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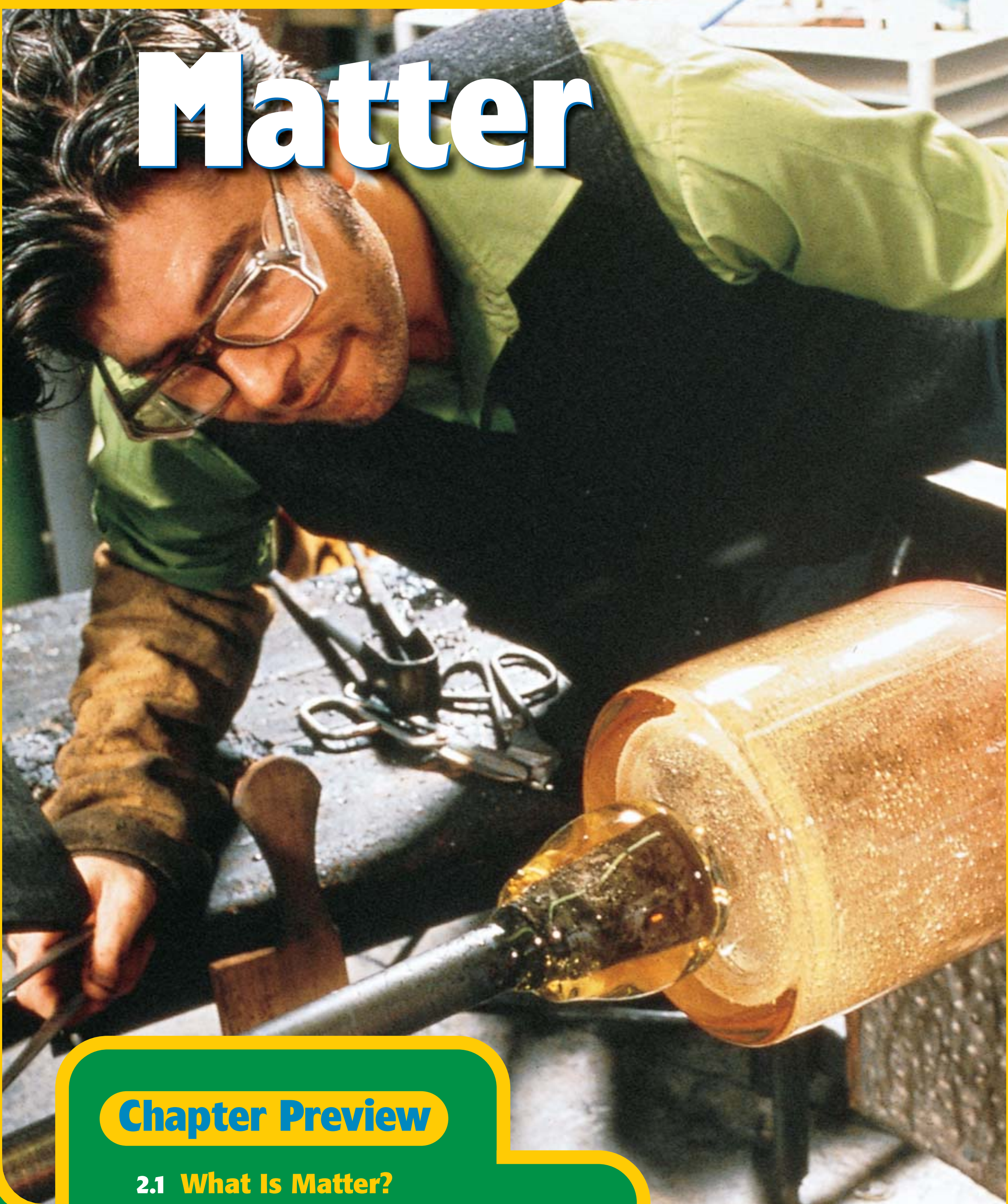
CHAPTER 2

Matter



Chapter Preview

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Glass changes from a solid to a liquid and back to a solid through heating and cooling.

Focus ACTIVITY

Background Ordinary sand is poured into pots with some finely ground limestone and a powder called soda ash. Then the mixture is heated to about 1500°C, and the sand begins to become transparent and flow like honey.

A glass blower dips a hollow iron blowpipe into the red-hot mixture. A gob of molten glass no larger than your hand sticks to the end of the blowpipe. Turning the sticky fluid mass on the pipe and blowing into the tube, the glass blower makes a hollow bulb.

The glass blower can pull, twist, and blow the soft bulb into many different shapes. The mass is reheated to stay soft until the glass blower achieves the desired final shape. Finally, the ball is broken off the tube. The original powder has become a fragile, clear glass object.

Activity 1 Visit a glass company that replaces automobile glass and window glass. Find out how many different types of glass the company has and what makes each type different.

Activity 2 Go to your local recycling center to find out how much glass and what kind of glass is recycled in your community. Why do you think glass is a popular material to recycle?

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2.1

What Is Matter?

KEY TERMS
- chemistry
- matter
- element
- atom
- compound
- molecule
- chemical formula
- pure substance
- mixture
- miscible
- immiscible

OBJECTIVES
- Explain the relationship between matter, atoms, and elements.
- Distinguish between elements and compounds.
- Interpret and write some common chemical formulas.
- Categorize materials as pure substances or mixtures.

Making glass, as shown in **Figure 2-1,** involves changing the raw materials sand, limestone, and soda ash into a different substance. This is what **chemistry** is all about: what things are made of and how things change. Everything you use daily, from soap to food to glue, you choose because of chemistry—either because of what it is made of or how it changes.

chemistry the study of matter and how it changes

Glass is used as a building material because its properties of being transparent, solid, and waterproof match the needs we have for windows. The properties of sand, on the other hand, do not match these needs. Chemistry keeps the choices among so many materials from being too confusing because it helps you recognize how the differences in material properties relate to what the materials are made of.

Matter

matter anything that has mass and occupies space

You are made of **matter.** This book is also matter. All the materials you can hold or touch are matter. The air you are breathing is matter, even though you can't see it. Light, sound, and electricity are not matter. Unlike air, they have no mass or volume.

Figure 2-1
Glass blowers have been practicing their craft with few changes for more than 2000 years.

Atoms are matter

Wood is matter. Because it is fairly rigid and lightweight, wood is a good choice for furniture and buildings. When wood gets hot enough, it chars—its surface turns black. The wood surface breaks down to form another kind of material with different properties, carbon. No chemical reactions of the carbon in the charred residue will cause the carbon to decompose. Carbon is an **element,** and elements are made of **atoms.** An image of some specially arranged iron atoms is shown in **Figure 2-2.**

Diamonds are made of atoms of the element carbon. The shiny foil wrapped around a baked potato is made of atoms of the element aluminum. The elements that are most abundant on Earth and most abundant in the human body are shown in **Figure 2-3.** Each element also has a one- or two-letter symbol used worldwide to designate it. For example, carbon is C, iron is Fe, copper is Cu, and aluminum is Al. Each of the more than 110 elements that we now know is unique and behaves differently from the rest.

