3.4 Compression of Fluids

Another useful property of some fluids is **compressibility**. When a force pushes on an object, the object is said to be under compression. Objects under compression tend to deform in shape. For example, when you kick a soccer ball, the force of your foot compresses the ball and temporarily deforms it, as shown in Figure 3.13. In this example, your foot is actually compressing the fluid (air) that fills the ball.

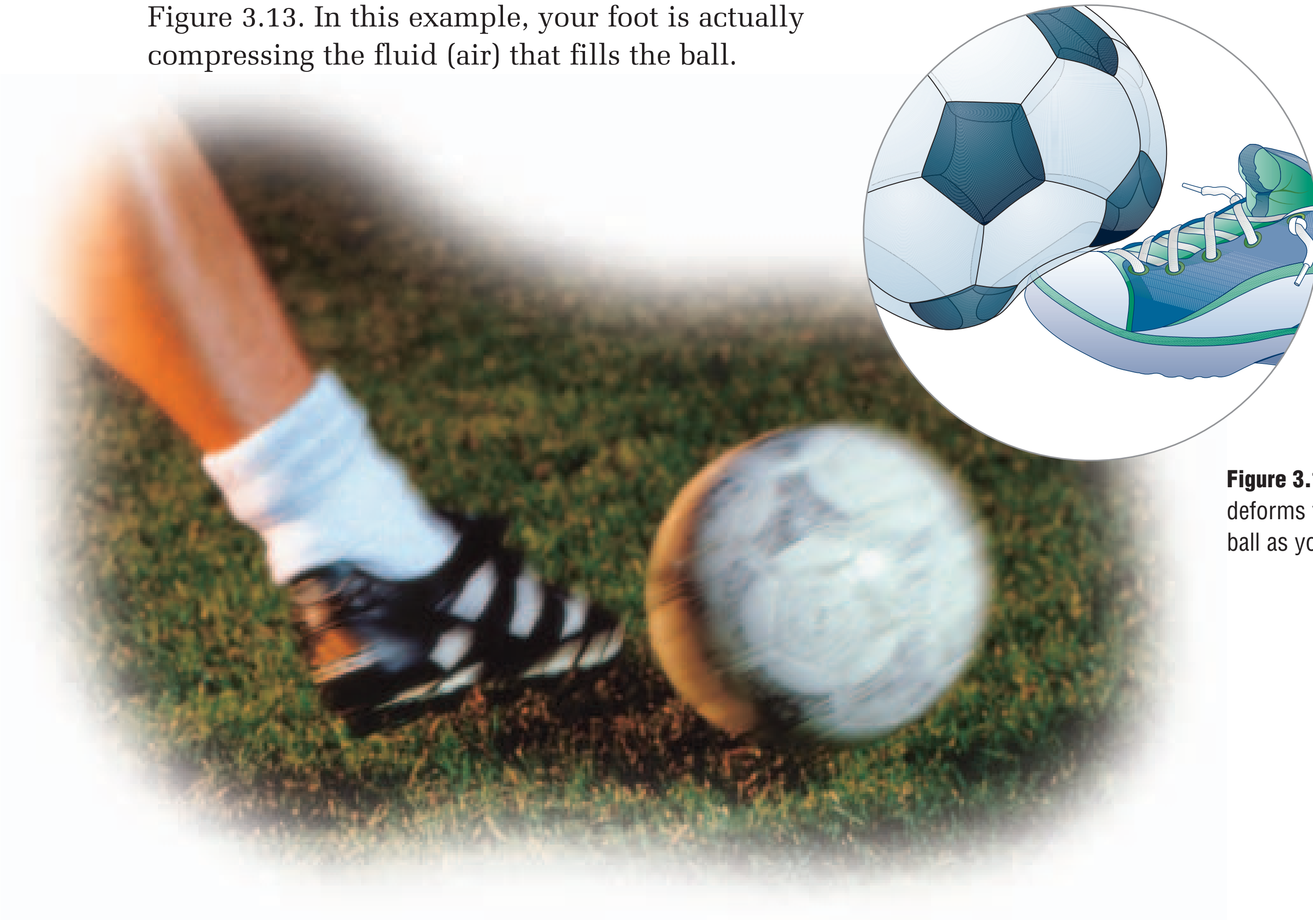

Figure 3.13 Your foot deforms the soccer ball as you kick it.

