

# UNIT 6



## Properties of Matter

### Introduction to Chapter 17

In this chapter, you learn how to describe matter—both solids and fluids. Solids are characterized by their hardness or malleability, for example. Terms that apply to fluids include buoyancy and viscosity. Density is a property of matter that can change with temperature.

### Investigations for Chapter 17

#### 17.1 Properties of Solids *How can you find the density of a solid?*

In this Investigation, you will be measuring the mass and volume as a means to determine the density of a set of objects. Using your understanding of density, you will solve a historical problem—whether or not the U.S. Congress passed a law to change the metal composition of a penny.

#### 17.2 Density of Fluids *Can you create a stack of liquids?*

In this Investigation, you will use a density column to estimate the density of a few solids. You then will use this estimate to predict the density of rubber.

#### 17.3 Buoyancy of Fluids *Can you make a clay boat float?*

In this Investigation, you will discover how the shape of an object influences whether it sinks or floats. You will explore the relationship between the weight of an object and the weight of the water the object displaces.

#### 17.4 Viscosity of Fluids *How can viscosity be measured?*

In this Investigation, you will learn how to measure the viscosity of fluids. You will set up a “viscometer” to measure the velocity of a marble as it travels through fluids of different viscosities.



## Chapter 17

## Properties of Matter



### Learning Goals

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In this chapter, you will:

- ✓ Learn the definitions of terms used to describe properties of matter.
- ✓ Learn how to calculate the density of solids.
- ✓ Learn how to find the density of liquids and use your understanding to make a density column.
- ✓ Use a density column to predict the density of a solid.
- ✓ Investigate how the shape of an object can determine whether it floats or sinks.
- ✓ Compare the weight of an object with the weight of the water it displaces.
- ✓ Learn why certain fluids are more viscous than others.
- ✓ Measure the viscosity of fluids using a viscometer.
- ✓ Compare the properties of viscosity and the density of fluids.

### Vocabulary

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|                       |            |              |                  |
|-----------------------|------------|--------------|------------------|
| Archimedes' principle | density    | hardness     | tensile strength |
| brittleness           | elasticity | malleability | viscosity        |
| buoyancy              |            |              |                  |



## 17.1 Properties of Solids

Different types of matter have different characteristics. They melt and boil at different temperatures. They might be different colors or have different odors. Some can stretch without breaking, while others shatter easily. These and other properties help us distinguish one kind of matter from another. They also help us choose which kind of material to use for a specific purpose. In this section, we will concentrate on the properties of matter in its solid form. By the end of this section, you should be able to understand and explain these terms: density, hardness, elasticity, brittleness, and malleability.

### Density

**What is density?** Earlier in this unit, you learned two different ways to measure matter: You can find its mass or its volume. **Density** is a property that describes the relationship between these two measurements. If the matter is a homogeneous mixture or a substance, each cubic centimeter ( $\text{cm}^3$ ) or milliliter will have the same mass. For example, one cubic centimeter of silver has a mass of 10.5 grams. Three cubic centimeters of silver have a mass of  $10.5 + 10.5 + 10.5$  grams, or 31.5 grams. Ten cubic centimeters of silver have a mass of 105 grams.

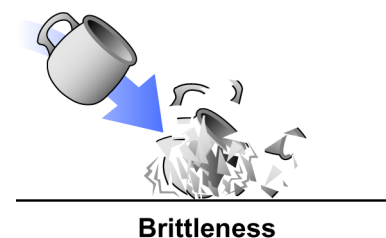
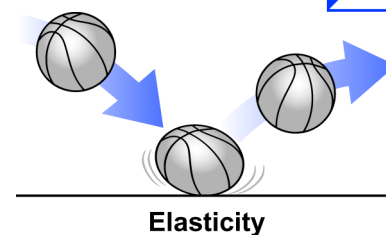
#### **Density**

$$\text{Density (g/cm}^3\text{)} \rightarrow D = \frac{m}{V} \leftarrow \begin{array}{l} \text{Mass (g)} \\ \text{Volume (cm}^3\text{)} \end{array}$$

**Density can be found by dividing mass by volume**

The density of a homogeneous material or substance is expressed as a ratio of grams per cubic centimeter. The density will stay the same no matter how large or small the sample of material. For example, a steel paper clip and a steel bicycle brake cable have the same density.

|                     | Mass       | Volume               | Density              |
|---------------------|------------|----------------------|----------------------|
| paper clip          | 0.36 grams | $0.046 \text{ cm}^3$ | $7.8 \text{ g/cm}^3$ |
| bicycle brake cable | 19.8 grams | $2.53 \text{ cm}^3$  | $7.8 \text{ g/cm}^3$ |



**Figure 17.1:** Elasticity and brittleness are properties of solids

#### **What is a cubic centimeter?**



The formula for the volume of a rectangular solid or a cube is length times width times height. If all the sides were measured in centimeters, the unit for this volume would be in cubic centimeters. A shorthand way of writing cubic centimeters is " $\text{cm}^3$ ." One cubic centimeter will hold 1 milliliter of liquid. In other words, one cubic centimeter =  $1 \text{ cm}^3 = 1$  milliliter.

Samples of heterogeneous mixtures will not always have the same density. Suppose you divide a chocolate chip cookie into three pieces and find the density of each. Why might one piece have a greater density than the others?

Density describes how tightly packed the atoms or molecules are in a substance

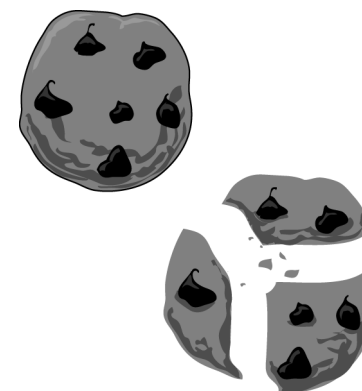
Density gives us information about how tightly the atoms or molecules of a particular material are “packed.” Lead, for example, has many atoms squeezed very close together in one cubic centimeter of space. This gives it a relatively high density of  $11.3 \text{ grams/cm}^3$ . Paraffin, or wax, doesn’t have nearly as many molecules packed into each cubic centimeter. Its density is a much lower:  $0.87 \text{ grams/cm}^3$ .

