Here is a summary of what you will learn in this section:

- Pascal's law states that when force is applied to an enclosed fluid, the increase in pressure is transmitted equally to all parts of the fluid.
- There are both natural fluid systems and manufactured fluid systems.
- Hydraulic systems are fluid systems that use liquid, such as water or oil, as the enclosed fluid.
- Pneumatic systems are fluid systems that use gas (usually air) as the enclosed fluid.
- Fluids can be transported within a fluid system by pumps and valves.

**A fluid system** is a group of parts, including at least one fluid, that interact with each other and function together as a whole. Natural fluid systems include our body's circulatory system and respiratory system, the movement of sap in trees, and the movement of sea stars (Figure 9.4). Sea stars have several rows of tube feet with suckers at the ends. Each tube foot contains fluid. The pressure in the fluid changes when a sea star contracts its muscles. These pressure changes allow the sea star to move and gather food by pushing down and pulling up its suckers.

**Figure 9.4** A sea star moves by changing the pressure of the fluid in its feet.

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**Pressure Push**

You can observe how pressure is transferred through a liquid.

1. Fill an empty 2-L plastic bottle to the top with water so that no air is allowed in. Screw the cap on tightly.

2. Lay the bottle on its side on a table in front of you. Hold each end of the bottle.

3. Push in with your left thumb at one end of the bottle. Hold your thumb in, and push in with your right thumb at the other end. What do you notice?

4. Repeat step 3 using two different positions on the bottle.

5. Each time you push in with your right thumb, what happens to the water pressure? How do you know?
Pascal's Law

An important breakthrough in our understanding of fluids occurred in the mid-1600s. The French mathematician, philosopher, and physicist Blaise Pascal (Figure 9.5) investigated what happens when a force is applied to a fluid in a closed system. After many experiments, a law was developed to describe his and others' observations. **Pascal's law** states that when force is applied to an enclosed fluid, the increase in pressure is transmitted equally to all parts of the fluid (Figure 9.6).

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**Figure 9.5** Blaise Pascal, 1623-1662

You have observed Pascal's law in effect if you have squeezed the end of a toothpaste tube and watched the fluid pushed out of the opening. If you have pressed on one end of an air mattress to push the air out of the opening at the other end, you have again used Pascal's law.

**Keeping in the Pressure**

What would happen if a hole was cut into the side of the bottle in Figure 9.6(b), above? When you pushed down on the cork, the increased pressure would force the water out through the hole. For a fluid system to function properly, the entire system must be completely sealed. Even the smallest hole or leak can cause the system to fail.
Hydraulic Systems

Hydraulic systems are systems that use a liquid under pressure to transmit a force. Some examples of hydraulic systems are shown in Figure 9.7.

![Figure 9.7(a) Hydraulic systems are used to move materials, such as rock, soil, and scrap metal.](image)

![Figure 9.7(b) Rescue workers use hydraulic systems in the Jaws of Life® to free people trapped in vehicles.](image)

Liquids Cannot Be Compressed

One of the useful properties of hydraulic systems is that liquids cannot be compressed by ordinary means. This means that when pressure is applied to a liquid in a pipe or tube, the force can be transmitted over a distance. For example, you could have a long hose connected to a water tap at the side of the building. When you turn on the water, the pressure is transmitted along the hose and forces water out at the other end of the hose. This property is useful for moving fluids over long distances, such as transporting water or oil in pipelines.

Multiplying the Force

Another benefit of hydraulic systems is that they can multiply the force exerted by a liquid. Figure 9.8, on the next page, shows a fluid system called a hoist. A hoist uses two pistons of different sizes to create pressure to lift a vehicle. A piston is a disk that moves inside a cylinder. The small piston is the input piston, which pushes down on the liquid to create pressure. This pressure is then transmitted through the liquid, where it pushes up on the large piston. The large piston is the output piston.
The arrows in the liquid in Figure 9.8, indicate the pressure transmitted throughout the system. The pressure is the same everywhere in the system.

You can see in Figure 9.8 that the output piston has a much larger area than the input piston does. The area of the output piston in this example is 16 times larger than the area of the input piston. The result is an output force 16 times greater than the input force — a force large enough to lift a car. In order to move the large piston, the small piston must move much farther than the large piston does.

