Chapter 9 • Fluids Under Pressure

KEY QUESTION: How do pressurized fluids affect our lives and the lives of other living things?

Looking Ahead

- Under pressure, some fluids behave differently than others.
- Systems use fluids to accomplish tasks.
- The skills of scientific inquiry can be used to study how fluids are used in hydraulic systems and pneumatic systems.
- Pressurized fluid systems occur in nature as well as in human-made devices.
- Technological problem-solving skills can be used to create a working model of a hydraulic or pneumatic device.
- Human use of fluids technology has social and environmental costs and benefits.

VOCABULARY

compress  atmospheric pressure
compressibility  Pascal’s Law
pneumatic system  valve
hydraulic system  internal combustion
pressure  engine
Hydrants, Hoses, and Hope

Shortly after midnight, the fire was still not completely out. Jason and Shauna continued to watch the scene. Two hours earlier, their neighbour, Mrs. Nguyen, had pounded on their door, asking to call 911. While she was cooking a late-night snack, some cooking oil had splashed onto the gas stove and caught fire. She tried to put the fire out with water but that made things worse. Getting herself and her pets out of the house became the priority.

The fire trucks arrived soon after. The firefighters rolled the hoses out and connected them to the fire hydrant down the street. Within minutes, water was flowing from the pumper trucks into hoses and onto the burning house. Hoses on extension ladders rained water down upon neighbouring homes to prevent the fire from spreading.

When the fire was under control, the firefighters entered the house to begin cleanup. They were wearing masks connected to air tanks on their backs. It was not only the smoke from burning materials the firefighters had to worry about; many household items give off poisonous fumes when heated or burned.

Mrs. Nguyen, although comforted by paramedics and friends, was devastated at her loss. Part of the house had been saved, but it would be many months before she could move back in. Still, the firefighters had done their work. They had salvaged some of her house and, most importantly, made sure that Mrs. Nguyen and her pets were safe. There was hope.

**LINKING TO LITERACY**

**Recounts**

A recount lists, in order, a series of small events that happened to a person or character. There are three types of recounts: personal, factual, and imaginative. The text on this page is a factual recount because it reports the facts of an incident as they occurred. Sometimes, to capture a reader’s interest, the writer begins with the last event of the recount, and then describes what happened before this event.

1. Create a sequence chart to list each of the events in this recount in order. Begin with a blank sheet of paper. Draw a text box and write the event that came first. Then draw a second box and write the second event. Connect the first box to the second box with an arrow. Continue adding text boxes and arrows until you have listed all of the recount’s events.
Putting the Squeeze on Fluids

Does a water-filled balloon bulge and move in the same way as an air-filled balloon when it is squeezed (Figure 1)? Air and water tend to flow from one place into another when you try to compress them or squeeze them into a smaller space.

Compress: to pack closely together; squeeze

Compressibility: the ability to be squeezed into a smaller volume

TRY THIS: Compressing Fluids

In this activity, you will use a syringe (Figure 2) to observe the effects of compressing a volume of air and then the same volume of water.

Equipment and Materials: eye protection; 20 mL syringe; water

1. Draw 20 mL of air into the syringe and cap the nozzle with your thumb so that no air escapes.
2. Press the plunger slowly and firmly while keeping the end sealed. Watch for any change in the volume of air. If air escapes from the end of the syringe, cap the end more tightly or use less force on the plunger.
3. Keep the end sealed, and release the plunger. Observe any changes in volume. Record your actions and observations.
4. Repeat steps 1 to 4 using water. Record your observations in your notebook.

A. Offer a possible explanation for any observed change in fluid volume.

Wear eye protection to work with fluids under pressure.

Making Connections: Text-to-Self
This text asks you to make a text-to-self connection. Think about the last time you squeezed a balloon and felt the air move from one part of the balloon to another.

Making a connection to the text, or thinking about a “time when…” helps you make sense of the scientific principle that is being explained.

Figure 1 Compressing a fluid is difficult when the sides of the container are free to move.

Figure 2 A syringe

The Try This activity demonstrates that air (a gas) can be compressed into a smaller volume much more easily than water (a liquid) can. Why is that?

The particles of a gas are much farther apart than those of a liquid, allowing us to force the particles of a gas closer together. There is less space between the particles of liquids so they have very little compressibility, while solids have almost none at all. Compressibility is the ability of a substance to become more compact when squeezed.
Types of Fluid Systems

Systems designed to put the squeeze on fluids can be divided into two main types. **Pneumatic systems** (Figure 3) use pressurized air or other gases to do work. **Hydraulic systems** (Figure 4) use pressurized liquids (often oil) to do work. These systems must keep their fluids contained within them in order to work. They are called closed systems. Closed systems are ones in which no material enters or leaves the system.

Hydraulic and pneumatic fluid systems consist of several components:

- a pump (sometimes including cylinders and pistons) forces fluids through a system
- conductors (tubing, hoses, or pipes) provide a pathway to carry the fluid
- valves keep the fluid moving in the desired direction at the desired time
- a pressure gauge monitors pressure within the system

Each component has its own job to do (Figure 5).

**Figure 3** Pressurized air provides the power for this pneumatic hammer.

**Figure 4** Rescue workers use hydraulic cutters and spreaders to rescue crash victims.

**Figure 5** A blood pressure gauge uses the pressure of air to measure the pressure of liquid blood in the body.

To learn more about how hydraulic and pneumatic systems work, **Go to Nelson Science**

**Unit Task** How might you address the compressibility of different fluids when planning for the Unit Task?

**CHECK YOUR LEARNING**

1. Define “compressibility” in your own words. Give an example from your daily life.
2. Using the particle theory, explain why liquids are less compressible than gases.
3. (a) What is a hydraulic system?  
   (b) What is a pneumatic system?
4. What are the components of both hydraulic and pneumatic fluid systems?
Investigating Fluids in Closed Systems

In this activity, you will connect a variety of syringes together to observe the effects of air and water in different systems.