## Hardness

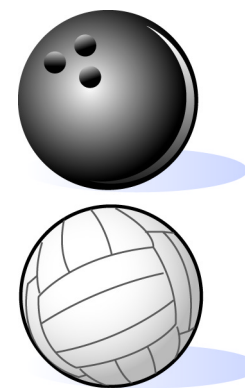
**What is hardness?** **Hardness** measures a solid’s resistance to scratching. Diamond is the hardest natural substance found on Earth. Geologists sometimes classify rocks based on hardness. Given six different kinds of rock, how could you line them up in order of increasing hardness?

## Elasticity

**What is elasticity?** If you pull on a rubber band, its shape changes. If you let it go, the rubber band returns to its original shape. The ability of rubber bands to stretch around things and hold them together is due to the property of **elasticity**. Elasticity is the measure of a solid’s ability to be stretched and then return to its original size. This property also gives objects the ability to bounce and to withstand impact without breaking. Based on the property of elasticity, which would you rather play basketball with: a bowling ball or a volleyball?



**Figure 17.2:** Why do pieces of a chocolate chip cookie have different densities?



**Figure 17.3:** Which ball would you rather play basketball with?



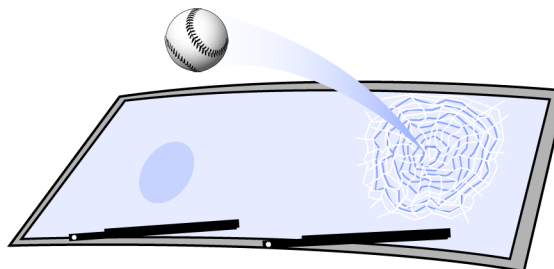
## Brittleness

**What is brittleness?** **Brittleness** measures a material's tendency to shatter upon impact. Brittleness is considered a hazardous property in the automobile industry, where, for instance, shattering glass can cause serious injuries.

**Safety glass** The first "safety glass," designed to reduce the brittle tendencies of regular glass, was discovered by accident. In 1903, a French chemist named Edouard Benedictus dropped a glass flask in the lab. The flask was full of cracks, but surprisingly, the pieces did not scatter across the floor. The shape of the flask remained intact.

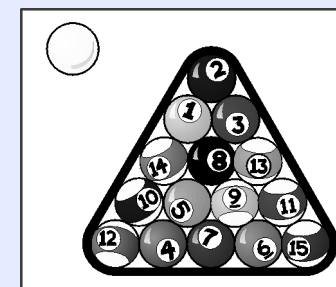
The glass had been used to store a chemical called cellulose nitrate. Although the chemical had evaporated, it left a plastic film on the inside of the glass.

Initially, Benedictus had a hard time selling his shatter-resistant glass to automobile manufacturers. During World War I, he did sell it for use in gas mask lenses. Soon after the war, the auto industry began using his glass.



**Enhanced Protective Glass is shatter-resistant** Materials scientists have continued to seek better materials for safety glass. Solutia Inc. of St. Louis, Missouri, recently began marketing a new glass product called enhanced protective glass (EPG) with Saflex. It consists of a sheet of a material called polyvinyl butyral (PVB) sandwiched between two pieces of glass under high heat and pressure. EPG with Saflex is so shatter-resistant that it can prevent occupants from being ejected from a vehicle in a collision. Because it is so hard to shatter, it is marketed as a deterrent to thieves as well. The material has another significant benefit: It is a sound insulator, reducing highway noise by about six decibels, resulting in a noticeably quieter ride.

### Cellulose nitrate



Cellulose is a polymer made by plants. Wood, paper, cotton, and plant fibers are all made of cellulose. When cellulose reacts with nitric acid, cellulose nitrate is produced.

In addition to being used to make safety glass, cellulose nitrate has been used to make billiard balls. Billiard balls used to be made of ivory from African elephants' tusks. The invention of cellulose nitrate created an excellent substitute for ivory. Elephants are now a protected species. Ivory is rare and it is no longer used to make billiard balls.



## Malleability

**What is malleability?** **Malleability** measures a solid's ability to be pounded into thin sheets. Aluminum is a highly malleable metal. Aluminum foil and beverage cans are two good examples of how manufacturers take advantage of the malleability of aluminum.

## Tensile strength

**What is tensile strength?** **Tensile strength** is a measure of how much pulling, or tension, a material can withstand before breaking. It is an important property of fibers, as it determines the strength of ropes and fabrics. It is also crucial to the manufacture of cables and girders used to support bridges.



### Inventing new materials: DuPont KEVLAR® brand fiber



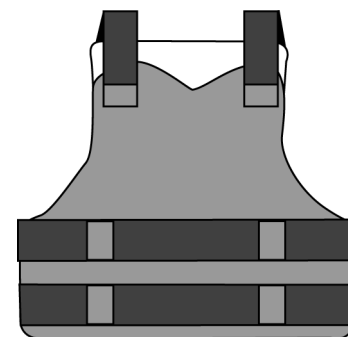
What has five times the tensile strength of steel on an equal weight basis, and can be used to make canoe hulls, windsurfer sails, tennis racquets, and, of a lifesaving nature, motorcycle helmets, cut-resistant gloves, and bullet-resistant vests?

It's KEVLAR® brand fiber, a synthetic fiber manufactured by the DuPont Company. It was invented in 1964 by Stephanie Kwolek, a chemist who was trying to dissolve polymers, which are chains of molecules that are hooked together like the boxcars of a train. Kwolek found that when the polymers were placed in certain

solvents, they formed liquid crystal fluids. This means that the chains of polymers were lined up in neat, repeating patterns.

She decided to spin one of her solutions to see if a fiber would form—and it did! She tested the tensile strength and stiffness of her new fiber and found that, although the fiber was very lightweight, it was extremely strong.

Kwolek and a team of researchers studied the properties of this new fiber, enabling them to modify the chains of molecules in order to make them even stronger. Kwolek has been the author or coauthor of 17 U.S. patents on polymers, polycondensation processes, liquid crystalline solutions, and fibers.



