13.2 Forces Within Liquids

The liquids considered thus far have been ideal liquids, in which the particles are totally free to slide past one another. The unexpected behavior of water between 0°C and 4°C, however, illustrates that in real fluids, particles exert electromagnetic forces of attraction, called **cohesive forces,** on each other. These and other forces affect the behavior of fluids.

▶ Objectives

- **Explain** how cohesive forces cause surface tension.
- **Explain** how adhesive forces cause capillary action.
- **Discuss** evaporative cooling and the role of condensation in cloud formation.

▶ Vocabulary

cohesive forces
adhesive forces

Cohesive Forces

Have you ever noticed that dewdrops on spiderwebs and falling drops of oil are nearly spherical? What happens when rain falls on a freshly washed and waxed car? The water drops bead up into rounded shapes, as shown in the spiderweb in **Figure 13-7.** All of these phenomena are examples of surface tension**,** which is the tendency of the surface of a liquid to contract to the smallest possible area. Surface tension is a result of the cohesive forces among the particles of a liquid.

Notice that beneath the surface of the liquid shown in **Figure 13-8a** on the next page, each particle of the liquid is attracted equally in all directions by neighboring particles, and even to the particles of the wall of the container. As a result, no net force acts on any of the particles beneath the surface. At the surface, however, the particles are attracted downward and to the sides, but not upward. There is a net downward force, which acts on the top layers and causes the surface layer to be slightly compressed. The surface layer acts like a tightly stretched rubber sheet or a film that is strong enough to support the weight of very light objects, such as the water strider in **Figure 13-8b** on the next page. The surface tension of water also can support a steel paper clip, even though the density of steel is nine times greater than that of water. Try it!

Why does surface tension produce spherical drops? The force pulling the surface particles into a liquid causes the surface to become as small as possible, and the shape that has the least surface for a given volume is a sphere. The higher the surface tension of the liquid, the more resistant the liquid is to having its surface broken. For example, liquid mercury has much stronger cohesive forces than water does. Thus, liquid mercury forms spherical drops, even when it is placed on a smooth surface. On the other hand, liquids such as alcohol and ether have weaker cohesive forces. A drop of either of these liquids flattens out on a smooth surface.

Figure 13-7 Rainwater beads up on a spider's web because water drops have surface tension.

Frank Cezus

Viscosity In nonideal fluids, the cohesive forces and collisions between fluid molecules cause internal friction that slows the fluid flow and dissipates mechanical energy. The measure of this internal friction is called the viscosity of the liquid. Water is not very viscous, but motor oil is very viscous. As a result of its viscosity, motor oil flows slowly over the parts of an engine to coat the metal and reduce rubbing. Lava, molten rock that flows from a volcano or vent in Earth's surface, is one of the most viscous fluids. There are several types of lava, and the viscosity of each type varies with composition and temperature.

Geology Connection

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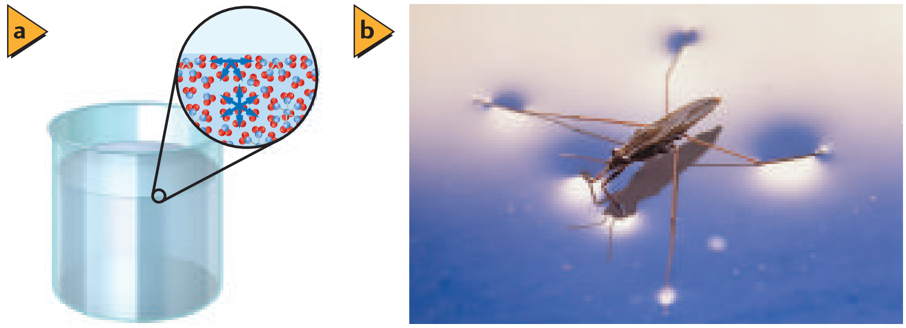


■ **Figure 13-8** Molecules in the interior of a liquid are attracted in all directions **(a).** A water strider can walk on water because molecules at the surface have a net inward attraction that results in surface tension **(b).**

Adhesive Forces

Similar to cohesive forces, **adhesive forces** are electromagnetic attractive forces that act between particles of different substances. If a glass tube with a small inner diameter is placed in water, the water rises inside the tube. The water rises because the adhesive forces between glass and water molecules are stronger than the cohesive forces between water molecules. This phenomenon is called capillary action. The water continues to rise until the weight of the water that is lifted balances the total adhesive force between the glass and water molecules. If the radius of the tube increases, the volume and the weight of the water will increase proportionally faster than the surface area of the tube. Thus, water is lifted higher in a narrow tube than in a wider one. Capillary action causes molten wax to rise in a candle's wick and water to move up through the soil and into the roots of plants.

