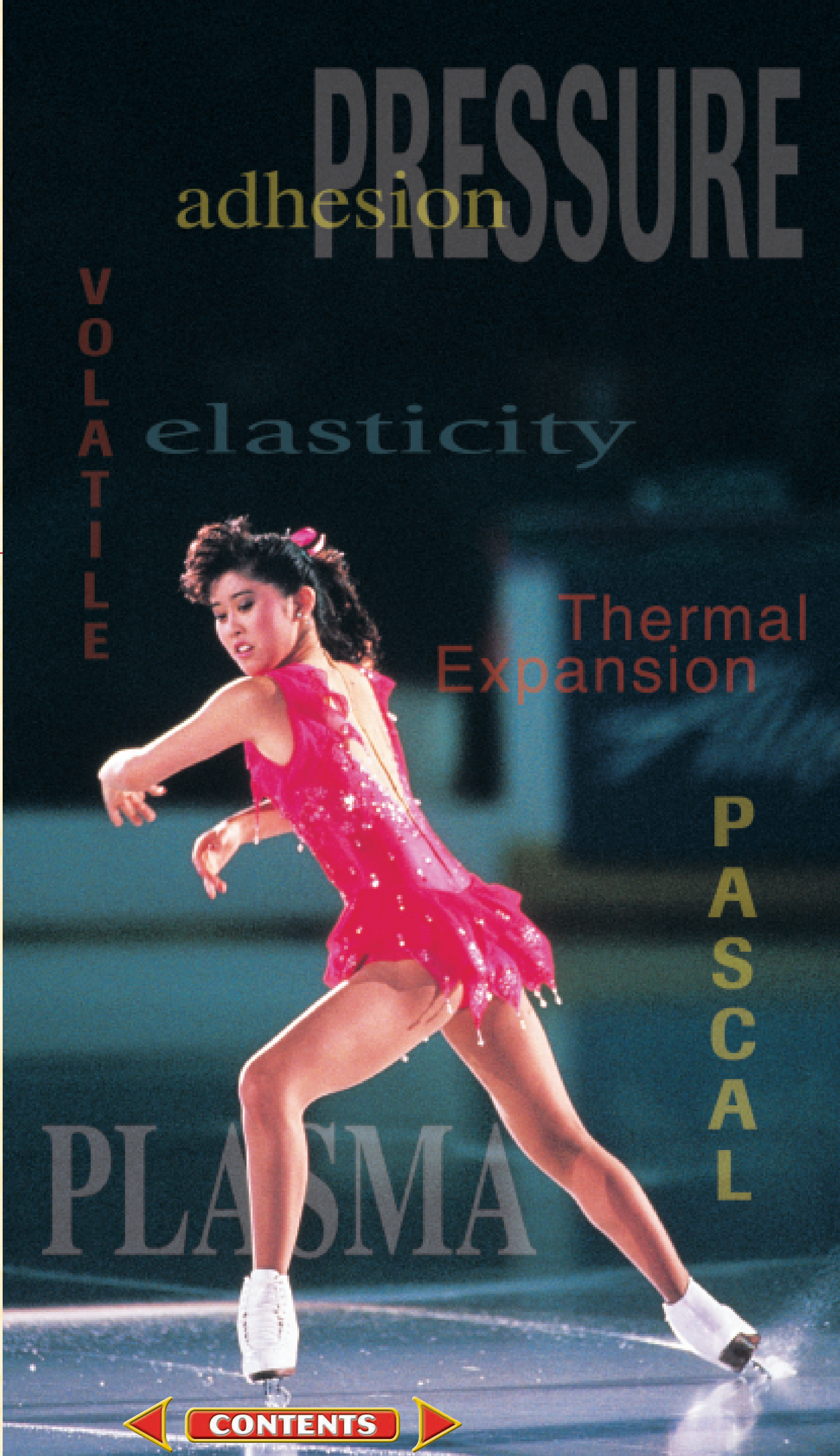
Skating Effortlessly

From your study of Newton's laws of motion, you will recognize that there must be very little friction between the skater's blades and the ice. What properties of ice and water make this possible?

Look at the text on page 315 for the answer.



CHAPTER

13 States of Matter

You are already familiar with the three common states of matter: solid, liquid, and gas. Solid objects litter the room around you. For example, you can easily recognize the shape of your desk; you know that your backpack cannot hold seven textbooks. You encounter liquids throughout the day as you drink water, take a shower, or perhaps swim, and you recognize that without a specific gas—oxygen—you would not be alive.

There is a fourth, less understood state of matter—plasma. At this moment, you are probably reading with the help of this state of matter. Whether your reading light comes from a fluorescent lamp or the sun, the light's source is plasma. Although plasma is still somewhat mysterious to humans, the plasma state of matter is the most common state in the universe.

In this chapter, your exploration of the states of matter will go far beyond everyday, casual observations. You will explore a characteristic shared by liquids and gases, and investigate how these substances produce pressure. You'll meet the physics principles that explain how huge wooden ships can float on water, and how enormous metal aircraft can fly. You will find out why some solids are elastic, while other substances seem to straddle the fence between solid and liquid. You will also learn that the expansion and contraction of matter that occurs when a substance's temperature changes can be important to your everyday life.

WHAT YOU'LL LEARN

- You will describe Pascal's, Archimedes', and Bernoulli's principles and relate them to everyday applications.
- You will explain how temperature changes cause the expansion and contraction of solids.

WHY IT'S IMPORTANT

- You will be able to explain how brakes stop a car.
- With an understanding of Archimedes' and Bernoulli's principles, it is possible to design larger ships, submarines, and aircraft.
- Thermal expansion allows you to control temperatures with thermostats.

PHYSICS Online

To find out more about the states of matter, visit the Glencoe Science Web site at **science.glencoe.com**

CLICK HERE

13.1 The Fluid States

If you think further about the air you breathe, a gas, and the water you drink, a liquid, you will realize they have some things in common. Both air and water flow and have indefinite shapes—unlike concrete, which is a solid. Because of their common characteristics, gases and liquids are called fluids.

OBJECTIVES

- **Describe** how fluids create pressure and **relate** Pascal's principle to some everyday occurrences.
- **Apply** Archimedes' and Bernoulli's principles.
- **Explain** how forces within liquids cause surface tension and capillary action, and **relate** the kinetic model to evaporation and condensation.

Properties of Fluids

How does a fluid differ from a solid? Suppose you put an ice cube in a glass. The ice cube has a certain mass and shape, and neither of these quantities depends on the size or shape of the glass. What happens, however, when the ice melts? Its mass remains the same, but its shape changes. The water flows to take the shape of its container and forms a definite upper surface, as in **Figure 13–1.** If you boiled the water, it would change into a gas, water vapor, and it also would flow and expand to fill whatever container it was in. But the water vapor would not have any definite surface. Both liquids and gases are fluids. **Fluids** are materials that flow and have no definite shape of their own.

FIGURE 13–1 The ice cube, a solid, has a definite shape. But water, a fluid, takes the shape of its container.

Pressure and fluids Can Newton's laws of motion and the laws of conservation of momentum and energy be applied to fluids? In most cases, the answer is yes. But in some cases, the mathematics is so complicated that even the most advanced computers can't reach definite solutions. By studying the concept of pressure, you can learn more about the motion of fluids. Applying force to a surface is **pressure**. Pressure, which can be represented by the following equation, is the force on a surface divided by the area of the surface.

Pressure $$P = \frac{F}{A}$$

The force (F) on the surface is assumed to be perpendicular to the surface area (A).

If you stand on ice, the ice exerts on your body an upward normal force that has the same magnitude as your weight. The upward force is spread over the area of your body that touches the ice, which is the soles of your feet. **Figure 13–2** helps illustrate the relationships between force, area, and pressure.

Pressure (P) is a scalar quantity. In the SI system, the unit of pressure is the **pascal** (Pa), which is one newton per square meter. Because the pascal is a small unit, the kilopascal (kPa), equal to 1000 Pa, is more commonly used. **Table 13–1** shows how pressures vary in different situations, and **Figure 13–3** shows a few commonly used instruments for measuring pressure.

How does matter exert pressure? Imagine that you are standing on the surface of a frozen lake. Your feet exert forces on the ice, a solid made up of vibrating water molecules. The forces that hold the water molecules apart cause the ice to exert upward forces on your feet that equal your weight.

What if the ice melts? Most of the bonds between the water molecules are broken and although the molecules continue to vibrate and remain close to each other they can also slide past one another. If the lake is deep enough, the water will eventually surround your entire body. The collisions of the moving water molecules continue to exert forces on your body.

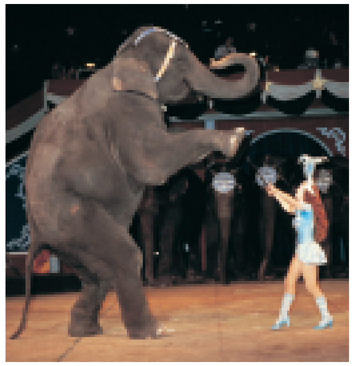


FIGURE 13–2 Pressure is the force exerted on a unit area of a surface. Similar forces may produce vastly different pressures; for example, the pressure on the ground under the high heel of a woman's shoe is far greater than that under an elephant's foot.