**Figure 17.4:** Bullet-resistant vests and tennis racquets are often made from KEVLAR®. This product is used when manufactured goods need to be strong, lightweight, and long-lasting.

KEVLAR® is a registered trademark of E.I. du Pont de Nemours and Company.



## 17.2 Density of Fluids

What is a fluid? A fluid is defined as any matter that is able to flow. Liquids, as you know, can be poured from one container to another. They flow. Gases exhibit this property as well. You may have noticed cool air flow into a room when a window was opened, or a waft of perfume drifting your way. In this section, we will investigate the first of three important properties of fluids: density.

### Density

**How could you find the density of liquid silver?**

A piece of pure silver in the shape of a candlestick has the same density as a pure silver necklace. Size and shape do not change a material's density. But what if you heated the silver until it completely melted? Could you measure its density in liquid form? Would the density change?

**Measuring mass**

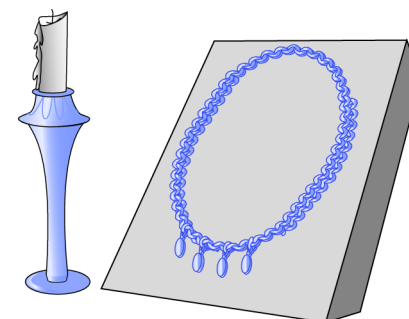
You could find the mass of your liquid silver using a balance. The amount of silver would not change when the candlestick melted. Therefore, the mass should not have changed.

**Atoms in liquid form tend to take up more space**

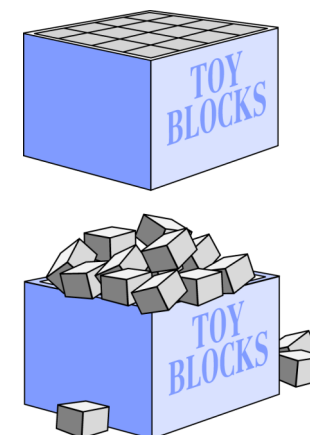
The volume of the liquid silver, however, is greater than the volume of the solid silver! The atoms or molecules in a solid, as you remember, are fixed in position. Although the silver atoms in the candlestick were constantly vibrating, they could not switch places with another atom. They were neatly stacked in a repeating pattern. The atoms in the liquid silver are less rigidly organized. They can slide over and around each other. Because they are not as neatly stacked, they tend to take up more space.

**Why liquids are less dense than solids**

The silver atoms in solid form could be compared to a brand-new box of children's wooden blocks. When you open the box, the blocks are tightly packed in an organized, repeating pattern. Now imagine that you empty the box of blocks into a large container, and then try to pour them back into their original box. Although the blocks would still be touching one another, they would not fit entirely inside the box. The blocks would now resemble the arrangement of silver atoms in liquid form.



**Figure 17.5:** The density of pure silver is the same, whether in the form of a necklace or a candlestick. Decorative “silver” items are often made of sterling silver, which is a mixture of 93 percent silver and 7 percent copper. Adding the copper creates a harder, more durable metal.



**Figure 17.6:** Toy blocks arranged in a tight, repeating pattern take up less space than those in a random arrangement.

### The density of liquid silver

How does the density of the silver in liquid form compare with its density in solid form? Remember, the mass stayed the same but the volume increased. The same mass divided by a larger volume results in a smaller value for density. Therefore, liquid silver is less dense than solid silver.

**Table 17.1: Density of solid and liquid silver**

|                                 | Mass   | Volume              | Density                 |
|---------------------------------|--------|---------------------|-------------------------|
| Candle holder<br>(at 20°C)      | 1313 g | 125 cm <sup>3</sup> | 10.5 g/ cm <sup>3</sup> |
| Melted candle holder<br>(962°C) | 1313 g | 141 ml              | 9.31 g/ml               |

### Temperature and solid density

The density of solids usually decreases slightly as temperature increases because solids expand when heated. As the temperature of the solid silver increases, the volume increases slightly, even before the silver melts. This is due to the increased vibration of the silver molecules.

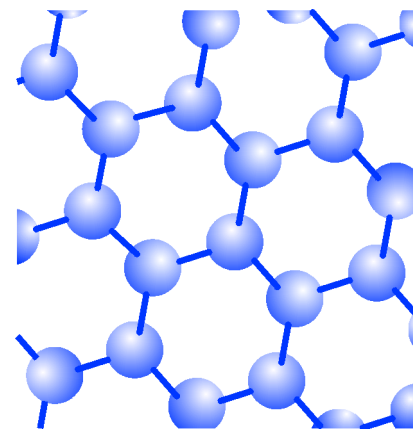
### Water is less dense in solid form

Most materials are more dense in their solid phase than in their liquid phase. Water is a notable exception. Ice is less dense than liquid water! When water molecules freeze into ice crystals, they form a pattern that has an unusually large amount of empty space. The molecules are more tightly packed in water's liquid form!

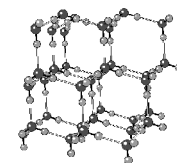
Because ice is less dense than liquid water, it floats on the surface in winter. If the ice were denser than the liquid, it would sink to the bottom. If you woke up one morning, and ice were denser than water, there would be serious consequences for life on Earth.

### What would happen if solid water was more dense?

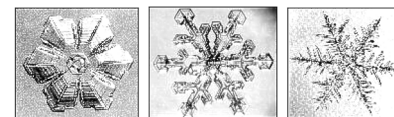
For example, each winter, more ice would sink to the bottom of rivers, lakes, or oceans. In some places, the water would be too deep for the sun's rays to reach the ice. Consequently, the ice would not melt in the summer. Many aquatic plants could no longer grow. Frogs and turtles that burrow in the mud at the bottom of ponds could not complete their life cycles. The climate of cities along the Mississippi River, the Great Lakes, and other large bodies of water would become much cooler.



**Figure 17.7:** Water molecules in solid form are arranged in a pattern with an unusually large amount of empty space. Water molecules in liquid form are more tightly packed with much less empty space!



**Ice crystals and snowflakes**



**Figure 17.8:** Because of the spacing, ice forms hexagonal crystals which give us the beautiful six-pointed shapes of snowflakes.