When a glass tube is placed in a beaker of water, the surface of the water climbs the outside of the tube, as shown in **Figure 13-9a.** The adhesive forces between the glass molecules and water molecules are greater than the cohesive forces between the water molecules. In contrast, the cohesive forces between mercury molecules are greater than the adhesive forces between the mercury and glass molecules, so the liquid does not climb the tube. These forces also cause the center of the mercury's surface to depress, as shown in **Figure 13-9b.**

APPLYING PHYSICS

▶ **Plants** Cohesive forces in liquids actually allow them to be stretched just like rubber bands. This stretching is difficult to achieve in the laboratory, but it is common in plants. The strength of the cohesive forces in water keeps the water from breaking and bubbling as it goes through the plant tissue to the leaves. If not for these forces, trees could not grow higher than about 10 m. ◀

Evaporation and Condensation

Why does a puddle of water disappear on a hot, dry day? As you learned in Chapter 12, the particles in a liquid are moving at random speeds. If a fast-moving particle can break through the surface layer, it will escape from the liquid. Because there is a net downward cohesive force at the surface, however, only the most energetic particles escape. This escape of particles is called evaporation.

■ **Figure 13-9** Water climbs the outside wall of this glass tube **(a),** while the mercury is depressed by the rod **(b).** The forces of attraction between mercury atoms are stronger than any adhesive forces between the mercury and the glass.

(t)Runk/Schoenberger/Grant Heilman Photography, (others)Matt Meadows

Evaporative cooling Evaporation has a cooling effect. On a hot day, your body perspires, and the evaporation of your sweat cools you down. In a puddle of water, evaporation causes the remaining liquid to cool down. Each time a particle with higher-than-average kinetic energy escapes from the water, the average kinetic energy of the remaining particles decreases. As you learned in Chapter 12, a decrease in average kinetic energy is a decrease in temperature. You can test this cooling effect by pouring a small amount of rubbing alcohol in the palm of your hand. Alcohol molecules evaporate easily because they have weak cohesive forces. As the molecules evaporate, the cooling effect is quite noticeable. A liquid that evaporates quickly is called a volatile liquid.

Have you ever wondered why humid days feel warmer than dry days at the same temperature? On a day that is humid, the water vapor content of the air is high. Because there are already many water molecules in the air, the water molecules in perspiration are less likely to evaporate from the skin. Evaporation is the body's primary cooling mechanism, so the body is not able to cool itself as effectively on a humid day.

Particles of liquid that have evaporated into the air can also return to the liquid phase if the kinetic energy or temperature decreases, a process called condensation. What happens if you bring a cold glass into a hot, humid area? The outside of the glass soon becomes coated with condensed water. Water molecules moving randomly in the air surrounding the glass strike the cold surface, and if they lose enough energy, the cohesive forces become strong enough to prevent their escape.

The air above any body of water, as shown in **Figure 13-10,** contains evaporated water vapor, which is water in the form of gas. If the temperature is reduced, the water vapor condenses around tiny dust particles in the air and produces droplets only 0.01 mm in diameter. A cloud of these droplets is called fog. Fog often forms when moist air is chilled by the cold ground. Fog also can form in your home. When a carbonated drink is opened, the sudden decrease in pressure causes the temperature of the gas in the container to drop, which condenses the water vapor dissolved in that gas.

Figure 13-10 Warm, moist, surface air rises until it reaches a height where the temperature is at the point at which water vapor condenses and forms clouds.

13.2 Section Review

17. Evaporation and Cooling In the past, when a baby had a high fever, the doctor might have suggested gently sponging off the baby with rubbing alcohol. Why would this help?

18. Surface Tension A paper clip, which has a density greater than that of water, can be made to stay on the surface of water. What procedures must you follow for this to happen? Explain.

19. Language and Physics The English language includes the terms *adhesive tape* and *working as a cohesive group.* In these terms, are *adhesive* and *cohesive* being used in the same context as their meanings in physics?

20. Adhesion and Cohesion In terms of adhesion and cohesion, explain why alcohol clings to the surface of a glass rod but mercury does not.

21. Floating How can you tell that the paper clip in problem 18 was not floating?

22. Critical Thinking On a hot, humid day, Beth sat on the patio with a glass of cold water. The outside of the glass was coated with water. Her younger sister, Jo, suggested that the water had leaked through the glass from the inside to the outside. Suggest an experiment that Beth could do to show Jo where the water came from.

Orville Andrews

13.3 Fluids at Rest and in Motion

▶ **Objectives**

- **Relate** Pascal's principle to simple machines and occurrences.
- **Apply** Archimedes' principle to buoyancy.
- **Apply** Bernoulli's principle to airflow.