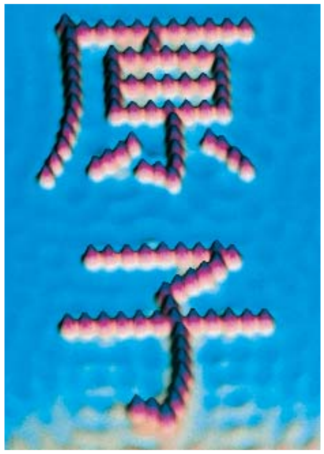


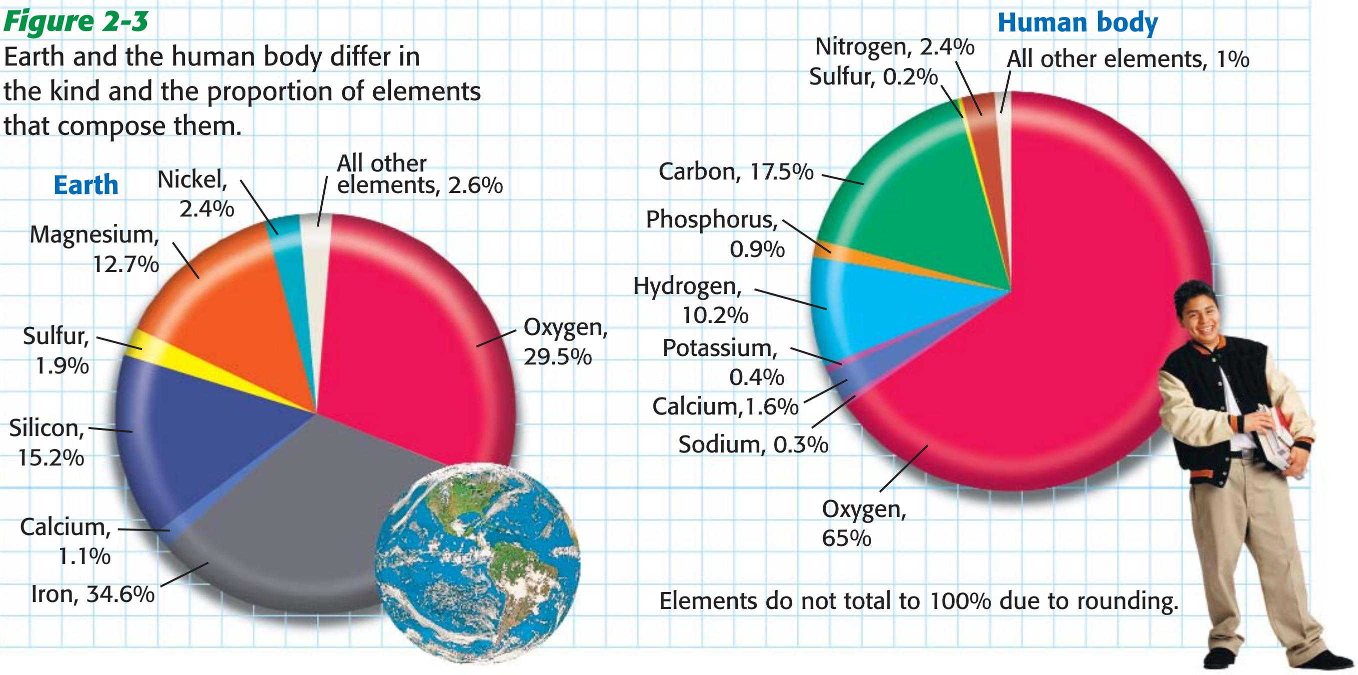
Figure 2-2
This scanning tunneling microscope image shows iron atoms (red) on copper atoms (blue).

- **element** a substance that cannot be broken down into simpler substances
- **atom** the smallest particle that has the properties of an element
- **compound** a substance made of atoms of more than one element bound together

Two or more elements combine chemically to make a compound

Many familiar substances, such as aluminum and iron, are elements. Nylon is another familiar substance, but it is not an element. Nylon is a **compound.** The basic unit that makes up nylon contains carbon, hydrogen, nitrogen, and oxygen atoms, but each strand actually contains thousands of these units linked together.

Figure 2-3
Earth and the human body differ in the kind and the proportion of elements that compose them.



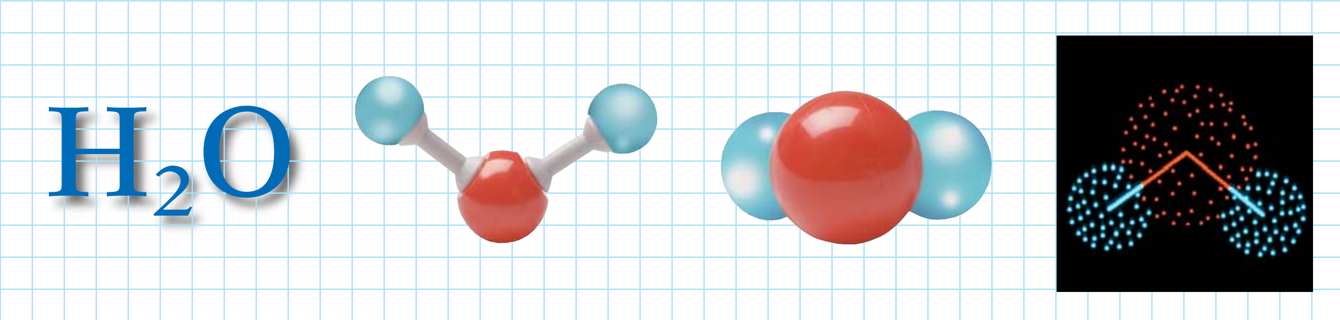


Figure 2-4
A water molecule can be represented as a formula, in physical models, or on a computer.

Every compound is unique and is different from the elements it contains. For example, the elements hydrogen, oxygen, and nitrogen occur in nature as colorless gases. Yet when they combine with carbon to form nylon, the strands of nylon are a flexible solid.

Each unit of iron(III) oxide, which we see often as rust, is made of two atoms of iron and three atoms of oxygen. When elements combine to make a specific compound, the elements always combine in the same proportions. Iron(III) oxide always has two parts of iron for every three parts of oxygen.

molecule the smallest unit of a substance that exhibits all of the properties characteristic of that substance

A molecule acts as a unit

Atoms can join together to make millions of different **molecules** just as letters of the alphabet combine to form different words. A molecular substance you are familiar with is water. A water molecule is made of two hydrogen atoms and one oxygen atom, as shown in **Figure 2-4.**

When oxygen and hydrogen form a molecule of water, the atoms combine and act as a unit. That is what a molecule is—the smallest unit of a substance that behaves like the substance. Most molecules are made of atoms of different elements, just as water is. But a molecule also may be made of atoms of the same element, such as those in **Figure 2-5.** Besides the elements shown in the figure, fluorine, nitrogen, iodine, and bromine form molecules of two atoms. Sulfur forms a molecule of eight atoms, S_8.

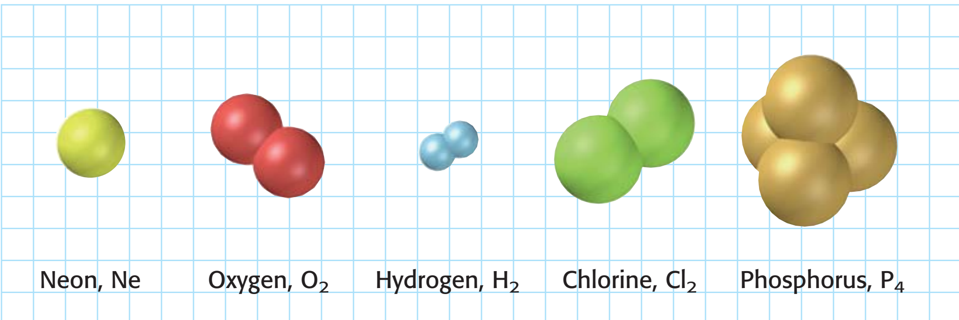


Figure 2-5
The atoms of elements like neon, Ne, are found singly in nature. Other elements like oxygen, hydrogen, chlorine, and phosphorus form molecules with more than one atom. Their unit molecules are O_2, H_2, Cl_2, and P_4.

