CHAPTER 5

The Use of Fluids

KEY IDEAS

- Knowledge of the properties of fluids is important in technology.
- An object immersed in a fluid will experience pressure.
- Forces can be transferred through confined fluids.
- Pressure, temperature, and volume of a fluid affect each other.
- Machines and other devices that use fluids can make work and movement easier.

LEARNING TIP

After you read the chapter introduction, try to answer the questions using what you already know.

How does a small force on a brake pedal stop a 2000 kg vehicle travelling at 100 km/h? How do fluids allow an airplane to fly? Cars and other vehicles depend on the flow of fuel in the engine to move, and on fluids in the brake system to stop. Airplanes rely on the flow of air over the wings to lift off, fuel and oil in the engines for power, and air under pressure in the tires for landing. Without fluids, highways would be much more dangerous and air travel would not be possible.

Fluids make our lives easier. Engineers can harness the energy of moving water and air to generate electricity. Vacuum cleaners use air to suck in dirt and dust. Overhead loaders use the movement of oil through hoses and cylinders to lift tonnes of rock into trucks.

What kinds of machines and devices that use fluids do people make? What problems can we solve by investigating and using fluids? In this chapter, you will examine how problems are solved by using the properties of fluids in machines and devices.

Career Profile: Food Scientist

5.1

Viscosity and the Chocolate Factory

Randy Droniuk is a food scientist (**Figure 1**). He runs tests during the chocolate-making process, and he researches how to improve the process. "I enjoy the variety of work involved in my job," says Randy. "It is really nice to work on anything that involves a better quality product for our customer."

To test and research the chocolate-making process, Randy needs to understand the property of viscosity and how it applies to liquid chocolate. "Viscosity testing is very important in this industry. Both temperature and ingredients greatly influence viscosity. By running regular tests, we can produce a dependable product."

One instrument used in routine tests is a viscometer (recall Section 4.4), which measures the viscosity of chocolate. A spindle rotates inside a sample of chocolate. If the chocolate has a high viscosity, there is more resistance to the turning of the spindle.

Figure 1
Randy Droniuk

TRY THIS: Hot Chocolate

Skills Focus: observing, measuring, analyzing

In this activity, you will look at how different the viscosity of chocolate can be for two different types of products. You will need chocolate from chocolate baking chips and from a moulded, solid milk-chocolate bar.

1. In separate glass measuring containers, carefully heat a small sample of each type of chocolate to 40 °C. Measure the temperature of each sample to confirm they are the same.

2. Stir each sample of liquid chocolate with a separate spoon.

(a) Does one sample seem thicker and more viscous than the other? If so, which one?

3. Fill each spoon with the liquid chocolate and hold it above the sample. Slowly pour the chocolate off the spoon onto a plate.

(b) Which sample is slower to start pouring?

(c) Which sample more quickly forms a pool of chocolate with a flat surface?

(d) Why is it necessary to heat each sample to the same temperature before testing its viscosity?

Because chocolate burns easily, use a microwave oven at a medium setting to melt the chocolate.

Never taste or drink anything in a science class.

Awesome SCIENCE

Chocolate Production

It is a well established fact that most kids and adults alike love chocolate. Last year chocolate lovers in North America consumed just under 4.5 kg of chocolate per person!

Most chocolate bars are made by pouring liquid chocolate into pre-formed heated moulds (**Figure 1**). Large chocolate companies have machines that can fill hundreds to thousands of moulds per minute. After the moulds are filled, they are vibrated to remove remaining air bubbles. The vibration also helps settle the chocolate evenly in the mould. Finally, the liquid chocolate moves through a cooling unit which gently cools the chocolate to form the final chocolate bar. This is a very brief summary of how chocolate bars are made. How does science fit in the production of chocolate?

The Importance of Viscosity

Not all chocolate bars are the same. Neither is the chocolate that goes into the many different varieties.

Scientists in a chocolate factory measure the flow rates of liquid chocolate. A different viscosity is required for moulded, or solid, bars than for bars that have many ingredients. Imagine what would happen if the chocolate that surrounds the other ingredients was too runny. Too much would run off and the centre would not be properly coated. What if the chocolate pouring into the moulds was too viscous? The mould might not fill before the conveyor belt moved it along, leaving air bubbles or gaps. Viscosity is a very important property in the production of chocolate bars.

Factors Affecting the Viscosity of Chocolate

An interesting part of chocolate production involves investigating how chocolate is ground down to the right smoothness. The pieces must be just the right size to ensure the chocolate product is smooth. The size of pieces and the temperature of the chocolate affect its viscosity.

When a lower viscosity is desired, scientists can add more fat to the chocolate. Fat, such as cocoa butter, coats the fine solid pieces in the chocolate so the chocolate flows more freely. Careful adjustments are made to obtain the right combination of smoothness, fat content, and temperature in liquid chocolate. This ensures its viscosity is perfect for each application.

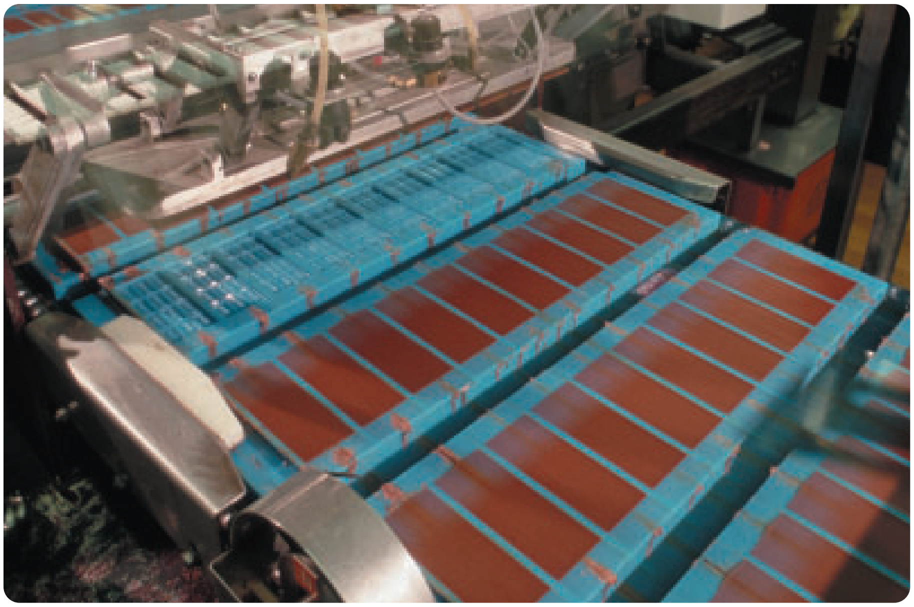


Figure 1
Some chocolate bars are made in moulds. Once the chocolate is cooled and solidified, the moulds are flipped over and out fall chocolate bars ready to be packaged.

