SECTION 1

Matter and Energy

KEY TERMS
plasma
energy
thermal energy
evaporation
sublimation
condensation

OBJECTIVES

- **Summarize** the main points of the kinetic theory of matter.
- **Describe** how temperature relates to kinetic energy.
- **Describe** four common states of matter.
- **List** the different changes of state, and describe how particles behave in each state.
- **State** the laws of conservation of mass and conservation of energy, and explain how they apply to changes of state.

If you visit a restaurant kitchen, such as the one in ***Figure 1,*** you can smell the food cooking even if you are a long way from the stove. One way to explain this phenomenon is to make some assumptions. First, assume that the particles (atoms and molecules) within the food substances are always in motion and are constantly colliding. Second, assume that the particles move faster as the temperature rises. A theory based on these assumptions, called the kinetic theory of matter, can be used to explain things such as why you can smell food cooking from far away.

When foods are cooking, energy is transferred from the stove to the foods. As the temperature increases, some particles in the foods move very fast and actually spread through the air in the kitchen. In fact, the state, or physical form, of a substance is determined, partly by how its particles move.

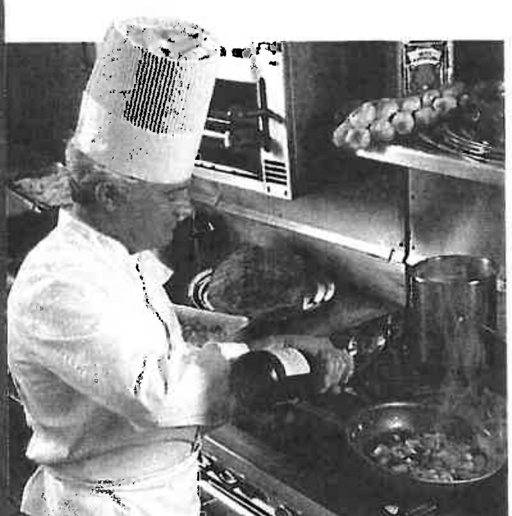


Figure 1
The ingredients in foods are chemicals. A skilled chef understands how the chemicals in foods interact and how changes of state affect cooking.

Kinetic Theory

Here are the main points of the kinetic theory of matter:

- All matter is made of atoms and molecules that act like tiny particles.
- These tiny particles are always in motion. The higher the temperature of the substance, the faster the particles move.
- At the same temperature, more-massive (heavier) particles move slower than less massive (lighter) particles.

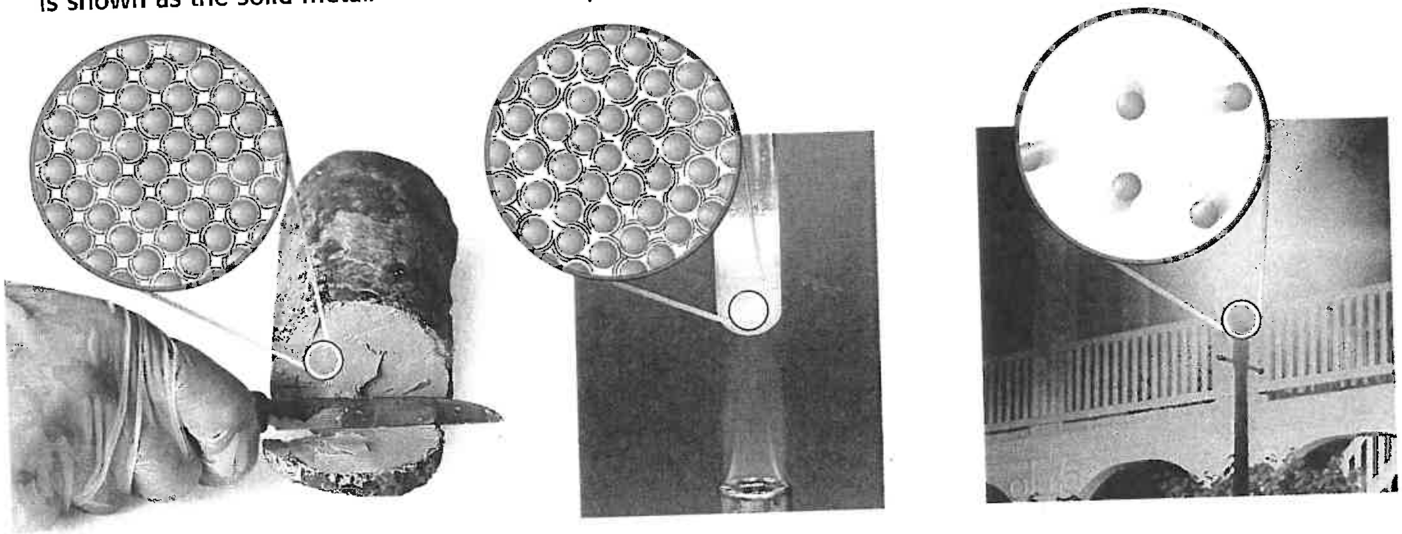
The kinetic theory helps you visualize the differences among the three common states of matter: solids, liquids, and gases.

Figure 2
Common States of Matter

A Here, the element sodium is shown as the solid metal.

B This is sodium melted as a liquid.

C Sodium exists as a gas in a sodium-vapor lamp.



The states of matter are physically different

The models for solids, liquids, and gases shown in ***Figure 2*** differ in the distances between the atoms or molecules and in how closely these particles are packed together. Particles in a solid, such as iron, are in fixed positions. In a liquid, such as cooking oil, the particles are closely packed, but they can slide past each other. Gas particles are in a constant state of motion and rarely stick together. Most matter found naturally on Earth is either a solid, a liquid, or a gas, although matter also exists in other states.

Figure 3
Particles in a crystalline solid have an orderly arrangement.

Solids have a definite shape and volume

Take an ice cube out of the freezer. The ice cube has the same volume and shape that it had in the ice tray. Unlike gases and liquids, a solid does not need a container in order to have a shape. The structure of a solid is rigid, and the particles have almost no freedom to change position. The particles in solids are held closely together by strong attractions, yet they vibrate.

Solids are often divided into two categories—crystalline and amorphous. *Crystalline solids* have an orderly arrangement of atoms or molecules. Examples of crystalline solids include iron, diamond, and ice. *Amorphous solids* are composed of atoms or molecules that are in no particular order. Each particle is in a particular place, but the particles are in no organized pattern. Examples of amorphous solids include rubber and wax. ***Figure 3*** and ***Figure 4*** illustrate the differences in these two types of solids.

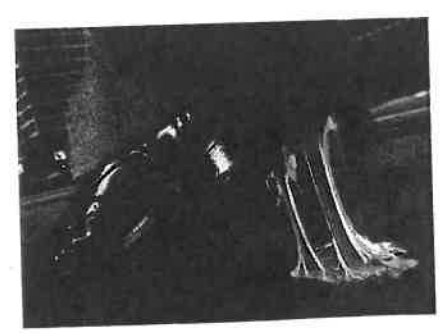


Figure 4
The particles in an amorphous solid do not have an orderly arrangement.

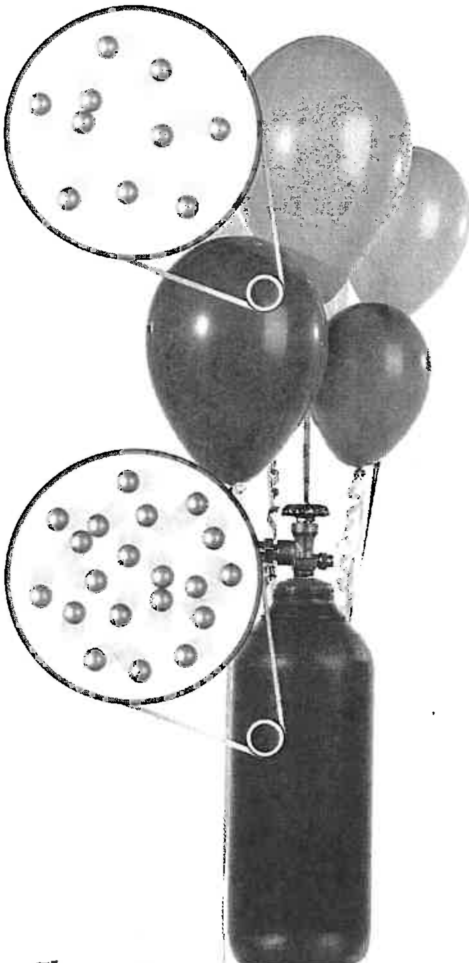


Figure 5
The particles of helium gas, He, in the cylinder are much closer together than the particles of the gas in the balloons.