**Using a Venn Diagram to Compare and Contrast**

As writers research their topics, they often record information in a graphic organizer. You have just been reading about hydraulic systems and will read next about pneumatic systems. Use a Venn diagram to show the similarities and differences between these two systems. You will use this research later to write a compare and contrast paragraph.
Imagine a visit to your dentist’s office. You sink back into the chair, and your dentist presses a pedal to turn on the drill. Do you picture that the drill is electric? Actually, it uses something much safer as its fuel: air (Figure 9.9). A **pneumatic system** is a system that uses a gas, usually air, under pressure to transmit a force.

In order for a gas to be put to work in a fluid system, it must first be compressed. For example, natural gas is compressed and transported through a system of pipes to reach the furnace or stove in a home. Two advantages of pneumatic systems are safety and reasonable cost. Compressed air is safe to use, as the devices do not create sparks within the system. You can see some examples of pneumatic systems at work in Figure 9.10.

Another advantage of pneumatic systems is that they are reliable over a large temperature range than are hydraulic systems. This is an important consideration is designing bus doors and ramps for use in Canadian winters.
Air under Pressure

People are able to dive deep below the surface of oceans and lakes because of the invention of a familiar pneumatic system — scuba. Scuba gear includes an air tank filled with compressed air and a regulator to maintain the flow of air.

Another fluid-based technology helps a scuba diver deal with the stress of making a deep dive. At greater water pressures, nitrogen gas dissolves in the blood and tissues at a much higher concentration than normal. When a scuba diver ascends slowly to the surface, the extra gas leaves the body gradually as the water pressure decreases.

However, a problem arises when a diver ascends too quickly. The sudden change in pressure causes the nitrogen gas to bubble out of the blood and tissues, a condition known as "the bends" or decompression sickness. These bubbles can collect in other body parts and cause considerable pain or even death.

One treatment for decompression sickness is to place the affected diver in a hyperbaric chamber (Figure 9.11). This chamber increases the pressure surrounding the diver’s body. The greater pressure forces the gas bubbles to redissolve into the blood and tissues. When the pressure in the chamber is slowly decreased back to normal, the gas slowly leaves the body.

Pumps

Suppose you want to add air to a basketball or filter the water in your aquarium (Figure 9.12). What would you use to move the fluid in each case? For both examples, you may have thought that a pump would be the solution.

Most fluid systems include the movement of fluids from one location to another. A pump is a device that moves a fluid through or into something. For example, your heart pumps blood to your lungs for oxygen and then pumps the blood through your body.

Figure 9.12 A pump moves air into the ball.
The Bicycle Pump
A bicycle pump has a piston that moves up and down in a cylinder (Figure 9.13). When you pull up the piston, air fills the cylinder. By pushing down on the piston, you apply a force to the air in the cylinder. This compresses the air. The pressure of the air in the pump therefore increases. If the opening at the bottom of the cylinder is connected to an area of lower pressure, the air will move to that area. For example, the area of lower pressure could be a flat bicycle tire or an uninflated soccer ball.

The Archimedes Screw Pump
Some pumps can raise water from a lower elevation to a higher elevation (Figure 9.14). Other pumps can force air into a bicycle tire or oil through a car’s engine. Although there are many different types of pumps, they work in a similar way, by creating areas of high and low pressure.

Talk Time — A Rehearsal for Writing
Share your Venn diagram on hydraulic and pneumatic systems with a partner. Take turns explaining one feature that is common to both systems. Make note of the “linking” words your partner uses to relate the two systems to each other. Record these in a T-chart as “Comparison Signal Words.” Now explain a difference between both systems. What “linking” words did you use? Record these in your chart as “Contrast Signal Words.”

You can now use the information in your Venn diagram and the T-chart above to help you write a paragraph comparing and contrasting hydraulic systems and pneumatic systems.
Valves

Valves are devices that control the flow of fluids. For example, valves also control the amount of water flowing through a faucet. Turning a tap one way allows water to flow out. Turning a tap the other way closes off the flow of water. There are also valves in your body, such as in your heart and blood vessels. Many veins in your body contain one-way valves that ensure that your blood flows in the correct direction (Figure 9.15).

Valves can also be used to control the water level in the toilet tank (Figure 9.16). The float in the toilet tank is connected to a valve that closes off the flow of water when the water reaches the right level. That is why your toilet tank does not overflow when you flush the toilet. Two other valves are shown in Figures 9.17 and 9.18.