▶ **Vocabulary**

Pascal's principle
buoyant force
Archimedes' principle
Bernoulli's principle
streamlines

You have learned how fluids exert pressure, the force per unit area. You also know that the pressure exerted by fluids changes; for example, atmospheric pressure drops as you climb a mountain. In this section, you will learn about the forces exerted by resting and moving fluids.

Fluids at Rest

If you have ever dived deep into a swimming pool or lake, you know that your body, especially your ears, is sensitive to changes in pressure. You may have noticed that the pressure you felt on your ears did not depend on whether your head was upright or tilted, but that if you swam deeper, the pressure increased.

Pascal's principle Blaise Pascal, a French physician, noted that the pressure in a fluid depends upon the depth of the fluid and has nothing to do with the shape of the fluid's container. He also discovered that any change in pressure applied at any point on a confined fluid is transmitted undiminished throughout the fluid, a fact that is now known as **Pascal's principle.** Every time you squeeze a tube of toothpaste, you demonstrate Pascal's principle. The pressure that your fingers exert at the bottom of the tube is transmitted through the toothpaste and forces the paste out at the top. Likewise, if you squeeze one end of a helium balloon, the other end of the balloon expands.

When fluids are used in machines to multiply forces, Pascal's principle is being applied. In a common hydraulic system, a fluid is confined to two connecting chambers, as shown in **Figure 13-11.** Each chamber has a piston that is free to move, and the pistons have different surface areas. If a force, F_1, is exerted on the first piston with a surface area of A_1, the pressure, P_1, exerted on the fluid can be determined by using the following equation.

$$P_1 = \frac{F_1}{A_1}$$

This equation is simply the definition of pressure: pressure equals the force per unit area. The pressure exerted by the fluid on the second piston, with a surface area A_2, can also be determined.

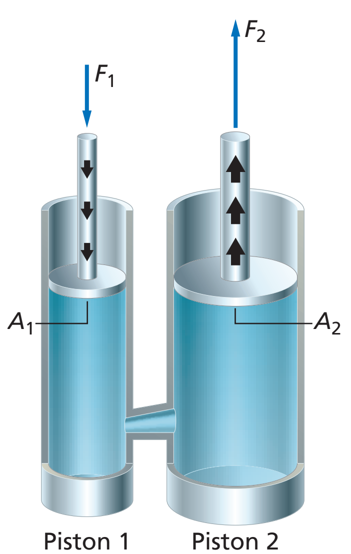
$$P_2 = \frac{F_2}{A_2}$$

According to Pascal's principle, pressure is transmitted without change throughout a fluid, so pressure P_2 is equal in value to P_1. You can determine the force exerted by the second piston by using $F_1/A_1 = F_2/A_2$ and solving for F_2. This force is shown by the following equation.

Force Exerted by a Hydraulic Lift $F_2 = \frac{F_1 A_2}{A_1}$

The force exerted by the second piston is equal to the force exerted by the first piston multiplied by the ratio of the area of the second piston to the area of the first piston.

■ **Figure 13-11** The pressure exerted by the force of the small piston is transmitted throughout the fluid and results in a multiplied force on the larger piston.



PRACTICE Problems

Additional Problems, Appendix B

23. Dentists' chairs are examples of hydraulic-lift systems. If a chair weighs 1600 N and rests on a piston with a cross-sectional area of 1440 cm^2, what force must be applied to the smaller piston, with a cross-sectional area of 72 cm^2, to lift the chair?

24. A mechanic exerts a force of 55 N on a 0.015 m^2 hydraulic piston to lift a small automobile. The piston that the automobile sits on has an area of 2.4 m^2. What is the weight of the automobile?

25. By multiplying a force, a hydraulic system serves the same purpose as a lever or seesaw. If a 400-N child standing on one piston is balanced by a 1100-N adult standing on another piston, what is the ratio of the areas of their pistons?

26. In a machine shop, a hydraulic lift is used to raise heavy equipment for repairs. The system has a small piston with a cross-sectional area of 7.0×10^{-2} m^2 and a large piston with a cross-sectional area of 2.1×10^{-1} m^2. An engine weighing 2.7×10^3 N rests on the large piston.

a. What force must be applied to the small piston to lift the engine?

b. If the engine rises 0.20 m, how far does the smaller piston move?