## 17.3 Buoyancy of Fluids

Have you ever noticed how easy it is to do a push-up to lift yourself up and out of a swimming pool? It's much easier than doing push-ups on land. That's because the water is exerting an upward force on you. In this section, you will learn more about the force that fluids exert on an object. By the end of the section, you should be able to define buoyancy and explain Archimedes' principle. You should also be able to explain how gases exert forces when they are confined in a container.

### What is buoyancy?

A simple experiment can be used to demonstrate the upward force of water you can feel in a swimming pool. A piece of string is tied to a rock, and its weight is measured with a spring scale. The rock weighs 2.25 newtons. Next, the rock is immersed in water, but not allowed to touch the bottom or sides of the container. Now the spring scale measures 1.8 newtons. The water has exerted a force of 0.45 newtons on the rock. We call this force *buoyancy*. **Buoyancy** is a measure of the upward pressure a fluid exerts on an object.

#### What is Archimedes' principle?

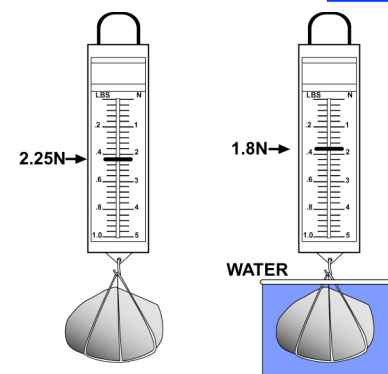
In the third century BC, a Greek mathematician named Archimedes made an important discovery about the buoyant force. He realized that the force exerted on an object in a liquid is equal to the weight of the fluid displaced by the object. We call this relationship **Archimedes' principle**.

Archimedes' principle tells us that the water displaced by the rock in the experiment above had a weight of 0.45 newtons.

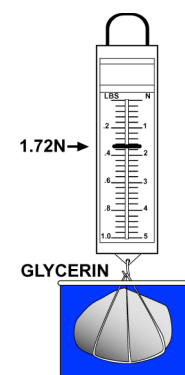
#### Do all fluids exert the same buoyant force on an object?

Archimedes' principle can be used to find the buoyant force of liquids other than water. For example, we could immerse the rock from the previous experiment in glycerin, which has a density of  $1.26 \text{ grams/cm}^3$ .

The rock will always displace the same volume of liquid, in this case, about 43 milliliters. Forty-three milliliters of glycerin weigh 0.53 newtons. Therefore, the glycerin exerts a buoyant force of 0.53 newtons on the rock.



**Figure 17.9:** Measuring the weight of a rock in newtons (N). When the rock is suspended in air, it weighs 2.25 N. In water, it weighs 1.8 N.



**Figure 17.10:** When the rock is suspended in glycerin, it weighs 1.72 N.

### Why objects sink and float

Buoyancy helps explain why some objects sink and others float. If the buoyant force is greater than its weight, the object floats. In the example above, we would need a buoyant force greater than 2.25 newtons to make our rock float.

If the buoyant force is less than its weight, then the object will sink. Neutral buoyancy occurs when the buoyant force is equal to the weight of the object. When an object is neutrally buoyant, it will stay immersed in the liquid at the level where it was placed. Scuba divers use weights and a buoyancy control device (BCD) to help them maintain neutral buoyancy. When a scuba diver is neutrally buoyant he or she can swim and move underwater without rising to the top or sinking.

### Why does a block of steel sink, but a steel boat float?

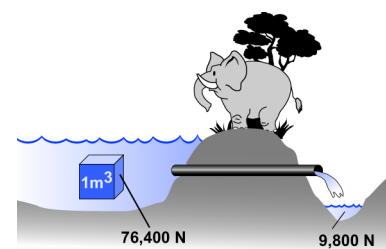
Archimedes' principle explains why a substance in one shape will float and in another shape will sink. A cubic meter of steel has a weight of 76,400 newtons. When placed in water, the block would displace one cubic meter of water. The water would have a weight of 9,800 newtons. The weight of the steel block is much greater than the weight of the displaced water. As expected, the block sinks.

### Why a steel boat floats

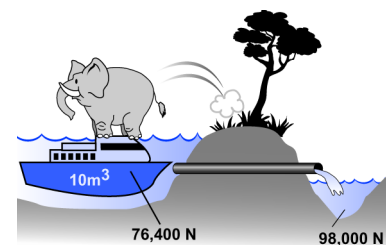
Imagine the same block of steel flattened into a thin sheet, its sides bent up into the shape of a boat. That original block of steel, now shaped to be hollow inside, might occupy 10 cubic meters of space instead of one. Ten cubic meters of displaced water has a weight of 98,000 newtons. Now the displaced water weighs more than the steel, which still weighs 76,400 newtons.

When placed in the water, your steel boat would settle in the water until it reached a level where it displaced 76,400 newtons of water. Then the upward force exerted by the water would equal the downward force exerted by the boat.

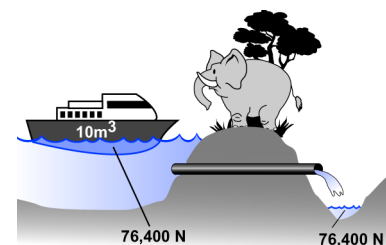
You can try a similar experiment with a stick of clay and a bucket of water. Drop the stick of modeling clay into the bucket and observe what happens. Now mold the clay into a boat shape. Can you make a clay boat float?



**Figure 17.11:** A solid cubic meter of steel weighs 76,400 N. It displaces 9,800 N of water.



**Figure 17.12:** The same amount of steel, shaped into a 10-cubic-meter boat, is pushed under water. Now it displaces 98,000 N of water.



**Figure 17.13:** When the boat floats, it displaces 76,400 N of water—which is equal to the boat's own weight.



## Buoyancy and gases

Why do hot air balloons float?

Buoyancy is a property of gases as well as liquids. A helium balloon floats because it displaces a very large volume of air. This volume of air weighs *more* than the total weight of the balloon, the gondola (the basket that the balloon carries), and the people in the gondola. The hot-air balloon floats because it weighs *less* than the volume of air displaced.