Take It Further

Doctors and engineers have been working for many years to develop artificial hearts that will help save lives. Find out how valves and pumps are being used in this technology. Visit PearsonScience.
The "Cost" of Extracting Oil

Issue
Our understanding of fluid technology allows us to extract oil from Earth's crust. We use this oil to heat our homes, run our factories, and fuel our cars. However, burning this oil has caused air pollution and possible climate change.

Background Information
Most of the crude oil that is extracted from Earth is located more than 1.5 km below the surface. Our scientific understanding of the properties of fluids combined with the technology of building pumps allows us to bring this oil to the surface (Figure 9.19). Without the use of science and technology, this oil would not be accessible to human needs.

Currently, Canada uses approximately 2 million barrels of oil each day. The world consumption is 76 million barrels per day. The oil industry provides employment to millions of people worldwide. In 2007, Canada's largest growth in employment was in the oil industry.

The consumption of fossil fuels also has a negative impact on our planet. Burning fossil fuels produces huge carbon emissions. These carbon emissions have been linked to the greenhouse effect and global warming. Even when the fuel is not burned, the impact of an oil spill can be devastating.

When you consider the social, economic, and environmental effects of burning oil for a fuel, is it a good choice or a poor choice to pump oil from deep inside Earth's crust?

Your task is to choose the "good" or "poor" side of the argument and research the issue. You will present your findings as a debate or in a class presentation. Your teacher will provide more details about how to present your information.
Golf Ball Loader

Recognize a Need
A hydraulic device or a pneumatic device is often used to lift heavy objects. Some systems involve the use of more than one hydraulic system or pneumatic system. For example, when an excavator moves dirt into a dump truck, one set of hydraulics lifts the soil into the bucket and another set of hydraulics is used to dump the soil.

Problem
Design and build an hydraulic arm or pneumatic arm that will lift a golf ball vertically a minimum of 15 cm and dump the ball into an empty coffee can.

Materials & Equipment
- syringes
- rubber tubing
- water
- golf ball
- empty coffee can
- wood, nails, glue, etc., as needed

Criteria for Success
- Motion should be produced by hydraulic pressure or pneumatic pressure created by the syringes.
- The golf ball should be lifted a minimum of 15 cm.
- The golf ball should be released into the empty coffee can.

Brainstorm Ideas
1. Working by yourself or in a small group, generate ideas on how you could design your device.

Build a Prototype
2. Create a plan for how you will build your device. Your plan must include a detailed sketch of your device and a list of the equipment you will need.
3. Show your plan to your teacher for approval.

Test and Evaluate
4. Build and test your device.
5. If you make changes to your original plan, make a note of these changes. Explain why you made these changes.
6. Continue to refine your device until it successfully meets the criteria.

Communicate
7. Make a technological drawing of your final design. Be sure to label the parts. Your drawing may be done using media such as poster paper or computer drawing.
8. Present your device to the class. Your presentation should include:
   - an explanation of the function of each part of your device (use your technological drawing to aid in your presentation)
   - any modification you made to your original design (as recorded in your journal)
   - a demonstration of your device accomplishing the task

Many technologies are based on the properties of fluids.
Key Concept Review

1. What does Pascal’s law state?
2. How is a hydraulic system different from a pneumatic system?
3. Explain why liquids are more difficult to compress than gases.
4. How is a force multiplied in a hydraulic system?
5. If the output piston in a car hoist was replaced by a piston of twice the area, what would happen to the output force of this system?
6. What is the purpose of a valve?

Connect Your Understanding

7. Suppose you used a needle to poke two holes in a sealed tube of toothpaste. One hole is near the cap and one hole is near the middle of the tube. You then squeeze the tube at the base. Compare how the toothpaste will leave each needle hole. Explain.

8. Why might a pump be needed in a hydraulic system?
9. Suppose that the oil in a hydraulic hoist is replaced by air. Would the hoist still operate as well? Explain.

Practise Your Skills

10. Look at the hand pump shown in the Exploring section of the Unit C opener, on page 184. How does the particle theory help to explain how a hand pump operates? Draw a labelled diagram to help explain your answer.

For more questions, go to PearsonScience.

Transporting Fluid

Our knowledge of fluids has allowed us to transport fluids in a variety of ways. A common way to transport fluid is through a pipeline.

1. With a partner, identify three types of fluids that might travel through pipelines near a larger town or city.
2. Suppose a pipeline did not exist for each of these fluids. Suggest an alternative way in which each of these fluids could be transported.
3. Discuss the environmental impact of transporting fluids by pipeline compared to your alternative methods.