**Testable Question**
What effect does changing the type of fluid (for example, air or water) have on the ability of a fluid system to transfer force?

**Hypothesis/Prediction**
Read over the rest of the investigation. Make a hypothesis regarding the ability of air and water to transfer force. Your hypothesis should include a prediction and reasons for your prediction.

**Experimental Design**
In this investigation, you will use syringes to observe how a pneumatic system is able to move plungers in syringes of different sizes. You will then compare those observations while using the same syringes to create a hydraulic system.

**Equipment and Materials**
- eye protection
- 2 syringes (30 mL)
- syringe (10 mL)
- 5 cm of vinyl tubing
- 50 cm of vinyl tubing
- wax crayon or masking tape
- water

**Procedure**
1. Read the rest of the procedure and decide how you will record your observations. Design an observation table that you can use.
2. Put on your eye protection. Begin with two 30 mL syringes. Use a wax pencil or masking tape to label one of the syringes “A” and the other “B.”
3. Pull the plunger of syringe A to the 30 mL mark, and push the plunger of syringe B all the way in. Connect them with the 5 cm piece of tubing.
4. Slowly push plunger A all the way in. Observe and record what happens to plunger B. How far did each plunger move? What is the final reading on syringe B?

5. Try pushing the plunger of one syringe in, while preventing the plunger of the other one from moving. What do you notice? Record your observations.

6. Repeat steps 3 to 5, using a 50 cm length of tubing between the syringes. What do you notice? Record your observations.

7. Repeat steps 3 to 5, using water as your fluid instead of air. To set this up correctly, begin by pushing both plungers all the way in. Then connect the tubing to one of the plungers, put the end in water, and pull the plunger back to the required volume. This will keep the tubing filled with water. Record your observations.

8. Empty and dry the syringes. Connect a 30 mL syringe (plunger all the way in) to a 10 mL syringe (plunger all the way out) with a 5 cm piece of plastic tubing (Figure 1). Move both plungers back and forth, with and without adding resistance (trying to prevent one of the plungers from moving). Observe the distance moved by the plungers. Observe the ease of moving the plungers. Record your observations.

9. Repeat step 8 using water in the system. Record your observations.

**Analyze and Evaluate**

(a) Which syringe systems were pneumatic systems? Which were hydraulic systems?

(b) Compare your observations using the two 30 mL syringes with air and water. What differences did you notice
   (i) when you added no resistance?
   (ii) when you added resistance?

(c) What did you notice when you used tubing of different lengths between the syringes?

(d) What did you notice when you used syringes of different sizes?

(e) When you used the 10 mL and 30 mL syringe systems, which plunger was easier to move against the resistance you provided?

(f) Did your results support your hypothesis? Explain.

(g) Answer the Testable Question.

**Apply and Extend**

(h) With your pneumatic system above, how do you think your results would have been affected if there had been a leak in the tubing?

(i) Given your observations for this investigation, would you rather have a hydraulic braking system or a pneumatic braking system in your car? Explain.

**Unit Task**

Do you think you could use one of the systems designed here in the toy you create for the Unit Task?

**LINKING TO LITERACY**

Summarize Your Learning: The Quick Write

Do a quick write to increase your learning. Take 5 minutes to write about what you have just learned from this experiment. Retell the process you followed to complete the investigation. Reflect on your findings. Relate what you learned about fluids to other systems that use the same principles.
9.3  PERFORM AN ACTIVITY

Putting Fluids to Work

Pressurized fluids in both hydraulic and pneumatic systems are used to do work. In this activity, you will compare work done by these two types of systems.

**Purpose**
To compare the effect of using hydraulic and pneumatic systems to move a load.

**Equipment and Materials**
- eye protection
- 2 syringes (30 mL)
- syringe (10 mL)
- 10 cm of vinyl tubing
- 50 cm of vinyl tubing
- force meter
- 1 kg standard mass, brick, or small pile of textbooks to act as a load
- syringe (60 mL)
- wax crayon or masking tape
- water

**Procedure**

**Part A: Pneumatics**

1. Read the rest of the procedure (Part A and Part B). Decide how you will record your observations and design a table in which to record them.

2. Put on your eye protection. Begin with two 30 mL syringes. Use a wax pencil or masking tape to label one of the syringes “A” and the other “B.”

3. Pull the plunger of syringe A to the 30 mL mark, and push the plunger of syringe B all the way in. Connect them with the 10 cm length of tubing.

4. Place both syringes flat on your desk. For the next steps, hold them firmly so that they do not move. Optional: You can easily make a simple device for holding the syringes in place using a spare board and a few nails (Figure 1).

**Figure 1** Setup for step 4
5. Place the standard mass (or other load) on the desk so that it is touching the plunger of syringe B.

6. Place the force meter against the plunger of syringe A. Then, as you slowly push in plunger A, measure the force needed to cause plunger B to move the load (Figure 2). Record this measurement.

7. Measure the distance moved by plunger A and the distance moved by the load pushed by plunger B. Record your observations.

8. Repeat steps 3 to 7 using
   - a 30 mL syringe (A) to push the plunger of a 10 mL syringe (B)
   - a 10 mL syringe (A) to push the plunger of a 30 mL syringe (B)
   - a 10 mL syringe (A) to push the plunger of a 60 mL syringe (B)

9. Repeat steps 2 to 7 using the 50 cm of tubing. Record your observations.

**Part B: Hydraulics**

10. Repeat steps 2 to 8 using the 10 cm length of tubing and water as the fluid. Make certain that there is no air trapped in your syringes or tubing. Record your observations.

**Analyze and Evaluate**

(a) Make a general statement about the force needed to move a load and the distance the load moves when
   (i) a small plunger pushes a larger plunger
   (ii) a large plunger pushes a smaller plunger

(b) Use evidence from your activity to answer the following questions:
   (i) What effect did changing the length of the tube have? Why might this happen?
   (ii) What effect did using water instead of air have? Give some reasons why this might happen.