The relationship between the temperature and volume of a gas

So how can you get a hot-air balloon to take up a lot of space? You probably know the answer to this question. “Hot air” is important. To get their balloons to take flight, balloonists use a torch to heat the air molecules inside the balloon. Heated molecules move with greater energy. As they collide with each other and the sides of the balloon, they take up more space. In effect, the air in the balloon expands. This illustrates an important relationship, known as **Charles’ law**, which was discovered by Jacques Charles in 1787. According to Charles’ law, the volume of a gas increases with increasing temperature. The volume of a gas shrinks with decreasing temperature.

Charles’ law

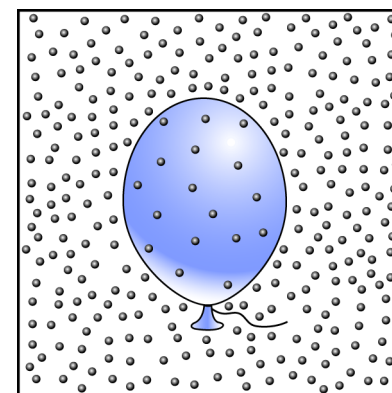
***The volume of a gas increases with increasing temperature.***  
***The volume of a gas decreases with decreasing temperature.***

The buoyancy of hot air

Charles law helps explain why the air inside the balloon becomes much less dense than the air outside the balloon. Because it is less dense, a hot-air balloon will rise in the atmosphere until the density of the air displaced by the balloon matches the average density of the air inside the balloon and the matter of the balloon itself. Stated another way, the weight of the air displaced by the balloon provides buoyant force to keep the balloon in flight.



**Figure 17.14:** A balloon uses the buoyancy of hot air to lift off.



**Figure 17.15:** A balloon will float when the volume of air displaced weighs more than the balloon weighs. To help objects like hot-air balloons take up a lot of space, air is heated to make it much less dense than the surrounding air. Helium is a low-density gas that is used to make party balloons and blimps float.

## Gases and pressure

**What is pressure?** Have you ever pumped up a bicycle tire? What is happening inside of the tire? As you pump more air into the tire, more and more particles of air are pushed into the tire, increasing the **pressure** inside. On a microscopic level, each particle of air collides with the inside walls of the tire, exerting a force which pushes the inner surface of the tire outward. As you pump more air into the tire, there are more particles that can exert forces on the inside walls of the tire. The forces of all of the particles of air inside the tire add together to create pressure.

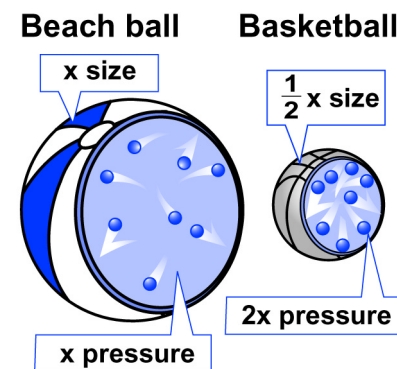
**Units of pressure** Pressure is the force acting on a unit area of surface. You may have noticed that tire pressure is usually measured in units of pound per square inch (psi). A typical bicycle tire should be inflated to about 60 psi. The SI unit for pressure is called a **pascal** (Pa). One pascal is equal to one newton of force acting on one square meter of surface area.

**What is atmospheric pressure?** The air you breathe is made of many different gases including carbon dioxide, oxygen, and nitrogen. The Earth's air, known as the atmosphere, is held in place by the force of gravity on the air particles. Without the force of gravity, the air you breathe would escape into space. At the Earth's surface, the atmosphere exerts a pressure of 101,300 pascals, or 101,300 newtons of force per square meter—about the weight of an elephant! Atmospheric pressure decreases with altitude. This is why the atmospheric pressure on top of a mountain is less than the atmospheric pressure at sea level. Does this explain why your ears pop when you fly in a plane?

**How are pressure and volume related?** Suppose you pump five liters of air into a beach ball. If you pump the same amount of air into a basketball *half* the size of the beach ball, which has a greater amount of pressure? Assuming that the temperature remains constant, the basketball has *twice* as much pressure as the beach ball. This is because if you squeeze the same amount of gas into a smaller container, the gas particles collide with the walls of the container *more* often, increasing the pressure. On the other hand, the gas particles inside of the beach ball occupy *twice* as much volume so they collide with the walls *less* often. This property of gases, called **Boyle's law**, was discovered by Robert Boyle in 1662.



**Figure 17.16:** The forces of all of the particles inside the tire add together to create pressure. As you add more particles, the pressure increases.



**Figure 17.17:** The beach ball and basketball each contain the same amount of air. The basketball has greater pressure than the beach ball because the air particles are squeezed into a smaller space and collide with the walls more often.



Boyle's law *As the pressure of a gas increases, its volume decreases proportionately.*  
*As the pressure of a gas decreases, its volume increases proportionately.*

Boyle's law equation The relationship between pressure and volume for a gas, when temperature remains constant, is evident in the graph in figure 17.18. This relationship can also be expressed by the following equation:

### Boyle's law

$$\begin{array}{c} \text{Initial volume} \rightarrow \\ \text{Initial pressure} \rightarrow \end{array} P_1 V_1 = P_2 V_2 \begin{array}{c} \leftarrow \text{New pressure} \\ \leftarrow \text{New volume} \end{array}$$

This equation shows that the product of the *initial* pressure and volume of a gas is equal to the product of the *final* pressure and volume of a gas when either pressure or volume is changed. The example below shows how to solve a problem using the equation.

### Example problem

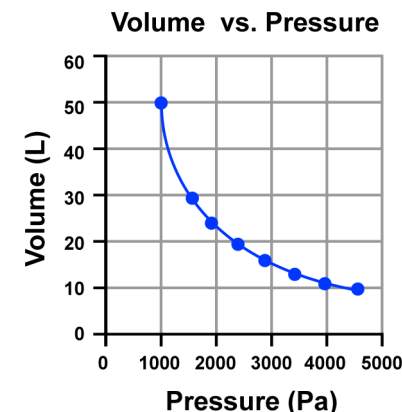
A kit used to fix flat tires consists of an aerosol can containing compressed air and a patch to seal the hole in the tire. Suppose 5 liters of air at atmospheric pressure (101.3 kilopascals) is compressed into a 0.5 liter aerosol can. What is the pressure of the compressed air in the can?