Liquids change shape, not volume

Liquids have a definite volume, but they change shape. The particles of a liquid can slide past one another. And the particles in a liquid move more rapidly than those in a solid—fast enough to overcome the forces of attraction between them. This allows liquids to flow freely. As a result, the liquids are able to take the shape of the container they are put into. You see this every time you pour yourself a glass of juice. But even though liquids change shape, they do not easily change volume. The particles of a liquid are held close to one another and are in contact most of the time. Therefore, the volume of a liquid remains constant.

Another property of liquids is *surface tension,* the force acting on the particles at the surface of a liquid that causes a liquid, such as water, to form spherical drops.

Gases are free to spread in all directions

If you leave a jar of perfume open, particles of the liquid perfume will escape as gas, and you will smell it from across the room. Gas expands to fill the available space. And under standard conditions, particles of a gas move rapidly. For example, helium particles can travel 1200 m/s.

One cylinder of helium, as shown in ***Figure 5,*** can fill about 700 balloons. How is this possible? The volume of the cylinder is equal to the volume of only five inflated balloons. Gases change both their shape and volume. The particles of a gas move fast enough to break away from each other. In a gas, the amount of empty space between the particles changes. The helium atoms in the cylinder in ***Figure 5,*** for example, have been forced close together. But, as the helium fills the balloon, the atoms spread out, and the amount of empty space in the gas increases.

plasma a state of matter that starts as a gas and then becomes ionized

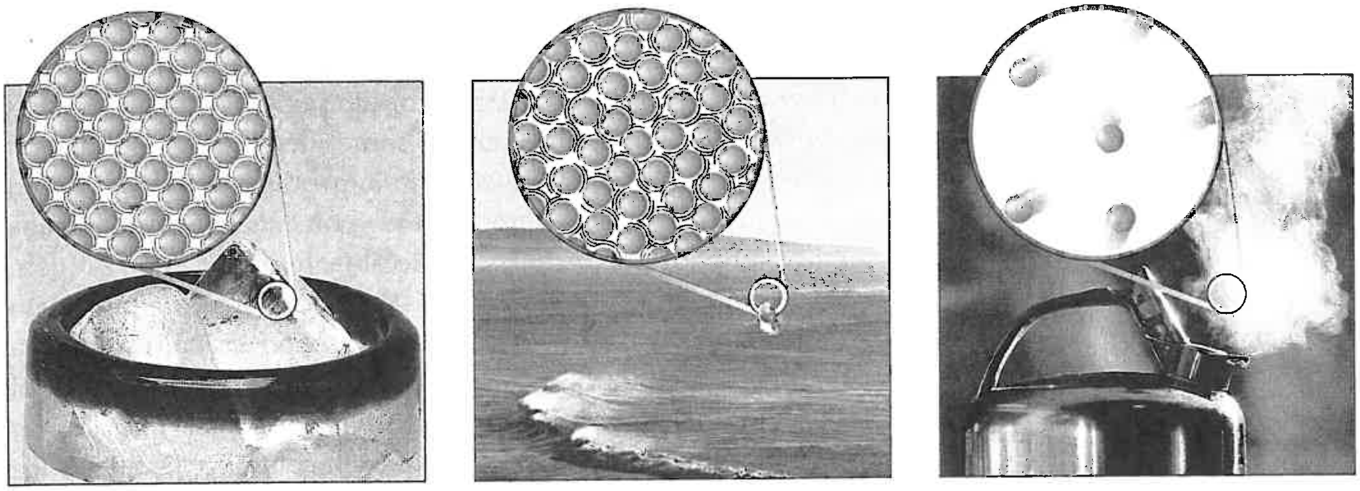
Plasma is the most common state of matter

Scientists estimate that 99% of the known matter in the universe, including the sun and other stars, is made of matter called **plasma.** Plasma is a state of matter that does not have a definite shape and in which the particles have broken apart.

Plasmas are similar to gases but have some properties that are different from the properties of gases. Plasmas conduct electric current, while gases do not. Electric and magnetic fields affect plasmas but do not affect gases. Natural plasmas are found in lightning, fire, and the aurora borealis, shown in ***Figure 6.*** The glow of a fluorescent light is caused by an artificial plasma, which is formed by passing electric currents through gases.

Figure 6
Auroras form when high-energy plasma collides with gas particles in the upper atmosphere.

Figure 7
The particles in the steam have the most kinetic energy, but the ocean has the most total thermal energy because it contains the most particles.



A The particles in an ice cube vibrate in fixed positions; therefore, they do not have a lot of kinetic energy.

B The particles in ocean water move around; therefore, they have more kinetic energy than the particles in an ice cube.

C The particles in steam move around rapidly; therefore, they have more kinetic energy than the particles in ocean water.

Energy's Role

What sources of energy would you use if the electricity were off? You might use candles for light and batteries to power a clock. Electricity, candles, and batteries are sources of energy. The food you eat is also a source of energy. Chemical reactions that release heat are another source of energy. You can think of **energy** as the ability to change or move matter. Later, you will learn how energy can be described as the ability to do work.

■ **energy** the capacity to do work

■ **thermal energy** the kinetic energy of a substance's atoms

Thermal energy is the total kinetic energy of a substance

According to the kinetic theory, all matter is made of particles—atoms and molecules—that are constantly in motion. Because the particles are in motion, they have *kinetic energy*, or energy of motion. **Thermal energy** is the total kinetic energy of the particles that make up an object. The more kinetic energy the particles in the object have, the more thermal energy the object has. At higher temperatures, particles of matter move faster. The faster the particles move, the more kinetic energy they have, and the greater the object's thermal energy is. Thermal energy also depends on the number of particles in a substance. Look at ***Figure 7.*** Which substance do you think has the most thermal energy? The answer might surprise you.

Temperature is a measure of average kinetic energy

Do you think of temperature as a measure of how hot or cold something is? Scientifically, temperature is a measure of the average kinetic energy of the particles in an object. The more kinetic energy the particles of an object have, the higher the temperature of the object is. Particles of matter are constantly moving, but they do not all move at the same speed. As a result, some particles have more kinetic energy than others have. So, when you measure an object's temperature, you measure the average kinetic energy of the particles in the object.

The temperature of a substance is not determined by how much of the substance you have. For example, a teapot contains more tea than a mug does, but the temperature, or average kinetic energy of the particles in the tea, is the same in both containers. However, the total kinetic energy of the particles in each container is different.

Quick ACTIVITY

Hot or Cold?

You will need three buckets: one with warm water, one with cold water, and one with hot water. **SAFETY:** Test a drop of the hot water to make sure it is not too hot.

Put both your hands into a bucket of warm water, and note how it feels. Now put one hand into a bucket of cold water and the other into a bucket of hot water. After a minute, take your hands out of the hot and cold water, and put them back in the warm water. Can you rely on your hands to determine temperature? Explain your observations.

Energy and Changes of State

A change of state—the conversion of a substance from one physical form to another—is a physical change. The identity of a substance does not change during a change of state, but the energy of a substance does change. In ***Figure 8,*** the ice, liquid water, and steam are all the same substance—water, H_2O—but they all have different amounts of energy.

If energy is added to a substance, its particles move faster, and if energy is removed, its particles move slower. The temperature of a substance is a measure of its energy. Therefore, steam, for example, has a higher temperature than liquid water does, and the particles in steam have more energy than the particles in liquid water do. A transfer of energy known as *heat* causes the temperature of a substance to change, which can lead to a change of state.

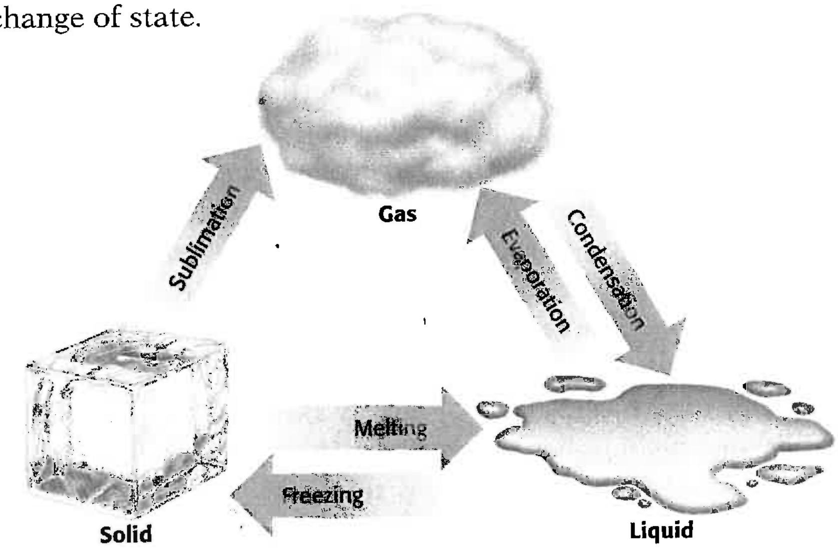


Figure 8
This figure shows water undergoing five changes of state: freezing, melting, sublimation, evaporation, and condensation.