TABLE 13–1

Some Typical Pressures

Location	Pressure (Pascals)
The center of the sun	2×10^{16}
The center of Earth	4×10^{11}
The deepest ocean trench	1.1×10^{8}
An automobile tire	2×10^{5}
Standard atmosphere	1.01325×10^{5}
Blood pressure	1.6×10^{4}
Air pressure on top of Mt Everest	4×10^{4}
Atmospheric pressure on Mars	7×10^{2}
The best vacuum	1×10^{-12}

Gas particles and pressure The force exerted by a gas can be understood by using the kinetic-molecular theory of gases. According to this theory, gases are made up of very small particles, the same particles that make up solids and liquids. But the particles are now widely separated, in constant, random motion at high speed, and making elastic collisions with each other. When gas particles hit a surface, they rebound without losing kinetic energy. The forces exerted by these collisions result in gas pressure on the surface.

a

b

FIGURE 13–3 A tire gauge measures tire air pressure **(a),** and an aircraft altimeter uses pressure to indicate altitude **(b).**

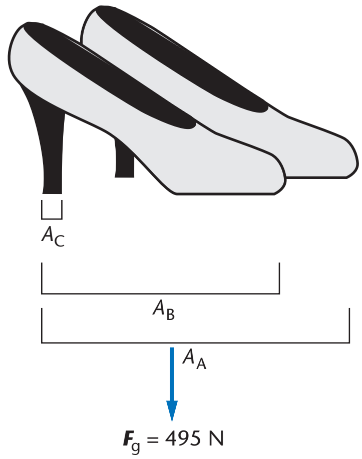
Atmospheric pressure On every square centimeter of Earth's surface at sea level, the atmosphere exerts a force of approximately 10 N, about the weight of a 1-kg object. The pressure of Earth's atmosphere on your body is so well balanced by your body's outward forces that you seldom notice it. You become aware of this pressure only when your ears "pop" as the result of pressure changes when you ride an elevator in a tall building, drive up a steep mountain road, or fly in an airplane. Atmospheric pressure is about 10 N divided by the area of 1 cm^2, or 10^{-4} m^2, which is about 1.0×10^{5} N/m^2, or 100 kPa.

Example Problem

Calculating Pressure

A woman weighs 495 N and wears shoes that touch the ground over an area of 412 cm^2.

a. What is the average pressure in kPa that her shoes exert on the ground?
b. How does the pressure change when she stands on only one foot?
c. What is the pressure if she puts all her weight on the heel of one shoe with the area of the high heel of 2.0 cm^2?



Sketch the Problem

- Sketch the shoes, labeling A_A, A_B, and A_C.
- Show the vector for the force the woman exerts on the ground, and indicate the area on which the force is exerted.

Calculate Your Answer

Known:

$F = 495$ N

$A_A = 412\ cm^2$

$A_B = 206\ cm^2$

$A_C = 2.0\ cm^2$

Unknown:

$P_A, P_B, P_C = ?$

Strategy:

Convert area to the correct units, m^2.

Find each pressure by dividing force by each area.

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

Calculations:

a. $$A_A = \frac{412\ cm^2 \times (1\ m)^2}{(100\ cm)^2} = 0.0412\ m^2$$

$$P_A = \frac{495\ N}{0.0412\ m^2}$$

$$= \frac{1.20 \times 10^4\ N/m^2 \times 1\ kPa}{1000 N/m^2} = 12.0\ kPa$$

b. $A_B = 0.0206\ m^2$

$$P_B = \frac{495\ N}{0.0206\ m^2}$$

$$= 24.0\ kPa$$

c. $A_C = 0.00020\ m^2$

$$P_C = \frac{495\ N}{0.00020\ m^2}$$

$$= 2500\ kPa$$

Check Your Answer

- Are your units correct? The units for pressure should be Pa, and 1 N/m^2 = 1 Pa.
- You can see that keeping the force the same but reducing the area increases the pressure.

Practice Problems

1. The atmospheric pressure at sea level is about 1.0×10^5 Pa. What is the force at sea level that air exerts on the top of a typical office desk, 152 cm long and 76 cm wide?
2. A car tire makes contact with the ground on a rectangular area of 12 cm by 18 cm. The car's mass is 925 kg. What pressure does the car exert on the ground?
3. A lead brick, $5.0 \times 10.0 \times 20.0$ cm, rests on the ground on its smallest face. What pressure does it exert on the ground? (Lead has a density of 11.8 g/cm^3.)
4. In a tornado, the pressure can be 15% below normal atmospheric pressure. Sometimes a tornado can move so quickly that this pressure drop can occur in one second. Suppose a tornado suddenly occurred outside your front door, which is 182 cm high and 91 cm wide. What net force would be exerted on the door? In what direction would the force be exerted?

Fluids at Rest

The fluid most familiar to you is probably liquid water. Other fluids include honey, oil, tar, and air. Think about how these fluids are alike, and how they differ. Every fluid has its own properties, such as sticky or watery. To make it easier to compare the behavior of fluids, you can use an ideal fluid as a model. An ideal fluid has no internal friction among its particles. For the following discussion, imagine that you are dealing with an ideal fluid.

Pascal's principle You are now familiar with how the atmosphere exerts pressure. If you have ever dived deep into a swimming pool or lake, you know that water also exerts pressure. Your body is sensitive to water pressure. You probably noticed that the pressure you felt on your ears did not depend on whether your head was upright or tilted. If your body is vertical or horizontal, the pressure is nearly the same on all parts of your body.

Blaise Pascal (1623–1662), a French physician, noted that the shape of a container has no effect on the pressure of the fluid it contains at any given depth. He discovered that any change in pressure applied at any point on a confined fluid is transmitted undiminished throughout the fluid. This fact became known as **Pascal's principle.** Every time you squeeze a tube of toothpaste, you demonstrate Pascal's principle. The pressure your fingers exert at the bottom of the tube is transmitted through the toothpaste, forcing the paste out at the top.

When fluids are used in machines, such as hydraulic lifts, to multiply forces, Pascal's principle is being applied. In a hydraulic system, a fluid is confined to two connecting chambers, as shown in

Pocket Lab

Foot Pressure

How much pressure do you exert when standing on the ground with one foot? Is it more or less than air pressure? Estimate your weight in newtons. **Hint:** 500 N = 110 lb. Stand on a piece of paper and have a lab partner trace the outline of your foot. Draw a rectangle that has about the same area as the outline.

Using SI Measurement Calculate the area of your rectangle in square meters, and use the definition of pressure to estimate your pressure. $P = F/A$.

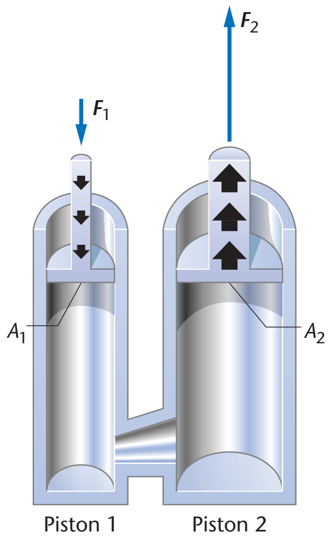


FIGURE 13–4 The pressure exerted by the force of the small piston is transmitted throughout the fluid and results in a multiplied force on the larger piston.

Figure 13–4. Each chamber has a piston that is free to move. If a force, F_1, is exerted on the first piston with a surface area of A_1, the pressure (P) exerted on the fluid can be determined by using the following equation.

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

According to Pascal's principle, pressure is transmitted without change throughout a fluid, and therefore, the pressure exerted by the fluid on the second piston, with a surface area A_2, can also be determined.

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

Because the pressure P_2 is equal in value to P_1, you can determine the force exerted by the hydraulic lift. Because $F_1/A_1 = F_2/A_2$, then the force exerted by the second piston is shown by the following equation.

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

Practice Problems

5. 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?

Swimming Under Pressure

While you are swimming, you can observe another property of fluids. You feel the pressure of the water as you dive deeper. Recall that the pressure in a fluid is the same in all directions, and that pressure is the force on a surface divided by its area. The downward pressure of the water is equal to the weight, F_g, of the column of water above its surface area, A.

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

You can find the pressure of the water above you by applying this equation. 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 column times its height, $V = Ah$. Therefore, $F_g = \rho A h g$. The pressure can now be determined.

Pressure of Water on a Body $P = \frac{F_g}{A} = \frac{\rho A h g}{A} = \rho h g$

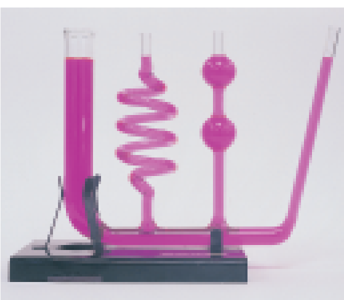


FIGURE 13–5 Equilibrium tubes show that a container's shape has no effect on pressure.

The pressure of the water on a body depends on the density of the fluid, its depth, and g. As noted by Pascal, the shape of the container, such as those shown in **Figure 13–5**, has no effect on pressure.