What do you know? The equation for Boyle's law is:  $P_1 V_1 = P_2 V_2$   
 $P_1 = 101.3 \text{ kPa}$ ;  $V_1 = 5 \text{ L}$ ;  $P_2 = \text{unknown}$ ;  $V_2 = 0.5 \text{ L}$

Rearrange the variables I am solving for  $P_2$  and the equation is:  $P_2 = \frac{P_1 \cdot V_1}{V_2}$

Plug in the numbers  $P_2 = \frac{101.3 \text{ kPa} \times 5.0 \text{ L}}{0.5 \text{ L}}$

Solve the problem The pressure inside the aerosol can is 1,013 kPa.



**Figure 17.18:** The graph shows the relationship between the pressure and volume of a gas when the temperature does not change.

### Atmospheric pressure

The pressure exerted by the Earth's atmosphere at sea level is 101,300 pascals (Pa). Since pascals are very small, other units of pressure are often used. The pressure of the Earth's atmosphere at sea level is also equal to:

- 101.3 kilopascals (kPa)
- 1.00 atmosphere (atm)
- 14.7 pounds per inch<sup>2</sup> (psi)
- 760 millimeters of mercury (mm Hg)



## 17.4 Viscosity of Fluids

**Viscosity** is another important property of fluids. It is a measure of the material's resistance to flow. High-viscosity fluids take longer to pour from their containers than low-viscosity fluids. Catsup, for example, has a higher viscosity than tomato juice. Tomato juice has a higher viscosity than water. In this section, you will learn how the size and shape of a molecule influences a liquid's viscosity, and how an increase in temperature changes the viscosity of a fluid.

### Why does viscosity matter?

Thick substances  
are very viscous

Viscosity is an important consideration in food production. Fast-food restaurants advertise that their chocolate shakes are thicker than the competitor's. Special ingredients such as carrageenan, which is made from seaweed, are used to bring yogurts, puddings, and pasta sauces to the viscosity that consumers prefer. One company even based a large advertising campaign on the fact that its brand of catsup was so viscous, a spoon would stand up in a cupful.

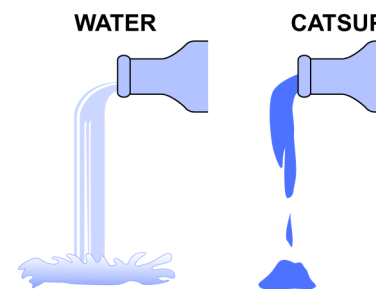
Substances like  
motor oil need to  
have the right  
viscosity to work  
effectively

Viscosity is also an important property of motor oils. If an oil is too thick, it may not flow quickly to the parts of an engine, leaving them vulnerable to excess wear. However, if the oil is too thin, it may not provide enough "cushion" to protect any part of the engine from the effects of friction. A motor oil must function properly when the engine is started on a very cold day, and when the engine is operating at high temperatures. As a result, manufacturers make very careful choices about which types of molecules will be included in their formulas for motor oil.

### Why are some liquids more viscous than others?

Large, bumpy  
molecules create  
more friction than  
small, smooth  
molecules

Viscosity is determined in large part by the shape of the molecules in a liquid. If the molecules are large and have bumpy surfaces, a great deal of friction will be created as they slide past each other. The liquid will flow at a slower rate than liquids made up of small molecules with a smoother surface.



**Figure 17.19:** Water is less viscous than catsup.



**Figure 17.20:** Numbers on the side of a quart of motor oil are based on a scale established by the Society of Automotive Engineers (SAE). The first number indicates the lowest temperature at which the oil will work well ( $-10^{\circ}\text{F}$  in this case). The "W" means the oil works well in cold weather. The second number is a grade for the oil: "50" is best for summer driving, "30" for winter driving, and "40" for mild weather temperatures.



## How does temperature effect viscosity?

As a liquid gets warmer, its viscosity decreases

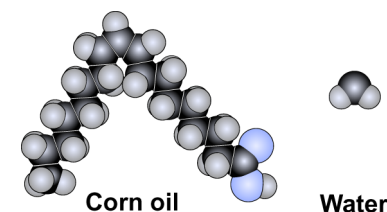
As the temperature of a liquid is raised, the viscosity of the liquid decreases. In other words, warm liquids have less viscosity than cold liquids. Warmed maple syrup or hot fudge, for example, is much easier to pour than the same syrup chilled. Why does this happen? Remember from your study of states of matter that when energy is added to a liquid, the movement of the molecules increases. The increasing speed allows the molecules to slide past each other with greater ease. As a result, the viscosity decreases.

The viscosity of a liquid is related to its temperature

The viscosity of some liquids changes a great deal as the temperature increases. Olive oil, for example, is more viscous at 20°C than 60°C. The oleic acid molecules that are in olive oil are made up of carbon, hydrogen, and oxygen atoms. At lower temperatures, the hydrogen atoms in the oleic acid molecules tend to form loose connections called “hydrogen bonds” with oxygen atoms in other oleic molecules. These connections make it hard for the individual oleic acid molecules to slide around. However, as molecular speed increases with an increase in temperature, some of the hydrogen-oxygen connections between neighboring molecules break apart. As a result, the oil’s viscosity decreases significantly.

As a gas gets warmer, its viscosity increases

It is interesting to note that gases exhibit the opposite property. As you raise the temperature of a gas, it becomes *more* resistant to flow. This is due to the fact that gas molecules are spaced far apart, so they do not have to slide over one another very often in order to flow. Increasing the temperature increases the number of collisions between the molecules. Therefore, the net effect is an increase in friction and a corresponding increase in viscosity.