**Apply and Extend**

(c) Why are hydraulic systems used in machinery such as bulldozers (Figure 3) and backhoes, while pneumatic systems are used for such things as opening and closing bus doors?

**Figure 2**  Slowly push on the force meter while taking the measurement.

**Figure 3**  Hydraulics are a major component of heavy equipment.

**Unit Task**  How might this activity inform you about the length of tubing to use in your toy?
9.4 Effects of External Pressure on Fluids

You have seen how increasing the pressure on a gas can force it into a smaller volume. In science and technology, pressure refers to the force applied to a unit of surface area.

Some devices, such as thumbtacks, are designed to increase pressure. The force you apply to the head of the tack is transferred to the tiny area of the point. As the force is concentrated on a smaller area, pressure increases. Other devices are designed to decrease pressure. When a person wears snowshoes or uses a snowboard, he or she can stay on top of the snow. The force of the person’s weight is spread over a larger area than if he or she were wearing boots. Spreading the force over a larger area reduces the pressure and prevents the person from sinking into the snow.

Mathematically, we write pressure \( p \) = force/unit area, or

\[
p = \frac{F}{A}
\]

Pressure is measured in pascals (Pa) and 1 Pa = 1 N/m\(^2\).

**Air and Water Pressure**

Fluids also exert pressure. Earth’s atmosphere is approximately 160 km thick, and gravity pulls on every particle of it. Think of a newspaper spread out on your table. It has an area of about 1 m\(^2\) and a weight of about 1 N. So the pressure on the table from only the newspaper is about \( 1 \text{ N/m}^2 \) or 1 Pa. Now consider the weight of all the air directly above that newspaper pressing down on it. Atmospheric pressure, or air pressure, is the force exerted by the atmosphere (Figure 1) on the newspaper. It is 100 000 times greater than the pressure caused by the newspaper alone! Atmospheric pressure decreases the higher you ascend, because there is less air above you pressing down.

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**TRY THIS: Observing Atmospheric Pressure**

**SKILLS MENU:** performing, observing, analyzing

Does atmospheric pressure only press downward? This activity will help you find an answer to this question.

**Equipment and Materials:** plastic cup; plastic catch basin; file card (large enough to cover the top of the cup); water

1. Fill a plastic cup about three-quarters full of water. Place a file card over the top of the cup.

2. With your hand pressing the card to the cup, turn the cup upside down and hold it over the catch basin.

3. Slowly and carefully remove your hand without disturbing the card. Record your observations.

A. Use the idea of atmospheric pressure to explain what happened.
The Try This activity demonstrates that air pressure acts in all directions. It can apply enough force on the card to keep the water in the glass. Even though water is much heavier than the same volume of air, the force of gravity on the water in the glass was not enough to overcome the force of air pressure pushing up on the card. This is why the water did not fall out.

Like air, water also exerts pressure. When you swim underwater, the water presses on all parts of your body and in all directions. Since water is much heavier than air, it exerts more pressure than does air. In fact, the pressure of deep water is so great that deep-sea divers require much greater protection than scuba divers swimming near the surface (Figure 2). Submarines must have special hulls to keep the pressure of the water from crushing them.

**Pressure and Pascal’s Law**
Blaise Pascal (1623–1662) was a French mathematician and physicist. Pascal is famous for many theories in mathematics and he developed one of the first mechanical calculators. Pascal also studied the behaviour of fluids and later invented the syringe. Pascal found that when fluids in a container are put under pressure, they push in all directions. That is why balloons bulge when filled or squeezed.

**Pascal’s Law** states that when pressure is applied from an outside source to a contained fluid, the force is transferred throughout the fluid in all directions (Figure 3). This ability of fluids to transfer force is used in nature and in many human-made devices.

**Applying Pascal’s Law**
When you connect two syringes of different sizes together and push on their plungers, you quickly notice two things:
- The plunger in the smaller syringe moves farther than the plunger in the larger syringe.
- The plunger in the smaller syringe is easier to move than the plunger in the larger syringe.
Figure 4 shows that when the fluid in a small chamber is pushed into a larger chamber, it is spread throughout a bigger volume. This is why the small plunger (or piston) moves much more than the large plunger. However, the force applied to the small piston is transferred to every part of the fluid equally. Since the large piston covers a greater area, the force that the large piston can apply is much greater than the force applied to the small piston.

We use Pascal’s Law today in devices like hydraulic brakes and heavy equipment. Using the ability of fluids to transfer force, we can control the amount of force applied in a system’s mechanisms, as well as the distances moved by the parts of the mechanisms.

Liquids cannot be compressed very much. When you apply force to one part of a hydraulic system, the force transfers immediately to all other parts. Since gases are much more compressible than liquids, pneumatic systems are often used when a “cushioning” effect is desired. For example, many bus and streetcar doors use pneumatic systems. Should something or someone get caught in the door, the door does not squeeze as hard or as quickly as a hydraulic system might (Figure 5).

Figure 4 The distance moved by the large piston is always less than the distance moved by the small one. However, since the large piston has an area five times larger than the small piston, the force from the small piston is multiplied five times.

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Figure 5 Many buses and streetcars use pneumatic systems to open and close the doors.

**CHECK YOUR LEARNING**

1. What is meant by “pressure” in a scientific sense? What units are used to measure pressure?

2. In your own words, describe atmospheric pressure and water pressure.

3. Describe Pascal’s Law in your own words. You may use a diagram to help.

4. Why do deep-sea divers require greater protection than scuba divers?
Hydraulic Marvel—The Falkirk Wheel

In Scotland, on May 24, 2002, Queen Elizabeth II opened the Falkirk Wheel—the world’s only rotating boat lift (Figure 1).

Each of the Falkirk Wheel’s two giant tanks can hold 360,000 L, or 600 tonnes, of combined boat and water. The tanks are designed to always weigh the same since, according to Archimedes’ principle, any boat entering one tank will always displace its own weight in water. The weight of the water and boats in the upper tank can then be used to help lift the water and boats in the lower tank. As the arms rotate, specially designed gear trains cause the tanks to rotate in the opposite direction so that the water always stays level (Figure 3).