Swimming Under Pressure

When you are swimming, you feel the pressure of the water increase as you dive deeper. This pressure is actually a result of gravity; it is related to the weight of the water above you. The deeper you go, the more water there is above you, and the greater the pressure. The pressure of the water is equal to the weight, F_g, of the column of water above you divided by the column's cross-sectional area, A. Even though gravity pulls only in the downward direction, the fluid transmits the pressure in all directions: up, down, and to the sides. You can find the pressure of the water by applying the following equation.

$$P = \frac{F_g}{A}$$

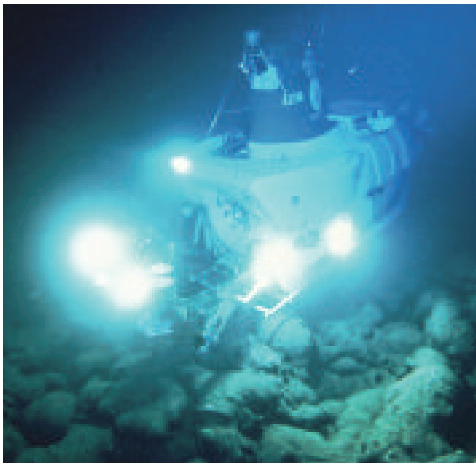
The weight of the column of water is $F_g = mg$, and the mass is equal to the density, ρ, of the water times its volume, $m = \rho V$. You also know that the volume of the water is the area of the base of the column times its height, $V = Ah$. Therefore, $F_g = \rho Ahg$. Substituting ρAhg for F_g in the equation for water pressure gives $P = F_g/A = \rho Ahg/A$. Divide A from the numerator and denominator to arrive at the simplest form of the equation for the pressure exerted by a column of water on a submerged body.

Pressure of Water on a Body $P = \rho hg$

The pressure that a column of water exerts on a body is equal to the density of water times the height of the column times the acceleration due to gravity.

This formula works for all fluids, not just water. The pressure of a fluid on a body depends on the density of the fluid, its depth, and g. If there were water on the Moon, the pressure of the water at any depth would be one-sixth as great as on Earth. As illustrated in **Figure 13-12,** submersibles, both crewed and robotic, have explored the deepest ocean trenches and encountered pressures in excess of 1000 times standard air pressure.

Figure 13-12 In 1960, the *Trieste*, a crewed submersible, descended to the bottom of the Marianas Trench, a depth of over 10,500 m. The crewed submersible *Alvin*, shown below, can safely dive to a depth of 4500 m.



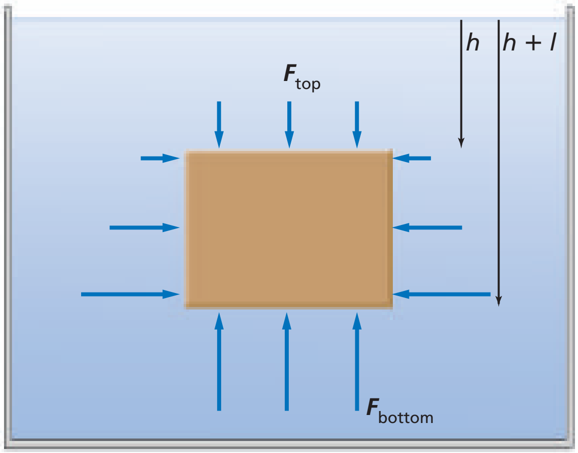


Figure 13-13 A fluid exerts a greater upward force on the bottom of an immersed object than the downward force on the top of the object. The net upward force is called the buoyant force.

Buoyancy What produces the upward force that allows you to swim? The increase in pressure with increasing depth creates an upward force called the **buoyant force.** By comparing the buoyant force on an object with its weight, you can predict whether the object will sink or float.

Suppose that a box is immersed in water. It has a height of l and its top and bottom each have a surface area of A. Its volume, then, is $V = lA$. Water pressure exerts forces on all sides, as shown in **Figure 13-13.** Will the box sink or float? As you know, the pressure on the box depends on its depth, h. To find out whether the box will float in water, you will need to determine how the pressure on the top of the box compares with the pressure from below the box. Compare these two equations:

$$F_{top} = P_{top}A = \rho hgA$$

$$F_{bottom} = P_{bottom}A = \rho(l + h)gA$$

On the four vertical sides, the forces are equal in all directions, so there is no net horizontal force. The upward force on the bottom is larger than the downward force on the top, so there is a net upward force. The buoyant force can now be determined.

$$\begin{aligned} F_{buoyant} &= F_{bottom} - F_{top} \\ &= \rho(l + h)gA - \rho hgA \\ &= \rho lgA = \rho Vg \end{aligned}$$

These calculations show the net upward force to be proportional to the volume of the box. This volume equals the volume of the fluid displaced, or pushed out of the way, by the box. Therefore, the magnitude of the buoyant force, ρVg, equals the weight of the fluid displaced by the object.