Fluids and the Confederation Bridge

5.2

Imagine the challenge of building a structure over 12 km long across a storm-tossed stretch of ocean. The structure has to last 100 years and be safe for motorists to drive on. This was the task that faced the engineers on the Confederation Bridge project (**Figure 1**). The connection from Prince Edward Island to New Brunswick opened on May 31, 1997. The 12.9 km bridge crosses the Northumberland Strait and is the world's longest bridge to cross ice-covered waters.

Some of the challenges faced by the engineers who designed the bridge are described in this section. To overcome these challenges, the engineers required a knowledge and understanding of the properties of fluids and how forces and motion affect fluids.

Figure 1
The Confederation Bridge connects Prince Edward Island to New Brunswick.

Barges

Much of the bridge construction took place from rectangular floating vessels called barges (**Figure 2**). These activities included positioning the pier bases and cementing them to the bedrock, and transporting supplies to workers. One barge was even equipped with a helicopter landing pad.

So building of the bridge could continue during the long winter season, sections for the bridge had to be first built on land and then floated out on barges to their final position. Each bridge section consisted of a pier and girders, and weighed about 7500 t (**Figure 3**).

LEARNING TIP

Active readers know when they have learned something new. After you read this section, ask yourself, "What have I learned about fluids that I did not know before?"

Figure 2
The *Svanen*, a barge with a floating crane, was used to carry and install the bridge sectors.

Figure 3
A section of the Confederation Bridge

Water and Ice

Water constantly exerts force on the bridge piers. Some days enormous waves crash into the piers. This pushing force increases as the water freezes and ice slams into the piers. The ice in the Northumberland Strait was a major concern for the engineers who designed the Confederation Bridge piers. A model of this situation was constructed. Several centimetres of ice were produced in an enormous basin. A model of a pier attached to a bridge was pushed through the ice and across the basin. The speed at which the pier was pushed was carefully controlled to mimic actual water current conditions. Engineers videotaped the investigation and took measurements throughout the testing. The results were used to determine the forces that the real piers had to withstand.

Figure 4
An apparatus that looks like the Canadarm was used to pour concrete.

Winds

High winds posed another challenge for the bridge designers. They considered how air would flow around the bridge and how winds would affect the bridge itself. They also considered how winds would affect the vehicles using the bridge, and they designed barrier walls on each side of the roadway to minimize this effect.

Concrete

The concrete used to build the bridge also was a major concern for the engineers. To make a pier that could withstand collisions from ice and possibly ships, a special high-strength, low-water concrete was used. The concrete had to be pumped through pipes and poured into forms to make the pier shapes (**Figure 4**). The engineers changed the viscosity of the concrete by adding special products. This allowed the concrete to remain liquid longer.

5.2 CHECK YOUR UNDERSTANDING

1. (a) What forces must engineers consider when designing a barge?
   (b) What could engineers do to ensure a barge is stable before use?
2. (a) Is the force of the water on the piers the same at the water surface as it is 30 m below the surface?
   (b) Why did engineers make a model of the piers?
3. (a) Why did engineers add special products to the concrete used in the bridge?
   (b) Why did the concrete need to fill the entire form it was poured into?

Inquiry Investigation 5.3

How Fluids Handle Pressure

"I'm under so much pressure!" How often have you heard that comment? An upcoming test or too much to do in a short period of time can make people say they are under a lot of pressure. Fluids can be under a different sort of pressure. What happens to fluids under pressure? What effects can we observe?

INQUIRY SKILLS

- ● Questioning
- ● Hypothesizing
- ○ Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

Question

(a) Read through this Investigation, and then write a question that you will try to answer.

LEARNING TIP

For help with writing a question and a hypothesis, see "Questioning" and "Hypothesizing" in the Skills Handbook section **Conducting an Investigation.**

Hypothesis

(b) Write a hypothesis for this Investigation.

Experimental Design

In this Investigation, you will investigate the effects of exerting pressure on air and water in closed systems.

(c) Copy **Table 1** and complete it as you carry out the Procedure.

Table 1 Investigating Water and Air Pressure

Investigation	Setup used	What happened?
1. air pressure	(a) large syringe + 3 cm tubing + large syringe (b) large syringe + 40 cm tubing + large syringe	
2. water pressure	(a) (b)	

Materials

- apron
- safety goggles
- two 20 mL syringes
- two 5 mL syringes
- three 3 cm lengths of 6 mm tubing
- 40 cm length of 6 mm tubing
- straight connector
- T-connector

Use equipment only as instructed. Be careful when working with syringes under pressure.

Procedure

1. Put on your apron and safety goggles. Connect both 20 mL syringes with a 3 cm piece of tubing. Can you pull one plunger back? If not, what do you have to do to one plunger before connecting the tubing?


Step 1

2. Depress one plunger. What happens to the other one?

3. Try moving one plunger and holding the other one still. What happens? What fluid are you investigating here?

4. Repeat step 1 using the 40 cm piece of tubing. Do you notice anything different happening when you move one plunger?


Step 4

5. Use a straight connector and two short pieces of tubing to join both 20 mL syringes. What is different about the movement of the plungers compared to the setup in step 1?

6. Join one 20 mL syringe to both 5 mL syringes using the T-connector and three short pieces of tubing. Record the volume of air that starts in the large syringe.


Step 6

7. Depress the plunger of the large syringe. What happens?

8. Predict what you think would happen if you were to use water in steps 1 to 7. Write your prediction.

9. Repeat steps 1 to 7 with the system full of water. You must ensure that there are no bubbles present.

LEARNING TIP

For help with writing a report, see **Writing a Lab Report** in the Skills Handbook.

Analysis

(d) What would happen if the tubing on the syringes, or the plunger in the syringe, did not make a tight seal?

(e) What differences did you observe between the two different fluids when you applied pressure to them?

(f) Write a report explaining your results.

PERFORMANCE TASK

Will your Performance Task design involve a closed system? How can you apply what you have learned about pressure in closed systems to your design?

Evaluation

(g) Did the results of this Investigation support your hypothesis? Explain.

(h) Describe some possible sources of error in this Investigation.

(i) How could you improve the procedure for this Investigation?

Fluids under Pressure 5.4

Imagine trying to walk across a field that is covered by a metre of freshly fallen snow. Now imagine the same challenge using skis or snowshoes. Either of these devices would allow you to cross the field without sinking into the snow up to your waist. What does this have to do with pressure?