Figure 1  This amazing structure stands more than eight stories tall with a huge tank at the end of each of its two giant arms.

The Falkirk Wheel is used to pass barges and other boats from one canal to another (Figure 2). It replaces eleven traditional boat locks that were once needed to connect two canals whose water levels differ by 35 m.

Figure 2  The Falkirk Wheel connects the Union Canal with the Forth and Clyde Canal 35 m below.

Figure 3  The small gear between the two large ones causes the large gears to turn in opposite directions.

Ten hydraulic motors are used to turn the massive central wheel and axle. This truly amazing lift can raise and lower its 600-tonne load in just 5.5 minutes and it does so using about the same amount of energy as that needed to boil eight kettles of water!

For more information on the Falkirk Wheel, Go to Nelson Science.
9.5 Relationships: Pressure, Volume, and Temperature

When you push a plunger in a sealed container, it compresses the air in the cylinder into a smaller volume. When a gas is under pressure in a closed system, its volume is decreased significantly (Figure 1). When liquids are under pressure, their volumes decrease as well; however, the decrease in volume is so small that it is barely noticeable. This is because particles of a liquid are much closer together than particles of a gas.

We use this property of fluids when we compress gases into scuba tanks and other rigid containers (Figure 2). All of these containers have a large amount of gas compressed into a small volume. As more gas particles are forced into the rigid container, the number of collisions between particles and the sides of the container increases. This increases the pressure that the gas particles exert on the interior walls of the container. The container is made of strong material (usually metal), so it does not burst. Why are most containers that hold gases under pressure curved?

If you have ever used a hand pump to fill a bicycle tire, you may have noticed that the barrel of the pump warms up. Some warming is due to friction between the piston and the cylinder walls. Rapidly pushing in the plunger of the pump also forces the air into a smaller volume. This compression causes more collisions among the particles of air and between the particles and the cylinder walls. This increase in collisions not only causes the pressure to increase, it also causes the temperature to rise. Conversely, increasing the volume causes the temperature to drop.

Figure 1  Increasing the pressure on a gas in a closed system reduces its volume significantly.

Figure 2  Pressure has been used to force a large amount of gas into a small volume in these welders’ tanks.
As temperature increases, the particles of a fluid move faster and farther apart. This causes the fluid to expand. As the temperature of a fluid drops, its volume decreases (contracts). This is generally true for all forms of matter. (As you saw in Chapter 8, water between 0 °C and 4 °C is a special case that does not follow this pattern.) Thermometers use this principle of thermal expansion during heating and thermal contraction during cooling to give us accurate temperature readings (Figure 3).

Figure 4 shows a familiar warning sign. Why is heating aerosol containers so dangerous? As the temperature inside the pressurized can increases, so does the speed of the particles. As the particles move faster, they hit the inside walls of the can with increased force, causing the pressure on the walls to build up. Eventually, the pressure could become so great that the walls of the container explode.

In the opposite way, decreasing the temperature causes particles to slow down and move closer together. There will be fewer collisions with the sides of the container, and the pressure inside the container will drop.

**Unit Task** Will you need to consider relationships between temperature, pressure, and volume when designing your toy? Why or why not?

**CHECK YOUR LEARNING**

1. What happens to the volume of a gas in a cylinder when you try to compress it? Use a diagram in your explanation.
2. How is the property of compressibility of gases used in everyday life? Give an example.
3. Explain why the barrel of a bicycle pump heats up when you use it to pump a tire.
4. Why is heating an aerosol can so dangerous?
Solving Problems with Hydraulics and Pneumatics

We use pressurized fluids to make our lives more manageable, to make work easier to do, and to increase human productivity. In this activity, you will create a working model of a hydraulic or pneumatic system.

Scenario
You and your class are part of an innovative design team. Each year, members of your team identify a challenge to solve, then pool their learning to form a community of learners. In this way, you share the knowledge and skills learned during the challenge in order to apply them to future challenges. This year’s challenge is to construct a working model of a hydraulic or pneumatic system, as described below.

Design Brief
You have learned how air and water inside syringes can transfer forces and do work. You will now use this knowledge to build a working model that uses a closed hydraulic or pneumatic system to perform a task. Choose one of the following devices:
- a dentist’s chair that can move up and down, and has an adjustable back
- a car hoist that can raise and lower a model car in a controlled way
- a device that can raise and lower a stage set in a controlled way
- a hydraulic brake that can stop a spinning wheel or disk
- a backhoe that can move its digging arm in two directions

Equipment and Materials
- eye protection
- variety of syringes
- vinyl tubing
- hand saw
- hand drill
- mitre box
- 1 cm x 1 cm basswood
- popsicle sticks, tongue depressors, or wood scraps
- low-temperature glue gun with glue sticks
- dowels
- paper gussets
- scrap materials (for example, cloth, cardboard)
Wear eye protection when using hand tools. Use glue guns in a low-traffic area with good airflow. Do not touch hot glue. Ensure the wood you are cutting or drilling is held securely to your work surface. When finished with your tools, put them away in a safe place.

Research and Consider
Research the items you might wish to build. On the Internet, see if you can find some models of what other students have built, but do not let this limit your imagination. Brainstorm a few possible solutions, making thumbnail sketches to guide you.

Plan and Construct
1. Choose the sketch or sketches you will use from your brainstorming sessions and make a working drawing of your prototype (roughly to scale). If you make changes to your plans along the way, include these changes on your working drawing as you make them.
2. Create a step-by-step plan for constructing your prototype. Include a list of materials you will use and equipment you will need.
3. Finalize the plan for your prototype and check it with your teacher.

Test and Modify
Test your prototype to see if it works the way you want it to. Does it meet the criteria you or the class set for the device? Make modifications and then test your revised prototype. Keep a written record of the modifications you make and the results of those modifications. Continue to improve your design as time permits.