Buoyant Force $F_{buoyant} = \rho_{fluid}Vg$

The buoyant force on an object is equal to the weight of the fluid displaced by the object, which is equal to the density of the fluid in which the object is immersed multiplied by the object's volume and the acceleration due to gravity.

This relationship was discovered in the third century B.C. by Greek scientist Archimedes. **Archimedes' principle** states that an object immersed in a fluid has an upward force on it that is equal to the weight of the fluid displaced by the object. The force does not depend on the weight of the object, only on the weight of the displaced fluid.

Sink or float? If you want to know whether an object sinks or floats, you have to take into account all of the forces acting on the object. The buoyant force pushes up, but the weight of the object pulls it down. The difference between the buoyant force and the object's weight determines whether an object sinks or floats.

Suppose that you submerge three objects in a tank filled with water ($\rho_{water} = 1.00\times10^3$ kg/m^3). Each of the objects has a volume of 100 cm^3, or 1.00×10^{-4} m^3. The first object is a steel block with a mass of 0.90 kg.

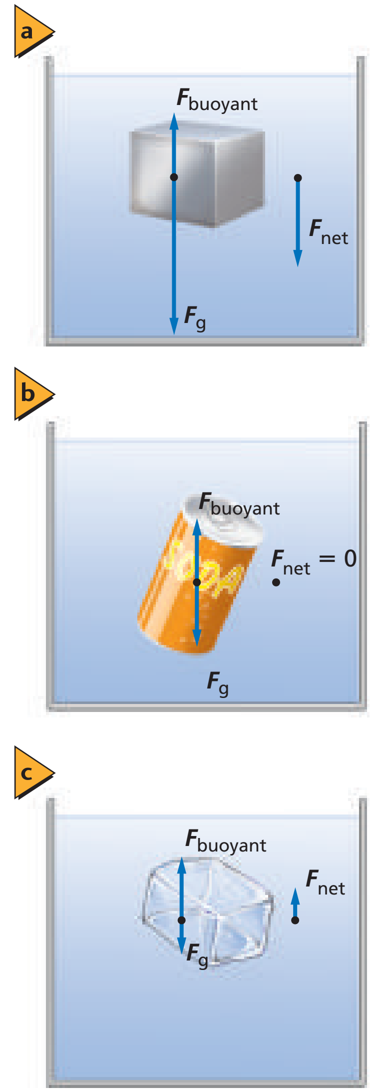
The second is an aluminum soda can with a mass of 0.10 kg. The third is an ice cube with a mass of 0.090 kg. How will each item move when it is immersed in water? The upward force on all three objects, as shown in **Figure 13-14,** is the same, because all displace the same weight of water. This buoyant force can be calculated as follows.

$$F_{\text{buoyant}} = \rho_{\text{water}} V g$$
$$= (1.00\times10^{3}\ \text{kg/m}^{3})(1.00\times10^{-4}\ \text{m}^{3})(9.80\ \text{m/s}^{2})$$
$$= 0.980\ \text{N}$$

The weight of the block of steel is 8.8 N, much greater than the buoyant force. There is a net downward force, so the block will sink to the bottom of the tank. The net downward force, its apparent weight, is less than its real weight. All objects in a liquid, even those that sink, have an apparent weight that is less than when the object is in air. The apparent weight can be expressed by the equation $F_{\text{apparent}} = F_{\text{g}} - F_{\text{buoyant}}$. For the block of steel, the apparent weight is 8.8 N − 0.98 N, or 7.8 N.

The weight of the soda can is 0.98 N, the same as the weight of the water displaced. There is, therefore, no net force, and the can will remain wherever it is placed in the water. It has neutral buoyancy. Objects with neutral buoyancy are described as being weightless; their apparent weight is zero. This property is similar to that experienced by astronauts in orbit, which is why astronaut training sometimes takes place in swimming pools.

The weight of the ice cube is 0.88 N, less than the buoyant force, so there is a net upward force, and the ice cube will rise. At the surface, the net upward force will lift part of the ice cube out of the water. As a result, less water will be displaced, and the upward force will be reduced. The ice cube will float with enough volume in the water so that the weight of water displaced equals the weight of the ice cube. An object will float if its density is less than the density of the fluid in which it is immersed.



■ **Figure 13-14** A block of steel **(a),** an aluminum can of soda **(b),** and an ice cube **(c)** all have the same volume, displace the same amount of water, and experience the same buoyant force. However, because their weights are different, the net forces on the three objects are also different.

Ships Archimedes' principle explains why ships can be made of steel and still float; if the hull is hollow and large enough so that the average density of the ship is less than the density of water, the ship will float. You may have noticed that a ship loaded with cargo rides lower in the water than a ship with an empty cargo hold. You can demonstrate this effect by fashioning a small boat out of folded aluminum foil. The boat should float easily, and it will ride lower in the water if you add a cargo of paper clips. If the foil is crumpled into a tight ball, the boat will sink because of its increased density. Similarly, the continents of Earth float upon a denser material below the surface. The drifting motion of these continental plates is responsible for the present shapes and locations of the continents.