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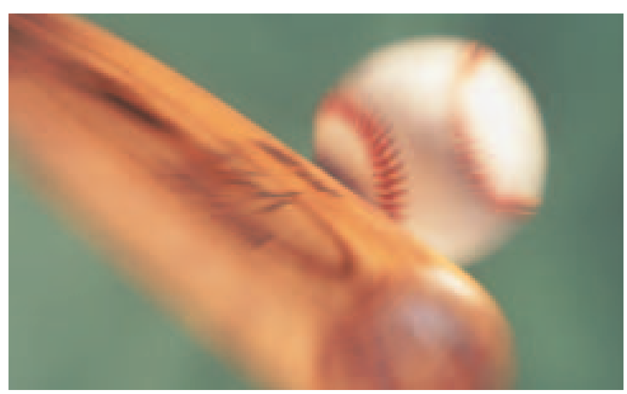
Compressing Solid Objects

A solid object can be compressed if a great enough force is applied to it. The photo shows that the force exerted by the baseball bat on the baseball compresses and deforms the ball.



The effect of a baseball bat on a baseball *re***SEARCH**

Engine Compression

Find out why compression is important in a car's engine.

Differences in Compressibility between Gases and Liquids

One of the properties of fluids is that gases can be compressed much more than liquids can. Think about squeezing a sealed plastic bottle when it's full of juice and then when it's empty. How much more can you compress it when it's empty than when it's full? The particle model can explain this situation. Figure 3.17 shows that there is much more space between particles in the gas than between those in the liquid.

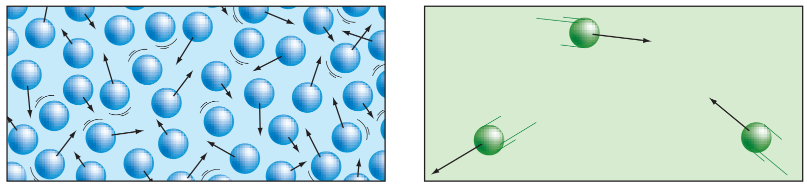
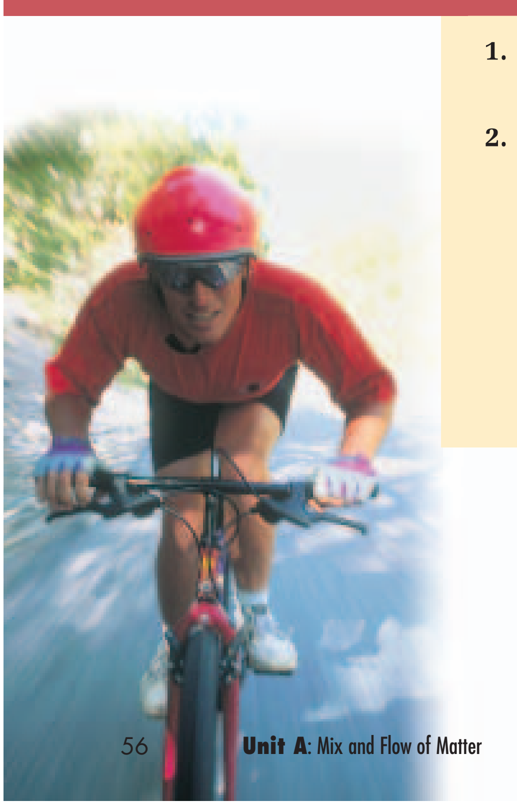


Figure 3.17 There is much more space between particles in a gas than there is between particles in a liquid.

As a result, when a force is applied to the particles, much more compression takes place in the gas than in the liquid. The gas particles have more space to move. In fact, very little compression occurs in liquids. Materials in a liquid state are said to be **incompressible**; that is, they cannot be compressed easily. This property of liquids is very useful. Can you think of any situations where it would be used?