Evaluate
Compare the performance of your device with the criteria in the Design Brief. When you test the device, make careful observations. Note any problems and think about how you might modify the design further. Consider the following questions:
1. How well did your product meet the criteria?
2. What difficulties did you encounter with your design? If you had more time, how might you overcome these difficulties?
3. (a) What skills do you need to work on to improve your ability to solve technological problems?
   (b) How can you develop these skills?
   (c) Discuss your plans with your teacher.

Communicate
(a) Oral presentation: Show how your device works and briefly describe the main things you learned during the process, as well as what you would change and why.
(b) Written communication: Create a permanent record of your design and the design process so that it can be displayed and added to the group’s combined knowledge. You may wish to use a graphic organizer, electronic presentation media, or written format to share your learning.
(c) Include a labelled diagram or technical drawing of your final product.

Unit Task
Be sure to keep a list of everything you learned from your work and the work shared by others. You can use what you learn in this activity to complete the Unit Task.
The Value of Valves

The circulatory system pumps blood (a fluid) throughout the body. It is a closed hydraulic system. It is a hydraulic system because it is fluid-filled, and it is closed because the heart and blood vessels form a long, convoluted, sealed compartment inside the body.

The circulatory system has special features that help it do its job. The heart is a pump that pushes blood through arteries and veins. The walls of arteries—the vessels that carry blood away from the heart—are thick and muscular to withstand the pressure created by the pumping heart.

Since the pressure in veins—the vessels that collect blood from the body and return it to the heart—is much lower, vein walls are not as thick. In fact, veins have very thin walls compared to those of arteries. However, veins are equipped with valves. Valves are devices that control the movement of a fluid through a hollow tube or pipe. Valves in veins (Figure 1) are like one-way gates that prevent blood from backing up or pooling.

Some people have valves that do not close completely, so blood backs up and pools in certain veins. The veins become large and swollen. These are called varicose veins (Figure 2).

The heart also has valves that force blood to move through it in one direction. As the heart muscle contracts and relaxes, four heart valves keep blood flowing in the right direction (Figure 3).

**Figure 1** As the heart relaxes, blood pressure in the veins is lowered, but backflow is prevented by closure of the valves.

**Figure 2** Incomplete closing of the valve allows blood to flow backwards and pool, causing varicose veins.

**Figure 3** The heart's four valves prevent blood from flowing in the wrong direction.
TRY THIS: Exploring Valves

**SKILLS MENU:** performing, observing, analyzing

In this activity, you will compare the way fluids flow between syringes, with and without the use of a valve.

**Equipment and Materials:** two 10 mL syringes; 20 mL syringe; three 5 cm pieces of vinyl tubing; T-connector; T-valve

1. Connect the three syringes to the T-connector, using the 5 cm pieces of tubing as shown in Figure 4.

2. Sketch this system.

3. Depress each of the plungers in turn and record your observations.

4. Switch the position of the 20 mL syringe with one of the 10 mL syringes and repeat step 3. Record your observations.

5. Replace the T-connector with the T-valve and repeat steps 3 and 4 as you turn the valve. Record your observations.

A. Describe the movement of the plungers in the two smaller syringes when you used the T-connector with the 20 mL syringe in the centre. How did this compare to the movement that resulted when a 10 mL syringe was in the middle?

B. Compare the results when using the T-valve versus using the T-connector.

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Many human-built systems also use valves. A car engine is called an **internal combustion engine** because it burns (combusts) fuel in chambers inside the engine. The engine relies on valves to allow fuel to enter the chambers and exhaust gases to escape at the correct time and in the correct direction (Figure 5).

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**CHECK YOUR LEARNING**

1. What kind of system—hydraulic or pneumatic—is the human circulatory system?
2. What is the role of valves in the human circulatory system?
3. In the human circulatory system, what is one result from a valve that does not work properly?
4. What is the function of valves in the internal combustion system of a car engine?
The Power of Fluids

We use fluids every day to help us do work. Machines such as excavators, backhoes, and front-end loaders use hydraulic rams to do work (Figure 1(a)). Rams are similar to syringes: they are composed of a piston (plunger) inside a cylinder. The cylinder is connected by pipes to a reservoir of hydraulic fluid. A pump provides the pressure, and fluid is directed into the cylinder on either side of the piston, depending on the movement desired (Figure 1(b)). This lets the piston move in or out with tremendous force and great precision.

![Rams](image1)

When fluid is pumped into the upper chamber, the piston is forced downward.

Pumping fluid into the lower chamber forces the piston upward.

![Rams Diagram](image2)

Figure 1  (a) Hydraulic rams allow this single worker to do the work of many people.  (b) The rams work by forcing fluid into either side of the piston, allowing powerful and precise movement in both directions.

Fire pumps and hoses are hydraulic systems designed to cause fluids (either water or foam) to leave the system with great force. Water coming from a fire hydrant is already under some pressure. The pumping unit and nozzle design significantly increase this pressure to project the water a considerable distance away (Figure 2(a)).

Human-made devices are not the only users of hydraulic power. Animals use it as well (Figure 2(b)).

![Fire Pump](image3)

![Arch Fish](image4)

Figure 2  Like water shooting from a fire hose (a), the archer fish uses hydraulic power to shoot insects off low-hanging vegetation (b).
While fire pumps take in water and eject it under pressure, hovercraft use the power of air in a similar way (Figure 3). Large motors draw in air from the atmosphere and drive it out under intense pressure below the craft, allowing the craft to ride on this cushion of air over land or water. Often, the craft uses rear propellers to move the machine forward.

Pneumatic power can also be used to move heavy loads. Kneeling buses (Figure 4) use forced air to raise and lower the bus, making it easier for people to enter or exit. One advantage of using pneumatics instead of hydraulics is that the viscosity of air, unlike many liquids, is not significantly affected by changes in temperature.