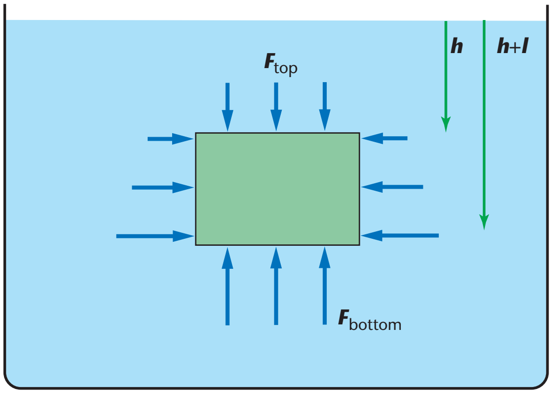


FIGURE 13–6 A fluid exerts a greater upward force on the bottom of an immersed object than the downward force on the top of the object. The net upward force is called the buoyant force.

Buoyancy The increase of pressure with depth has an important consequence. It allows you to swim. That is, it creates an upward force, called the **buoyant force,** on all objects. By comparing the buoyant force on an object with its weight, you will know if the object will sink or float.

Suppose that a box is immersed in water. It has a height l, and its top and bottom each have surface area A. Its volume, then, is $V = lA$. Water pressure exerts forces on all sides, as shown in **Figure 13–6.** Will the box sink or float? As you know, the pressure on the box depends on its depth, h. To find out if the box will float in the 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.

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

Buoyant Force $F_{buoyant} = \rho Vg$

This shows that the net upward force is proportional to the volume of the box. This volume is equal to the volume of the fluid that was displaced, or pushed out of the way, by the box. Therefore, the magnitude of the buoyant force, ρVg, is equal to the weight of the fluid displaced by the object. This relationship was discovered in 212 B.C. by the Greek scientist Archimedes. **Archimedes' principle** states that an object immersed in a fluid has an upward force on it 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.

F.Y.I.

The Heimlich maneuver is a sharp pressure applied to the abdomen of a person to dislodge a foreign object caught in the throat. It is an application of Pascal's principle.

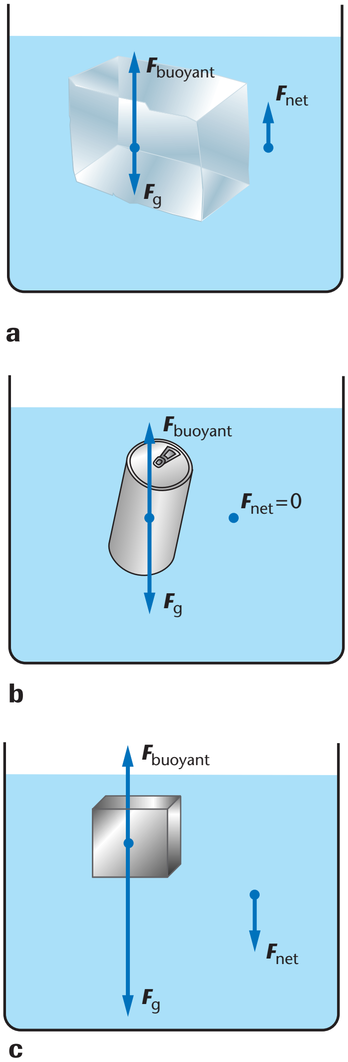


FIGURE 13–7 An ice cube **(a),** an aluminum can of soda **(b),** and a block of steel **(c)** all have the same volume, displace the same amount of water, and experience the same buoyant force. However, because their weights are different, the net forces on the three objects are also different.

Sink or float? What are the forces that act on an object that is placed in a fluid? One force is the upward force, or buoyant force, of the liquid on the object. There is also the downward force of the object's weight. The difference between the buoyant force and the object's weight determines whether an object sinks or floats.

Suppose you submerge three items in a tank filled with water ($\rho_{water} = 1.00 \times 10^3$ kg/m^3). They all have the same volume, 100 cm^3 or 1.00×10^{-4} m^3. One item is an ice cube with a mass of 0.090 kg. The second is an aluminum can of soda with a mass of 0.100 kg. The third is a block of steel with a mass of 0.90 kg. How will each item move in the water? The upward force on all three objects, as shown in **Figure 13–7,** is the same, because all displace the same weight of water. The upward force can be calculated as shown by the following equation.

$$F_{buoyant} = \rho_{water} V g$$

$$= (1.00 \times 10^3 \text{ kg/m}^3)(1.00 \times 10^{-4} \text{ m}^3)(9.80 \text{ m/s}^2)$$

$$= 0.980 \text{ N}.$$

The weight of the ice cube ($F_g = mg$) is 0.88 N, so there is a net upward force, and the ice cube will rise. When it reaches the surface there will still be a net upward force that 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 just enough volume in the water so that the weight of water displaced equals the weight of the ice cube. An object will float because its density is less than the density of the fluid.

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 at neutral buoyancy are described as being weightless; this property is similar to that experienced by astronauts in orbit. This environment is simulated for astronauts when they train in swimming pools.

The weight of the block of steel is 8.8 N. It has a net downward force, so it 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 $F_{apparent} = F_g - F_{buoyant}$.

As a result of the buoyant force of Archimedes' principle, ships can be made of steel and still float as long as the hull is hollow and large enough so that the density of the ship is less than the density of water. You may have noticed that a ship loaded with cargo rides much lower in the water than a ship with an empty cargo hold.

Submarines take advantage of Archimedes' principle as water is pumped into or out of a number of different chambers to change the submarine's net vertical force, causing it to rise or sink. Archimedes' principle also explains the buoyancy of fishes that have air bladders.

The density of a fish is about the same as that of water. Fishes that have an air bladder can expand or contract the bladder. By expanding its air bladder, a fish can move upward in the water. The expansion displaces more water and increases the buoyant force. The fish moves downward by contracting the volume of the air bladder.

Example Problem

Archimedes' Principle

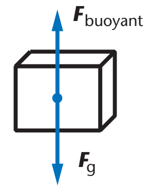
A cubic decimeter, 1.00×10^{-3} m^3, of aluminum is submerged in water. The density of aluminum is 2.70×10^3 kg/m^3.

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

b. What is the apparent weight of the block?

Sketch the Problem

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



Calculate Your Answer

Known:

$V = 1.00 \times 10^{-3}$ m^3

$\rho_{aluminum} = 2.70 \times 10^3$ kg/m^3

$\rho_{water} = 1.00 \times 10^3$ kg/m^3

Unknown:

$F_{buoyant} = ?$

$F_{apparent} = ?$

Strategy:

a. Calculate the buoyant force on the aluminum block.

b. The aluminum's apparent weight equals its weight minus the upward buoyant force.

Calculations:

$$F_{buoyant} = \rho_{water} V g$$
$$= (1.00 \times 10^3 \text{ kg/m}^3)(1.00 \times 10^{-3} \text{ m}^3)(9.80 \text{ m/s}^2)$$
$$= 9.80 \text{ N}$$

$$F_g = mg = \rho_{aluminum} V g$$
$$= (2.70 \times 10^3 \text{ kg/m}^3)(1.00 \times 10^{-3} \text{ m}^3)(9.80 \text{ m/s}^2)$$
$$= 26.5 \text{ N}$$

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

Check Your Answer

- Are your 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 aluminum, a sensible answer because the density of water is about one third that of aluminum.

Float or Sink?

Problem

How can you measure the buoyancy of objects?

Materials

beaker
water
film canister with lid
25 pennies
250-g spring scale
pan balance

Procedure

1. Measure and calculate the volume of a film canister. Record the volume in a data table like the one shown.
2. Fill the canister with water. Find the mass of the filled canister on the pan balance. Record the value in your data table.
3. Empty the canister of water.
4. Place a few pennies in the canister and put the top on tightly. Find its mass and record the value in your data table.
5. Put the capped film canister into a beaker of water to see if it floats.
6. If it floats, estimate the percentage that is under water. Record this amount in your data table.
7. If it sinks, use the spring scale to measure the apparent weight while it is under water (but not touching the bottom). Record this value in your data table.
8. Repeat steps 4 through 7 using different numbers of pennies for each trial.
9. Calculate the density for each trial in g/cm^3.
10. Dispose of the water as instructed by your teacher. Dry wet materials before putting them away.

Data and Observations		
Volume of canister = ____ cm^3		
Mass of canister with water = ____ g		
Floaters		
Mass with pennies	% below water	Density
Sinkers		
Mass with pennies	Apparent weight	Density

Analyze and Conclude

1. **Recognizing Spatial Relationships** Look closely at the mass of the floaters and the percentages below the water. What seems to be the rule?
2. **Comparing and Contrasting** Look closely at the sinkers. How much lighter are the canisters when weighed underwater?

Apply

1. Explain why a steel-hulled boat can float, even though it is quite massive.
2. Icebergs float in salt water (density 1.03 g/cm^3) with 1/9 of their volume above water. What is the density of an iceberg?

Practice Problems

6. A girl is floating in a freshwater lake with her head just above the water. If she weighs 600 N, what is the volume of the submerged part of her body?
7. What is the tension in a wire supporting a 1250-N camera submerged in water? The volume of the camera is 8.3×10^{-2} m^3.

FIGURE 13–8 Blowing across the surface of a sheet of paper demonstrates Bernoulli's principle.