Some changes of state require energy

Changes, such as melting, that require energy are called *endothermic changes.* A solid changes to a liquid by melting. Heating a solid transfers energy to the atoms, which vibrate faster as they gain energy. Eventually, they break from their fixed positions, and the solid melts. The *melting point* is the temperature at which a substance changes from a solid to a liquid. The melting point of water is 0°C. Table salt has a melting point of 801°C.

Evaporation is the change of a substance from a liquid to a gas. Boiling is evaporation that occurs throughout a liquid at a specific temperature and pressure. The temperature at which a liquid boils is the liquid's *boiling point.* Like the melting point, the boiling point is a characteristic property of a substance. The boiling point of water at sea level is 100°C, and the boiling point of mercury is 357°C.

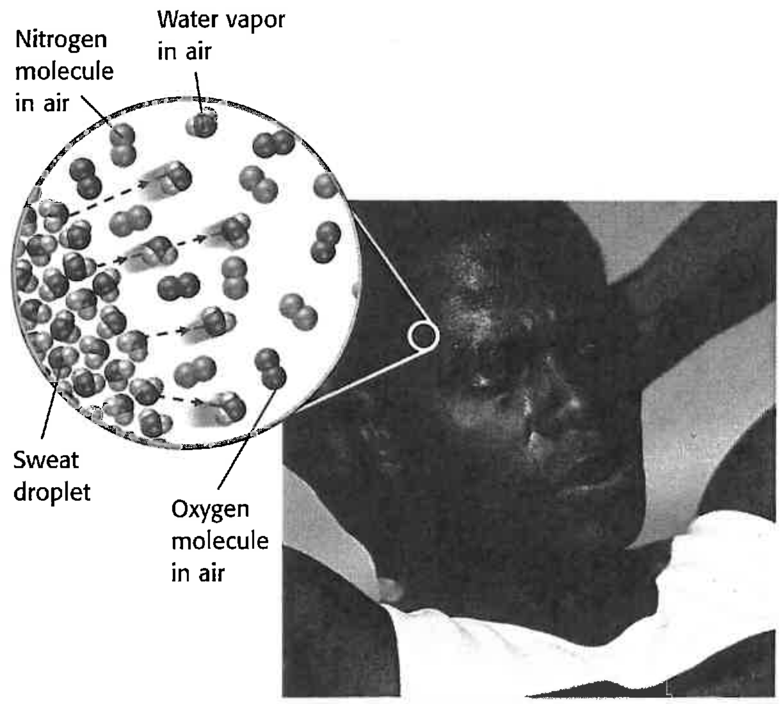


Figure 9

Your body's heat provides the energy for sweat to evaporate.

You can feel the effects of an energy change when you sweat. Energy from your body is transferred to sweat molecules as heat. When this transfer occurs, your body cools off. The molecules of sweat on your skin gain energy and move faster, as shown in ***Figure 9.*** Eventually, the fastest-moving molecules break away, and the sweat evaporates. Energy is needed to separate the particles of a liquid to form a gas.

Solids can also change to gases. ***Figure 10*** shows solid carbon dioxide undergoing **sublimation,** that is, the process by which a solid turns directly into a gas. Sometimes ice sublimes to form a gas. When left in the freezer for a while, ice cubes get smaller as the ice changes from a solid to a gas.

evaporation the change of a substance from a liquid to a gas

sublimation the process in which a solid changes directly into a gas (the term is sometimes also used for the reverse process)

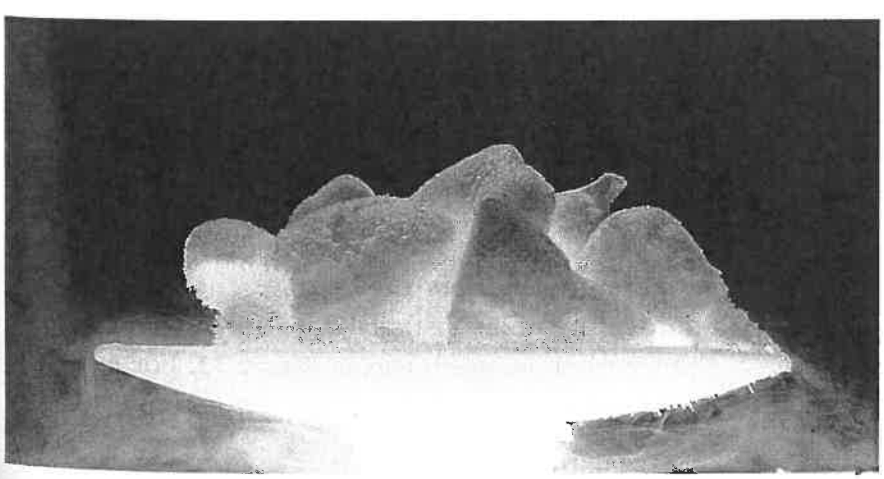


Figure 10

Dry ice (solid carbon dioxide) sublimes to form gaseous carbon dioxide.

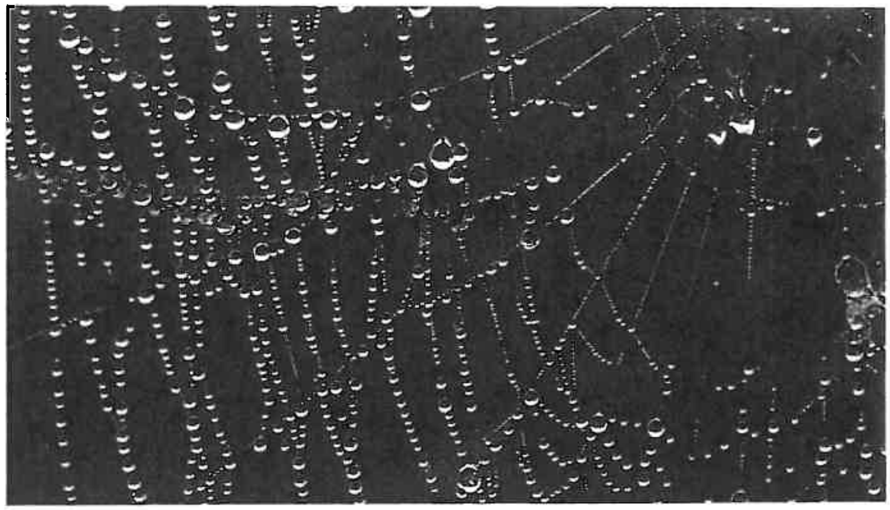


Figure 11

Gaseous water in the air will become liquid when it contacts a cool surface.

Energy is released in some changes of state

When water vapor becomes a liquid, or when liquid water freezes to form ice, energy is released from the water to its surroundings. For example, the dew drops in ***Figure 11*** form as a result of **condensation,** which is the change of state from a liquid to a gas. During this energy transfer, the water molecules slow down. For a gas to become a liquid, large numbers of atoms clump together. Energy is released from the gas and the particles slow down.

condensation the change of a substance from a gas to a liquid

Condensation sometimes takes place when a gas comes in contact with a cool surface. Have you ever noticed drops of water forming on the outside of a glass containing a cool drink? The *condensation point* of a substance is the temperature at which the gas becomes a liquid.

Energy is also released during freezing, which is the change of state from a liquid to a solid. The temperature at which a liquid changes into a solid is its *freezing point.* Freezing is the reverse of melting, so freezing and melting occur at the same temperature, as shown in ***Figure 12.*** For a liquid to freeze, the motion of its particles must slow down, and the attractions between the particles must overcome their motion. Like condensation, freezing is an *exothermic change* because energy is released from the substance as it changes state.

