should be able to stand on the platform and pull on a rope that lifts the platform with your own weight on it. Sketch your pulley system.

21. Why might you choose a gear that would make you pedal extremely fast while your bicycle was travelling slowly?

22. Assume that you are able to exert a force of 200 N on the piston of a hydraulic lift that has an area of 25 cm^2. What would the area of the other plunger have to be if you wanted to lift a load of 1000 N?

23. Sketch and describe a lever and a hydraulic lift that would both have a mechanical advantage of 4. Use numerical values to describe the length of the lever arms and the areas of the pistons in the hydraulic lift.

24. **Design Your Own** You have been given the task of creating an orange-juicing machine. The "juicer" of your machine (the part that will hit the orange) is a piece of Styrofoam™ with one or more nails pushed through it. You can design the other subsystems of the machine in any way you wish. Sketch your design and explain how all of the subsystems work. Clearly explain how you decided on the number of nails you used in your juicer. Design an experiment to test different juice designs. Identify the manipulated and responding variables in your experiment. Also, list criteria for evaluating your design.

25. Describe how your body is similar to a machine consisting of various subsystems. List the subsystems present in your body.

26. Describe the simple machines that are found in this mechanical device.

27. Give two examples of a technological product or device that has caused a problem for the environment, and suggest an existing or potential solution to the problem.

28. Describe two jobs that use hydraulic and/or pneumatic systems.

Critical Thinking

29. Design a manually operated machine that will load a 5 t elephant onto a truck.

30. Machines make work easier, but you always have to do more work than the machine does on the load. Explain this statement.

31. Hydraulic systems operate automobile brakes. Describe one problem that could occur in a

hydraulic system. Think of one reason why a hydraulic system is more appropriate for brakes than a mechanical system made of levers, gears, or pulleys.

32. Think of one advantage and one disadvantage of using pneumatic systems to power rescue equipment such as the inflatable rescue walkway on page 313.

33. The Heimlich manoeuvre is an emergency technique used to dislodge an object caught in the throat. How is this technique an application of Pascal's law?

34. If you were sinking in quicksand, would it be better to remain standing or to lie down? Explain your answer.

35. Why do you think it is important to continue looking for ways to make machines more efficient?

36. How do you think it was possible for Thomas Savery and James Watt to build steam engines when they did not know the scientific principles and theory of heat engines?

37. The steam engine allowed factories to produce goods faster and more efficiently than production by hand. Why would the speed and efficiency of the engine encourage more people to open factories? Why did the growth in the number of factories change people's lives so dramatically?

38. Explain how changes in society and/or the environment can affect science and technology. Give two examples.

Pause & Reflect

Review the ideas described in Unit at a Glance on page 356. Write a paragraph that summarizes what you have learned about these ideas.

39. Describe the changes in society, science, and technology that have led to changes in wheelchair design from the older model shown here, to modern, more efficient designs.