Fluids in Motion

To see an effect of moving fluids, try the experiment in **Figure 13–8.** Hold a strip of notebook paper just under your lower lip. Now blow hard across the top surface. The strip of paper will rise. This is because the pressure on top of the paper, where air is flowing rapidly is lower than the pressure beneath it, where air is not in motion.

The relationship between the velocity and pressure exerted by a moving fluid is described by **Bernoulli's principle,** named for the Swiss scientist Daniel Bernoulli (1700–1782). Bernoulli's principle states that as the velocity of a fluid increases, the pressure exerted by that fluid decreases.

When a fluid flows through a constriction, its velocity increases. You may have seen this happen as the water flow in a stream speeds up as it passes through narrowed sections. 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 13–9.** 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. If the velocity increases, so does the kinetic energy. This means that net work must be done on the fluid. The net work is the difference between the work done on the mass of fluid to move it into the pipe and the work 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.

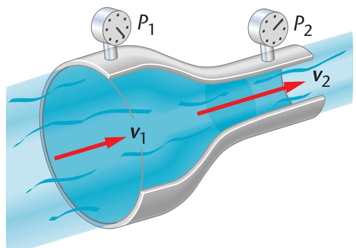
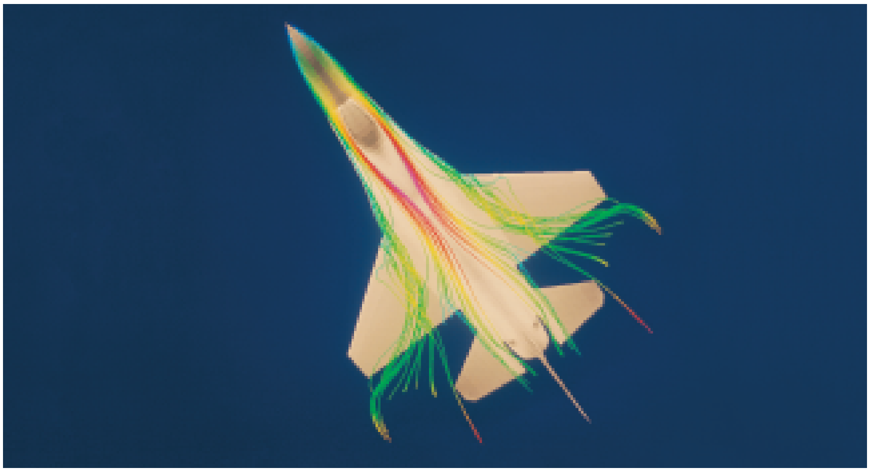


FIGURE 13–9 The pressure P_1 is greater than P_2 because v_1 is less than v_2.

Most aircraft get part of their lift by taking advantage of Bernoulli's principle. Airplane wings are airfoils, devices designed to produce lift when moving through a fluid. The curvature of the top surface of a wing is greater than that of the bottom. As the wing travels through the air, the air moving over the top surface travels farther, and therefore must go faster than air moving past the bottom surface. The decreased air pressure created on the top surface results in a net upward pressure that produces an upward force on the wings, or lift, which helps to hold the

FIGURE 13–10 The smooth streamlines shown in this computer simulation indicate smooth air flow around a jet fighter.



airplane aloft. Race cars use airfoils with a greater curvature on the bottom surface. The airfoils, called spoilers, produce a net downward pressure that helps to hold the rear wheels of the cars on the road at high speeds.

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, a fluid. The flow of fluids around objects is represented by streamlines, as shown in **Figure 13–10.** Objects require less energy to move through a smooth streamline 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.

Forces Within Liquids

The liquids considered thus far have been ideal liquids, in which the particles are totally free to slide over and around one another. In real liquids, however, particles exert electromagnetic forces of attraction on each other. These forces, called **cohesive forces,** affect the behavior of liquids.

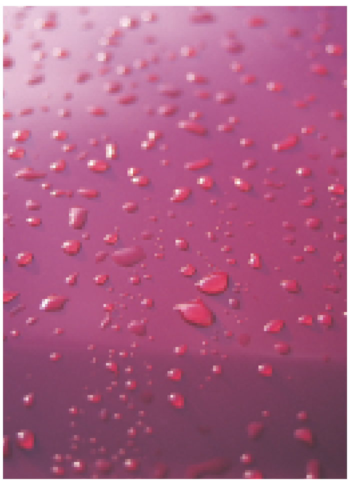
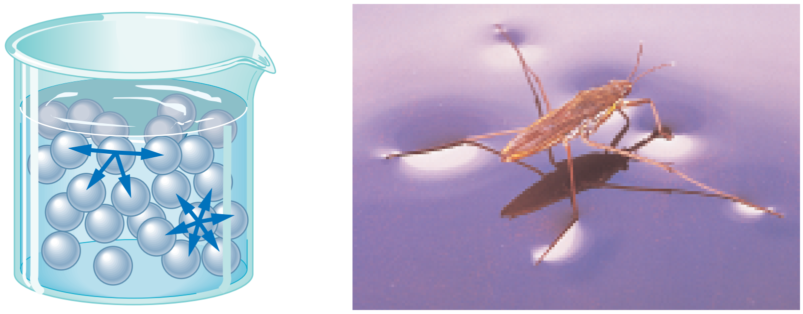


FIGURE 13–11 Rainwater beads up on a freshly waxed automobile because water drops have surface tension.

Surface tension Have you ever noticed that dewdrops on spiderwebs and falling drops of oil are nearly spherical? What happens when it rains just after you have washed and waxed your car? The water drops bead up into rounded shapes, as shown in **Figure 13–11.** All of these phenomena are examples of surface tension. **Surface tension** is a result of the cohesive forces among the particles of a liquid. It is the tendency of the surface of a liquid to contract to the smallest possible area.



a b

FIGURE 13–12 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).**

Notice that beneath the surface of the liquid shown in **Figure 13–12,** 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 water bugs. The surface tension of water also can support a steel razor blade, 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 the liquid causes the surface to become as small as possible. 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. Liquid mercury has much stronger cohesive forces among its particles than water does. Mercury forms spherical drops, even when placed on a smooth surface. On the other hand, liquids such as alcohol and ether have weaker cohesive forces among their particles. A drop of either of these liquids flattens out on a smooth surface.

Capillary action A force similar to cohesion is adhesion. **Adhesion** is the attractive force that acts between particles of different substances. Like cohesive forces, adhesive forces are electromagnetic in nature. If a piece of glass tubing 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 lifted balances the total adhesive force between the glass and water molecules. If the radius of the tube increases, the volume, and therefore the weight, of the water increases proportionally faster than does the surface area of the tube. For this reason, water is lifted higher in a narrow tube than in one that is wider.

F.Y.I.

If all the water vapor in Earth's atmosphere were condensed to liquid water at the same time, there would be enough water to cover the United States with a layer of water 25 feet deep.

Pocket Lab

Floating?

Pour water into a glass or small beaker until it is three-fourths full. Gently place a needle on the surface of the water. Try to float it. Then try to float a paper clip, a metal staple, or a steel razor blade.

Relate Cause and Effect Explain your results.

CHEMISTRY CONNECTION

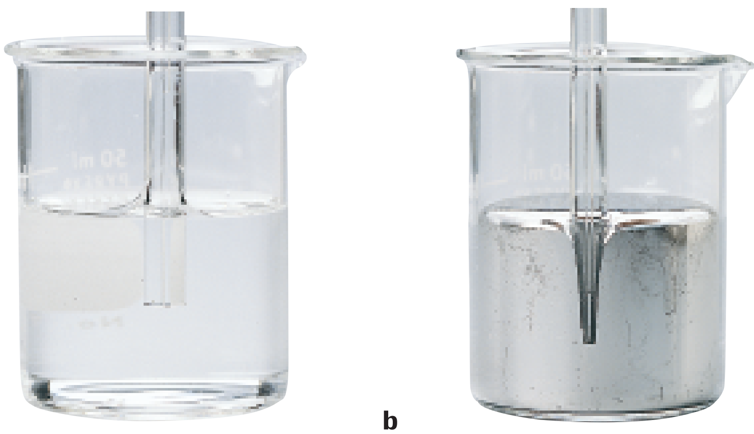
Chromatography
Most types of matter you encounter every day are mixtures of two or more components. Chemists must often determine the identity of the components. Chromatography is a method of separating a mixture into its components. Chromatography involves two phases—a stationary phase and a mobile phase. Separation occurs when the mobile phase moves through the stationary phase. Adhesion to the stationary phase causes the components of the mixture to move with the mobile phase at different rates and eventually separate. Once separated, the components can be identified.

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 13–13a.** This is because the adhesive forces between the glass molecules and water molecules are greater than the cohesive force between the water molecules. In contrast, the cohesive forces between the mercury molecules are greater than the adhesive forces between the mercury and glass molecules, and 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 13–13b.**

Molten wax rises in the wick of a candle because of capillary action. Paint moves up through the bristles of a brush for the same reason. It is also capillary action that causes water to move up through the soil and into the roots of plants.