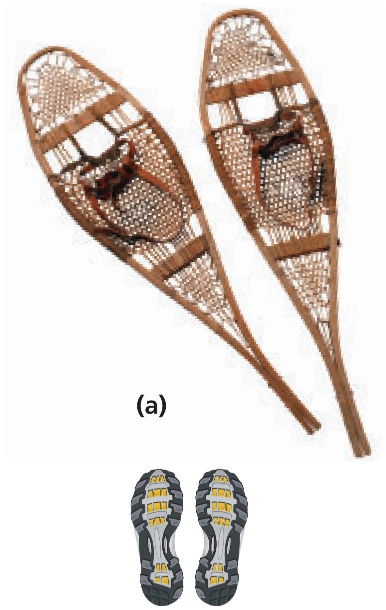
Pressure

Pressure is defined as the force per unit of area. It can be calculated using the following formula:

$$\text{pressure} = \frac{\text{force}}{\text{area}} \quad \text{or} \quad p = \frac{F}{A}$$

Force is measured in newtons (N). The area is measured in square metres (m^2) or square centimeters (cm^2), depending on the size.

Why is it easier to cross the snow-covered field using skis or snowshoes? Consider the pressure under your feet as you stand on any surface. Your weight is a measurement of the force of gravity pulling down on you. Like all forces, it is measured in newtons. Force (your weight) is exerted on the area covered by your shoes. With skis or snowshoes, this same force (your weight) is distributed over a much larger area and the pressure is therefore lower (**Figure 1**). The lower pressure does not compact the snow as much as the higher pressure, so you do not sink as deep. A snowshoe hare's feet are similar to snowshoes. Their large surface area reduces the downward pressure, enabling the hare to walk on the surface of the snow (**Figure 2**).



(a)

(b)

Figure 1
Snowshoes **(a)** distribute a person's weight over a larger area than a pair of shoes **(b)**. That means the pressure exerted on the snow is less than it would be for the smaller area of the shoes.

Figure 2
The hare's large hind feet act like snowshoes. They distribute its weight over a larger area, enabling it to walk on the surface of the snow.

The following sample problem shows how to calculate the difference in the pressures acting on a surface.

SAMPLE PROBLEM

Determine the Pressure When You Know the Force and Area

Jill weighs 500 N. She wears size 6 shoes. The area of each shoe is 200 cm^2. Jill buys cross-country skis that are 8 cm wide by 170 cm long. Determine the pressure on the surface of the snow when Jill is standing in shoes and when she is wearing skis. Explain why the skis are better able to keep Jill on the surface of the snow.

Solution

Pressure while wearing shoes:

force = 500 N

area = 400 cm^2 (2 shoes × 200 cm^2 per shoe)

$$p = \frac{F}{A}$$
$$= \frac{500\ \text{N}}{400\ \text{cm}^2}$$
$$p = 1.25\ \text{N/cm}^2$$

Pressure while wearing skis:

force = 500 N

area = 2720 cm^2 (2 skis × 8 cm wide × 170 cm long)

$$p = \frac{F}{A}$$
$$= \frac{500\ \text{N}}{2720\ \text{cm}^2}$$
$$p = 0.18\ \text{N/cm}^2$$

The pressure on the surface of the snow while Jill is wearing shoes is 1.25 N/cm^2. This is approximately seven times as great as the pressure exerted while Jill is wearing skis, 0.18 N/cm^2. In other words, the skis have nearly seven times as much surface area as the shoes. Since Jill's weight is spread out over this larger area, the pressure under the skis is less than it would be under the shoes. With reduced pressure, the snow will not be compacted as much and Jill will not sink too deeply when wearing skis.

Practice

A ballet dancer weighs 450 N. The total surface area of the soles of her two feet is 150 cm^2. When she stands on the tips of her toes, only 10 cm^2 of surface area is in contact with the floor. Compare the pressure on the floor (and on her body) when she is standing flat-footed with the pressure when she is standing on the tips of her toes.

The unit of pressure is the **pascal** (Pa), which is equivalent to one newton per square metre (1.0 N/m^2). The pascal is named after Blaise Pascal (1623–1662). He was a French mathematician who investigated barometric pressure, or the pressure of the atmosphere at different altitudes on Earth.

DID YOU KNOW?

Inventing Snowshoes

Snowshoes were invented by Aboriginal people (**Figure 3**). The first snowshoes were bent saplings with rawhide binding straps to hold the feet in place.

Figure 3

Since the pascal is a fairly small force over a large area, pressure is often measured in kilopascals. One kilopascal (kPa) is equal to 1000 pascals. For example, a single sheet of newspaper resting on a flat surface exerts a pressure of approximately 1.0 N/m^2 or 1.0 Pa. The air above the paper exerts a pressure of 100 000 Pa (100 kPa)! The atmospheric pressure, then, is measured in kilopascals.

Atmospheric Pressure

We do not often think of air as having much mass or being very heavy. But Earth's atmosphere is approximately 160 km thick. That's a lot of air! Gravity exerts a force on all the molecules and particles in the atmosphere. The force of gravity on any object is known as its weight (recall Section 4.5). The weight of the air pushing down on itself and on Earth's surface is known as **atmospheric pressure**. The average pressure exerted by the atmosphere at sea level is approximately 100 kPa. This pressure changes with the elevation above sea level and with weather conditions or the movement of air systems over Earth's surface (**Figure 4**).

LEARNING TIP

After you finish reading the section on Atmospheric Pressure, ask yourself, "How can I put what I have just read into my own words (or paraphrase)?" Try to explain atmospheric pressure to a partner.

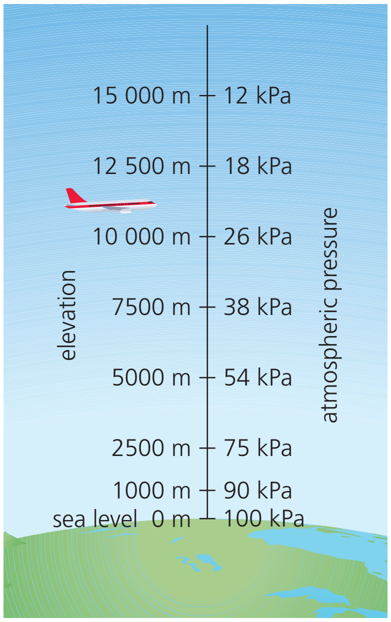


Figure 4
Atmospheric pressure at 12 500 m is 18 kPa or approximately one-fifth of that at Earth's surface.

When an object is immersed in a fluid, pressure is exerted in all directions. The pressure of the atmosphere on your body is balanced between the inside and the outside. This is why you do not normally sense the pressure of the atmosphere. However, if you go to a high altitude—for example, to the top of a tall mountain or even a tall building—the air pressure outside your body decreases immediately. You may experience a "pop" in your ears because the pressure inside your body does not change as quickly. The "pop" is the air pressure equalizing on the inside and outside of your eardrums.