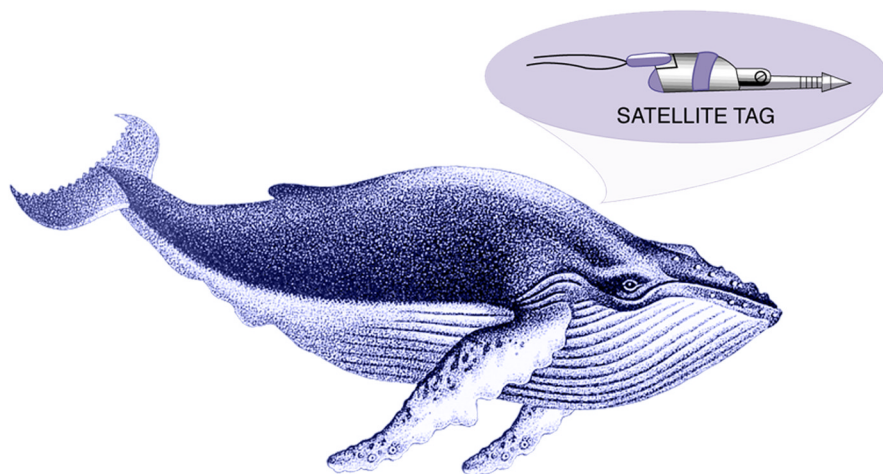
**Figure 17.21:** Here are diagrams of two molecules. Which liquid is likely to have a higher viscosity?

| Substance (Temp)   | Viscosity value |
|--------------------|-----------------|
| Water (25°C)       | 0.89            |
| Acetic acid (18°C) | 1.3             |
| Oleic acid (30°C)  | 25.6            |
| Olive oil (20°C)   | 84              |
| Glycerin (20°C)    | 1490            |

**Figure 17.22:** Viscosity depends on temperature. Viscosity values are usually in units of (force  $\times$  time)/area. The unit that represents this fraction is the “poise.” The viscosity values above are given in “centipoise.” One centipoise is 1/100 of a poise. The viscosity of water, shown above as 0.89 centipoise, can also be written as 0.0089 poise.

## Physical science in action: Student research provides new hope for whales

Although many people in the United States and elsewhere become familiar with the plight of great whales through the classic Herman Melville novel, *Moby Dick*, they may not realize that the hazards faced by both Atlantic and Pacific whales have changed. They are no longer threatened by commercial hunting, which is now forbidden by law, but by collisions with ships.



Whale researchers such as J. Michael Williamson, principal investigator with the Boston, Massachusetts, organization WhaleNet (<http://whale.wheelock.edu>), have used satellite tracking to follow the paths of migrating whales. This research has enabled scientists to better predict where the whales are at a given time during the year, so that ships can be warned of their presence and avert accidental contact.

The satellite tracking program works like this: Researchers (in a somewhat risky maneuver!) travel in a small, rigid, inflatable boat to within 3 to 7.5 meters (10 to 25 feet) of a whale. They use a crossbow to implant a radio tag in the whale's blubber, behind the blowhole. The whale's blubber does not contain many nerve endings, so the whale feels very little, if any, discomfort. The tag records the geographical location of the whale at regular intervals, and transmits this information to a satellite when the whale surfaces to breathe.

Williamson said that the greatest difficulty with satellite tagging is that the tags don't always stay in the blubber. "Just as our bodies will push out a foreign object like a splinter, the whale's body sometimes ejects the tag. And at a cost of \$3,500 to \$5,000 per tag, that is a significant loss."

In 1999, Williamson teamed up with John Vesalo at the University of Akron (Ohio) polymer research lab in hopes of finding a type of adhesive that would help keep the tag in the blubber.

Vesalo put some of his best researchers to work: high school students chosen through a program called Upward Bound Math/Science, which gives teenagers from nontraditional situations an opportunity to spend a summer exploring their interest in science, with the help of college professors in a modern, well-equipped lab. Six students participated in 1999, and another four in 2000.



The students used their knowledge of properties of matter to design their own investigations. First, they searched for a material with surface texture, elasticity, and tensile strength similar to whale skin. Squares of vinyl worked best. They designed an apparatus using pulleys, clamps, string, and 50-gram masses to test the strength of glue bonds in a way that would simulate the pushing and pulling forces the satellite tag would encounter when the whale swam at various depths and speeds.

Next, the students chose commercial glues to test. They considered the physical environment in which the glue must be effective: an oily substance immersed in salt water for long periods of time. For inspiration, they examined the “glue” that blue mussels secrete to affix themselves to rocks. One student chose denture adhesive, because it works in a moist environment. Another studied “superglue,” while a third investigated a new type of glue designed to replace the stitches that doctors and veterinarians have traditionally used to sew up cuts.

Whitni Milton, 16, of Cincinnati, Ohio, explained, “I’m learning that science takes a lot of creativity. You couldn’t have done this project without ingenuity.”

After eliminating some glues based on their performance on vinyl, the students tested the best adhesives on blubber provided by WhaleNet. They experimented with three glue mixtures, but discovered that the viscosity of each was too great to penetrate the whale skin.

At the end of each summer, the participants shared their methods and results in a scientific paper. Their conclusions will provide a starting point for the next group of researchers. For example, through interviews with veterinarians at SeaWorld in Cleveland, Ohio, they learned that living whale skin is not as oily as their samples. Therefore, the students suggested that attempts should be made to attach the tag to the underside of the skin, which provided a much better bonding surface than the oily blubber.

Even though the project remains a work in progress, the 1999 and 2000 participants say they have already gained valuable insights. They know what it takes to do real research: time, patience, and, above all, creativity.