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Chemical formulas represent compounds and molecules

Indigo is the dye originally used to turn jeans blue. The **chemical formula** for a molecule of indigo, $C_{16}H_{10}N_2O_2$, is shown in **Figure 2-6.** The chemical formula shows how many atoms of each element are in the basic unit of a substance. When the chemical formula is written, the number of atoms of each element in the basic unit is written after the element's symbol as a *subscript*. No subscript number is used if only one atom of an element is present, so the chemical formula for carbon dioxide is CO_2, not ~~C_1O_2~~.

Numbers placed in front of the chemical formula show the number of molecules. For example, three molecules of table sugar are written as $3C_{12}H_{22}O_{11}$. Each molecule of the sugar contains 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms.

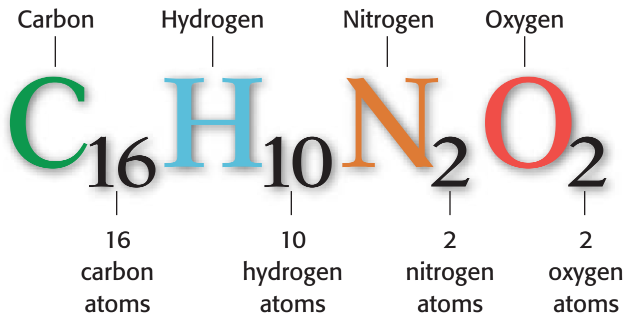


Figure 2-6
The chemical formula for a molecule of indigo shows that it is made of four elements and 30 atoms.

chemical formula the chemical symbols and numbers indicating the atoms contained in the basic unit of a substance

Pure Substance or Mixture?

When people use the word *pure,* they usually mean "not mixed with anything else." "Pure grape juice" contains only the juice of grapes, with nothing added or taken away. In chemistry, the word *pure* means more than this. A **pure substance** is matter with a fixed composition and definite properties.

Grape juice isn't a pure substance. It is a **mixture** of many different pure substances, such as water, sugars, acids, and vitamins. The composition of grape juice is not fixed; it can have different amounts of water or sugar or other compounds. Elements and compounds are pure substances, but mixtures are not. Practically all of the things we eat are mixtures. The air we breathe is mainly a mixture of nitrogen and oxygen.

A mixture like grape juice can be separated. The water in grape juice can evaporate, leaving the sugar, acids, and other compounds. Yet the water molecules are not changed by evaporation. A pure substance, like water, cannot be broken down by physical changes.

pure substance any matter that has a fixed composition and definite properties

mixture a combination of more than one pure substance

Pure substances blended together make mixtures

While a compound is different from the elements that make it, a mixture may have some properties similar to the pure substances that make it. Although you can't see the different substances in grape juice, the mixture has chemical and physical properties in common with its components. For example, grape juice is wet like the water and sweet like the sugar that is in it.

INTEGRATING

BIOLOGY

Indigo is a natural plant dye made from members of the genus *Indigofera,* which is in the pea family. Before synthetic dyes were developed, indigo was widely grown in the East Indies, in India, and in the Americas. Most indigo species are shrubs 1 to 2 m in height. Leaves and branches of the plants are fermented to yield a paste, which is formed into blocks and then finely ground. The blue color develops as the material is exposed to air.

Figure 2-7

A Flour is suspended in water. **B** Salt dissolves in water.

Mixtures are classified by how thoroughly the substances mix

Some mixtures are made by putting solids and liquids together. In **Figure 2-7,** two white powdery solids, flour and salt, are each mixed with water. Despite the physical similarities of these solids, the mixtures they form with water are very different.

The flour doesn't mix well with the water, yielding a cloudy white mixture. You can see that flour does not dissolve in water. A mixture of flour and water is called a *heterogeneous mixture* because the substances aren't uniformly mixed.

The salt-and-water mixture looks very different from the flour-and-water mixture. You cannot see the salt, and the mixture is clear. That's because salt dissolves in water. Even if you leave the mixture for a long time, the salt will not settle out. Salt and water yield a *homogeneous mixture* because the mixing occurs between the individual units and is the same throughout.

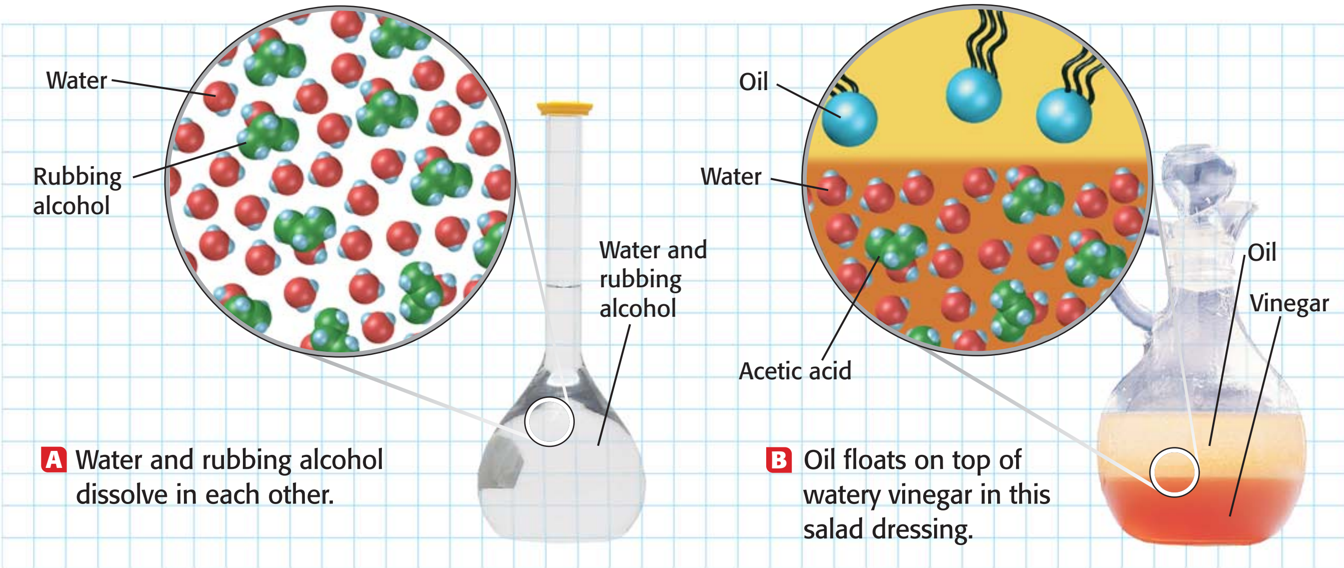
Gasoline is a liquid mixture—a homogeneous mixture of at least 100 compounds in various quantities. Because the compounds are **miscible,** gasoline looks like a pure substance even though it isn't.

If you shake a mixture of oil and water, the water will settle out after a while. Oil and water form a heterogeneous mixture. Because oil and water are **immiscible,** you can see two layers in the mixture. **Figure 2-8** shows examples of liquid mixtures.

miscible describes two or more liquids that are able to dissolve into each other in various proportions

immiscible describes two or more liquids that do not mix into each other

Figure 2-8 **Examples of Miscible and Immiscible Liquids**



A Water and rubbing alcohol dissolve in each other.

B Oil floats on top of watery vinegar in this salad dressing.

Science and the Consumer

Dry Cleaning: How Are Stains Dissolved?