Geology Connection

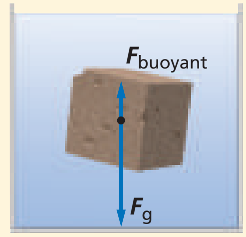
Other examples of Archimedes' principle in action include submarines and fishes. Submarines take advantage of Archimedes' principle as water is pumped into or out of a number of different chambers to change the submarine's average density, causing it to rise or sink. Fishes that have swim bladders also use Archimedes' principle to control their depths. Such a fish can expand or contract its swim bladder, just like you can puff up your cheeks. To move upward in the water, the fish expands its swim bladder to displace more water and increase the buoyant force. The fish moves downward by contracting the volume of its swim bladder.

EXAMPLE Problem 3

Archimedes' Principle A cubic decimeter, 1.00×10^{-3} m^3, of a granite building block is submerged in water. The density of granite is 2.70×10^{3} kg/m^3.

a. What is the magnitude of the buoyant force acting on the block?

b. What is the apparent weight of the block?



1 Analyze and Sketch the Problem

- Sketch the cubic decimeter of granite immersed in water.
- Show the upward buoyant force and the downward force due to gravity acting on the granite.

Known:	Unknown:
$V = 1.00\times10^{-3}$ m^3	$F_{buoyant} = ?$
$\rho_{granite} = 2.70\times10^{3}$ kg/m^3	$F_{apparent} = ?$
$\rho_{water} = 1.00\times10^{3}$ kg/m^3	

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2 Solve for the Unknown

a. Calculate the buoyant force on the granite block.

$$F_{buoyant} = \rho_{water}Vg$$
$$= (1.00\times10^{3}\ \text{kg/m}^3)(1.00\times10^{-3}\ \text{m}^3)(9.80\ \text{m/s}^2)$$
$$= 9.80\ \text{N}$$

Substitute $\rho_{water} = 1.00\times10^{3}$ kg/m^3, $V = 1.00\times10^{-3}$ m^3, $g = 9.80$ m/s^2

b. Calculate the granite's weight and then find its apparent weight.

$$F_g = mg = \rho_{granite}Vg$$
$$= (2.70\times10^{3}\ \text{kg/m}^3)(1.00\times10^{-3}\ \text{m}^3)(9.80\ \text{m/s}^2)$$
$$= 26.5\ \text{N}$$

Substitute $\rho_{granite} = 2.70\times10^{3}$ kg/m^3, $V = 1.00\times10^{-3}$ m^3, $g = 9.80$ m/s^2

$$F_{apparent} = F_g - F_{buoyant}$$
$$= 26.5\ \text{N} - 9.80\ \text{N} = 16.7\ \text{N}$$

Substitute $F_g = 26.5$ N, $F_{buoyant} = 9.80$ N

3 Evaluate the Answer

- **Are the units correct?** The forces and apparent weight are in newtons, as expected.
- **Is the magnitude realistic?** The buoyant force is about one-third the weight of the granite, a sensible answer because the density of water is about one-third that of granite.

PRACTICE Problems

Additional Problems, Appendix B

27. Common brick is about 1.8 times denser than water. What is the apparent weight of a 0.20 m^3 block of bricks under water?

28. A girl is floating in a freshwater lake with her head just above the water. If she weighs 610 N, what is the volume of the submerged part of her body?

29. What is the tension in a wire supporting a 1250-N camera submerged in water? The volume of the camera is 16.5×10^{-3} m^3.

30. Plastic foam is about 0.10 times as dense as water. What weight of bricks could you stack on a 1.0 m × 1.0 m × 0.10 m slab of foam so that the slab of foam floats in water and is barely submerged, leaving the bricks dry?

31. Canoes often have plastic foam blocks mounted under the seats for flotation in case the canoe fills with water. What is the approximate minimum volume of foam needed for flotation for a 480-N canoe?

Fluids in Motion: Bernoulli's Principle

Try the experiment shown in **Figure 13-15.** Hold a strip of notebook paper just under your lower lip. Then blow hard across the top surface. Why does the strip of paper rise? The blowing of the air has decreased the air pressure above the paper. Because this pressure decreases, the pressure in the still air below the paper pushes the paper upward. The relationship between the velocity and pressure exerted by a moving fluid is named for Swiss scientist Daniel Bernoulli. **Bernoulli's principle** states that as the velocity of a fluid increases, the pressure exerted by that fluid decreases. This principle is a statement of work and energy conservation as applied to fluids.