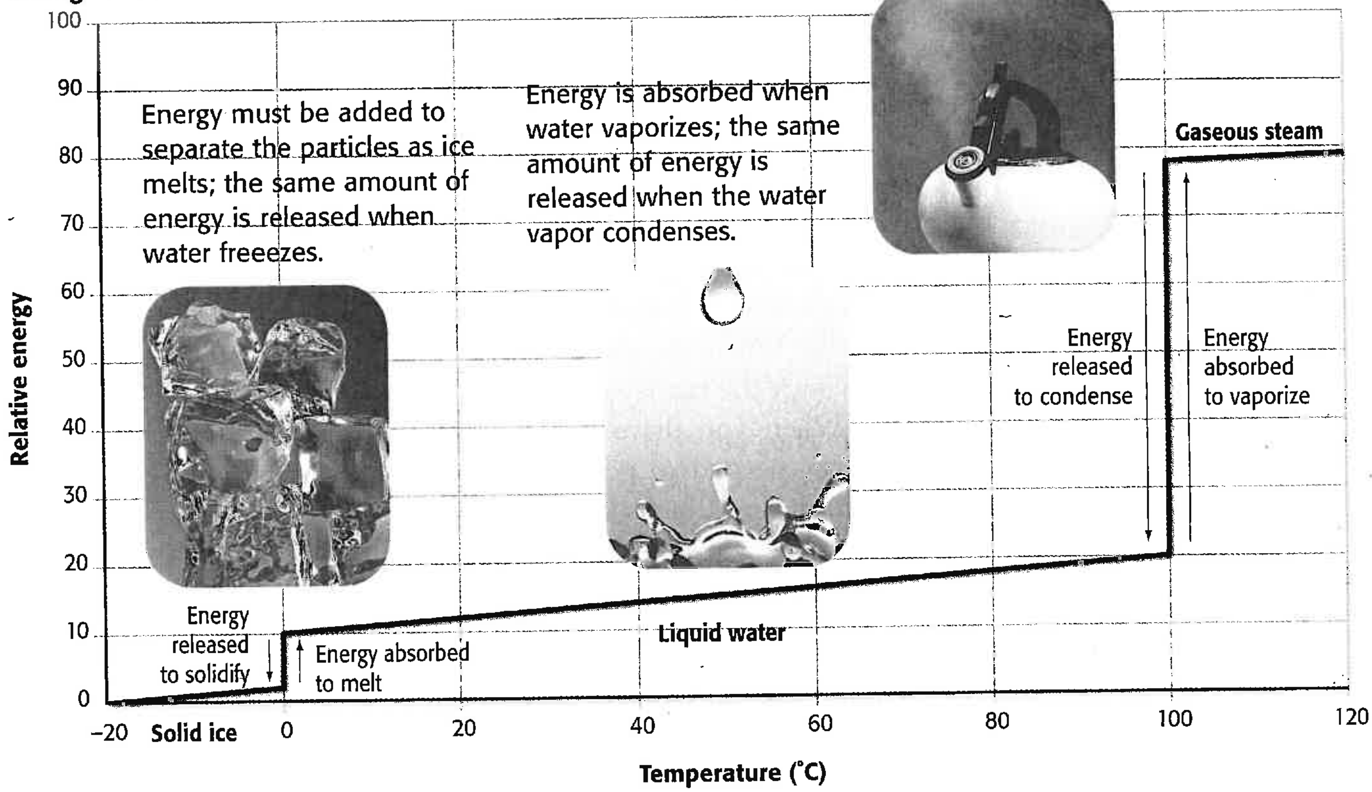
Figure 12

Liquid water freezes at the same temperature that ice melts: 0°C.

Temperature change verses change of state

When a substance loses or gains energy, either its temperature changes or its state changes. But the temperature of a substance does not change during a change of state, as shown in ***Figure 13.*** For example, if you add heat to ice at 0°C, the temperature will not rise until all the ice has melted.

Figure 13
Changes of State for Water



Conservation of Mass and Energy

Look at the changes of state shown in ***Figure 13.*** Changing the energy of a substance can change the state of the substance, but it does not change the composition of a substance. Ice, water, and steam are all made of H_2O. When an ice cube melts, the mass of the liquid water is the same as the mass of the ice cube. When water boils, the number of molecules stays the same even as the liquid water loses volume. The mass of the steam is the same as the mass of the water that evaporated.

Mass cannot be created or destroyed

In chemical changes, as well as in physical changes, the total mass of matter stays the same before and after the change. Matter changes, but the total mass stays the same. The law of conservation of mass states that mass cannot be created or destroyed. For instance, when you burn a match, it seems to lose mass. The ash has less mass than the match. But there is also mass in the oxygen that reacts with the match, in the tiny smoke particles, and in the gases formed in the reaction. The total mass of the reactants (the match and oxygen) is the same as the total mass of the products (the ash, smoke, and gases).

INTEGRATING

SPACE SCIENCE Studies of the chemical changes that stars and nebulae undergo are constantly adding to our knowledge. Present estimates are that hydrogen makes up more than 90% of the atoms in the universe and constitutes about 75% of the mass of the universe. Helium atoms make up most of the remainder of the mass. The total of all the other elements contributes very little to the total mass of the universe.

Energy cannot be created or destroyed

Energy may be converted to another form during a physical or chemical change, but the total amount of energy present before and after the change is the same. The law of conservation of energy states that energy cannot be created or destroyed.

Starting a car may seem to violate the law of conservation of energy. For the small amount of energy needed to turn the key in the ignition, a lot of energy results. But the car needs gasoline to run. Gasoline releases energy when it is burned. Because of the properties of chemicals that make up gasoline, it has stored energy. When the stored energy is considered, the energy before you start the car is equal to the energy that is produced.

When you drive a car, gasoline is burned to produce the energy needed to power the car. However, some of the energy from the gasoline is transferred to the surroundings as heat. That is why a car's engine gets hot. The total amount of energy released by the gasoline is equal to the energy used to move the car, plus the energy transferred to the surroundings as heat.

SECTION 1 REVIEW

SUMMARY

- The kinetic theory states that all matter is made of tiny, moving particles.
- Solids have a definite volume and shape. Liquids have a definite volume but a variable shape. Gases have a variable shape and volume.
- Thermal energy is the total kinetic energy of the particles of a substance.
- Temperature is a measure of average kinetic energy.
- A change of state is a physical change that requires or releases energy.
- Mass and energy are conserved in changes of state.

1. **List** three main points of the kinetic theory of matter.
2. **Describe** the relationship between temperature and kinetic energy.
3. **State** two examples for each of the four common states of matter.
4. **Describe** the following changes of state, and explain how particles behave in each state.
   a. freezing **c.** sublimation
   b. boiling **d.** melting
5. **State** whether energy is released or energy is required for the following changes of state to take place.
   a. melting **c.** sublimation
   b. evaporation **d.** condensation
6. **Compare** the shape and volume of solids, liquids, and gases.
7. **Describe** the role of energy when ice melts and when water vapor condenses to form liquid water. Portray each state of matter and the change of state using a computer drawing program. COMPUTER SKILL
8. **State** the law of conservation of mass and the law of conservation of energy, and explain how they apply to changes of state.
9. **Critical Thinking** Use the kinetic theory to explain how a dog could find you by your scent.

SECTION 2

Fluids

KEY TERMS

fluid
buoyant force
pressure
Archimedes' principle
pascal
Pascal's principle
viscosity

OBJECTIVES

- **Describe** the buoyant force and explain how it keeps objects afloat.
- **Define** Archimedes' principle.
- **Explain** the role of density in an object's ability to float.
- **State** and apply Pascal's principle.
- **State** and apply Bernoulli's principle.

What do liquids and gases have in common? Liquids and gases are states of matter that do not have a fixed shape. They have the ability to flow, and they are both referred to as **fluids.** Fluids are able to flow because their particles can move past each other easily. Fluids, especially air and water, play an important part in our lives. The properties of fluids allow huge ships to float, divers to explore the ocean depths, and jumbo jets to soar across the skies.

Buoyant Force

fluid a nonsolid state of matter in which the atoms or molecules are free to move past each other, as in a gas or liquid

buoyant force the upward force exerted on an object immersed in or floating on a fluid

Why doesn't a rubber duck sink to the bottom of a bath tub? Even if you push a rubber duck to the bottom, it will pop back to the surface when you release it. A force pushes the rubber duck to the top of the water. The force that pushes the duck up is the **buoyant force**—the upward force that fluids exert on matter. When you float on an air mattress in a swimming pool, the buoyant force keeps you and the air mattress afloat. A rubber duck and a large steel ship, such as the one shown in ***Figure 14,*** both float because they are less dense than the water that surrounds them and because the buoyant force pushes against them to keep them afloat.

Figure 14
Despite its large size and mass, this ship is able to float because its density is less than that of the water and because the buoyant force keeps it afloat.

Buoyancy explains why objects float

The buoyant force, which keeps the ice in ***Figure 15*** floating, is a result of pressure. All fluids exert **pressure,** which is the amount of force exerted on a given area. The pressure of all fluids, including water, increases as the depth increases. The water exerts fluid pressure on all sides of each piece of ice. The pressure exerted horizontally on one side of the ice is equal to the pressure exerted horizontally on the opposite side. These equal pressures cancel one another. The only fluid pressures affecting the pieces of ice are above and below. Because pressure increases with depth, the pressure below the ice is greater than the pressure on top of the ice. Therefore, the water exerts a net upward force—the buoyant force—on the ice above it. Because the buoyant force is greater than the weight of the ice, the ice floats.