Why do some clothes need to be dry cleaned, while others do not? Washing with water and detergents cleans most clothes. But if your clothes have a stubborn stain—such as ink or rust, if you have spilled something greasy on your clothes, or if the label on the clothing recommends dry cleaning, then dry cleaning may be necessary. Dry cleaning is recommended on a clothing label when the fabric does not respond well to water. Certain fabrics, like silk and wool, are usually cleaned without water because water causes them to shrink, take on stubborn wrinkles, or lose their shape.

Stain Removal

Knowing the composition of a stain helps dry cleaners decide how to treat it. Removing a stain that doesn't dissolve in water, such as oil or grease, involves two steps. First, the stain is treated with a substance that loosens the stain. Then the stain is removed when the garment is washed in a mechanical dry cleaner.

If a stain is water-soluble, it will dissolve in water. A water-soluble stain is first treated with a stain remover that is specific to that stain. The stain is then flushed away with a steam gun. After the garment is dry, it is cleaned in a dry-cleaning machine to remove any stains that do not dissolve in water.

Once the fabric has been treated for tough stains, the garment is washed in a dry-cleaning machine.

Dry Cleaning Isn't Really Dry

In spite of its name, dry cleaning does involve liquids. The process uses a liquid solvent instead of water. It is always difficult to remove fats, greases, and oils from fabrics with water-based washing.

A good dry-cleaning solvent must dissolve oil and grease, which trap the water-insoluble particles in the cloth fibers. The most commonly used dry-cleaning solvent is tetrachloroethylene, C_2Cl_4. Tetrachloroethylene is the preferred solvent because oil, grease, and alcohols dissolve in it. Also, tetrachloroethylene is not flammable, and it evaporates easily. This allows it to be recycled by distillation.

In distillation, the components of a mixture are separated based on their rates of evaporation. Upon heating, the component that evaporates most quickly is the first to vaporize and separate from the mixture. When the vapors are cooled, they condense to form a purified sample of that component.

Tetrachloroethylene is suspected of causing some kinds of cancer. To meet the standards of the United States Occupational Safety and Health Administration (OSHA) and other federal guidelines, dry-cleaning machines must be airtight so that no C_2Cl_4 escapes.

Your Choice

1. **Critical Thinking** Explain why it is difficult to remove fats, greases, and oils from fabrics with water-based washing alone.
2. **Critical Thinking** Tetrachloroethylene evaporates more quickly than the fats, grease, and oils it dissolves. Describe how C_2Cl_4 can be recycled by distillation.

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Gases can mix with liquids

Air is a mixture of gases consisting mostly of nitrogen and oxygen. You get oxygen every time you breathe because the gases in air form a homogeneous mixture. Carbonated drinks are also homogeneous mixtures. They contain sugar, flavorings, and carbon dioxide gas, CO_2, dissolved in water. When carbonated drinks are manufactured, the carbon dioxide gas is mixed into the liquid under pressure and forms a solution.

Even a liquid that is not mixed with gas under pressure can contain dissolved gases. If you let a glass of cold water stand overnight, you may be able to see bubbles on the sides of the glass the next morning. The bubbles are some of the air that was dissolved in the cold water.

Carbonated drinks often have a foam on top. A foam is a different kind of gas-liquid mixture. The gas is not dissolved in the liquid but has formed tiny bubbles in it. Eventually, the tiny bubbles join together to form bigger bubbles that can escape from the foam, and the foam collapses.

Other foams are stable and last for a long time. If you whip egg white with enough air, you get a foam. If you heat that foam in an oven, the liquid egg white dries and hardens, and you have a solid foam—meringue.

INTEGRATING

EARTH SCIENCE

The molten rock in some types of volcanoes contains large quantities of gas. Pumice, a solid foam that occurs naturally on Earth, is a volcanic rock formed by the violent separation of these extremely hot gases from lava. As the exploding lava cools, it traps the gas bubbles. Some pumice is so soft that it is spongy, and some is so light that it floats on water. Often pumice occurs as small pea-size lumps, but it also occurs in deposits large enough to be mined and sold commercially as an abrasive.

SECTION 2.1 REVIEW

SUMMARY

- Matter has mass and occupies space.
- An element is a substance that cannot be broken down into a simpler substance.
- An atom is the smallest particle of matter that has the properties of a particular element.
- Atoms can join together to form molecules.
- A pure substance that contains two or more elements is a compound.
- A pure substance can be represented by a chemical formula.

CHECK YOUR UNDERSTANDING

1. **Define** *chemistry.*
2. **List** the two types of pure substances.
3. **Explain** why light is not matter.
4. **Complete** the following analogy:
   A heterogeneous mixture is to a homogeneous mixture as immiscible liquids are to __________.
5. **Classify** each of the following as an element or a compound:
   a. sulfur, S_8 **c.** carbon monoxide, CO
   b. methane, CH_4 **d.** cobalt, Co
6. **Describe** the makeup of pure water, and write its chemical formula.
7. **Compare and Contrast** mixtures and pure substances. Give an example of each.
8. **Critical Thinking** David and Susan are looking at a jar of honey labeled "Pure Honey." David says, "That means it's natural honey, with nothing else added." Susan says, "It isn't really pure. It's a mixture of lots of different substances." Who is right? Explain your answer. WRITING SKILL

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2.2

Matter and Energy

OBJECTIVES

- Use the kinetic theory to describe the properties and structures of the different states of matter.
- Describe the energy transfers involved in changes of state.
- Describe the laws of conservation of mass and conservation of energy, and explain how they apply to changes of state.

KEY TERMS

pressure
viscosity
energy
evaporation
condensation
sublimation

If you go to a bakery, such as the one in **Figure 2-9,** you can smell the cookies baking even though you are a long way from the oven. One way to explain this phenomenon is to make some assumptions. First, assume that the particles (molecules and atoms) within substances can move. Second, assume that the molecules and atoms move faster as the temperature rises. A theory based on these assumptions, called the kinetic theory of matter, can be used to explain things like why you can smell cookies baking from far away.

When cookies are baking, energy is transferred from the oven to the cookies. As the temperature in the oven is increased, some molecules within the cookie dough move fast enough to become gases, which in turn spread through the air in the bakery.

Figure 2-9
The substances that make the fresh cookies smell so good may be vanillin, $C_8H_8O_3$, or cinnamaldehyde, C_9H_8O.

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, the faster the particles move.**
- **At the same temperature, more massive (heavier) particles move slower than less massive (lighter) particles.**

The kinetic theory is a useful tool for visualizing the differences between the three common states of matter: solids, liquids, and gases.