The influence of gravity on fluid pressure increases with depth (**Figure 5**). If you dive under water, you feel the increase in pressure. As you return to the surface, the pressure returns to normal. Likewise, if you climb higher into the atmosphere, the pressure decreases and your breathing becomes more difficult because of the decrease in air pressure.

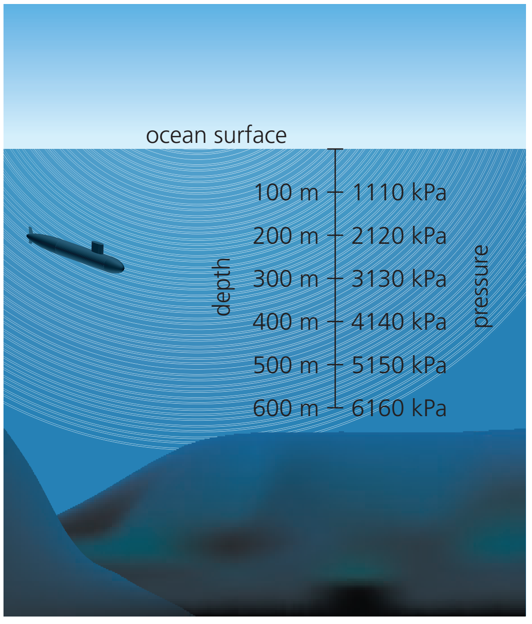


Figure 5
Submarines have reinforced hulls to withstand the increase in pressure in deep water.

5.4 CHECK YOUR UNDERSTANDING

1. (a) In your own words, explain why you would find it difficult to cross a snow-covered field wearing running shoes.
   (b) Explain how using snowshoes would make this task easier.
2. Calculate the pressure in each of the following:
   (a) 650 N over an area of 50 cm^2
   (b) 1500 N over an area of 3.0 m^2 (answer in pascals)
   (c) 17 000 N over an area of 2.0 m^2 (answer in kilopascals)
3. Describe the relationship between the depth of a fluid and the pressure it exerts.
4. A mountain climber experiences an atmospheric pressure of 85 kPa. Use **Figure 4** on page 149 to estimate her elevation above sea level.
5. A person weighing 450 N breaks through the ice while walking across a frozen pond. The area of her feet is 150 cm^2. A second person, weighing 900 N, attempts to rescue the first person by using a 20 cm by 200 cm wooden plank to distribute his weight. Do you think it is safe for the rescuer? Explain your reasoning showing your calculations.

Pressure in Confined Fluids

5.5

What are confined fluids? They are any fluids in a closed system. Confined fluids can move around within the system, but they cannot enter or leave the system. The blood moving through your body is a confined fluid (as long as you do not cut yourself!), and so is the air in a tire. When fluids are confined, they have some very interesting effects.

There are two types of systems that use confined fluids to transmit forces from one location to another. A **hydraulic system** is a confined, pressurized system that uses moving liquids (**Figure 1**). A **pneumatic system** is a confined, pressurized system that uses moving air or other gases, such as carbon dioxide (**Figure 2**).

In Investigation 5.3, you discovered that moving one plunger causes another plunger to move. In other words, applying a force to one part of a fluid system results in movement in another part of the system. The force was transmitted through the fluid to another movable part, some distance away. This is one effect of a pressurized fluid system: forces can be applied in one place and have an effect somewhere else—even in another direction. The brakes in a car are an example of this. The driver presses down on the brake pedal, which exerts pressure on the fluid. This pressure is transmitted through the fluid in the brake lines toward the wheels, where it forces the brake pads against the wheels to stop the moving car (**Figure 3**).

Figure 1
A hypodermic syringe is a simple hydraulic system.

Figure 2
A bicycle tire inflator is a simple pneumatic system that is powered by a cylinder of pressurized carbon dioxide (CO_2) gas.

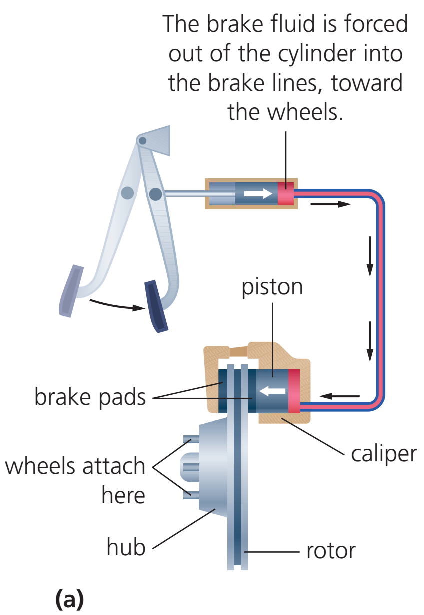


Figure 3
Pushing the brake pedal forces a piston against the hydraulic brake fluid in the main cylinder.

LEARNING TIP

Vocabulary are often illustrated. When you come across a term you do not know, examine the pictures and diagrams, along with the captions.

You might have noticed a difference in the effects of water and air in Investigation 5.3. Did you notice that there was a short delay, or bounce, in the air-filled system, whereas the water-filled system reacted immediately? Why might this be? Can you explain it using the kinetic molecular theory? Think of the particles in liquids and gases, and the spaces between them.

Pressure and Forces in a Hydraulic System

LEARNING TIP

Try reading with your notes open. When you come across information from your student book that supports or adds to your notes, record that page number in your notes. This makes a simple reference system for future studying and reviewing.

Hydraulic systems are useful in many ways. A force can be transmitted from one location to another. The force applied to a system can be multiplied to exert a much greater force to do work.

In Investigation 5.3, you worked with two syringes. When these were connected with a tube, they became a hydraulic system. Depressing the plunger in one syringe lifted the plunger in the other syringe. The force was transferred directly from one syringe to the other. Because the syringes were the same size

- both plungers moved the same distance, but in opposite directions
- one plunger moved down and the other plunger moved up
- the force pushing down on one plunger was the same as the force pushing up on the other plunger

To make a hydraulic system more effective, you have to change the relative sizes of the cylinders. One cylinder must be larger than the other (**Figure 4**). The force on the smaller cylinder is multiplied in the larger cylinder. The amount that the force is multiplied by is determined by the ratio of the areas of the larger and smaller pistons. For example, if the area of the larger piston is nine times larger than the area of the smaller piston, the force on the larger cylinder is nine times larger than the force on the smaller cylinder. To do the same amount of work, however, the smaller piston must move a greater distance. The Sample Problem on the next page shows how to calculate the amount by which the force is multiplied in a simple hydraulic system.