## Chapter 17 Review

### Vocabulary Review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

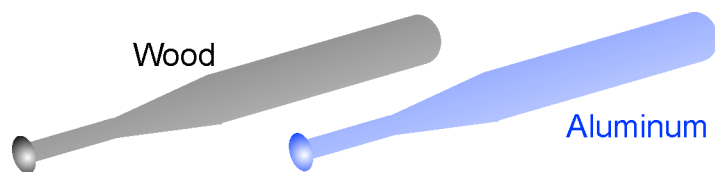
#### Set One

- |                 |   |
|-----------------|---|
| 1. density      | a. A measurement of how easily a solid can be pounded into thin sheets                              |
| 2. hardness     | b. A measurement of the “compactness” of a substance; the ratio of its mass to volume               |
| 3. brittleness  | c. A measure of a solid’s ability to return to its original shape after it is stretched or squeezed |
| 4. elasticity   | d. A measurement of how easily a solid will shatter   |
| 5. malleability | e. A measurement of how easily a solid can be scratched   |
|                 | f. A measurement of how well a solid resists breaking when it is under tension                      |

#### Set Two

- |                          |  |
|--------------------------|--|
| 1. tensile strength      | a. The upward force of a liquid or gas upon an object immersed in it                       |
| 2. fluid                 | b. Any material that flows; commonly refers to matter in the liquid or gas state           |
| 3. buoyancy              | c. A measure of a fluid’s resistance to flow   |
| 4. Archimedes’ principle | d. A measurement of how well a solid resists breaking when it is pulled on                 |
| 5. viscosity             | e. The force exerted on an object in a fluid is equal to the volume of the displaced fluid |
|                          | f. The force exerted on an object in a fluid is equal to the weight of the displaced fluid |

### Concept review



1. A wooden baseball bat and an aluminum bat have the exact same shape, size and mass. Aluminum is much denser than wood. Explain how the two bats could be the same size and mass.
2. At 20°C, the density of copper is 8.9 g/cm<sup>3</sup>. The density of platinum is 21.4 g/cm<sup>3</sup>. What does this tell you about how the atoms are “packed” in each material?
3. You are an engineer who must choose a type of plastic to use for the infant car seat that you are designing. Name two properties of solids that would help you decide, and explain why each is important.
4. Would a cube of solid silver sink or float in liquid silver? How do you know?






5. The Dead Sea is a body of water that lies between Israel and Jordan. It is so salty that almost no organisms other than a few types of bacteria can survive in it. The density of its surface water is 1.166 g/ml. Would you find it easier to float in the Dead Sea or in a freshwater lake? Give a reason for your answer.
6. You pump your soccer ball up with a certain volume of air the night before a game. The next morning, you wake up and go outside to get your ball. You notice that it is much colder outside than the night before. When you pick up the ball, you notice that it appears to need more air. Assuming that the ball does not have a leak, can you explain why it appears that the volume of air in the ball may have decreased?

## Problems

1. The density of gasoline at 20°C is 0.7 g/ml. What is the mass of 4 liters of gasoline?
2. Your teacher gives you 2 stainless steel ball bearings. The larger has a mass of 25 g and a volume of 3.2 cm<sup>3</sup>. The smaller has a mass of 10 g. Calculate the volume of the smaller ball bearing.
3. Ice has a density of 0.92 g/cm<sup>3</sup>. What is the volume of 100 grams of ice? If the ice completely melted, what would the volume of the water be? (The density of water is 1.00g/ml).
4. A chunk of pure gold weighs 2.00 N. Its volume is 10.6 cm<sup>3</sup>.
  - a. If the gold is immersed in water at 20°C, find the weight of the displaced water. Hints: 1 cm<sup>3</sup> of water = 1 g; 1 g = 0.0098 N.
  - b. If the gold were attached to a spring scale and suspended in the water, how much would it appear to weigh?
5. Six liters of helium gas held at 2,500 kilopascals are pumped into a balloon that holds 1 liter. What is the pressure inside the balloon? Assume that the temperature does not change.

## Applying your knowledge

1. Ancient peoples learned to make tools out of bronze before they learned to make iron. Bronze is harder than copper, but not as hard as iron.  
Bronze is a homogeneous mixture made up of 90 percent copper and 10 percent tin. At 20°C, the density of pure copper is 8.9 g/cm<sup>3</sup> and the density of tin is 7.3 g/cm<sup>3</sup>. What is the density of bronze at 20°C?
2.  Scientists believe that if the density of ice were greater than that of water, the states of Michigan, Wisconsin, Ohio, and New York would be much colder in the summer than they currently are. Why? Research this phenomenon and create a poster presentation to explain your findings.

3. In the reading, you learned that the Earth's atmosphere exerts a pressure of about 101,300 newtons per square meter of surface—about the weight of an elephant. Why doesn't this pressure crush you? What conditions need to exist so that atmospheric pressure does not crush you?
  - a. Research how humans (and other organisms that live on land) are adapted to live in this atmospheric pressure. Make a list of these adaptations and an explanation of each.
  - b. Some organisms are adapted to life in the depths of the ocean. Research the amount of pressure these organisms need to be able to withstand. Make a list of their adaptations to life under tremendous pressure, and explain your findings.
4. Hardness is a property of matter that is easy to confuse with toughness or durability. Look around your classroom, your home, or outside, and name one object that has high hardness but low durability and one object that has low hardness but high durability.
5. Observe the world around you and find different objects or materials that fit each of the following descriptions:
  - a. has both high elasticity and high tensile strength
  - b. has both high hardness and low malleability
  - c. has both high hardness and high brittleness
  - d. has some elasticity but low tensile strength

6. JAN  
FEB  
MAR In the first century BC, the Roman architect Vitruvius related a story of how Archimedes uncovered a fraud in the manufacture of a golden crown commissioned by Hiero II, the king of Syracuse. The crown (*corona* in Latin) would have been in the form of a wreath, like the picture. Hiero would have placed such a wreath on an important statue. Suspecting that the goldsmith might have replaced some of the gold given to him by an equal weight of silver, Hiero asked Archimedes to determine whether the wreath was pure gold. Because the wreath was precious, he could not disturb the wreath in any way. (In modern terms, he was to perform nondestructive testing.)



The solution occurred to Archimedes when he stepped into his bath and caused it to overflow. He decided to put a weight of gold equal to the crown and known to be pure into a bowl that was filled with water to the brim. Then the gold would be removed and the king's crown put in its place. An alloy of lighter silver would increase the bulk of the crown and cause the bowl to overflow.

Explain whether you think Archimedes' method was correct and would have spotted the fake crown.

7. Quite a number of studies have been done on the viscosity of lava from various volcanic eruptions around the world. Do some research to find out how scientists determine the viscosity of lava, and discover if there is much variation in the viscosity of different lava flows.