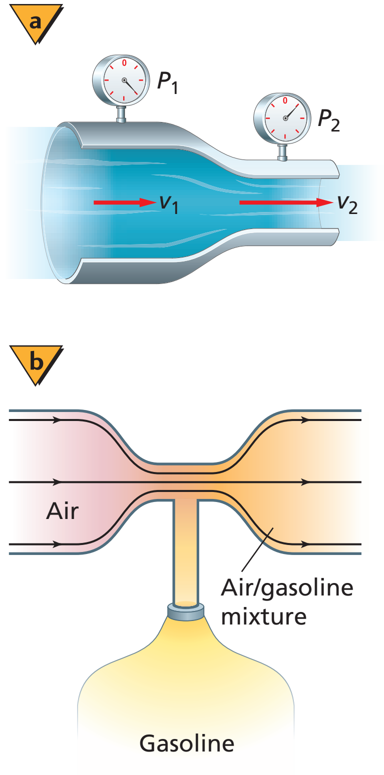
One instance in which fluid velocity can increase is when it flows through a constriction. The nozzles on some garden hoses can be opened or narrowed so that the velocity of the water spray can be changed. You may have seen the water in a stream speed up as it passed through narrowed sections of the stream bed. As the nozzle of the hose and the stream channel become wider or narrower, the velocity of the fluid changes to maintain the overall flow of water. In addition to streams and hoses, the pressure of blood in our circulatory systems depends partly on Bernoulli's principle. Treatments of heart disease involve removing obstructions in the arteries and veins and preventing clots in the blood.

Consider a horizontal pipe completely filled with a smoothly flowing ideal fluid. If a certain mass of the fluid enters one end of the pipe, then an equal mass must come out the other end. Now consider a section of pipe with a cross section that becomes narrower, as shown in **Figure 13-16a.** To keep the same mass of fluid moving through the narrow section in a fixed amount of time, the velocity of the fluid must increase. As the fluid's velocity increases, so does its kinetic energy. This means that net work has been done on the swifter fluid. This net work comes from the difference between the work that was done to move the mass of fluid into the pipe and the work that was done by the fluid pushing the same mass out of the pipe. The work is proportional to the force on the fluid, which, in turn, depends on the pressure. If the net work is positive, the pressure at the input end of the section, where the velocity is lower, must be larger than the pressure at the output end, where the velocity is higher.

Applications of Bernoulli's principle There are many common applications of Bernoulli's principle, such as paint sprayers and perfume bottles. The simple atomizer on a perfume bottle works by blowing air across the top of a tube sunk into perfume, which creates lower pressure at the top of the tube than in the bottle. As a result, perfume is forced into the air flow. A gasoline engine's carburetor, which is where air and gas are mixed, is another common application of Bernoulli's principle. Part of the carburetor is a tube with a constriction, as shown in the diagram in **Figure 13-16b.** The pressure on the gasoline in the fuel supply is the same as the pressure in the thicker part of the tube. Air flowing through the narrow section of the tube, which is attached to the fuel supply, is at a lower pressure, so fuel is forced into the air flow. By regulating the flow of air in the tube, the amount of fuel mixed into the air can be varied. Newer cars tend to have fuel injectors rather than carburetors, but carburetors are common in older cars and the motors of small gasoline-powered machines, such as lawn mowers.

Figure 13-15 Blowing across the surface of a sheet of paper demonstrates Bernoulli's principle.

Figure 13-16 Pressure P_1 is greater than P_2 because v_1 is less than v_2 **(a).** In a carburetor, low pressure in the narrow part of the tube draws fuel into the air flow **(b).**



■ **Figure 13-17** The smooth streamlines show the air flowing above a car that is being tested in a wind tunnel.

Streamlines Automobile and aircraft manufacturers spend a great deal of time and money testing new designs in wind tunnels to ensure the greatest efficiency of movement through air. The flow of fluids around objects is represented by **streamlines,** as shown in **Figure 13-17.** Objects require less energy to move through a smooth streamlined flow.

Streamlines can best be illustrated by a simple demonstration. Imagine carefully squeezing tiny drops of food coloring into a smoothly flowing fluid. If the colored lines that form stay thin and well defined, the flow is said to be streamlined. Notice that if the flow narrows, the streamlines move closer together. Closely spaced streamlines indicate greater velocity and therefore reduced pressure. If streamlines swirl and become diffused, the flow of the fluid is said to be turbulent. Bernoulli's principle does not apply to turbulent flow.

13.3 Section Review

32. Floating and Sinking Does a full soda pop can float or sink in water? Try it. Does it matter whether or not the drink is diet? All soda pop cans contain the same volume of liquid, 354 mL, and displace the same volume of water. What is the difference between a can that sinks and one that floats?