Some systems use a combination of hydraulic and pneumatic power. Some automobile hoists, for example, pump compressed air into a master cylinder filled with hydraulic fluid (usually oil). This oil is then forced into a closed chamber that drives a piston upward. The piston is attached to a platform on which the car sits (Figure 5).

**CHECK YOUR LEARNING**

1. What is a hydraulic ram?
2. What benefits have you enjoyed personally from using the power of hydraulics and pneumatics?
3. What is one advantage of using pneumatic power over hydraulic power?

**Unit Task** How might you use some of these examples of hydraulics and pneumatics to help you with the Unit Task?
We benefit greatly from our knowledge of fluids and how they behave, and we have put this knowledge to work for us. However, costs accompany these benefits. For example, dialysis machines, artificial hearts, and lung transplants enable us to replace or repair human fluid systems. However, the cost of health care is always increasing.

Heavy hydraulic equipment allows a small number of people to do the work of many. This reduces the cost of construction, but also eliminates jobs. What are the costs and benefits of being able to change the environment so easily?

Pipelines allow us to move water, oil, and natural gas over vast distances. Sometimes these lines run through environmentally sensitive areas (Figure 1) or places where people are living. People may be affected during the construction of pipelines or later by leaking pipes, which may also damage the environment.

The benefits of fluid technology always have costs—economic, social, and environmental. Responsible action requires that we try to reduce the negative impact of our choices while we enjoy the benefits of the technology.

The Issue
Select one example of fluid technology and use it to support or refute the statement below:

The benefits of using this form of fluid technology outweigh the costs.

Also, identify individual actions that could help alleviate some of the costs, or enhance the benefits, of the technology you have chosen.
**Goal**
Select an example of fluid technology that is of interest and importance to you. Briefly explain the technology and state whether or not you support the issue statement. Justify your stance by describing the benefits and costs related to the technology. Finally, offer suggestions as to how Grade 8 students might help reduce those costs or increase the benefits.

**Gather Information**
Review some of the uses of fluids described in this unit, plus others that may be of interest to you. Research how the technology works, as well as the benefits and costs. You can begin by asking these questions:
- Who benefits from this technology?
- What are the costs?
- Who pays the costs?
- Whose voices are not being heard but should be?

**Identify Solutions**
Whether or not you feel the benefits outweigh the costs, you need to identify some actions that Grade 8 students in your school could take to help reduce the negative impact of the technology. These do not have to be huge actions; specific, targeted actions by individuals can have considerable impact. For example, if more of us committed to walk or bike to get places, reduced fuel consumption and less air pollution would be the result.

**Make a Decision**
Use your research to decide whether or not to support the issue statement and to provide justification. Also suggest some actions for reducing the negative impact of our choices or increasing the benefits.

**Communicate**
The results of your research and your decisions must be communicated effectively and concisely in an interesting manner to your classmates and others in your school. You may choose to create a poster, brochure, or computer presentation. Depending on the issue you have chosen, a letter to the student council seeking some action on their part might also be appropriate. Check with your teacher if you would like to use a different way to communicate your work.
BIG Ideas

- Fluids are an important component of many systems.
- Fluids have different properties that determine how they can be used.
- Fluids are essential to life.

Looking Back

Under pressure, some fluids behave differently than others.

- Pressure is a measure of the force per unit area.
- Gases are more compressible than liquids.
- The particle theory explains the different behaviour of gases and liquids under pressure.
- There are strong relationships between the temperature, pressure, and volume of a fluid.

Systems use fluids to accomplish tasks.

- Hydraulic systems use pressurized liquids to perform tasks.
- Pneumatic systems use pressurized gases to perform tasks.
- Valves allow us to use hydraulic and pneumatic systems in controlled ways.

The skills of scientific inquiry can be used to study how fluids are used in hydraulic systems and pneumatic systems.

- Hydraulic and pneumatic systems can be created using syringes, tubing, water, and air.
- Applications of Pascal’s Law can be modelled using syringes, tubing, water, and air.
- The ability of hydraulic and pneumatic systems to move a load can be observed using syringes, tubing, water, and air.
Pressurized fluid systems occur in nature as well as in human-made devices.

- Atmospheric pressure is exerted by the weight of the atmosphere.
- Water pressure increases with depth due to the weight of the water.
- Pressure applied to a fluid is distributed evenly throughout all parts of the fluid.

Technological problem-solving skills can be used to create a working model of a hydraulic or pneumatic device.

- Everyday materials and a knowledge of Pascal’s Law can be used to design, build, and test a working model of an everyday object that operates using hydraulics or pneumatics.

Human use of fluids technology has social and environmental costs and benefits.

- We use pressurized fluids daily to make our lives more manageable and to increase the amount of work that humans can do.
- We use pressurized fluids at home, at work, and at play.
- Our use of hydraulic and pneumatic systems allows us to make major changes to society and the environment.
- Our ability to make such changes must be accompanied by a commitment to make these choices responsibly.
What Do You Remember?

1. Use the particle theory to compare the compressibility of liquids and gases. [K/U]
2. Give two examples each of hydraulic systems and pneumatic systems. [K/U]
3. (a) What components make up a typical fluid system?
   (b) Make a simple sketch of a fluid system and label the parts. [K/U] [C]
4. In your notebook, complete Table 1 using the terms “increases” or “decreases” to replace the blanks. [K/U]

<table>
<thead>
<tr>
<th>Change to a fluid</th>
<th>Results in</th>
</tr>
</thead>
<tbody>
<tr>
<td>increase in pressure</td>
<td>volume: ___________</td>
</tr>
<tr>
<td></td>
<td>temperature: ___________</td>
</tr>
<tr>
<td>increase in temperature</td>
<td>volume: ___________</td>
</tr>
<tr>
<td></td>
<td>pressure: ___________</td>
</tr>
<tr>
<td>increase in volume of the container</td>
<td>pressure: ___________</td>
</tr>
<tr>
<td></td>
<td>temperature: ___________</td>
</tr>
</tbody>
</table>

5. (a) Define “pressure” in your own words.
   (b) What units are used for measuring pressure? [K/U]
6. In which direction does air pressure push on your body? [K/U]
7. What does Pascal's Law state? Use a graphic in your explanation. [K/U] [C]
8. Describe one way in which modern machinery uses Pascal’s Law. [K/U]
9. Explain the importance of valves in the human circulatory system. [K/U]
10. How are hydraulic and pneumatic systems similar? How are they different? [K/U]
11. How are atmospheric pressure and water pressure similar? How are they different? [K/U]
12. What are valves and what is their purpose in hydraulic and pneumatic systems? [K/U]
13. Where have you seen or used valves in your daily life? [K/U]

What Do You Understand?