Check and Reflect



1. Use the particle model to explain the differences in compressibility between liquids and gases.
2. Use your explanation in question 1 to identify which material in each pair below would compress more than the other. Provide a brief reason for each answer.
   a) a helium balloon or a water balloon
   b) a solid rubber bicycle tire and an inflated mountain bike tire
   c) plastic bubble-wrap or a liquid-filled baby's teething ring
   d) a golf ball or a soccer ball

3.5 Pressure in Fluids—Pascal's Law

Fluids can be very useful in helping us perform tasks because of the way they transmit pressure. For example, you may already know something about hydraulics and pneumatics, where fluids are used in devices. In this subsection, you'll learn why this property makes fluids so useful.

An important part of understanding how to use fluids in devices is knowing the relationship between force, area, and pressure. **Pressure** is the amount of force applied to a given area. It is measured in pascals (Pa). A pascal equals the force of 1 N (newton) over an area of 1 m^2 (1 Pa = $\frac{1\ \text{N}}{1\ \text{m}^2}$). The more force you can apply to a given area, the greater the pressure. You can write this relationship as an equation: $p = F/A$, where p is pressure, F is force, and A is area.

Here is an example of how to calculate pressure. You have a force of 10 N on an area of 2 m^2. What would the pressure be?

$$\text{Pressure } (p) = \frac{\text{Force } (F)}{\text{Area } (A)} = \frac{10\ \text{N}}{2\ \text{m}^2} = \frac{5\ \text{N}}{\text{m}^2} = 5\ \text{Pa}$$

Look at the examples of pressure measurements in the *info*BIT on this page. They are all in kilopascals (1 kPa = 1000 Pa). Scientists use kilopascals because 1 Pa is a very small amount of pressure. It's about the amount of pressure exerted on your desk by a small sheet of paper lying on it. Note that pressure can also be measured in newtons per square centimetre (N/cm^2).

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Examples of Pressure

- The average air pressure at sea level is 101.3 kPa (kilopascals).
- The jaws of an ant exert a pressure of 0.005 kPa.
- A ballet dancer standing on the toes of one foot exerts a pressure of 2500 kPa on the floor.

Blaise Pascal Investigates

In the mid-1600s, the French mathematician Blaise Pascal was curious about how pressure is exerted in a fluid. In one of his first experiments, he investigated the relationship between water pressure and depth. Look at Figure 3.18, showing water flowing out of two holes at the same level in a can. Working with a partner, develop an explanation for what you observe. Use the following words in your explanation: *pressure*, *sides of the can*, *force*, *equal*, and *depth*. Be prepared to share your explanation with your class.

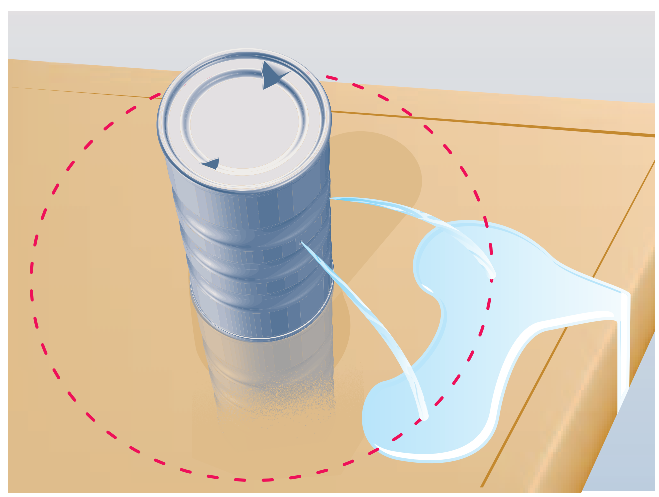


Figure 3.18 Why does the water flow out of the can in this way?

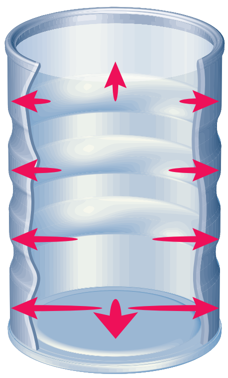


Figure 3.19 The water exerts pressure in all directions in the container.