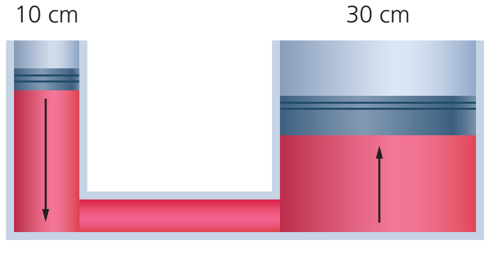


Figure 4
A hydraulic system

SAMPLE PROBLEM

Multiplication of Force in a Hydraulic System

In the hydraulic system shown in **Figure 4**, a force of 50 N is applied to the piston in the small cylinder.

1. What is the maximum weight that could be lifted on the large piston?
2. How far will the small piston have to be moved downward to lift the large piston upward 1 cm?

Solution

The diameter of the small piston is 10 cm. The area of this piston is calculated using the formula $A = \Theta r^2$, where $\Theta = 3.14$ and r is the radius of the piston.

If the diameter of the piston is 10 cm, then the radius is 5 cm.

$$\begin{aligned} A &= \Theta r^2 \\ &= 3.14 \text{ x } (5 \text{ cm})^2 \\ &= 3.14 \text{ x } 25 \text{ cm}^2 \\ A &= 78.5 \text{ cm}^2 \end{aligned}$$

The diameter of the large piston is 30 cm. The area of the large piston is

$$\begin{aligned} A &= \Theta r^2 \\ &= 3.14 \text{ x } (15 \text{ cm})^2 \\ &= 3.14 \text{ x } 225 \text{ cm}^2 \\ A &= 706.5 \text{ cm}^2 \end{aligned}$$

The ratio of the area of the large piston to the area of the small piston is 9:1. Thus, the area of the large piston is nine times the area of the smaller piston.

The force transferred from the small piston is therefore multiplied nine times. So the force exerted on the large piston is 9×50 N or 450 N. This is the maximum weight that can be lifted on the large piston.

The movement of the pistons is also proportional to the ratio of the areas of the pistons, except that the opposite relation is true. The small piston moves nine times farther than the large piston. Since the large piston moves 1 cm, the small piston must move 9 cm.

Practice

The diameter of the hydraulic cylinder at the pedal end of a car's brake system is 5 cm in diameter. The diameter of the cylinder at the wheel end is 25 cm. A force of 100 N is applied to the brake pedal.

(a) What force is transmitted to the wheel?

(b) How far will the brake pedal need to move to move the brake pads 0.1 cm?

Using the Kinetic Molecular Theory

We can use the kinetic molecular theory of matter to understand what happens to confined fluids when an external force is applied to them. Remember that the spaces between the particles in a liquid are very small. When an external force is applied, only a very small decrease occurs in the volume of the liquid.

LEARNING TIP

Always try to connect information to what you have already learned. Ask yourself, "What do I already know about the kinetic molecular theory?" Consider the information that you have learned from other sections of the text.

In a gas, the particles are far apart from each other. For the force to be transmitted from one particle to another, the volume that the gas occupies must be reduced. This is referred to as **compression.** When an external force is applied to a gas, the force pushes the particles closer together and reduces the volume. This is why there is a delay in the air-filled system. It takes time to compress the air. Gases are very easily reduced in volume or **compressible**. The change in volume of a liquid under pressure is so small, however, that liquids are almost incompressible.

Be careful when working with fluids under pressure.

TRY THIS: *Exploring Valves*

Skills Focus: controlling variables, observing, recording

Find out how using a valve alters a pneumatic system (**Figure 5**).

1. Add a valve to the pneumatic system you used in steps 1 to 7 of Investigation 5.3. The valve could go anywhere in the system.

(a) Draw your system.

2. Move each of the plungers in turn and record your observations.

3. Move the valve to another position in the system and repeat the procedure.

4. Continue until you have tested all possible positions for the valve.

(b) Does the position of the valve affect the operation of the pneumatic system? Explain your answer.

(c) Predict how adding a second valve might affect the system.

Figure 5

There is another effect that can occur when a force is applied to a gas or a liquid. Its state can be changed. By increasing the pressure on a gas, the particles can be pushed close enough together that the gas will changing to a liquid. For example, propane is normally a gas, but in a barbecue tank, under pressure, it is a liquid (**Figure 6**). Similarly, with sufficient force, a liquid can be compressed until it changes into a solid.

Figure 6
Putting propane under pressure and storing it as a liquid allows a barbecue tank to hold more.

5.5 CHECK YOUR UNDERSTANDING

1. Using the kinetic molecular theory and this new information about pressure, explain your results with syringes in Investigation 5.3.
2. A brick measures approximately 230 cm long, 110 cm wide, and 7.6 cm high. It weighs 25 N. Does the brick apply the same pressure to a desk if the brick is on its end, its side, or its base? Explain.
3. Compare liquids and gases in terms of their compressibility. Draw a diagram to illustrate your comparison.

PERFORMANCE TASK

Describe how you will put a fluid under pressure in the Performance Task.

How Scuba Works

Have you ever snorkelled around a rocky reef or tried to hold your breath under water and wished you could stay there longer or explore deeper? If so, you might be interested in scuba diving. How does the equipment used by divers actually work?

A scuba diver (**Figure 1**) needs two essential pieces of equipment to be able to breathe under water. The first piece of equipment is the gas cylinder, or air tank. The air in the gas cylinder is 21 % oxygen gas and 78 % nitrogen gas, just like the air we normally breathe. The only difference is in a scuba tank the air is compressed to 20 685 kPa. This is over 200 times greater than normal atmospheric pressure at sea level! Obviously you could not breathe this air directly from the tank. If you did, major lung damage would result. The second piece of equipment, the regulator, reduces the pressure of the air in the tank to a safe level for the diver to inhale through the mouthpiece.

A system of levers and valves regulates the movement of air during this process. When a diver inhales, the air pressure in the mouthpiece drops and causes a valve to open, allowing air from the regulator to flow into the mouthpiece. The regulator controls the pressure in two stages. In the first stage, the pressure of the air from the tank is lowered to around 1000 kPa. The second stage of the regulator lowers the air pressure even further to an appropriate level, from 100 kPa to 500 kPa depending on the depth. This is a comfortable air pressure that will not damage your lungs.

Dangers of Scuba Diving

There are dangers of scuba diving. One is nitrogen narcosis. If a diver goes more than 30 m below the surface, the increased pressure causes too much nitrogen to dissolve in the diver's blood. Symptoms of nitrogen narcosis include a loss of decision-making ability, and impaired judgement and coordination.