Evaporation and condensation What happens to a puddle of water on a hot, dry day? After a few hours the water is gone. Why? The particles in a liquid move at random speeds. The temperature of a liquid is dependent on the average kinetic energy of its particles. Some are moving rapidly; others are moving slowly. Suppose a fast-moving particle is near the surface of the liquid. If it can break through the surface layers, it will escape from the liquid. Because there is a net downward cohesive force at the surface, only the more energetic particles escape. The escape of particles from a liquid is called **evaporation.**

Evaporation has a cooling effect. On a hot day your body perspires. 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 liquid, the average kinetic energy of the remaining particles decreases. A decrease in kinetic energy is a decrease in temperature. You can test this cooling effect by pouring a little rubbing alcohol into the palm of your hand. Alcohol molecules evaporate easily because they have weak cohesive forces. The cooling effect is quite noticeable. A liquid that evaporates quickly is called a **volatile** liquid.



a b

FIGURE 13–13 Water climbs the wall of this glass tube **(a),** while the mercury is depressed in the tube **(b).** The forces of attraction between mercury atoms are stronger than any adhesive forces between the mercury and the glass.

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. High humidity reduces the evaporation of perspiration from the skin, which is the body's primary mechanism for regulating body temperature.

Particles of liquid that have evaporated into the air can also return to the liquid phase if the kinetic energy or temperature decreases in 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 contains evaporated water vapor, which is water in the form of gas, as shown in **Figure 13–14.** If the temperature is reduced, the water vapor condenses around tiny dust particles in the air, producing 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 be formed in your home. When a carbonated drink is opened, the sudden decrease in pressure causes the temperature of the liquid to drop, which condenses the surrounding water vapor.

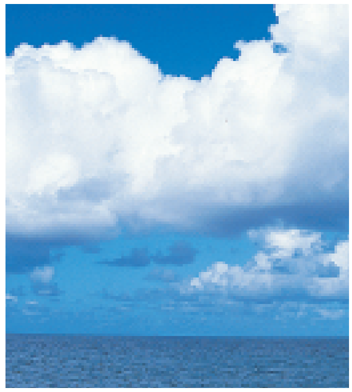


FIGURE 13–14 Warm moist surface air rises until it reaches a height where the temperature is at the point at which water vapor condenses and forms clouds.

13.1 Section Review

1. You have two boxes. One is 20 cm by 20 cm by 20 cm. The other is 20 cm by 20 cm by 40 cm.
   - **a.** How does the pressure of the air on the outside of the two boxes compare?
   - **b.** How does the magnitude of the total force of the air on the two boxes compare?
2. Does a full soft-drink can float or sink in water? Try it. Does it matter whether the drink is diet or not? All drink cans contain the same volume of liquid, 354 mL, and displace the same volume. What is the difference between a can that sinks and one that floats?
3. When a baby had a high fever, some doctors used to suggest gently sponging off the baby with rubbing alcohol. Why would this help?
4. How does fluid physics impact careers in the airplane and aerospace industry?
5. Research and describe Pascal's contributions to physics.
6. **Critical Thinking** It was 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.

13.2 The Solid State

How does a liquid differ from a solid? Solids are stiff. You can push them. Liquids are soft. Can you rest your finger on water? No, it goes right in. Of course, if you belly flop into a swimming pool, you recognize that a liquid may feel solid.

OBJECTIVES

- **Compare** solids, liquids, gases, and plasmas at a microscopic level, and **relate** their properties to their structures.
- **Explain** why solids expand and contract when the temperature changes.
- **Calculate** the expansion of solids and discuss the problems caused by expansion.

Solid Bodies

Under certain laboratory conditions, solids and liquids are not easily distinguished, as suggested by the computer images in **Figure 13–15.** Researchers have made clusters containing only a few dozen atoms. These clusters have properties of both liquids and solids at the same temperature. Studies of this strange state of matter may help scientists to invent new and useful materials in the future.

When the temperature of a liquid is lowered, the average kinetic energy of the particles is lowered. As the particles slow down, the cohesive forces become more effective, and the particles are no longer able to slide over one another. The particles become frozen into a fixed pattern called a **crystal lattice,** shown in **Figure 13–16.** Although the 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 the crystal lattice. In some solid materials, such as butter and glass, the particles do not form a fixed crystalline pattern. These substances have no regular crystal structure but have definite volume and shape, so they are called **amorphous solids.** Amorphous solids are also classified as viscous, or slowly flowing, liquids.

The effects of freezing As a liquid freezes, its particles usually fit more closely together than in the liquid state. Solids usually are more dense than liquids. However, water is an exception because it is most dense at 4°C. As water freezes, the cohesive forces between particles decrease and the particles take up more space. At 0°C, ice has a lower density than liquid water does, which is why it floats.

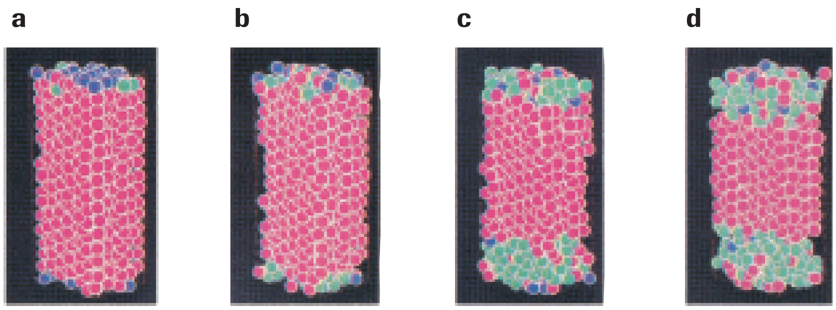
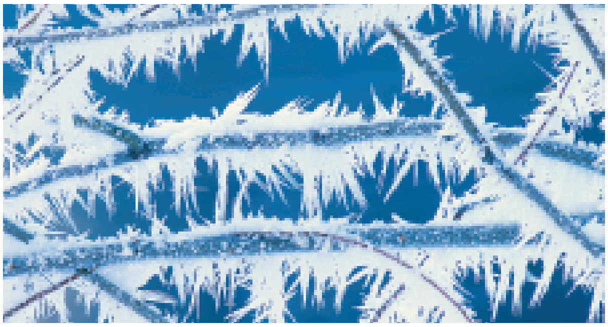
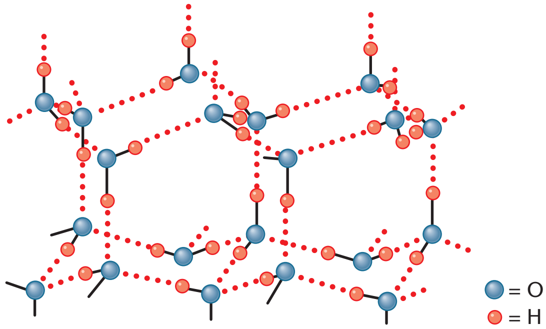


FIGURE 13–15 The melting of a solid is represented by this computer model. The green and blue spheres represent the liquid phase, and the red spheres represent the solid phase. Notice how similar they are.



a



b

FIGURE 13–16 Ice, the solid form of water, has a larger volume than an equal mass of its liquid form **(a).** The crystalline structure of ice is in the form of a lattice **(b).**

For most liquids, an increase in the pressure on the surface of the liquid increases its freezing point. Water is an exception. Because water expands as it freezes, an increase in pressure forces the molecules closer together and increases the cohesive forces among them. The freezing point of water is lowered very slightly.

It has been hypothesized that the drop in water's freezing point caused by the pressure of an ice skater's blades may produce a thin film of liquid between the ice and the blades, which makes them move so effortlessly. Some calculations of the pressure caused by even the sharpest blade show that the ice would still be too cold to melt. But, more recent measurements have shown that the friction between the blade and the ice generates enough thermal energy to melt the ice and create a thin layer of water. If you've ever tried to walk on ice covered with water, you know how slippery it is. This explanation is supported by measurements of the spray of ice particles, such as those in the photo of the ice skater at the beginning of the chapter, which are considerably warmer than the ice itself. The same process of melting occurs during snow skiing.

Skating Effortlessly

Answers question from page 298.

Elasticity of solids External forces applied to a solid object may twist or bend it out of shape. The ability of an object to return to its original form when the external forces are removed is called the **elasticity** of the solid. If too much deformation occurs, the object will not return to its original shape—its elastic limit has been exceeded. Elasticity depends on the electromagnetic forces that hold the particles of a substance together. Malleability and ductility are two properties that depend on the structure and elasticity of a substance. Gold is a malleable metal because it can be flattened and shaped by hammering into thin sheets. Copper is a ductile metal because it can be pulled into thin strands of wire and used in electric circuits.

Thermal Expansion of Matter

Temperature changes cause materials in both solid and fluid states, to expand when heated and to contract when cooled. This property, known as **thermal expansion,** has many useful applications such as using a thermometer to monitor your body temperature as the mercury expands up a glass tube. When heated, all forms of matter—solid,

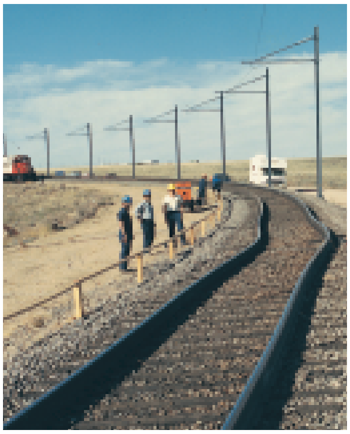


FIGURE 13–17 The extreme temperatures of a July day caused these railroad tracks to buckle.

liquid, or gas—generally become less dense and expand to fill more space. When the air near the floor of a room is warmed, gravity pulls the denser, colder ceiling air down, which pushes the warmer air upward. This motion results in the circulation of air within the room, called a convection current.