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Common States of Matter

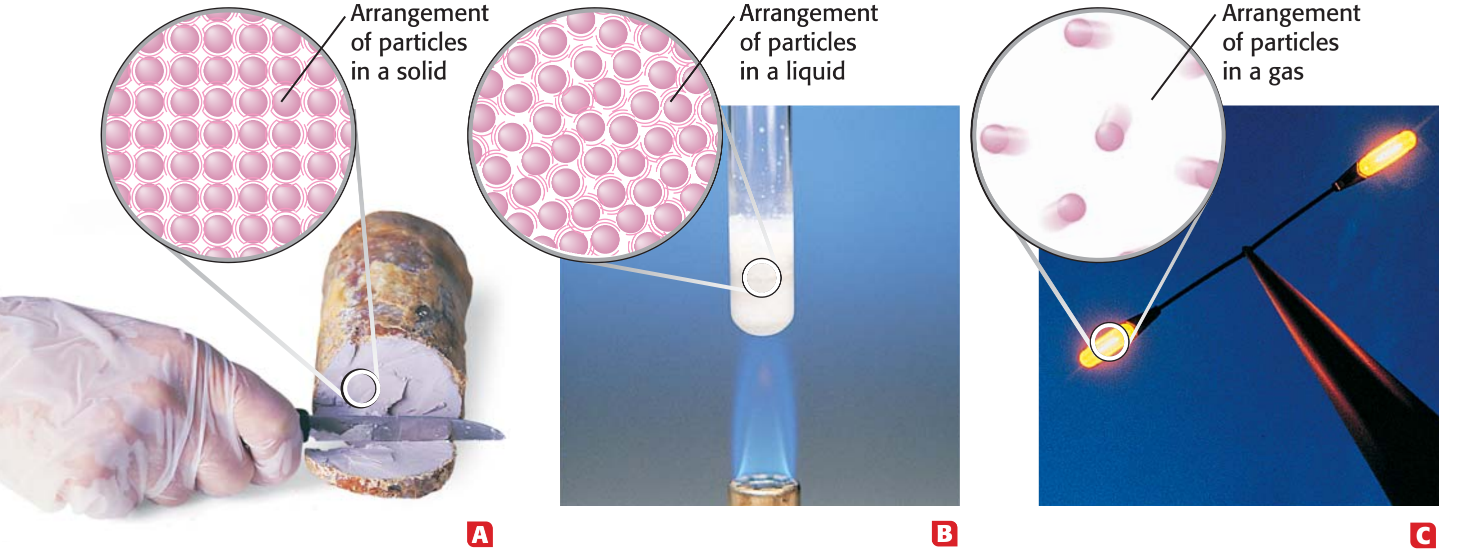

Figure 2-10
Gases, liquids, and solids are the most common states of matter on Earth. Here, the element sodium is shown as (A) the solid metal, (B) melted as a liquid, and (C) as a gas in a sodium-vapor lamp.

The states of matter are physically different

The models for solids, liquids, and gases shown in **Figure 2-10** differ in the distances and angles between molecules or atoms and in how closely these particles are packed together. Gas particles, like those in helium, are in a constant state of motion and rarely stick together. In a liquid, like cooking oil, the particles are closely packed, but they can still slide past each other. Particles in a solid, like iron, are in fixed positions. Most matter found naturally on Earth is either a solid, a liquid, or a gas, but matter also exists in other states.

Gases are free to spread in all directions

Have you noticed that a balloon filled with a "light" gas such as helium goes flat more quickly than a balloon filled with air? You can use the kinetic theory to explain this. The wall of the balloon has tiny holes through which gas particles can escape. The helium particles are smaller and less massive than the nitrogen and oxygen particles found in air. The smaller and less massive particles move faster, so they get through the holes more quickly.

If you leave a jar of perfume open, you will soon smell it from across the room. This is one of the characteristics of a gas—it expands to fill the available space. Kinetic theory can be used to explain this property as well. Under standard conditions of temperature and pressure, particles of a gas move rapidly. Oxygen, O_2, averages almost 500 m/s, and helium, He, travels at more than 1200 m/s. At these speeds, gas particles collide billions of times a second. Like all particles of gas, helium atoms bounce off each other when they collide. As helium atoms bounce around and move freely, they spread to fill the available space.

Did You Know?

Very dense neutron stars and plasmas are examples of two other generally accepted states of matter. Our sun and most stars are plasmas made of fast-moving charged particles. In the Bose-Einstein condensate, atoms are at temperatures so close to absolute zero that they behave as one atom. This state of matter was first observed in 1995. Einstein predicted it in 1925 when he furthered the calculations of S. N. Bose, an Indian physicist.

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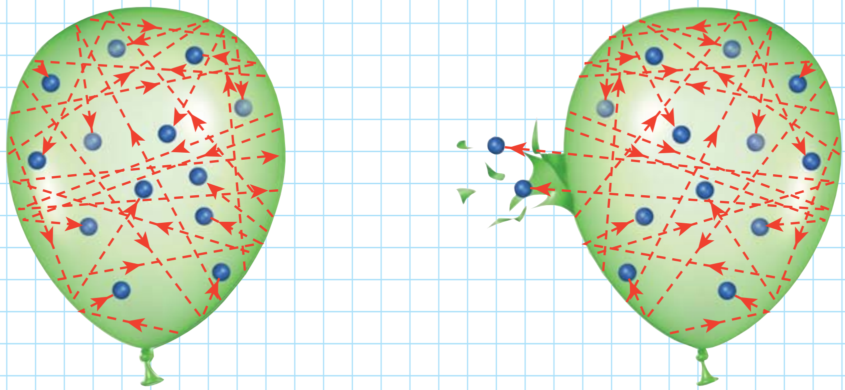
Figure 2-11



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

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

Gases can exert pressure

You may know that a balloon filled with helium is under **pressure.** The gas in the balloon is pushing out against the balloon walls. The kinetic theory also helps to explain pressure. Helium atoms in the balloon are moving very quickly and are constantly hitting each other and the walls of the balloon, as shown in the model in **Figure 2-11.** Each particle's effect on the balloon wall is tiny, but the battering by millions of particles adds up to a steady force. The pressure inside the balloon is the measure of this steady force per unit area. If too many particles of gas 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've held pinched at the neck, most of the gas inside rushes out, causing the balloon to shoot through the air. Gases under pressure will escape their 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 cylinders and similar containers, like propane tanks for gas grills, can be dangerous and must be handled carefully.

pressure the force exerted per unit area of a surface

PHYSICAL SCIENCE INTERACTIVE TUTOR

Disc One, Module 1:
States of Matter/Classes of Matter
Use the Interactive Tutor to learn more about this topic.

Solids have a rigid structure

If you take an ice cube out of the freezer and put it on a table, the ice will stay there as long as it remains solid. It has the same volume and shape that it had in the ice tray. Unlike gases, a solid does not need a container to have a shape. This is because the structure of a solid is very rigid, and the particles have almost no freedom to change position. The crystals of salt in **Figure 2-12** reflect the ordered arrangement of particles in most solids. The particles are held closely together by strong attractions, yet they can still vibrate around a fixed location.

Figure 2-12
The particles in these crystals of salt cannot move freely like the particles in a liquid or a gas can. These crystals of sodium chloride have been magnified 840 times.

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Quick ACTIVITY

Kinetic Theory

You will need water, vegetable oil, and rubbing alcohol.

SAFETY CAUTION The alcohol is flammable and toxic.

1. Dip one index finger into the water. Dip your other index finger into the oil. Wave each finger in the air. Do your fingers feel cool? How quickly does each liquid evaporate?
2. Repeat the experiment, using water and rubbing alcohol on different fingers.
3. Which of the three liquids evaporates the quickest? the slowest? Which liquid cools your skin the most? the least?
4. Use the kinetic theory to explain your observations.
5. Identify which liquid has the highest viscosity.

viscosity the resistance of a fluid to flow

energy the ability to change or move matter

Liquids take the shape of their container

The particles of a liquid are close together, but they are not attracted to each other as strongly as they are in a solid. So the particles in a liquid have more freedom of movement. Because particles in a liquid can move randomly, liquids can spread out on their own. And because liquids and gases can spread, both are classified as *fluids*.

Liquids vary in the rate at which they spread. You know from experience that honey is thicker and flows more slowly than lemonade. This property, **viscosity,** is determined by the attraction between particles in a liquid. The stronger the attraction, the more slowly the liquid will flow, and the higher the viscosity will be.

Energy's Role

What sources of energy would you use if the electricity was off? You might use candles for light and batteries to power a clock. Electricity, candles, and batteries are sources of energy. So is the food you eat. Substances that release heat when they are mixed together are another source of energy. You can think of **energy** as the ability to change or move matter. In Chapter 9, you will learn how energy can be described as the ability to do work.