After a long time under water, some nitrogen from the air dissolves in the water in the diver's body. If the diver swims too quickly to the surface, the gas is released all at once, which causes a painful condition known as "the bends." This can be avoided by swimming slowly to the surface, allowing the nitrogen gas to release a little bit at a time.

Figure 1

5.6 Inquiry Investigation

INQUIRY SKILLS

- ○ Questioning
- ● Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

Pressure, Volume, and Temperature

Have you ever felt the cylinder of a bicycle pump as you pumped air into a tire? Have you ever seen frost form around the valve of a propane barbecue tank when the filler hose was disconnected? What happens to a balloon that is left outside overnight when the temperature drops? What would you expect to observe if you opened a bottle of pop that has been left in the Sun and a bottle that has been kept in the refrigerator? Answering questions like these will help you understand how the pressure, volume, and temperature of a fluid affect each other.

Question

How do the pressure, volume, and temperature of a gaseous fluid affect each other?

Prediction

(a) Predict the relationship between each pair of properties:

(i) temperature and volume
(ii) pressure and volume
(iii) temperature and pressure

LEARNING TIP

For help with making a prediction and a hypothesis, see "Predicting" and "Hypothesizing" in the Skills Handbook section **Conducting an Investigation**.

Hypothesis

(b) Write a hypothesis for this Investigation to explain the relationship between each pair of properties:

(i) temperature and volume
(ii) pressure and volume
(iii) temperature and pressure

Experimental Design

In this Investigation, you will investigate the relationship between the temperature and volume of a gas, the pressure and volume of a gas, and the temperature and pressure of a gas. This is a qualitative investigation so you will not be required to take any measurements. You will simply write a description of your observations.

Materials

- balloon
- bicycle pump or other hand pump
- large deflated balloon or sports ball
- 20 mL syringes
- block of wood with a hole to fit the tip of the syringe
- bucket or deep pan half filled with hot water
- bucket or deep pan half filled with cold (ice) water
- hot water
- three 2 L pop bottles
- weights

Use equipment only as instructed. Ensure that the water is not hot enough to scald you.

Procedure

Part 1: Temperature and Volume

1. Place a balloon over the top of the pop bottle. Have as little air as possible in the balloon. Use string or tape, if necessary, to ensure that the balloon is securely attached.

Step 1

2. Hold the pop bottle in the bucket of hot water for a few minutes, and observe what happens.

3. Remove the pop bottle from the bucket of hot water, and hold it in the ice water for a few minutes. Record your observations of the balloon as it is heated and cooled.

4. Is the fluid in this case a confined fluid? What is happening to the air contained in the bottle and balloon?

Part 2: Pressure and Volume

5. Place the tip of the syringe into the hole in the block of wood, and ensure that it fits tightly. Insert the plunger so that its bottom edge is aligned with the beginning of the scale on the syringe. Carefully balance a weight on top of the plunger, and observe what happens. Double the weight on the plunger, and again observe what happens. Record the original volume inside the syringe and the changes that occur when the weights are added.

Step 5

Part 3: Temperature and Pressure

6. Put approximately 200 mL of hot water in one pop bottle and approximately 200 mL of ice water in a second pop bottle. (Use the ice water from Part 1.) Leave the pop bottles for about 1 min, and then screw on the caps tightly. Observe the bottles for a few minutes. (To speed up the process, you could use a hair dryer to gently warm the bottle with the cold water.) Observe and record any changes in the bottles.

Procedure (continued)

7. Use a hand pump to inflate a large balloon or sports ball. You could also use a hand pump to pump air into a bicycle tire. As you pump, place your hand on the barrel of the pump. After you make your observations, be sure to return the tire to the proper inflation pressure. Record your observations.

Do not keep your hand on the pump any longer than necessary to observe what is happening.

8. Explain what is happening to the quantity of air in the ball or tire as you pump.

Analysis

(c) Assuming that the pressure remains the same, how does temperature affect the volume of a confined fluid? How would the volume affect the temperature of a confined fluid?

(d) Assuming that the temperature remains the same, how does pressure affect the volume of a confined fluid? How would the volume affect the pressure of a confined fluid?

(e) Assuming that the volume is held constant, how does pressure affect the temperature of a confined fluid? How would temperature affect the pressure in a confined fluid?

(f) Use the kinetic molecular theory to explain each of the relationships in parts (c) to (e).

Evaluation

(g) Did your observations support your hypotheses? If not, modify your hypotheses to reflect your observations.

(h) This is a quantitative investigation. Explain why it would be difficult to conduct a qualitative investigation of the same ideas.

(i) When conducting this Investigation, did your group share the recording and physical work equally? How might you work differently with a group in upcoming Investigations?

PERFORMANCE TASK

Do any of the relationships among temperature, pressure, and volume of a fluid affect the design of the pneumatic or hydraulic device in your Performance Task? How do the properties of the fluid vary?

Solve a Problem 5.7

A Closer Look at Fluid Power

There are many kinds of fluid-power systems all around us. At an airport, for example, fluid-power systems are used for moving passengers and baggage, as well as for controlling aircraft systems such as doors, wheels, rudders, and flaps (**Figure 1**). Hair stylists and barbers move clients up and down in chairs controlled by fluid pressure (**Figure 2**). Even very large, heavy objects can be moved using fluid-power systems (**Figure 3**).

PROBLEM-SOLVING SKILLS

- Identifying a Problem
- Designing
- Building
- Testing
- Recording
- Evaluating
- Communicating

Figure 1
Hydraulic systems that control the moving parts on aircrafts are safer and more efficient than using other devices such as electric motors.

Figure 2
A pump on a hair stylist's chair increases the pressure on its hydraulic system. The increased pressure raises the chair.

Figure 3
At this marina, hydraulic cylinders operate slings that lower boats into the water.

Problem

Re-read the introductory paragraph. Think of a need for a fluid-power lift. You have been hired by a management company to design this lift.

Design Brief

You will design a hydraulic or pneumatic system that will raise or lower objects. You will build a model of your design to test and to present to the management company.

LEARNING TIP

For help with this Investigation, see **Solving a Problem** in the Skills Handbook.

Materials

- apron
- safety goggles
- support stand
- screw-on clamp
- two 20 mL syringes
- 5 mL syringe
- 2 one way valves
- 40 cm of clear 6 mm tubing, plus several shorter pieces
- water
- plastic container or beaker with a pour spout
- 500 g ball of modelling clay
- sponge

Design Criteria

Your system must meet the following criteria:

- Your model must raise a mass of 500 g to a height of 6 cm, remain stationary for at least 30 s, and then descend in a controlled manner.
- Your model must use only the materials listed.