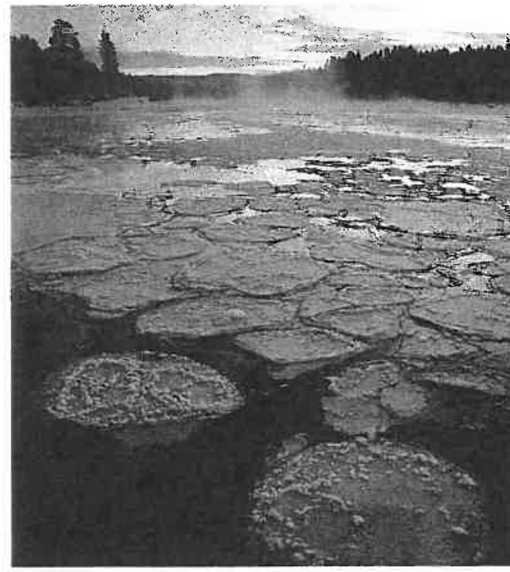


Figure 15
Ice floats in water because it is less dense than water and because of the upward buoyant force on the ice.

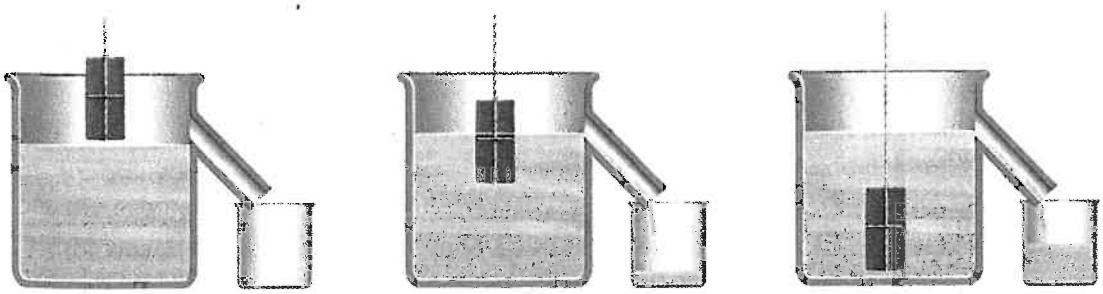
Determining buoyant force

Archimedes, a Greek mathematician in the third century BCE, discovered a method for determining buoyant force. **Archimedes' principle** states that the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid that the object displaces. For example, imagine that you put a brick in a container of water, as shown in ***Figure 16.*** A spout on the side of the container at the water's surface allows water to flow out of the container. As the object sinks, the water rises and flows through the spout into another container. The total volume of water that collects in the smaller container is the displaced volume of water from the larger container. The weight of the displaced fluid is equal to the buoyant force acting on the brick. An object floats only when it displaces a volume of fluid that has a weight equal to the object's weight—that is, an object floats if the buoyant force on the object is equal to the object's weight.

pressure the amount of force exerted per unit area of a surface

Archimedes' principle the principle that states that the buoyant force on an object in a fluid is an upward force equal to the weight of the volume of fluid that the object displaces

Figure 16



A An object is lowered into a container of water.

B The object displaces water, which flows into a smaller container.

C When the object is completely submerged, the volume of the displaced water equals the volume of the object.

Figure 17

Helium in a balloon floats in air for the same reason a duck floats in water–the helium and the duck are less dense than the surrounding fluid.

An object will float or sink based on its density

By knowing the density of a substance, you can determine if the substance will float or sink. For example, the density of a brick is 1.9 g/cm^3, and the density of water is 1.00 g/cm^3. The brick will sink because it is denser than the water.

One substance that is less dense than air is helium, a gas. Helium is about seven times less dense than air. A given volume of helium displaces a volume of air that is much heavier, so helium floats. That is why helium is used in airships and parade balloons, such as the one shown in ***Figure 17.***

Steel is almost eight times denser than water. And yet huge steel ships cruise the oceans with ease, and they even carry very heavy loads. But hold on! Substances that are denser than water will sink in water. So, how does a steel ship float?

The shape of the ship allows it to float. Imagine a ship that was just a big block of steel, as shown in ***Figure 18.*** If you put that steel block into water, it would sink because it is denser than water. Ships are built with a hollow shape, as shown below. The amount of steel is the same, but the hollow shape decreases the boat's density. Water is denser than the hollow boat, so the boat floats.

INTEGRATING

BIOLOGY

Some fish can adjust their density so that they can stay at a certain water depth. Most fish have an organ called a *swim bladder,* which is filled with gases. The inflated swim bladder increases the fish's volume, decreases its overall density, and keeps it from sinking. The fish's nervous system controls the amount of gas in the bladder according to the fish's depth in the water. Some fish, such as sharks, do not have a swim bladder, so they must swim constantly to keep from sinking.

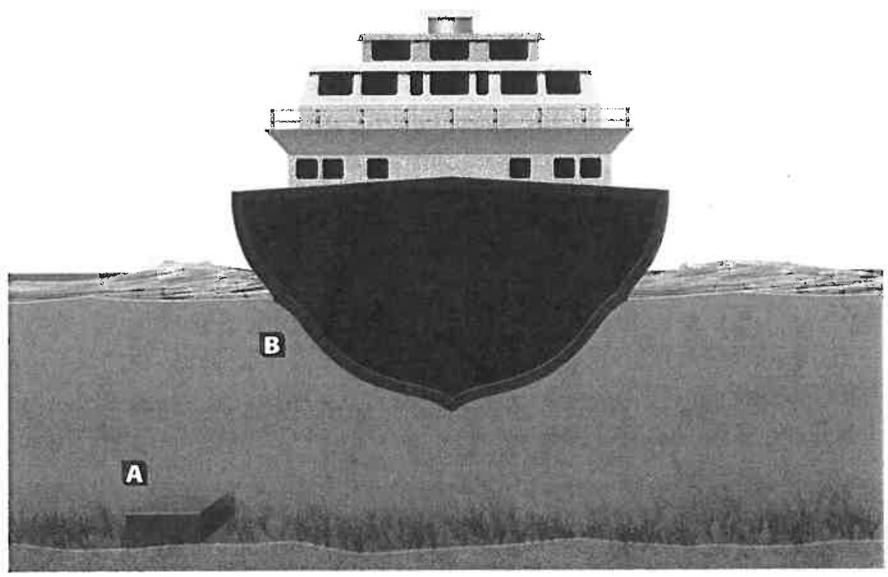


Figure 18

A A block of steel is denser than water, so it sinks.

B Shaping the block into a hollow form increases the volume occupied by the same mass, which results in a reduced overall density. The ship floats because it is less dense than water.

Fluids and Pressure

You probably have heard the terms *air pressure, water pressure,* and *blood pressure.* Air, water, and blood are all fluids, and all fluids exert pressure. So, what is pressure? For instance, when you pump up a bicycle tire, you push air into the tire. Inside the tire, tiny air particles are constantly pushing against each other and against the walls of the tire, as shown in ***Figure 19.*** The more air you pump into the tire, the more the air particles push against the inside of the tire, and the greater the pressure against the tire is. Pressure can be calculated by dividing force by the area over which the force is exerted:

$$pressure = \frac{force}{area}$$

The SI unit for pressure is the **pascal.** One pascal (Pa) is the force of one newton exerted over an area of one square meter (1 N/m^2). You will learn more about newtons, but remember that a newton is a measurement of force. Weight is a force, and an object's weight can be given in newtons.

When you blow a soap bubble, you blow in only one direction. So, why does the bubble get rounder as you blow, instead of longer? The shape of the bubble is due partly to an important property of fluids: fluids exert pressure evenly in all directions. The air you blow into the bubble exerts pressure evenly in all directions, so the bubble expands in all directions and creates a round sphere.