Pressure and Depth

From Figure 3.18, you and your class may have determined that the pressure of the water on the sides of the can was equal at the same depth. You could infer this because the water that came out of the holes travelled the same distance outward before hitting the ground. This observation leads to another question: How does pressure change as the depth of the water changes? What do you think would happen if you put holes in the can at different depths?

The Greater the Depth, the Greater the Pressure

In the introduction to this subsection, you saw that pressure forced water out of holes in a container. The water was exerting pressure on the walls of the container. The weight of water in the upper part of the container also pressed down on the water in the lower part of the container. The more water above a hole, the greater the pressure, and the farther water will flow out of the container. So, the greater the depth of water, the greater the pressure at that point.

Pascal's Law

Pascal continued his investigations into pressure by studying enclosed fluids. He wondered what would happen if a force was applied to a fluid in a closed system. Through experimentation, he found that the force created pressure that was transmitted equally in all directions throughout the fluid. He developed a law to describe his observations. **Pascal's law** states that an enclosed fluid transmits pressure equally in all directions. The examples of applications of Pascal's law below will help to explain it further.

Hydraulic Devices

Pascal's discovery of this law led to the invention of many different types of hydraulic and pneumatic devices. **Hydraulic systems** use a liquid as the enclosed fluid. **Pneumatic systems** use air. Figure 3.20 shows a hydraulic device that is used for lifting cars. You may have noticed these in car repair garages. Such a device uses two pistons of different sizes to create pressure and to lift the car. 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, which is the output piston.

Recall that pressure equals force divided by area ($p=F/A$), and look at Figure 3.20. You can see that the output piston has a much larger area than the input piston does, but the pressure is the same everywhere in the system. So, because $p=F/A$, the force of the larger piston is greater than the force of the smaller piston.

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 strong enough to lift a car! One of the benefits of a hydraulic system is that it can multiply force. However, to move the large piston, the small piston must move much farther that the large piston does. You will learn more about hydraulic systems in Unit D: Mechanical Systems.

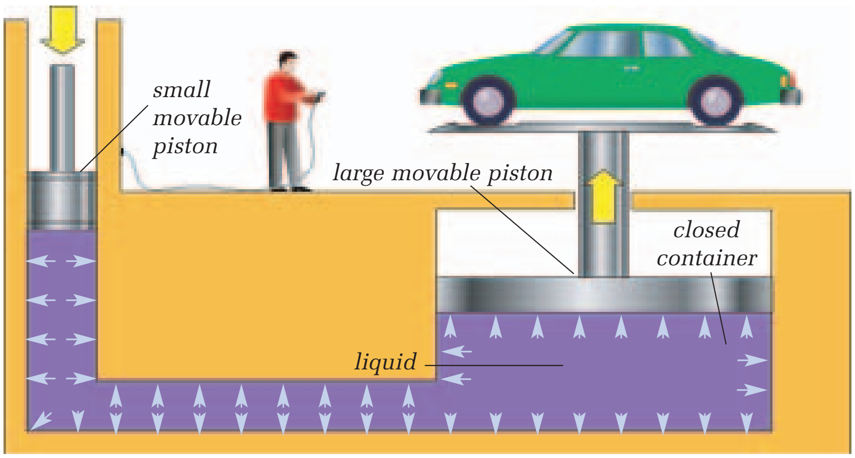
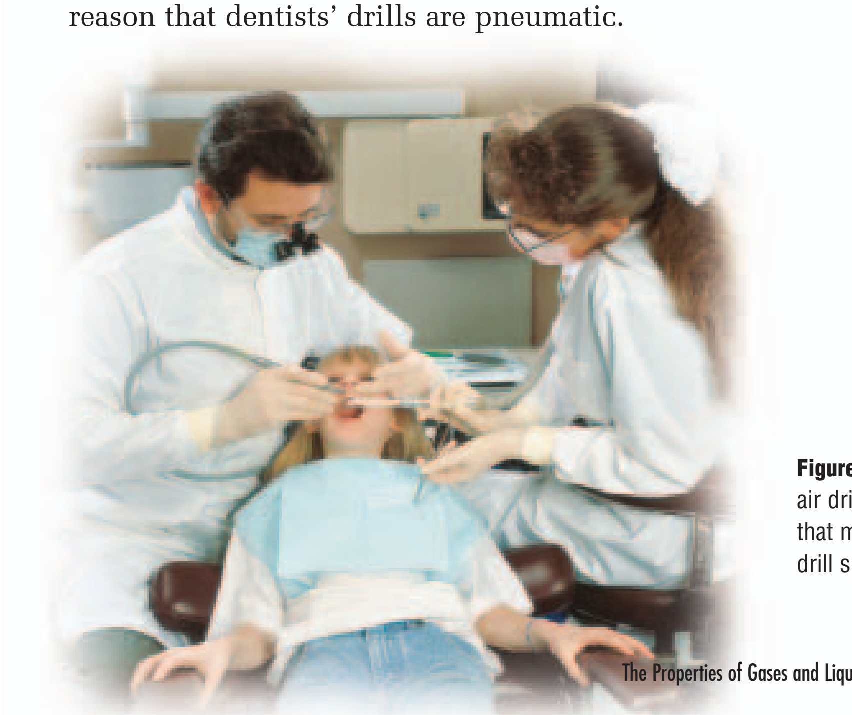