Build

1. Design your model lift. After your teacher has approved your design, build your model. Be sure to wear your apron and safety goggles.
2. Record challenges or problems that come up during the design and construction of your model.
3. Draw your completed model. Include the following labels on your drawing: cylinder, piston, and conductor.

Water-filled syringes can be quite dangerous when under pressure. Check your connections carefully first.

Test

4. How well does your model meet the design criteria?
5. If your model does not meet all of the design criteria, what changes do you need to make to your design? Make the necessary changes.

Evaluate

(a) When is the fluid in your model being compressed?

(b) Why must no air be present in a system filled with water?

(c) How would you notice if your air-filled system were leaking?

(d) What difference might you notice if you filled your hydraulic model with oil?

(e) How would you modify your model to lift a load twice as heavy?

(f) You used clay as the object to be lifted. What changes would you need to make to your model lift a stiff, rectangular object?

(g) Exchange the syringe providing the effort force in your model with a smaller syringe. Describe the change in the effort required to lift the load on the larger syringe.

PERFORMANCE TASK

What skills did you use in designing and building a model fluid power system that might be useful in the Performance Task? What problems in design and construction can you avoid?

Fluid Power at Work for Us

5.8

Hydraulic and pneumatic systems are versatile. They are combined with electrical systems and mechanical systems (pulleys and levers) in an amazing variety of ways to meet the needs of society. For example, they can be used to do very heavy or extremely delicate work. Tiny hand-held drills operated by pneumatics are used for medical surgery. Hydraulic and pneumatic robots prevent human injury by performing dangerous jobs on assembly lines. Hydraulic machines save industries money, quickly and efficiently doing heavy tasks that would take many people long hours to perform.

LEARNING TIP

Headings and subheadings act as a guide for your reading. To check for understanding as you read, turn each heading into a question and then answer it.

Working to Entertain Us

Fluid power systems work to frighten and thrill us. Hydraulic systems are used in movies and television shows to create special effects (**Figure 1**). For example, many of the dinosaurs used in the movie *Jurassic Park* were built using hydraulic systems. Each system was connected to a different part of the dinosaur. Operators used remote controls to operate the hydraulic systems and create all the dinosaur's movements, even the blinking of an eye.

Pneumatic systems are used in amusement park rides (**Figure 2**). Compressed air is used to push the train's brakes against the track, which causes the train to slow down and eventually come to a stop.

Figure 1
Animated movie figures appear lifelike because of hydraulic systems.

Figure 2
A pneumatic system is used to slow and stop roller coasters.

Hydraulics to the Rescue

There are many kinds of hydraulic rescue tools. Some can cut with a force as high as 169 kN. Others, such as the Jaws of Life, can pry things apart (**Figure 3**). These hydraulic tools are used to open the sides of vehicles or slice guardrails at the roadside to get accident victims to the hospital quickly.

Figure 3
The Jaws of Life is a hydraulic prying tool. It uses a hydraulic fluid made especially for accident scenes, where the risk of fire or explosion is high. The fluid is fire resistant and does not conduct electricity.

Training Uses

Hydraulic systems are used to create motion in flight, driving, and ship-handling simulators (**Figure 4**). Operators sit inside a model of a real vehicle and respond to computer-generated situations as if they were real. Hydraulic cylinders move the model back and forth and from side to side. Because this is a simulation, dangerous manoeuvres can be tried without anyone getting hurt. Hydraulic systems help to give us the best trained pilots, drivers, and ship captains.

Moving Earth Beneath Our Feet

Figure 5 shows a section of a Tunnel Boring Machine (TBM) building a subway tunnel. This machine has two functions: it bores through the earth to form the tunnel, and it installs the lining of the tunnel.

Figure 4
The hydraulic system of an airplane simulator provides realistic movement for training pilots.

Figure 5
A Tunnel Boring Machine emerges from a section of tunnel.

To form the tunnel, hydraulic motors rotate the cutting head that excavates the ground. While the cutting head digs, hydraulic-thrust cylinders push the machine forward. The excavated soil passes through hydraulically operated doors to a screw-type conveyor. A second conveyor belt takes this soil to waiting rail cars, which haul it away. As the tunnel is being formed, the lining is installed. The fluid-power systems in this modern machine enable it to bore 1 m of tunnel an hour.

5.8 CHECK YOUR UNDERSTANDING

1. List three benefits of fluid-power systems.
2. You can run a flight simulator on your desktop computer. Why is it an advantage to train pilots on hydraulically operated simulators?
3. List 10 devices or machines that use fluid power. State whether each is a hydraulic or pneumatic system.
4. Would oil be a good fluid to use in the Jaws of Life? Explain why or why not.
5. Do you think roller coasters would be possible without pneumatic or hydraulic systems? Explain.
6. Why do you think Tunnel Boring Machines were developed?

CHAPTER 5 *Review* The Use of Fluids

Key Ideas

Knowledge of the properties of fluids is important in technology.

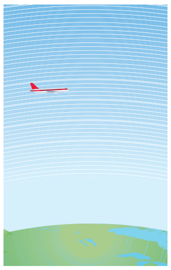
- Construction in fluid environments must take fluid flow into account.
- Air and water are two important fluids that affect structures.

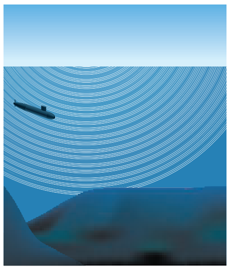
An object immersed in a fluid will experience pressure.

- Pressure, defined as force per unit of area, can be calculated using the following formula:

$$\text{pressure} = \frac{\text{force}}{\text{area}} \quad \text{or} \quad p = \frac{F}{A}$$

- The unit of pressure is the pascal (Pa), 1.0 Pa = 1.0 N/m^2.
- Fluids exert a pressure in all directions. The pressure exerted toward the surface of Earth is known as atmospheric pressure.
- The pressure in a fluid increases with depth.





Forces can be transferred through confined fluids.

- A force exerted on a fluid in a confined system is transmitted through the fluid to cause movement in another part of the system.

Vocabulary

pressure, p. 147

pascal, p. 148

atmospheric pressure, p. 149

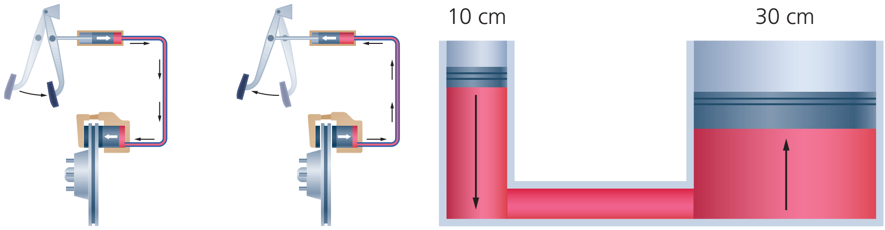
hydraulic system, p. 151

pneumatic system, p. 151

compression, p. 154

compressible, p. 154

- Liquids are nearly incompressible. Liquids in a confined system transmit forces more quickly than gases in a confined system.
- Gases are compressible, so the particles in a gas must be squeezed closer together before the force can be transferred.
- The force applied in the small cylinder of a hydraulic system is multiplied in the larger cylinder by the same ratio as the ratio of the areas of the cylinders.