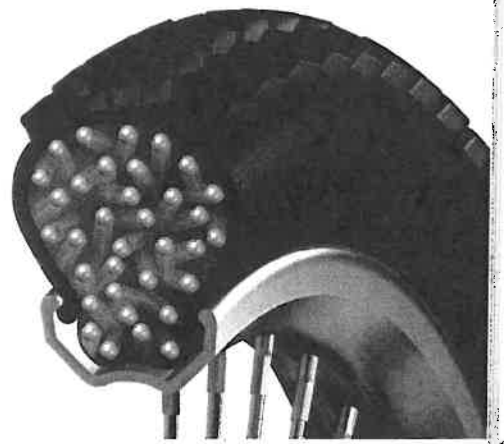


Figure 19
The force of air particles inside the tire creates pressure, which keeps the tire inflated.

pascal the SI unit of pressure; equal to the force of 1 N exerted over an area of 1 m^2 (abbreviation, Pa)

REAL WORLD APPLICATIONS

Density on the Move A submarine is a type of ship that can travel both on the surface of the water and underwater. Submarines have special ballast tanks that control their buoyancy. When the submarine dives, the tanks can be opened to allow sea water to flow in. This water adds mass and increases the submarine's density, so the submarine can descend into the ocean. The crew can control the amount of water taken in to control the submarine's depth. To bring the submarine through the water and to the surface, compressed air is blown into the ballast tanks to force the water out. The first submarine, *The Turtle,* was used in 1776 against British warships during the American War of Independence. It was a one-person, hand-powered, wooden vessel. Most modern submarines are built of metals and use nuclear power, which enables them to remain submerged almost indefinitely.

Applying Information

1. Identify the advantages of using metals instead of wood in the construction of today's submarines.

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Pascal's Principle

Have you ever squeezed one end of a tube of paint? Paint usually comes out the opposite end. When you squeeze the sides of the tube, the pressure you apply is transmitted throughout the paint. So, the increased pressure near the open end of the tube forces the paint out. This phenomenon is explained by Pascal's principle, which was named for the 17th-century scientist who discovered it. **Pascal's principle** states that a change in pressure at any point in an enclosed fluid will be transmitted equally to all parts of the fluid. Mathematically, Pascal's principle is stated as $p_1 = p_2$ or $pressure_1 = pressure_2$.

Pascal's principle the principle that states that a fluid in equilibrium contained in a vessel exerts a pressure of equal intensity in all directions

Math Skills

Pascal's principle

A hydraulic lift, shown in ***Figure 20,*** makes use of Pascal's principle, to lift a 19,000 N car. If the area of the small piston (A_1) equals 10.5 cm^2 and the area of the large piston (A_2) equals 400 cm^2, what force needs to be exerted on the small piston to lift the car?

1 List the given and unknown values.

Given: $F_2 = 19{,}000$ N
$A_1 = 10.5$ cm^2
$A_2 = 400$ cm^2

Unknown: F_1

2 Write the equation for Pascal's principle.

According to Pascal's principle, $p_1 = p_2$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \qquad F_1 = \frac{(F_2)(A_1)}{A_2}$$

3 Insert the known values into the equation, and solve.

$$F_1 = \frac{(19{,}000 \text{ N})(10.5 \text{ cm}^2)}{400 \text{ cm}^2}$$

$$F_1 = 499 \text{ N}$$

Practice HINT

Pressure, Force, and Area

The pressure equation

$$pressure = \frac{force}{area}$$

can be used to find pressure or can be rearranged to find force or area.

$$force = (pressure)(area)$$

$$area = \frac{force}{pressure}$$

Practice

Pascal's principle

1. In a car's liquid-filled hydraulic brake system, the master cylinder has an area of 0.5 cm^2, and the wheel cylinders each have an area of 3.0 cm^2. If a force of 150 N is applied to the master cylinder by the brake pedal, what force does each wheel cylinder exert on its brake pad?

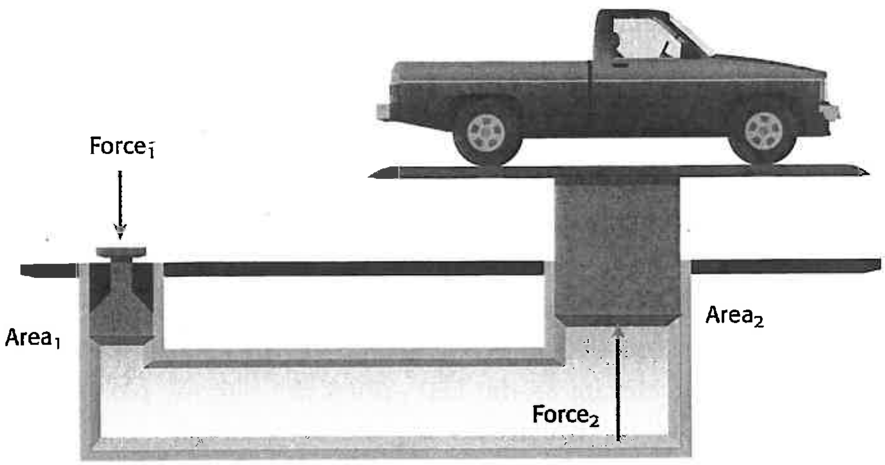


Figure 20

Because the pressure is the same on both sides of the enclosed fluid in a hydraulic lift, a small force on the smaller area (left) produces a much larger force on the larger area (right).

Hydraulic devices are based on Pascal's principle

Devices that use liquids to transmit pressure from one point to another are called *hydraulic devices.* Hydraulic devices use liquids because liquids cannot be compressed, or squeezed, into a much smaller space. This property allows liquids to transmit pressure more efficiently than gases, which can be compressed.

Hydraulic devices can multiply forces. For example, in ***Figure 20,*** a small downward force (F_1) is applied to a small area. This force exerts pressure on the liquid in the device, such as oil. According to Pascal's principle, this pressure is transmitted equally to a larger area, where it creates a force (F_2) larger than the initial force. Thus, the initial force can be multiplied many times.

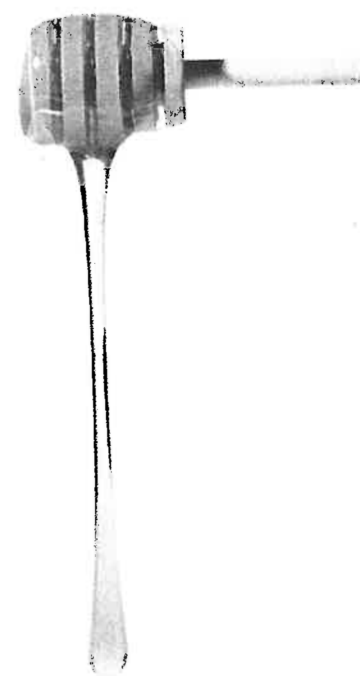


Figure 21

The honey shown above has a higher viscosity than water.

Fluids in Motion

Examples of moving fluids include liquids flowing through pipes and air moving as wind. Have you ever used a garden hose? What happens when you place your thumb over the end of the hose? Your thumb blocks some of the area through which the water flows out of the hose, so the water exits at a faster speed. Fluids move faster through smaller areas than through larger areas, if the overall flow rate remains constant. Fluid speed is faster in a narrow pipe and slower in a wider pipe.

Viscosity is resistance to flow

Liquids vary in the rate at which they flow. For example, honey flows more slowly than lemonade. **Viscosity** is a liquid's resistance to flow. In general, the stronger the attraction between a liquid's particles the more viscous the liquid is. Honey flows more slowly than lemonade because it has a higher viscosity than lemonade. ***Figure 21*** shows a liquid that has a high viscosity.

viscosity the resistance of a gas or liquid to flow

Fluid pressure decreases as speed increases

Figure 22 shows a water-logged leaf being carried along by water in a pipe. The water will move faster through the narrow part of the pipe than through the wider part, which is a property of fluids. Therefore, as the water carries the leaf into the narrow part of the pipe, the leaf moves faster. If you measure the pressure at point 1 and point 2, labeled in ***Figure 22,*** you would find that the water pressure in front of the leaf is less than the pressure behind the leaf. The pressure difference causes the leaf and the water around it to accelerate as the leaf enters the narrow part of the tube. This behavior illustrates a general principle, known as *Bernoulli's principle,* which states that as *the speed of a moving fluid increases, the pressure of the moving fluid decreases.* This property of moving fluids was first described in the 18th century by Daniel Bernoulli, a Swiss mathematician.

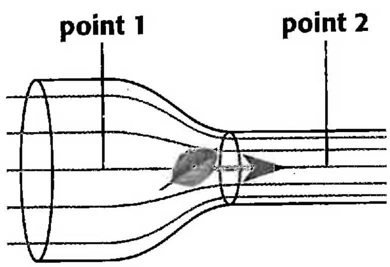


Figure 22
As a leaf passes through the drainage pipe, it speeds up. The water pressure on the right is less than the pressure on the left.

SECTION 2 REVIEW

SUMMARY

- Gases and liquids are fluids.
- Buoyancy is the tendency of a less dense substance to float in a denser liquid; buoyant force is the upward force exerted by fluids.
- Archimedes' principle states that the buoyant force on an object equals the weight of the fluid displaced by the object.
- Pressure is a force exerted on a given area; fluids exert pressure equally in all directions.
- Pascal's principle states that a change in pressure at any point in an enclosed fluid will be transmitted equally to all parts of the fluid.
- Bernoulli's principle states that fluid pressure decreases as the speed of a moving fluid increases.