Figure 3.20 A car lift or hoist. The arrows in the liquid indicate the pressure transmitted throughout the system. Hoists are used in repair garages so that mechanics can work under cars more easily.

PNEUMATIC DEVICES

Pneumatic devices use compressed air to do tasks. Dentists' drills, jack hammers, paint sprayers, and air brakes on trucks are all examples of pneumatic devices.

Reasonable cost and safety are two advantages of pneumatic systems. Compressed air is cheap and safe, as the devices do not create sparks within the system. This can be important if you are working in a mine where a spark could cause an explosion. Pneumatic devices are also free of electrical hazards, which is one reason that dentists' drills are pneumatic.



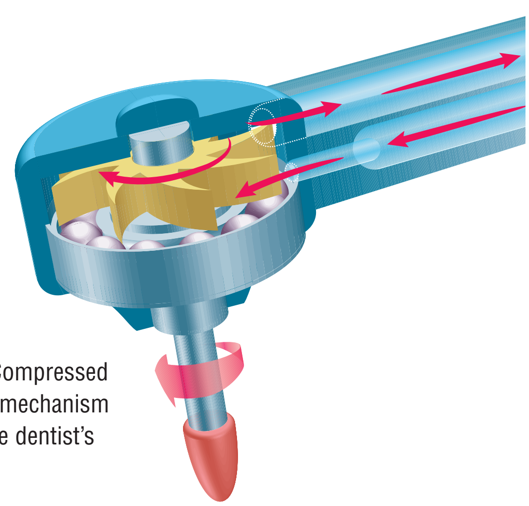


Figure 3.21 Compressed air drives the mechanism that makes the dentist's drill spin.

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Ultrahigh-Pressure Water Systems

An ultrahigh-pressure water system forces water out of a hose at 275 000 kPa of pressure. This water jet can be used for cleaning, blasting, cutting, and processing materials. Using the library or the Internet, research applications of ultrahigh-pressure water systems.

Maintaining the Pressure

For a pneumatic or hydraulic system to function properly, the entire system must be completely sealed. Even the smallest hole or leak can cause the system to fail. For example, cars have hydraulic brakes. If there is a leak in the hydraulic line, the brakes can fail. Pneumatic bus doors also depend on a sealed system, so that the door can open and close. A leak in the system allows air to escape. This loss of pressure means that the system can't generate enough force to close the door if it's already open, or to open the door if it's already closed!

Figure 3.22 Pneumatic systems are used for bus doors and for brakes in large vehicles like buses and trucks.

Check and Reflect

1. Describe how pressure is transferred in a fluid.
2. If 10 N of force is applied to an area of 1 m^2, what is the pressure?
3. What is the difference between a hydraulic and a pneumatic system?
4. A hydraulic lift has 1000 N applied to an input piston that has an area of 30 cm^2.
   a) What is the pressure exerted on the liquid by the input piston?
   b) If the force were doubled, what would be the pressure?
   c) If the area were reduced to 15 cm^2, what would be the pressure?