Expansion allows a liquid to be heated rapidly. When a container of liquid is heated from the bottom, convection currents form, just as they do in air. Cold, more dense liquid sinks to the bottom where it is warmed and then pushed up by the continuous flow of cooler liquid from the top. Thus, all the liquid is able to come in contact with the hot surface.

Thermal expansion in solids The expansion of concrete and steel in highway bridges means that the structures are longer in the summer than in the winter. Temperature extremes must be considered when bridges are designed. Gaps, called expansion joints, are built in to allow for seasonal changes in length. High temperatures can damage railroad tracks that are laid without expansion joints, as shown in **Figure 13–17.**

Physics & Technology

Aerogels

A gel is a mixture consisting of a network of solid particles surrounded by liquid. Gelatin and butter are examples of gels. Removing the liquid in a gel without disturbing its network of solids results in an aerogel—the lightest of all known solid materials. An aerogel has the same shape as the liquid-solid gel it is made from, but it is riddled with microscopic pores filled with air. Some aerogels are 95 percent air. A piece the size of an average adult person weighs less than a pound. Aerogels also have an extremely large surface area. If you could unfold a one-inch cube of aerogel and lay it out flat, it could cover two basketball courts. These characteristics make aerogels amazingly useful.

Aerogels are excellent thermal insulators. Because they contain so much air, they block heat transfer very effectively. A small piece can protect a flower from the heat of an open flame. Aerogels have been experimented with for many years for use in heating and cooling applications. Researchers are now developing ways to make very thin aerogel films for use as electronic insulators. Electric charge can sometimes leak out of computer components. Insulators that prevent this leakage could help increase the efficiency and reduce the size of all kinds of electronic devices.

Most aerogels are made from silica, which is the same material used to make glass. Aerogels produced in the microgravity of Earth's orbit are clear. Clear aerogels would make very energy-efficient windows, but those made on Earth are hazy and have a bluish color. NASA scientists are now working on a method for making silica aerogels in space.

Thinking Critically What do you think would be the most challenging step in producing an aerogel from a liquid-solid gel?

Some materials, such as Pyrex glass for cooking and laboratory glassware, are designed to have the least possible thermal expansion. Blocks used as standard lengths in machine shops are often made of Invar, a metal alloy that does not expand significantly when heated. Large telescope mirrors are made of a ceramic material called Zerodur, designed to have a coefficient of thermal expansion that is essentially zero.

The expansion of heated solids can be explained in terms of the kinetic theory. One model pictures a solid as a collection of particles connected by springs. The springs represent the forces that attract the particles to each other. When the particles get too close, the springs push them apart. If a solid did not have these forces of repulsion, it would collapse into a tiny sphere. When a solid is heated, the kinetic energy of the particles increases, and they vibrate rapidly and move farther apart. When the particles move farther apart, the attractive forces between particles become weaker. As a result, when the particles vibrate more violently with increased temperature, their average separation increases and the solid expands. The coefficients of thermal expansion for a variety of materials are given in **Table 13–2.**

TABLE 13–2

Coefficients of Thermal Expansion at 20°C

Material	Coefficient of linear expansion, α(°C)$^{-1}$	Coefficient of volume expansion, β(°C)$^{-1}$
Solids		
Aluminum	25×10^{-6}	75×10^{-6}
Iron, steel	12×10^{-6}	35×10^{-6}
Glass (soft)	9×10^{-6}	27×10^{-6}
Glass (Pyrex)	3×10^{-6}	9×10^{-6}
Concrete	12×10^{-6}	36×10^{-6}
Copper	16×10^{-6}	48×10^{-6}
Liquids		
Methanol		1100×10^{-6}
Gasoline		950×10^{-6}
Mercury		180×10^{-6}
Water		210×10^{-6}
Gases		
Air (and most other gases)		3400×10^{-6}

The change in length of a solid is proportional to the change in temperature, as shown in **Figure 13–18.** A solid will expand twice as much if the temperature is increased by 20°C than if it is increased by 10°C. The change is also proportional to its length. A 2-meter bar will expand twice as much as a 1-meter bar. The length, L, of a solid at temperature T can be found with the following equation.

$$L_2 = L_1 + \alpha L_1(T_2 - T_1)$$

Pocket Lab

Jumpers

Put on a pair of safety goggles. Examine the jumping disk. Notice that it is slightly curved. Now rub the disk for several seconds until it becomes curved in the other direction. Place the disk on a flat, level surface and stand back.

Make a Hypothesis Suggest a hypothesis that might explain the jumping. Suggest a method to test your hypothesis.

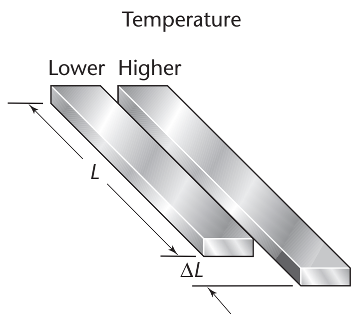


FIGURE 13–18 The change in length of a material is proportional to the original length and the change in temperature.

CONTENTS

L_1 is the length at temperature T_1, and the alpha, α, is called the **coefficient of linear expansion.** Using simple algebra, α can be defined by the following equations.

$$L_2 - L_1 = \alpha L_1(T_2 - T_1)$$

$$\Delta L = \alpha L_1 \Delta T$$

$$\Delta L/L_1 = \alpha \Delta T$$

Coefficient of Linear Expansion $\alpha = \Delta L/L_1\Delta T$

Therefore, the unit for the coefficient of linear expansion is 1/°C or $(°C)^{-1}$. The **coefficient of volume expansion,** β, is approximately three times the coefficient of linear expansion because volume expansion is three dimensional. The equation to determine volume expansion is $\Delta V = \beta V \Delta T$.

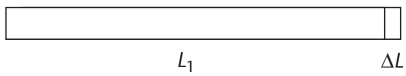
Example Problem

Linear Expansion

A metal bar is 2.60 m long at room temperature, 21°C. The bar is put into an oven and heated to a temperature of 93°C. It is then measured and found to be 3.4 mm longer. What is the coefficient of linear expansion of this material?

Sketch the Problem

- Sketch the bar, which is 3.4 mm longer at 93°C than at 21°C.
- Identify the initial length of the bar, L1, and the change in length, DL.



Calculate Your Answer

Known:

$L_1 = 2.60$ m

$\Delta L = 3.4 \times 10^{-3}$ m

$T_1 = 21°C$

$T_2 = 93°C$

Unknown:

$\alpha = ?$

Strategy:

Calculate the coefficient of linear expansion using the known length, change in length, and temperature change.

Calculations:

$$\Delta L = \alpha L_1(T_2 - T_1)$$

$$\alpha = \frac{\Delta L}{L_1(T_2 - T_1)} = \frac{3.4 \times 10^{-3}\,\text{m}}{(2.60\ \text{m})(93°\text{C} - 21°\text{C})} = 1.8 \times 10^{-5}\ °\text{C}^{-1}$$

Check Your Answer

- Are your units correct? The unit is correct, $°C^{-1}$.
- Is the magnitude realistic? The magnitude of the coefficient is close to the accepted value for copper.

Practice Problems

8. A piece of aluminum house siding is 3.66 m long on a cold winter day of $-28°C$. How much longer is it on a very hot summer day at $39°C$?

9. A piece of steel is 11.5 m long at $22°C$. It is heated to $1221°C$, close to its melting temperature. How long is it?

10. An aluminum soft drink can, with a capacity of 354 mL is filled to the brim with water and put in a refrigerator set at $4.4°C$. The can of water is later taken from the refrigerator and allowed to reach the temperature outside, which is $34.5°C$.

a. What will be the volume of the liquid?

b. What will be the volume of the can?

Hint: The can will expand as much as a block of metal the same size.

c. How much liquid will spill?

11. A tank truck takes on a load of 45 725 liters of gasoline in Houston at $32.0°C$. The coefficient of volume expansion, β, for gasoline is $950 \times 10^{-6}(°C)^{-1}$. The truck delivers its load in Omaha, where the temperature is $-18.0°C$.

a. How many liters of gasoline does the truck deliver?

b. What happened to the gasoline?

Thermal expansion in liquids Most liquids also expand when heated. A good model for all liquids does not exist, but it is useful to think of a liquid as a ground-up solid. Groups of two, three, or more particles move together as if they were tiny pieces of a solid. When a liquid is heated, particle motion causes these groups to expand in the same way that particles in a solid are pushed apart. The spaces between groups increase. As a result, the whole liquid expands. With an equal change in temperature, liquids expand considerably more than solids. Gases expand even more.