Energy must be added to cause melting or evaporation

The first major step in the process of recycling aluminum cans is to melt the aluminum. Heating solid aluminum transfers energy to the aluminum atoms. As the atoms gain energy, they vibrate faster. Eventually, they break away from their fixed positions, and the aluminum melts, becoming a liquid. Energy is required to melt aluminum or any solid because the particles must break away from their fixed positions.

You can feel the effects of an energy change when you feel a breeze after you have been perspiring. Energy from your body's molecules is transferred as heat to the water on your skin. When this transfer occurs, your body's molecules cool off and slow down, while the water molecules gain energy and move faster, as shown in **Figure 2-13.**

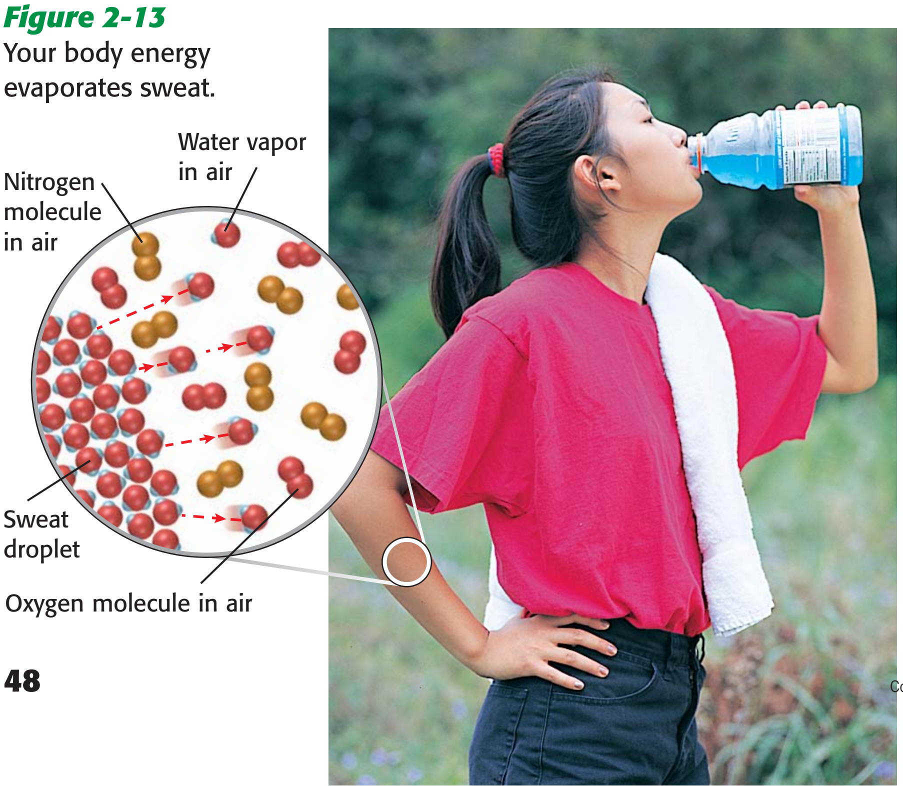

Figure 2-13
Your body energy evaporates sweat.

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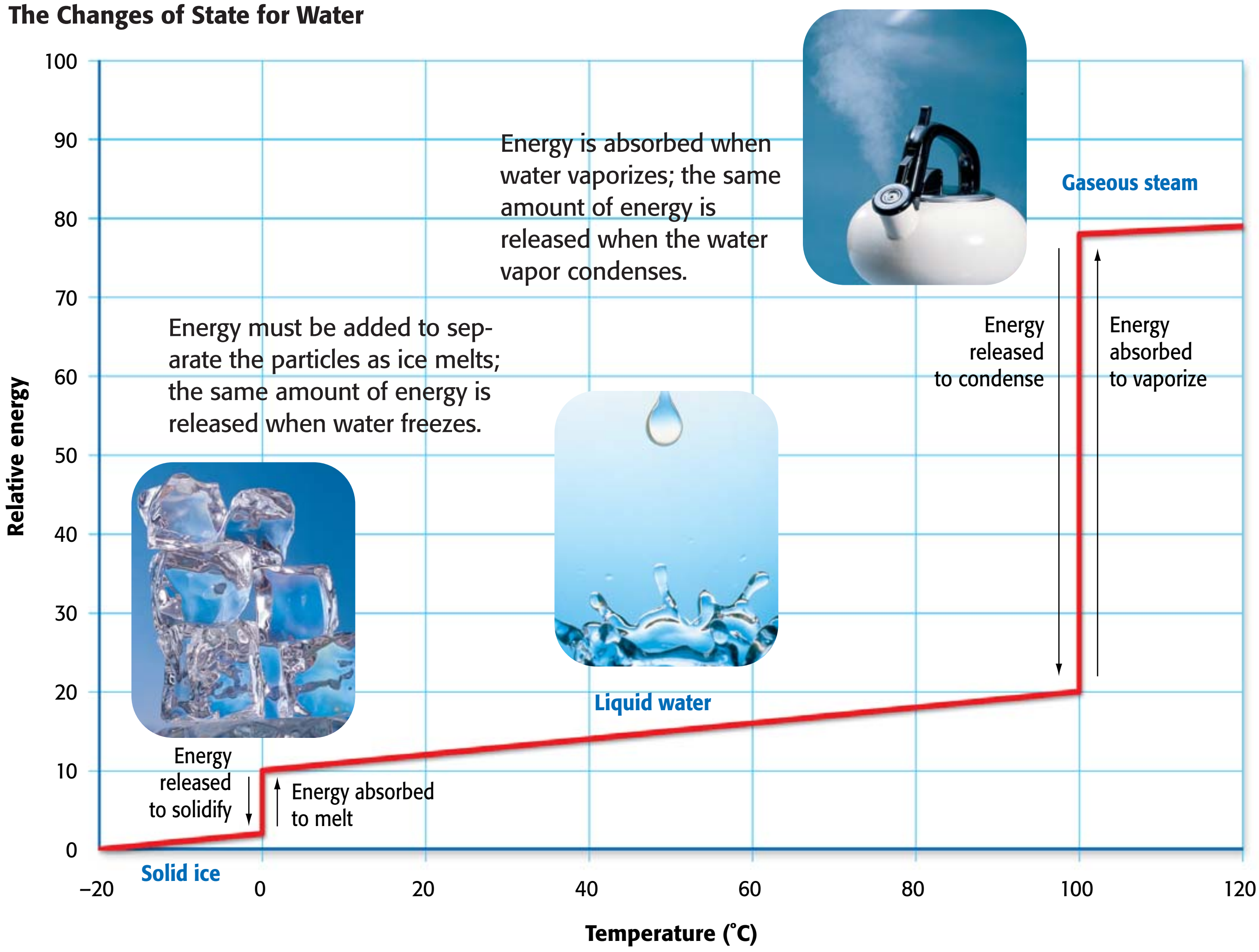
Figure 2-14
The Changes of State for Water



Eventually, the fastest moving molecules break away from the liquid surface to form a gas. The water is said to **evaporate.** It takes energy to separate the particles of a liquid to form a gas.

Evaporation occurs slowly when liquids are cool. But as the temperature of the liquid increases, more of the molecules gain enough energy to break away from the liquid surface and form a gas. If the liquid is heated enough, so many molecules become gas that bubbles form below the surface of the liquid and the liquid boils.

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

Energy is transferred in all changes of state

When water vapor **condenses** to become a liquid or liquid water freezes to form ice, energy is transferred from the water to its surroundings. The water molecules slow down during this energy transfer. The graph in **Figure 2-14** shows the energy transfers that occur as water changes among the three common states of matter.