14. List three benefits of fluid-powered systems. List three costs. [K/U]
15. You have created a lift system using syringes. You would like the system to respond in such a way that when you push one plunger, the plungers in other syringes move immediately. Should this be a hydraulic system or a pneumatic system? Explain. [T/I] [A]
16. Use the concept of pressure to explain how people can lie on a bed of sharp nails without individual nails piercing their skin. [K/U] [A]
17. Figure 1 shows a simple pneumatic system.
   (a) If you wanted to use this system to increase force, should the effort be applied to piston A or piston B? Explain.
   (b) What advantage would you gain if you applied the force to the other piston? Explain why this is so. [K/U] [T/I] [B] [A]

Figure 1
18. When travelling in an airplane, as you descend to land, your ears sometimes “pop.” Use the Internet to find out why this occurs. K/U T/I

19. Use the Internet to find out how hydraulics are used in roller coasters. K/U T/I

20. Figure 2 shows someone using a snorkel to breathe while swimming along the water’s surface. He thinks it might be interesting to try extending the length of the snorkel to 1 m. However, when he tries it, he finds he cannot breathe. Explain why. T/I

21. Describe how the air pressure inside a tennis ball changes when you hit it. T/I

22. A scuba diver stays underwater for about 30 minutes. How is this possible when the air tank on her back is so small? K/U T/I

23. Give two examples of hydraulic systems that you have seen used. Do the same for pneumatic systems. K/U T/I

Solve a Problem!

24. Design an experiment to investigate whether changing the temperature of different liquids (water and rubbing alcohol) will affect their volume equally.
   (a) Describe how you will do this investigation.
   (b) What is the variable that you are changing? What variables will you control?
   (c) What steps will you take to ensure safety? T/I

Create and Evaluate!

25. Research a type of valve. Make a labelled drawing explaining how that valve works. Have a classmate ask you questions about your chosen valve to check how well you understand it. K/U C

26. We use pipelines to move oil and natural gas great distances. Investigate the environmental costs and benefits of pipelines. Which are greater, the costs or the benefits? K/U C

27. Continue to build your concept map from the Let’s Get Started activity, using ideas and key terms from this chapter. Again, have a classmate evaluate your work. K/U C

Reflect on Your Learning

28. (a) Which of the ideas in the chapter relates the most to your everyday life?
   (b) Describe how this idea relates to your life outside of school.

29. Think back to the Key Question on the first page of this chapter.
   (a) In a brief paragraph, answer the Key Question. You may use diagrams.
   (b) Write one or two more questions about the topic of this unit that you would like to explore.
Playing with Fluids

Scenario
Your local public school is holding a toy fair. Your class has been asked to create toys for a display called “Playing with Fluids.” The Grade 5 classes have just finished the unit called “Forces Acting on Structures and Mechanisms.” These students are interested in examining the forces acting on your creations.

You will create a toy that moves by using some of the properties of fluids. As with many toys, controlled movement is preferable to uncontrolled movement. Your three options are described below. You will also develop a brochure that uses at least one drawing and correct use of scientific and technological terminology. Your brochure will help the Grade 5 students understand how your toy works. The brochure should also explain how your toy is environmentally friendly.

1. Land Roamer Toys move across the ground or floor in many different ways. Design and build a toy that uses the properties of fluids to move on land (Figure 1).

2. Water Wonder Boats, submarines, and diving machines all move using the properties of fluids—either the fluids inside them or the fluids that flow around them. Design and build a toy that uses these properties to move over or through water.

3. Air Rider People who design toys and other devices that move through the air must understand and use the properties of gases (Figure 2). Use these properties to design and build a toy that can move through the air.

Design Brief

- Begin by describing which type of toy you are designing.
- List the properties of fluids that you will use to make your toy move.
- Describe how you will construct your toy. You may wish to use diagrams and sketches to help you explain the system you will be building.
Equipment and Materials
Make a list of the items you intend to use. You may be using a number of materials found around the home or classroom. You might use construction materials (for example, wood, plastic, and glue) to build your toy. If so, they should be listed. Do not use pieces from toy-making kits unless you use them in new ways. You will be able to use some school equipment, such as syringes and tubing. Check with your teacher to see if these need to be returned to the school after your toy has been assessed.

Plan and Construct
Review the steps you took when designing your hydraulic and pneumatic devices in Section 9.5. Look back over the Try This activities. You may want to use these as a guide in planning and performing your task. Your toy should be environmentally friendly. Try to design your toy using the three R’s—reduce, reuse, and recycle.

Test and Modify
Allow enough time to test your device and make changes to your work, if needed.

Research and Consider
- Investigate other devices that perform tasks similar to your toy.
- Visit toy stores to gather ideas.
- Look on the Internet and in the library.

If you find ideas that you would like to use, change them to make them your own. Modifying the designs of others is an acceptable form of innovation in technological problem solving. Use your notebook to brainstorm ideas with thumbnail sketches, then choose the one you would like to develop.

Communicate
Create a brochure to help explain to younger students how your toy works. You must also explain the properties of fluids on which your toy is based. Your brochure must include at least one diagram. Your brochure should also describe how your toy is environmentally friendly. In addition to the brochure, submit your working notes. These should include early thoughts, drawings, plans, and any changes you made to your toy.