Pressure, temperature, and volume of a fluid affect each other.

- If the pressure of a fluid remains constant, an increase in the temperature of the fluid will cause the volume to increase. If the volume of a fluid is decreased, the temperature will also decrease.
- If the temperature of a fluid remains constant, an increase in the pressure of the fluid will cause a decrease in the volume. If the volume is increased, the pressure will decrease.
- If the volume of a fluid is held constant, an increase in the temperature will cause an increase in the pressure, and a decrease in the temperature will cause a decrease in the pressure.

Machines and other devices that use fluids can make work and movement easier.

- Hydraulic systems use a liquid to transfer forces. Pneumatic systems use a gas to transfer forces.
- Hydraulic and pneumatic devices are useful because they multiply forces to perform tasks that cannot easily be performed by people.

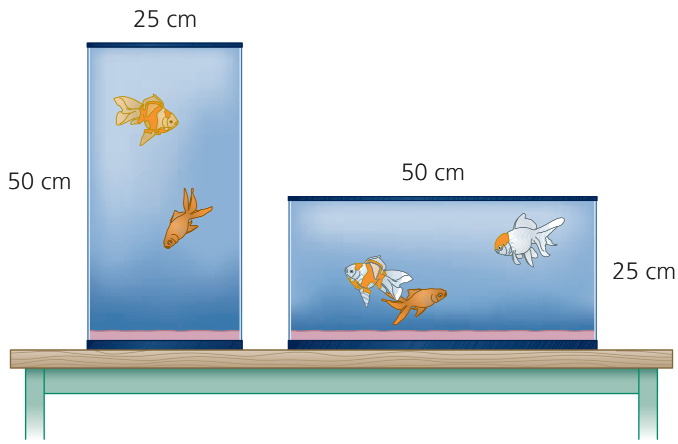


Review Key Ideas and Vocabulary

1. The ratio of the areas of the two pistons in a hydraulic system is 6:1. If a force of 15 N is applied to the smaller piston, what force is transferred to the larger piston?
   (a) 15 N
   (b) 30 N
   (c) 60 N
   (d) 90 N
   (e) 120 N
2. Assuming that the volume of a quantity of gas is constant, what will happen to the pressure on the gas as the temperature is increased?
   (a) increase
   (b) decrease
   (c) remain the same
   (d) increase, then decrease
   (e) increase until the gas condenses
3. Indicate which of the following statements are true (T) and which are false (F). Rewrite the false statements to make them true.
   (a) Buoyancy is an important property in the manufacture of chocolate.
   (b) Increasing the area over which a force is applied reduces the pressure.
   (c) Atmospheric pressure increases with elevation.
   (d) Car brakes are an example of a pneumatic system.
   (e) To multiply the force transferred in a fluid system, the cylinders must have different areas.
   (f) Liquids are more compressible than gases.
4. List and briefly describe three examples of how a knowledge of fluids played a role in the construction of the Confederation Bridge.
5. Identify five industries in which the properties of fluids play an important role. For each industry, provide an example of fluid use.
6. Using the kinetic molecular theory, explain the effects of temperature changes on solids, liquids, and gases. Draw diagrams to support your explanation.
7. Predict the effect of applying external pressure on a gas, like air, in a closed system, such as the system in Investigation 5.3.

Use What You've Learned

8. Suggest some design features that might reduce the amount of air turbulence around the Confederation Bridge.
9. Needles are attached to syringes when injections are given to people or animals. How do health-care personnel remove air from a syringe?
10. Two fish tanks have the following dimensions:



   (a) Which of the two fish tanks contains the larger mass?
   (b) Which exerts the greater pressure on the tabletop? Explain your answer.
11. Divers carry a supply of air in order to breathe underwater. Apply your knowledge from investigating fluids to explain how divers can remain underwater for long periods of time with only a small tank of air.

12. **Figure 2** shows a plastic tube with a straight stopper plugging the left end and a tapered stopper plugging the right end. If you slowly push in the straight stopper, what will happen if the tube is filled with air? What will happen if you slowly push in the straight stopper and the tube is filled with water? Explain why there is a difference.

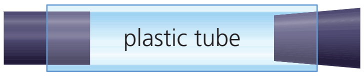


Figure 2

13. A hydraulic system is set up to lift heavy weights on to a platform. The ratio of the area of the pistons in the system is 15:1.
    (a) What force must be exerted on the smaller piston in order to lift a crate weighing 15 000 N resting on the larger piston?
    (b) If the platform that the crate must be lifted to is 1 m high, how far must the smaller piston move to raise the larger piston that distance?
14. Use what you have learned about syringes to explain the benefit of having two lungs instead of one.
15. A warning on an aerosol can states, "Caution! Container may explode if heated." Using the kinetic molecular theory, explain why such a warning is necessary.
16. Describe how the air pressure inside a soccer ball changes when the ball is kicked.

Think Critically

17. Do you think that a device with a hydraulic system or a device with a pneumatic system is more effective? Explain your answer.
18. A tire manufacturer is required to recall some of its tires because they may explode at high speeds. The plan is to recall the tires in tropical countries first. Prepare a press release to explain the reasoning behind the company's recall plan.
19. Canning is a way of preserving food. Research canning and answer the following questions:
    (a) Why is it necessary to leave some space at the top of the jar before sealing it?
    (b) What happens in the space at the top of the jar when the cooking water is boiling?
    (c) Why is it important not to seal the lid before heating the jar?
    (d) What happens after you tighten the lid to seal the jar?
    (e) Why does the lid "pop"?
    (f) Why do you think is canning a good way to preserve food?

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20. Two lakes are of equal depth. Each has a dam across the end where it runs out into a river. One lake is 1.0 km long and the other is 2.0 km long. How does the pressure at the base of the first dam compare with the pressure at the base of the other dam? Explain your answer.
21. How would your life be different if there were no hydraulic or pneumatic systems? Give three examples to support your answer.

Reflect on Your Learning

22. What problem-solving skills did you develop in this chapter that you might use in other situations?
23. How do you think your knowledge of fluids and fluid power systems will affect your life?

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