You have learned that water is most dense at $4°C$. When water is heated from $0°C$ to $4°C$, instead of the expected expansion, water contracts as the cohesive forces increase and ice crystals collapse. The result is that the liquid form of water has a smaller volume than an equal mass of its solid form. The forces between water molecules are strong, and the crystals that make up ice have a very open structure. Even when ice melts, tiny crystals remain. These remaining crystals are melting, and the volume decreases. However, once the temperature of water moves above $4°C$, the volume increases because of greater molecular motion. The practical result is that ice floats and lakes, rivers, and other bodies of water freeze from the top down.

HELP WANTED
MATERIALS ENGINEER

A leading corporation that develops new materials and new uses for old ones seeks an engineer to join our research and development team. A creative yet analytical mind, a bachelor's degree in materials, metallurgical, or ceramics engineering, and the ability to work both independently and on teams are required.

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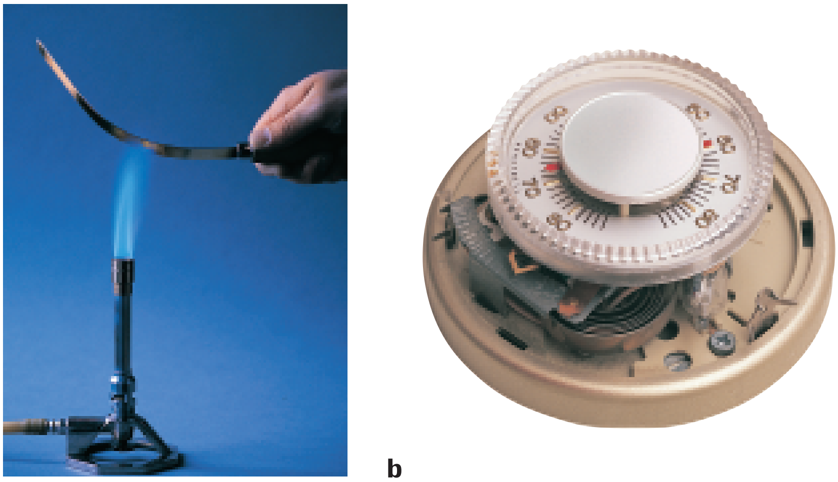

a b

FIGURE 13–19 The properties of a bimetallic strip cause it to bend when heated **(a).** In this thermostat, a coiled bimetallic strip controls the flow of mercury for opening and closing electrical switches **(b)**.

Importance of thermal expansion Different materials expand at different rates, as indicated by the different coefficients of expansion given in **Table 13–2.** Engineers must consider these different expansion rates when designing structures. Steel bars are often used to reinforce concrete, and therefore, the steel and concrete must have the same expansion coefficient. Otherwise, the structure may crack on a hot day. Similarly, a dentist must use filling materials that expand and contract at the same rate as tooth enamel.

Different rates of expansion are sometimes useful. Engineers have taken advantage of these differences to construct a useful device called a bimetallic strip, which is used in thermostats. A bimetallic strip consists of two strips of different metals welded or riveted together. Usually, one strip is brass and the other is iron. When heated, brass expands more than iron does. Thus, when the bimetallic strip of brass and iron is heated, the brass part of the strip becomes longer than the iron part. The bimetallic strip bends with the brass on the outside of the curve. If the bimetallic strip is cooled, it bends in the opposite direction. The brass is then on the inside of the curve.

In a home thermostat shown in **Figure 13–19**, the bimetallic strip is installed so that it bends toward an electric contact as the room cools**.** When the room cools below the setting on the thermostat, the bimetallic strip bends enough to make electric contact with the switch, which turns on the heater. As the room warms, the bimetallic strip bends in the other direction. The electric circuit is broken, and the heater is switched off.

Plasma

If you heat a solid, it melts to form a liquid. Further heating results in a gas. What happens if you increase the temperature still further? Collisions between the particles become violent enough to tear the particles apart. Electrons are pulled off the atoms, producing positively charged ions. The gaslike state of negatively-charged electrons and positively-charged ions is called **plasma.** Plasma is another fluid state of matter.

The plasma state may seem to be uncommon, however, most of the matter in the universe is plasma. Stars consist mostly of plasma. Much of the matter between the stars and galaxies consists of energetic hydrogen that has no electrons. This hydrogen is in a plasma state. The primary difference between a gas and plasma is that plasma can conduct electricity, whereas a gas cannot. A lightning bolt is in the plasma state. Neon signs, such as the one in **Figure 13–20,** fluorescent bulbs, and sodium vapor lamps contain glowing plasmas.

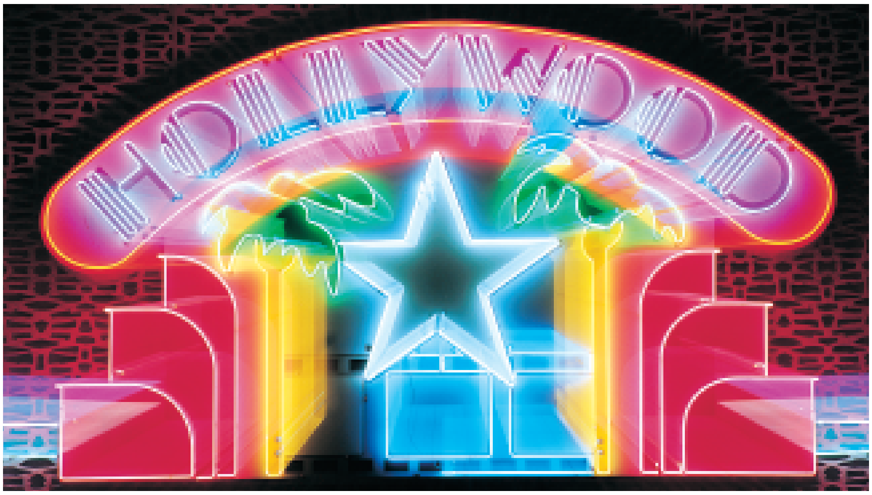

FIGURE 13–20 The spectacular lighting effects in "neon" signs are caused by luminous plasmas formed in the glass tubing.

13.2 Section Review

1. Starting at 0°C, how will the density of water change if it is heated to 4°C? To 8°C?
2. You are installing a new aluminum screen door on a hot day. The door frame is concrete. You want the door to fit well on a cold winter day. Should you make the door fit tightly in the frame or leave extra room?
3. Why could candle wax be considered a solid? Why might it also be a viscous liquid?
4. **Critical Thinking** If you heat an iron ring with a small gap in it, as in **Figure 13–21,** will the gap become wider or narrower?

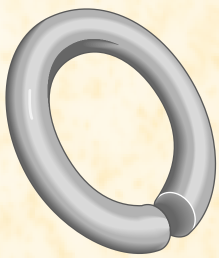

FIGURE 13–21

CHAPTER 13 REVIEW

Summary

Key Terms

13.1
- fluid
- pressure
- pascal
- Pascal's principle
- buoyant force
- Archimedes' principle
- Bernoulli's principle
- cohesive force
- surface tension
- adhesion
- capillary action
- evaporation
- volatile
- condensation

13.2
- crystal lattice
- amorphous solids
- elasticity
- thermal expansion
- coefficient of linear expansion
- coefficient of volume expansion
- plasma

13.1 The Fluid States

- Solids have fixed volumes, definite surfaces, and shapes. A liquid has a fixed volume and a definite surface, but takes the shape of its container. The volume of a gas expands to fill its container. Plasma is similar to a gas but is electrically charged, and thus other forces can contain it.
- Pressure is the force divided by the area on which it is exerted. The SI unit of pressure is the pascal, Pa.
- The constantly moving particles that make up a fluid exert pressure as they collide with all surfaces in contact with the fluid.
- According to Pascal's principle, an applied pressure is transmitted undiminished throughout a fluid.
- The buoyant force is an upward force exerted on an object immersed in a fluid.
- According to Archimedes' principle, the buoyant force on an object immersed in a fluid is equal to the weight of the fluid displaced by that object.
- Bernoulli's principle states that the pressure exerted by a fluid decreases as its velocity increases.
- Cohesive forces are the attractive forces that like particles exert on one another.
- Adhesive forces are the attractive forces that particles of different substances exert on one another.
- Evaporation, the process in which a liquid becomes a gas, occurs when the most energetic particles in a liquid have enough energy to escape into the gas phase.
- In condensation, the least energetic particles in a gas phase bind to each other and form or add to the liquid phase. Evaporation cools the remaining liquid; condensation warms the remaining gas.

13.2 The Solid State

- A crystalline solid has a regular pattern of particles. An amorphous solid has an irregular pattern of particles.
- As a liquid solidifies, its particles become frozen into a fixed pattern.
- The elasticity of a solid is its ability to return to its original form when external forces are removed.
- When the temperature of a solid or liquid is increased, the kinetic energy of its particles increases and it generally increases in size, or expands. The expansion is proportional to the temperature change and original size, and depends on the material.
- Plasma is a gaslike state of matter made up of positive or negative particles or a mixture of them.