Assessment
You will be assessed on how well you

- state the design problem or challenge
- identify several possible solutions
- develop a plan for solving the problem based on one of your possible solutions
- complete the plan you develop

- test your device and record observations about which parts work efficiently and which do not
- make or identify modifications that could improve the effectiveness and efficiency of the system and its components
- use your brochure to explain the principles behind how your toy works (or should work)
Fluids

Make a Summary
At the start of this unit, you created a table with some classmates to activate your knowledge of fluids (what they are, where they are found, how they are used, and some harmful effects of and to fluids). You have also developed a concept map as you worked through the material in the chapters. You will now use that table and initial concept map to finish examining and summarizing what you have learned since then.

Concept Mapping
1. With your group, review the table you made at the start of the unit. Discuss any changes you would make to the paper now that you have completed this unit.
2. Record the changes either on the paper or in your notes.
3. Use your revised table to continue developing your concept map. Include what you have learned about
   - the properties of fluids
   - how fluids are used by humans and other living things
   - how our use of fluids affects society and the environment
4. Extend the concept map by creating a special code or symbol to indicate skills you feel you gained during the unit.

Unit C Review Questions
What Do You Remember?
1. Identify each of the following statements as either true or false. If false, explain why. (K/U)
   (a) Viscosity is a measure of how easily a fluid flows.
   (b) Although important, fluids are not essential to many living things.
   (c) A meniscus forms when water particles adhere to the sides of their container.
   (d) Buoyancy, like water pressure, acts in all directions.
2. Describe the relationship between mass, volume, and density of matter. (A)
3. Use the particle theory to explain the differences between solids, liquids, and gases. (K/U)
4. Comment on the accuracy of the statement below. Describe some exceptions to the statement if there are any. (K/U)
   *In general, solids are more dense than liquids, and liquids are more dense than gases.*
5. Use the particle theory to explain why changing the temperature of a fluid can also change its density. (K/U)
6. The density of a fluid usually decreases as the temperature rises. Explain how the behaviour of water differs from this pattern. (K/U)
7. What is a hydrometer and what is it used for? Describe how to use a hydrometer. (K/U)
8. Do hydrometers float higher in liquids that are more dense or less dense? (K/U)
9. Using the particle theory, describe the relationship between temperature and the viscosity of a fluid. Explain any exceptions to the rule.

10. (a) What is the purpose of a valve? (b) Choose a type of valve and draw at least two sketches to show how that valve works.

11. Describe the location of valves in the heart and explain their role. Use a diagram, if you find it helpful.

12. List six devices or machines that use fluid power. State whether each is a hydraulic system, a pneumatic system, or a combination of both. If any are a combination, describe which parts are hydraulic and which are pneumatic.

13. Describe how water striders and other small insects are able to walk across the surface of water.

14. Why are wind tunnels useful in studying fluid flow?

15. In your notebook, complete Table 1 to show how each property changes when the temperature changes. An upward arrow means “increasing,” and a downward arrow means “decreasing.”

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Volume</th>
<th>Density</th>
<th>Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

What Do You Understand?

16. When the mustard container in Figure 1 is squeezed, on which part of the container does the mustard exert the greatest force?

Figure 1

17. In what ways does human use of fluids have a positive effect on society and the environment? In what ways does it have a negative effect?

18. Describe, or show using a graphic organizer (for example, a Venn diagram), the relationship between fluid mechanics, fluid dynamics, aerodynamics, and hydrodynamics.

19. People who have poor circulation should not sit with their legs crossed. Consider what you have learned about fluid flow and explain why this is so.

20. Would you prefer turbulent flow or laminar flow in your blood vessels? Explain.

21. Explain how the difference in compressibility between liquids and gases affects their use in fluid systems.

22. Explain why scuba divers use weight belts when diving. Would they require more or less weight when diving in colder waters? Explain your answer.
23. Cars use a hydraulic braking system. If the system used air instead of hydraulic brake fluid, how different might pushing on the brake pedal feel? Explain. 

24. During the production of a batch of maple syrup, a hydrometer is placed in four test samples taken at different times throughout the evaporation process (Figure 2).
(a) Rank the liquids from least dense to most dense.
(b) Which sample was collected earliest in the evaporating process? How do you know?
(c) Which sample would taste the sweetest? Explain.

26. Figure 3 shows water coming from a bottle with three punctures. Describe why the water is flowing the way it does.

27. When a person donates blood, doctors can use the various components of that blood for different purposes. Research and describe how blood is separated into its components.

28. You have seen that ice cubes float on water. How do you explain what is happening in Figure 4?
29. The mass of four different liquids was measured and then recorded in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Mass (g)</th>
<th>Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>40</td>
</tr>
</tbody>
</table>

(a) Determine the mass-to-volume ratio of each fluid.

(b) Show this information in a line graph.

(c) Make a sketch of what you would expect to see if equal volumes of these fluids were poured into a single tall, narrow cylinder.

30. In Figure 5, plunger A has an area of 5 cm² and plunger B has an area of 15 cm². How much more force can be exerted by plunger B?

Create and Evaluate!

32. Which is of greater importance, the benefits that dams bring or the damage that they do? Explain your reasoning.

33. Choose a living thing and a human-built object that both use fluids in a similar way. Create an interesting way of showing how these systems are similar and how they are different in the way they use fluids. Evaluate how well your method shows what you want it to show.

34. Choose an idea in the unit that interests you. Clearly identify the concept or idea, and then create a poem, short story, or cartoon that describes or explains the idea. How useful is this form of writing in describing the idea to others?

35. Dialysis and blood separation techniques save lives, but come with substantial costs. Research one of these techniques and the costs associated with it. Report on (a) what the costs are; (b) whether, in your opinion, the benefits are worth the costs; and (c) who should be responsible for paying the costs.

Reflect on Your Learning

36. Describe the idea about fluids that you found most challenging in this unit. What did you do to help you understand this idea better?

37. What was the most useful idea you learned in this unit? Why?