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

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Figure 2-15
Dry ice (solid carbon dioxide) sublimes to form gaseous carbon dioxide but no liquid.

Some substances do not have a liquid form at normal temperature and pressure. **Figure 2-15** shows solid carbon dioxide, CO_2, undergoing **sublimation,** that is, turning directly into a gas without becoming a liquid. Sometimes, ice made of water molecules sublimes, forming a gas. When left in the freezer for a couple of months, ice cubes get smaller as the ice sublimes.

sublimation the change of a substance from a solid to a gas

Changing state does not change composition or mass

Heating or cooling can change the state of a substance. Look at the changes of state that are happening in **Figure 2-16.** Some of the steam is condensing. As this happens, heat is transferred to the surroundings, so the steam cools and turns back into liquid water. Changing the energy of a substance can change the state of the substance, but changing energy does not change the composition of a substance. Ice, water, and steam are all made of H_2O molecules. All that changes is the nature of the attractions between the molecules—strong in a solid and almost nonexistent in a gas.

When an ice cube melts, the mass of the liquid water is the same as the mass of the ice cube. Even though the ice underwent a physical change to produce the water, the mass was not increased or reduced. Similarly, when water boils, the number of water molecules stays the same even as the liquid water loses volume. The mass of the steam is the same as the mass of the liquid water that boiled off.

Figure 2-16
Whether it is ice, water, or steam, water in any form is always made of H_2O molecules.

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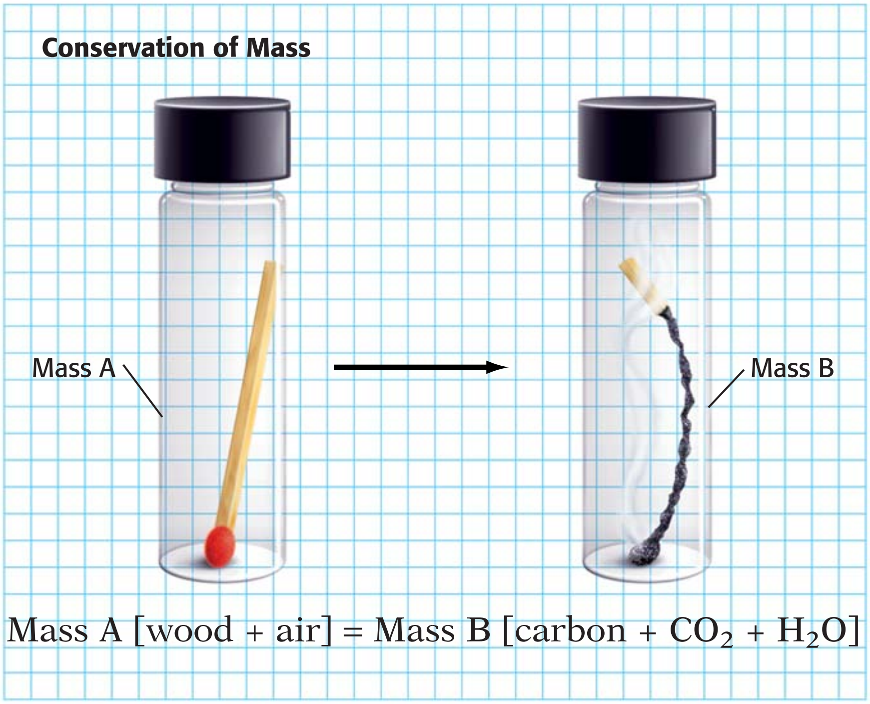

Figure 2-17
The match is changed by burning, but the mass of the contents of the vial remains the same.

The law of conservation of mass

In chemical changes as well as in physical changes, the total mass of all matter stays the same before and after a change. Matter changes from one form to another, but the total mass stays the same. This is called the law of conservation of mass. The law of conservation of mass is stated as follows.

Mass cannot be created or destroyed.

When you burn a match, it seems to lose mass. The ash has less mass than the original match. But the burning reaction involves gases too, and gases have mass, even though they may be difficult to see or measure. There is also mass in the oxygen that reacts with the match, in the tiny particles that we see as smoke, and in the gases formed in the reaction. The total mass of the reactants (match and oxygen) is the same as the total mass of the products (ash, smoke, and gases), as you can see in **Figure 2-17.**

The law of conservation of energy

Although energy may be converted from one form to another during a physical or chemical change, the total amount of energy before and after the change is always the same. This is the law of conservation of energy, which can be stated as follows.

Energy cannot be created or destroyed.

The law of conservation of energy is described in more detail in Chapter 9.

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 percent of the atoms in the universe and constitutes about 75 percent of the mass of the universe. Helium atoms make up most of the remainder. The total of all the other elements contributes very little to the total mass of the universe.

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At first glance, starting a car may seem to violate this law. For the tiny amount of energy needed for a person 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 arrangement and properties of compounds that make up gasoline, gasoline has stored energy. When this stored energy is considered, the energy before you start the car is equal to the energy afterward.

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.

When you study nuclear changes and radioactivity in Chapter 7, you will learn that the law of conservation of mass and the law of conservation of energy can be made into one law, which covers all the changes discussed here.

internetconnect

SCILINKS NSTA

TOPIC: States of matter
GO TO: www.scilinks.org
KEYWORD: HK1023

SECTION 2.2 REVIEW

SUMMARY

- The kinetic theory assumes that all matter is made of tiny particles that are always moving.
- Solids have a fixed volume and shape.
- Gases have a variable volume and shape.
- Liquids have a fixed volume but variable shape.
- Pressure is the force exerted per unit area of a surface.
- The viscosity of a fluid is its resistance to flow.
- Energy is the ability to heat, change, or move matter.
- Mass and energy are conserved in all changes.

CHECK YOUR UNDERSTANDING

1. **Define** *energy.*
2. **State** the law of conservation of mass and the law of conservation of energy.
3. **List** two examples for each of the three common states of matter.
4. **Rank** the following in order of increasing strength of forces between molecules:
   a. honey **b.** marble **c.** water **d.** candle wax **e.** nitrogen gas
5. **Compare and Contrast** the shape and volume of solids, liquids, and gases.
6. **Predict** which two of the following involve the same energy transfer. Assume that the same substance and the same mass is involved in all four processes.
   a. melting **b.** evaporation **c.** sublimation **d.** condensation
7. **Describe** the energy transfers that occur when ice melts and 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. **Creative Thinking** Describe a characteristic of gases, and use the kinetic theory to explain how a dog could find you by your scent.

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2.3

Properties of Matter

OBJECTIVES

- Distinguish between chemical and physical properties of matter.
- Perform calculations involving density.
- Distinguish between chemical and physical changes in matter.
- Apply the laws of conservation of mass and conservation of energy to chemical and physical changes.
- Evaluate materials and their properties for different uses.

KEY TERMS

- chemical property
- reactivity
- physical property
- melting point
- boiling point
- density
- buoyancy
- chemical change
- physical change

The frame and engine of a car are made of steel. Steel is a mixture of iron, small amounts of other metallic elements, and carbon. It is a strong, rigid solid that provides structure and support. The tires are made of a soft, pliable solid that cushions your ride. Liquid gasoline becomes a gas before it burns in the presence of a spark and oxygen. You may not think of the cars you see in **Figure 2-18** as examples of chemistry. However, each of the properties and changes that make these substances useful in cars is described by chemistry.