1. **Explain** how differences in fluid pressure create buoyant force on an object.
2. **State** Archimedes' principle and give an example of how you could determine a buoyant force.
3. **State** Pascal's principle, and give an example of its use.
4. **Compare** the viscosity of milk and molasses.
5. **Define** the term *fluids.* What does Bernoulli's principle state about fluids?
6. **Critical Thinking** Two ships in a flowing river are sailing side-by-side with only a narrow space between them.
   - **a.** What happens to the fluid speed between the two boats?
   - **b.** What happens to the pressure between the boats?
   - **c.** How could this change lead to a collision of the boats?

Math Skills

7. A water bed that has an area of 3.75 m^2 weighs 1025 N. Find the pressure that the water bed exerts on the floor.
8. An object weighs 20 N. It displaces a volume of water that weighs 15 N. (a) What is the buoyant force on the object? (b) Will the object float or sink? Explain.
9. Iron has a density of 7.9 g/cm^3. Mercury has a density of 13.6 g/cm^3. Will iron float or sink in mercury? Explain.

SECTION 3

Behavior of Gases

OBJECTIVES

- **Explain** how gases differ from solids and liquids.
- **State and explain** the following gas laws: Boyle's law, Charles's law, and Gay-Lussac's law.
- **Describe** the relationship between gas pressure, temperature, and volume.

KEY TERMS

Boyle's law
Charles's law
Gay-Lussac's law

Because many gases are colorless and odorless, it is easy to forget that they exist. But, every day you are surrounded by gases. Earth's atmosphere is a gaseous mixture of elements and compounds. Some examples of gases in Earth's atmosphere are nitrogen, oxygen, argon, helium, and carbon dioxide, as well as methane, neon and krypton. In the study of chemistry, as in everyday life, gases are very important. In this section, you will learn how pressure, volume, and temperature affect the behavior of gases.

Properties of Gases

As you have already learned, the properties of gases are unique. Some important properties of gases are listed below.

- Gases have no definite shape or volume, and they expand to completely fill their container, as shown in ***Figure 23.***
- Gas particles move rapidly in all directions.
- Gases are fluids.
- Gas molecules are in constant motion, and they frequently collide with one another and with the walls of their container.
- Gases have a very low density because their particles are so far apart. Because of this property, gases are used to inflate tires and balloons.
- Gases are compressible.
- Gases spread out easily and mix with one another. Unlike solids and liquids, gases are mostly empty space.

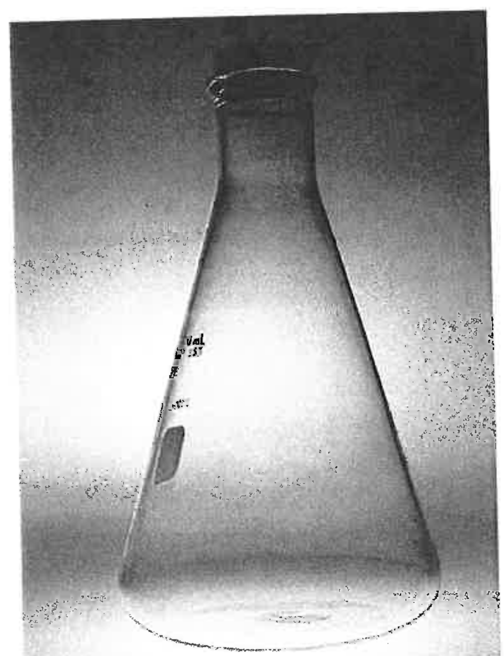


Figure 23
As you can see in this photo of chlorine gas, gases take the shape of their container.

Did You Know?

The ability of gas particles to move and the relative sizes of gas particles have practical applications. Garrett Morgan was an African American born in Kentucky in 1875. Although he had only six years of formal education, he was an inventor of many useful products. For example, he invented a gas mask that allowed air, but not harmful gases, to pass through it. The mask received little recognition until Morgan used it to rescue 30 workers who were trapped underground in a tunnel that contained poisonous gases.

Gases exert pressure on their containers

A balloon filled with helium gas is under pressure. The gas in the balloon is pushing against the walls of the balloon. The kinetic theory helps to explain pressure. Helium atoms in the balloon are moving rapidly and they are constantly hitting each other and the walls of the balloon, as shown in ***Figure 24.*** Each gas particle's effect on the balloon wall is small, but the battering by millions of particles adds up to a steady force. The pressure inside the balloon is the measure of this force per unit area. If too many gas particles are in the balloon, the battering overcomes the force of the balloon holding the gas in, and the balloon pops.

If you let go of a balloon that you have held pinched at the neck, most of the gas inside rushes out and causes the balloon to shoot through the air. A gas under pressure will escape its container if possible. If there is a lot of pressure in the container, the gas can escape with a lot of force. For this reason, gases in pressurized containers, such as propane tanks for gas grills, can be dangerous and must be handled carefully.

Gas Laws

You can easily measure the volume of a solid or liquid, but how do you measure the volume of a gas? The volume of a gas is the same as the volume of its container but there are other factors, such as pressure, to consider.

The gas laws describe how the behavior of gases is affected by pressure and temperature. Because gases behave differently than solids and liquids, the gas laws will help you understand and predict the behavior of gases in specific situations.

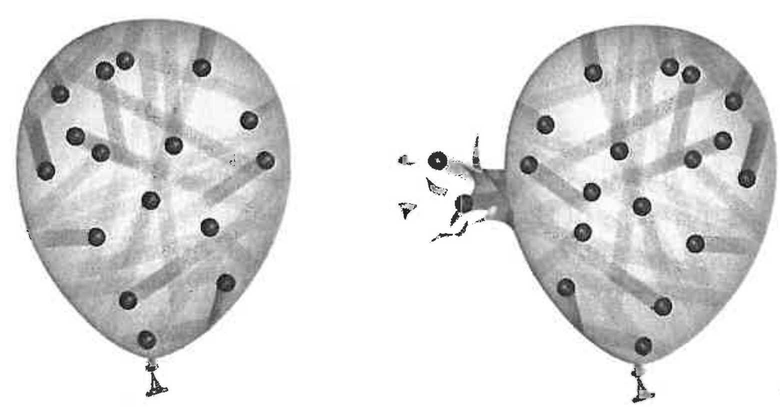


Figure 24

A Gas particles exert pressure by hitting the walls of the balloon.

B The balloon pops because the internal pressure is more than the balloon can hold.

Figure 25

Boyle's law Each illustration shows the same piston and the same amount of gas at the same temperature.

A Lifting the plunger decreases the pressure of the gas; the gas particles spread farther apart.

B Releasing the plunger allows the gas to change to an intermediate volume and pressure.

C Pushing the plunger increases the pressure, and decreases the volume of the gas.

Boyle's law relates the pressure of a gas to its volume

A diver at a depth of 10 m blows a bubble of air. As the bubble rises, its volume increases. When the bubble reaches the water's surface, the volume of the bubble will have doubled because of the decrease in pressure. The relationship between the volume and pressure of a gas is known as **Boyle's law.** Boyle's law states that for a fixed amount of gas at a constant temperature, the volume of a gas increases as its pressure decreases. Likewise, the volume of a gas decreases as its pressure increases. Boyle's law is illustrated in ***Figure 25.*** Boyle's law can be expressed as: $(pressure_1)(volume_1) = (pressure_2)(volume_2)$ or $P_1V_1 = P_2V_2$.

Boyle's law the law that states that for a fixed amount of gas at a constant temperature, the volume of the gas increases as the pressure of the gas decreases and the volume of the gas decreases as the pressure of the gas increases

Quick Lab

Does temperature affect the volume of a balloon?

Materials

- *aluminum pans (2)*
- *ice*
- *balloon*
- *hot plate*
- *beaker 250 ml*
- *ruler*
- *gloves*
- *water*

1. Fill an aluminum pan with 5 cm of water. Put the pan on the hot plate.
2. Fill another pan with 5 cm of ice water.
3. Blow up a balloon inside a beaker. The balloon should fill the beaker but should not extend outside it. Tie the balloon at its opening.
4. Place the beaker and balloon in the ice water. Record your observations.
5. Remove the balloon and beaker from the ice water. Observe the balloon for several minutes, and record any changes.
6. Next, put the beaker and balloon in the hot water. Record your observations.