Key Equations

13.1

$$P = \frac{F}{A} \qquad P = \frac{F_g}{A} = \rho h g$$

$$F_2 = \frac{F_1 A_2}{A_1} \qquad F_{buoyant} = \rho V g$$

13.2

$$\alpha = \Delta L / L_1 \Delta T$$

Reviewing Concepts

Section 13.1

1. How are force and pressure different?
2. According to Pascal's principle, what happens to the pressure at the top of a container if the pressure at the bottom is increased?
3. How does the water pressure one meter below the surface of a small pond compare with the water pressure the same distance below the surface of a lake?
4. Does Archimedes' principle apply to an object inside a flask that is inside a spaceship in orbit?
5. A river narrows as it enters a gorge. As the water speeds up, what happens to the water pressure?
6. A gas is placed in a sealed container and some liquid is placed in a container the same size. They both have definite volume. How do the gas and the liquid differ?
7. A razor blade, which has a density greater than that of water, can be made to float on water. What procedures must you follow for this to happen? Explain.
8. In terms of adhesion and cohesion, explain why alcohol clings to the surface of a glass rod and mercury does not.
9. A frozen lake melts in the spring. What effect does it have on the temperature of the air above it?
10. Canteens used by hikers are often covered with a canvas bag. If you wet the bag, the water in the canteen will be cooled. Explain.
11. Why does high humidity make a hot day even more uncomfortable?

Section 13.2

12. How does the arrangement of atoms in a crystalline substance differ from that in an amorphous substance?
13. Can a spring be considered elastic?
14. Does the coefficient of linear expansion depend on the unit of length used? Explain.
15. In what way are gases and plasmas similar? In what way are they different?
16. Some of the mercury in a fluorescent lamp is in the gaseous form; some is in the form of plasma. How can you distinguish between the two?

Applying Concepts

17. A rectangular box with its largest surface resting on a table is rotated so that its smallest surface is now on the table. Has the pressure on the table increased, decreased, or remained the same?
18. Show that a pascal is equivalent to $kg/m{\cdot}s^2$.
19. Is there more pressure at the bottom of a bathtub of water 30 cm deep or at the bottom of a pitcher of water 35 cm deep? Explain.
20. Compared to an identical empty ship, would a ship filled with table-tennis balls sink deeper into the water or rise in the water? Explain.
21. Research and describe Archimedes experiment with the crown. Discuss the physics behind his experiment.
22. Drops of mercury, water, and acetone are placed on a smooth, flat surface, as shown in **Figure 13–22.** The mercury drop is almost a perfect sphere. The water drop is a flattened sphere. The acetone, however, spreads out over the surface. What do these observations tell you about the cohesive forces in mercury, water, and acetone?
23. Alcohol evaporates more quickly than water does at the same temperature. What does this observation allow you to conclude about the properties of the particles in the two liquids?
24. Based on the observation in Question 22, which liquid would vaporize easier? Which would have the lower boiling point? Explain.
25. Suppose you use a punch to make a circular hole in aluminum foil. If you heat the foil, will the size of the hole decrease or increase? Explain. **Hint:** Pretend that you put the circle you punched out back into the hole. What happens when you heat the foil now?

FIGURE 13–22

26. Equal volumes of water are heated in two narrow tubes that are identical except that tube A is made of soft glass and tube B is made of Pyrex glass. As the temperature increases, the water level rises higher in tube B than in tube A. Give a possible explanation. Why are many cooking utensils made from Pyrex glass?

27. A platinum wire can be easily sealed in a glass tube, but a copper wire does not form a tight seal with the glass. Explain.

28. Often before a thunderstorm, when the humidity is high, someone will say, "The air is very heavy today." Is this statement correct? Describe a possible origin for the statement.

29. Five objects with the following densities are put into a tank of water:

a. 0.85 g/cm^3
b. 0.95 g/cm^3
c. 1.05 g/cm^3
d. 1.15 g/cm^3
e. 1.25 g/cm^3

The density of water is 1.00 g/cm^3. The diagram in **Figure 13–23** shows six possible positions of these objects. Select a position, 1 to 6, for each of the five objects. Not all positions need be selected.

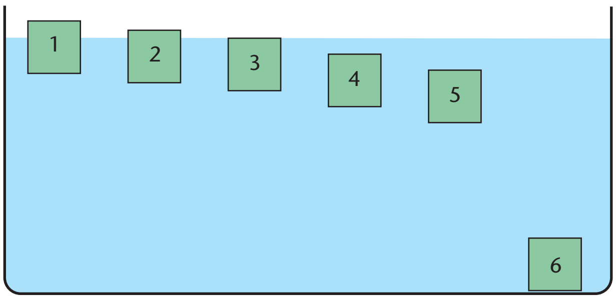

FIGURE 13–23

Problems

Section 13.1

30. A 0.75-kg physics book with dimensions of 24.0 cm by 20.0 cm is on a table.
a. What force does the book apply to the table?
b. What pressure does the book apply?

31. A reservoir behind a dam is 15 m deep. What is the pressure of the water in the following situations?
a. at the base of the dam
b. 5.0 m from the top of the dam

32. A 75-kg solid cylinder, 2.5 m long and with an end radius of 5.0 cm, stands on one end. How much pressure does it exert?

33. A test tube standing vertically in a test-tube rack contains 2.5 cm of oil ($\rho = 0.81$ g/cm^3) and 6.5 cm of water. What is the pressure on the bottom of the test tube?

34. A metal object is suspended from a spring scale. The scale reads 920 N when the object is suspended in air, and 750 N when the object is completely submerged in water.
a. Find the volume of the object.
b. Find the density of the metal.

35. During an ecology experiment, an aquarium half filled with water is placed on a scale. The scale reads 195 N.
a. A rock weighing 8 N is added to the aquarium. If the rock sinks to the bottom of the aquarium, what will the scale read?
b. The rock is removed from the aquarium, and the amount of water is adjusted until the scale again reads 195 N. A fish weighing 2 N is added to the aquarium. What is the scale reading with the fish in the aquarium?

36. What is the size of the buoyant force that acts on a floating ball that normally weighs 5.0 N?

37. What is the apparent weight of a rock submerged in water if the rock weighs 54 N in air and has a volume of 2.3×10^{-3} m^3?

38. If a rock weighing 54 N is submerged in a liquid with a density exactly twice that of water, what will be its new apparent weight reading in the liquid?

39. A 1.0-L container completely filled with mercury has a weight of 133.3 N. If the container is submerged in water, what is the buoyant force acting on it? Explain.

40. What is the maximum weight that a balloon filled with 1.00 m^3 of helium can lift in air? Assume that the density of air is 1.20 kg/m^3 and that of helium is 0.177 kg/m^3. Neglect the mass of the balloon.

41. A hydraulic jack used to lift cars is called a three-ton jack. The large piston is 22 mm in diameter, the small one 6.3 mm. Assume that a force of 3 tons is 3.0×10^4 N.
a. What force must be exerted on the small piston to lift the 3-ton weight?

b. Most jacks use a lever to reduce the force needed on the small piston. If the resistance arm is 3.0 cm, how long is the effort arm of an ideal lever to reduce the force to 100.0 N?

42. 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 in order to lift the engine?

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

43. What is the acceleration of a small metal sphere as it falls through water? The sphere weighs 2.8×10^{-1} N in air and has a volume of 13 cm^3.

Section 13.2

44. What is the change in length of a 2.00-m copper pipe if its temperature is raised from 23°C to 978°C?

45. Bridge builders often use rivets that are larger than the rivet hole to make the joint tighter. The rivet is cooled before it is put into the hole. A builder drills a hole 1.2230 cm in diameter for a steel rivet 1.2250 cm in diameter. To what temperature must the rivet be cooled if it is to fit into the rivet hole that is at 20°C?

46. A steel tank filled with methanol is 2.000 m in diameter and 5.000 m high. It is completely filled at 10.0°C. If the temperature rises to 40.0°C, how much methanol (in liters) will flow out of the tank, given that both the tank and the methanol will expand?

47. An aluminum sphere is heated from 11°C to 580°C. If the volume of the sphere is 1.78 cm^3 at 11°C, what is the increase in volume of the sphere at 580°C?

48. The volume of a copper sphere is 2.56 cm^3 after being heated from 12°C to 984°C. What was the volume of the copper sphere at 12°C?

Extra Practice For more practice solving problems, go to Extra Practice Problems, Appendix B.

Critical Thinking Problems

49. Persons confined to bed are less likely to develop bedsores if they use a water bed rather than an ordinary mattress. Explain.

50. Hot air balloons contain a fixed volume of gas. When the gas is heated, it expands, and pushes some gas out at the lower open end. As a result, the mass of the gas in the balloon is reduced. Why would the air in a balloon have to be hotter to lift the same number of people above Vail, Colorado, which has an altitude of 2400 m, than above the tidewater flats of Virginia, at an altitude of 6 m?

Going Further

Team Project The braking systems of cars are combinations of many simple machines, one of which applies Pascal's principle. As a team, analyze the system for a real car with the goal of constructing a physical model that predicts the force on the brake pedal needed to stop the car from a given speed in a certain distance. Answer the following questions: Does the brake pedal function as a lever when exerting a force on the master cylinder? What is the ratio of areas of the master and wheel cylinders? For disc brakes, what is the coefficient of friction between the brake pads and rotor? For drum brakes, what is the mechanical advantage (*MA*) of the lever that converts the force exerted by the wheel piston to the normal force of the pad on the drum? For all kinds of brakes, how do the brake and tire act as a wheel-and-axle machine? What force is needed to slow the car from the chosen speed in the chosen distance? Devise a realistic and safe means of testing your model.

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