33. Floating and Density A fishing bobber made of cork floats with one-tenth of its volume below the water's surface. What is the density of cork?

34. Floating in Air A helium balloon rises because of the buoyant force of the air lifting it. The density of helium is 0.18 kg/m^3, and the density of air is 1.3 kg/m^3. How large a volume would a helium balloon need to lift a 10-N lead brick?

35. Transmission of Pressure A toy rocket launcher is designed so that a child stomps on a rubber cylinder, which increases the air pressure in a launching tube and pushes a foam rocket into the sky. If the child stomps with a force of 150 N on a 2.5×10^{-3} m^2 area piston, what is the additional force transmitted to the 4.0×10^{-4} m^2 launch tube?

36. Pressure and Force An automobile weighing 2.3×10^4 N is lifted by a hydraulic cylinder with an area of 0.15 m^2.

a. What is the pressure in the hydraulic cylinder?

b. The pressure in the lifting cylinder is produced by pushing on a 0.0082 m^2 cylinder. What force must be exerted on this small cylinder to lift the automobile?

37. Displacement Which of the following displaces more water when it is placed in an aquarium?

a. A 1.0-kg block of aluminum or a 1.0-kg block of lead?

b. A 10-cm^3 block of aluminum or a 10-cm^3 block of lead?

38. Critical Thinking As you discovered in Practice Problem 4, a tornado passing over a house sometimes makes the house explode from the inside out. How might Bernoulli's principle explain this phenomenon? What could be done to reduce the danger of a door or window exploding outward?

Physics Online physicspp.com/self_check_quiz

13.4 Solids

How do solids and liquids differ? Solids are stiff, they can be cut in pieces, and they retain their shapes. You can push on solids. Liquids flow and if you push your finger on water, your finger will move through it. However, if you have ever watched butter warm and begin to lose its shape, you may have wondered if the line between solids and liquids is always distinct.

▶ Objectives

- **Relate** the properties of solids to their structures.
- **Explain** why solids expand and contract when the temperature changes.
- **Calculate** the expansion of solids.
- **Explain** the importance of thermal expansion.

▶ Vocabulary

crystal lattice
amorphous solid
coefficient of linear expansion
coefficient of volume expansion

Solid Bodies

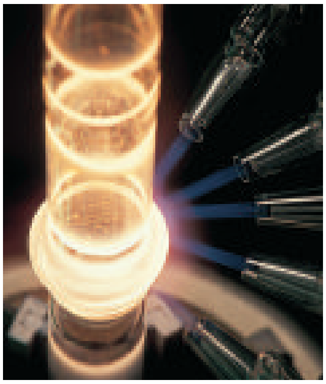
Under certain conditions, solids and liquids are not easily distinguished. As bottle glass is heated through the molten state, the change from solid to liquid is so gradual that it is difficult to tell which is which. Some solids, such as crystalline quartz, are made of particles that are lined up in orderly patterns. Other solids, such as glass, are made of jumbled arrangements of particles, just like a liquid. As shown in **Figure 13-18,** quartz and fused quartz (also called quartz glass) are the same chemically, but their physical properties are quite different.

When the temperature of a liquid is lowered, the average kinetic energy of the particles decreases. As the particles slow down, the cohesive forces have more effect, and for many solids, the particles become frozen into a fixed pattern called a **crystal lattice,** shown in **Figure 13-19** on the next page. Although the cohesive forces hold the particles in place, the particles in a crystalline solid do not stop moving completely. Rather, they vibrate around their fixed positions. In other materials, such as butter and glass, the particles do not form a fixed crystalline pattern. Such a substance, which has no regular crystal structure but does have a definite volume and shape, is called an **amorphous solid.** Amorphous solids also are classified as viscous, or slowly flowing, liquids.

Pressure and freezing As a liquid becomes a solid, its particles usually fit more closely together than in the liquid state, making solids more dense than liquids. As you have learned, however, water is an exception because it is most dense at 4°C. Water is also an exception to another general rule. For most liquids, an increase in the pressure on the surface of the liquid increases its freezing point. Because water expands as it freezes, an increase in pressure forces the molecules closer together and opposes the freezing. Therefore, higher pressure lowers the freezing point of water very slightly.

a

b



■ **Figure 13-18** In crystalline quartz, the particles are arranged in an orderly pattern **(a).** A crystalline solid melts at a specific temperature. Fused quartz is the same chemical as crystalline quartz, but the particles are jumbled randomly in the solid. When fused quartz melts, its properties change slowly over a range of temperatures, allowing it to be worked in a fashion similar to everyday glass **(b).**