Analysis

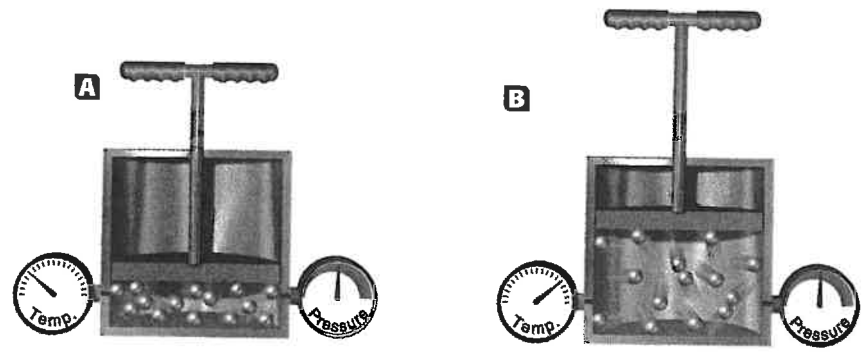
1. How did changing the temperature affect the volume of the balloon?
2. Is the density of a gas affected by temperature?

Figure 26

Each illustration shows the same piston and the same amount of gas at the same pressure.

A Decreasing the temperature causes the gas particles to move more slowly; they hit the sides of the piston less often and with less force. As a result, the volume of the gas decreases.

B Raising the temperature of the gas causes the particles to move faster. As a result, the volume of the gas increases.



Charles's law relates the temperature of a gas to its volume

Charles's law the law that states that for a fixed amount of gas at a constant pressure, the volume of the gas increases as the temperature of the gas increases and the volume of the gas decreases as the temperature of the gas decreases

An inflated balloon will also pop when it gets too hot which demonstrates another gas law—Charles's law. **Charles's law** states that for a fixed amount of gas at a constant pressure, the volume of the gas increases as its temperature increases. Likewise, the volume of the gas decreases as its temperature decreases. Charles's law is illustrated by the model in ***Figure 26.*** You can see Charles's law in action by putting an inflated balloon in the freezer and waiting about 10 minutes to see what happens!

As shown in ***Figure 27,*** if the gas in an inflated balloon is cooled (at constant pressure), the gas will decrease in volume and cause the balloon to deflate.

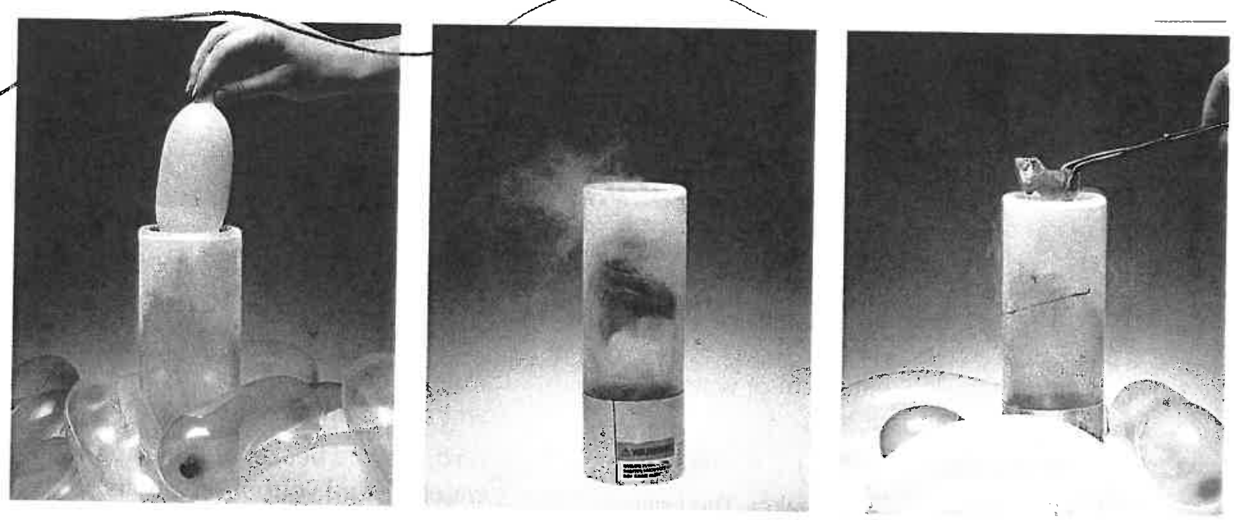


Figure 27

A Air-filled balloons are exposed to liquid nitrogen.

B The balloons shrink in volume.

C The balloons are removed from the liquid nitrogen and are warmed. The balloons expand to their original volume.

Math Skills

Boyle's Law

The gas in a balloon has a volume of 7.5 L at 100 kPa. The balloon is released into the atmosphere, and the gas expands to a volume of 11 L. Assuming a constant temperature, what is the pressure on the balloon at the new volume?

1 List the given and unknown values.

Given: $V_1 = 7.5$ L

$P_1 = 100$ kPa

$V_2 = 11$ L

Unknown: P_2

2 Write the equation for Boyle's law, and rearrange the equation to solve for P_2.

$$P_1V_1 = P_2V_2$$

$$P_2 = \frac{P_1V_1}{V_2}$$

3 Insert the known values into the equation, and solve.

$$P_2 = \frac{(100\ \text{kPa})(7.5\ \text{L})}{11\ \text{L}}$$

$$P_2 = 68\ \text{kPa}$$

Practice HINT

Boyle's Law

The equation for Boyle's law can be rearranged to solve for volume in the following way. Use the equation $P_1V_1 = P_2V_2$. Divide both sides by P_2

$$\frac{P_1V_1}{P_2} = \frac{P_2V_2}{P_2}$$

$$\frac{P_1V_1}{P_2} = V_2$$

You will need to use this form of the equation in Practice Problems 2, 3, and 4.

Practice

Boyle's Law

1. A flask contains 155 cm^3 of hydrogen collected at a pressure of 22.5 kPa. Under what pressure would the gas have a volume of 90.0 cm^3 at the same temperature? (Recall that 1 cm^3 5 1 mL.)
2. If the pressure exerted on a 300.0 mL sample of hydrogen gas at constant temperature is increased from 0.500 atm to 0.750 atm, what will be the final volume of the sample?
3. A helium balloon has a volume of 5.0 L at a pressure of 101.3 kPa. The balloon is released and reaches an altitude of 6.5 km at a pressure of 50.7 kPa. If the gas temperature remains the same, what is the new volume of the balloon? Assume that the pressures are the same inside and outside of the balloon.
4. A sample of oxygen gas has a volume of 150 mL at a pressure of 0.947 atm. What will the volume of the gas be at a pressure of 1.000 atm if the temperature remains constant?

Gay-Lussac's law relates gas pressure to temperature

You have just learned about the relationship between the volume and temperature of a gas at constant pressure. What would you predict about the relationship between the pressure and temperature of a gas at constant volume? Remember that pressure is the result of collisions of gas molecules against the walls of their containers. As temperature increases, the kinetic energy of the gas particles increases. The energy and frequency of the collision of gas particles against their containers increases. For a fixed quantity of gas at constant volume, the pressure increases as the temperature increases.

Joseph Gay-Lussac is given credit for recognizing this property in 1802. **Gay-Lussac's law** states that the pressure of a gas increases as the temperature increases if the volume of the gas does not change. So if pressurized containers that hold gases, such as spray cans, are heated, they may explode. You should always be careful to keep containers of pressurized gas away from heat.

Gay-Lussac's law the law that states that the pressure of a gas at a constant volume is directly proportional to the absolute temperature

SECTION 3 REVIEW

SUMMARY

- Gases are fluids, their particles are in constant motion, they have low density, they are compressible, and they expand to fill their container.
- Gas pressure increases as the number of collisions of gas particles increases.
- Boyle's law states that the volume of a gas increases as the pressure decreases if the temperature does not change.
- Charles's law states that the volume of a gas increases as the temperature increases if the pressure does not change.
- Gay-Lussac's law states that the pressure of a gas increases as the temperature increases if the volume does not change.

1. **List** four properties of gases.
2. **Explain** why the volume of a gas can change.
3. **Describe** how gases are different from solids and liquids and give examples.
4. **Identify** what causes the pressure exerted by gas molecules on their container.
5. **Restate** Boyle's law, Charles's law, and Gay-Lussac's law.
6. **Identify** a real-life example for each of the three gas laws.
7. **Critical Thinking** When scientists record the volume of a gas, why do they also record the temperature and the pressure?
8. **Critical Thinking** Predict what would happen to the volume of a balloon left on a sunny windowsill. Which gas law predicts this result?

Math Skills

9. A partially inflated weather balloon has a volume of 1.56×10^3 L and a pressure of 98.9 kPa. What is the volume of the balloon when it is released to a height where the pressure is 44.1 kPa?