Chemical and Physical Properties

Some elements, like sodium, react easily with other elements and usually are found as compounds in nature. Other elements, like gold, are much less reactive and often are found uncombined in nature. Magnesium is so reactive it is used to make emergency flares. Light bulbs are filled with argon gas because argon does not react, so the tungsten filament burns longer. All of these are examples of **chemical properties.**

chemical property the way a substance reacts with others to form new substances with different properties

Figure 2-18
How substances combine and are used in these cars depends on their physical and chemical properties.

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Figure 2-19
Rust is formed when oxygen in moist air reacts with iron to form iron(III) oxide, Fe_2O_3.

Chemical properties describe how a substance reacts

You can see rust on the bumper of a truck in **Figure 2-19.** The steel parts rust, but the rubber and plastic parts, such as those that surround the mirror, do not. The rust results when iron atoms in the steel react to form iron(III) oxide and other compounds. Rubber and plastic do not change in this way; they don't contain iron atoms. Steel, rubber, and plastic have different chemical properties. A chemical property describes how a substance acts when it changes, either by combining with other elements or by breaking apart into new substances. Chemical properties involve the **reactivity** of elements or compounds.

> **reactivity** the ability of a substance to combine chemically with another substance

Chemical properties are related to the specific elements that make up substances. The carbon in charcoal will burn and is *flammable*. Flammability is a chemical property that describes whether substances will react in the presence of oxygen and burn when exposed to a flame.

Physical properties remain the same for a pure substance

Unlike chemical properties, **physical properties** can be observed or measured without a change in composition. You can use your senses to observe some of the basic physical properties of a substance: shape, color, odor, and texture. Other physical properties, such as **melting point, boiling point,** strength, hardness, and the ability to conduct electricity, magnetism, or heat, can be measured.

> **physical property** a characteristic of a substance that can be observed or measured without changing the composition of the substance

> **melting point** the temperature at which a solid becomes a liquid

> **boiling point** the temperature at which a liquid becomes a gas below the surface

Physical properties remain constant for specific pure substances. At room temperature and atmospheric pressure, all samples of pure water are always colorless and liquid; pure water is never something like a powdery green solid.

Back

Water boils at 100°C and freezes at 0°C. At atmospheric pressure, pure water always has the same boiling point and melting point. A characteristic of any pure substance is that its boiling point and its melting point are constant. It doesn't matter if you have a lot of water or a little water; the physical properties of the water are constant, regardless of the mass or volume involved. This is true for all pure substances.

density the mass per unit volume of a substance

Density is a physical property

A substance that has a low **density** is sometimes referred to as being "light." The balloons in **Figure 2-20** float because they are lighter than the air around them. A substance that has a high density is sometimes referred to as being "heavy." Earth's core is made of iron because it is heavier—more dense—than other substances that are abundant on our planet.

One way to compare the density of two objects of the same size is to hold one in each hand. The lighter one is less dense; the heavier one is more dense. If you held a brick in one hand and an equal-sized piece of sponge in the other hand, you would know instantly that the brick is more dense than the sponge. **Table 2-1** lists the densities of some common substances.

By knowing the density of a substance, you can know if the substance will float or sink. The density of an object is calculated by dividing the object's mass by its volume.

Figure 2-20
Helium-filled balloons float upward because helium is lighter—or less dense—than air. Similarly, hot-air balloons rise because hot air is less dense than cool air.

Density Equation

$$D = m/V$$

$$density = mass/volume$$

Table 2-1 **Densities of Some Substances**

Substance	Chemical formula	Density in g/cm^3
Air, dry	Mixture	0.00129
Brick, common	Mixture	1.9
Gasoline	Mixture	0.7
Helium	He	0.00018
Ice	H_2O	0.92
Iron	Fe	7.86
Lead	Pb	11.3
Nitrogen	N_2	0.00125
Steel	Mixture	7.8
Water	H_2O	1.00

Did You Know?

The elements osmium and iridium are the two densest substances on Earth. The density of osmium is 22.57 g/cm^3. Iridium has a density of 22.42 g/cm^3. A piece of either metal the size of a baseball has a mass of approximately 4700 g.

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The density of a liquid or a solid is usually reported in units of grams per cubic centimeter (g/cm^3). For example, 10.0 cm^3 of water has a mass of 10.0 g. Its density is 10.0 g for every 10.0 cm^3, or 1.00 g/cm^3. As you learned in Section 1.2, a cubic centimeter contains the same volume as a milliliter. Therefore, in some cases, you may see the density of water expressed as 1 g/mL.

Math Skills

Density If we know that 10.0 cm^3 of ice has a mass of 9.17 g, what is the density of ice?

1 List the given and unknown values.

Given: *mass*, $m = 9.17$ g

volume, $V = 10.0\ cm^3$

Unknown: *density*, $D = ?\ g/cm^3$

2 Write the equation for density.

$$D = \frac{m}{V} \qquad density = \frac{mass}{volume}$$

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

$$D = \frac{9.17\ g}{10.0\ cm^3}$$

$$D = 0.917\ g/cm^3$$

Practice HINT

- When a problem requires you to calculate density, you can use the density equation.

$$D = \frac{m}{V}$$

- You can solve for mass by multiplying both sides of the density equation by volume.

$$DV = \frac{m\cancel{V}}{\cancel{V}} \qquad m = DV$$

You will need to use this form of the equation in Practice Problems 6 and 7.

- You can solve for volume by dividing both sides of the equation shown above by density.

$$\frac{m}{D} = \frac{\cancel{D}V}{\cancel{D}} \qquad V = \frac{m}{D}$$

You will need to use this form of the equation in Practice Problems 8 and 9.

Practice

Density

1. A piece of tin has a mass of 16.52 g and a volume of 2.26 cm^3. What is the density of tin?
2. A man has a 50.0 cm^3 bottle completely filled with 163 g of a slimy green liquid. What is the density of the liquid?
3. A sealed 2500 cm^3 flask is full to capacity with 0.36 g of a substance. Determine the density of the substance. Guess if the substance is a gas, a liquid, or a solid.
4. A piece of metal has a volume of 6.7 cm^3 and a mass of 75.7 g. Find the metal's density. Using the data in **Table 2-1,** suggest what element the metal could be.
5. The mass of a 125 cm^3 piece of a material is 83.75 g. Determine the density of this material.
6. What is the mass of an object that has a density of 8 g/cm^3 and a volume of 64 cm^3?
7. Different kinds of wood have different densities. The density of pine is generally about 0.5 g/cm^3. What is the mass of a 800 cm^3 piece of pine?
8. What is the volume of 325 g of metal with a density of 9.0 g/cm^3?
9. Diamonds have a density of 3.5 g/cm^3. How big is a diamond that has a mass of 0.10 g ?

Back

The difference in the densities of cream and milk allows us to make skim milk. If whole milk, which has not been homogenized, is allowed to stand, the cream will rise to the top, leaving the more watery milk on the bottom. When the cream is skimmed off, what is left is called skim milk.

In **Figure 2-21,** ice is floating in water because of a difference in the densities of the two substances. Water pushes ice to the surface because ice is less dense than water. The tendency of a less dense substance, like ice, to rise and float in a more dense liquid, like water, is called **buoyancy.** A cork floats in water because it is less dense than water and the water pushes up against it.

Figure 2-21
Ice floats in water because ice is less dense than water.

buoyancy the force with which a more dense fluid pushes a less dense substance upward

Properties help determine uses

We use physical properties to help us select a substance that may be useful to us. Copper is used in electrical power lines, telephone lines, and electric motors because of its good electrical conductivity. Antifreeze, which contains ethylene glycol (a poisonous liquid), remains a liquid at temperatures that would freeze or boil the water in a car radiator.

Inquiry Lab

How are the mass and volume of a substance related?

Materials
- ✔ *100 mL graduated cylinder*
- ✔ *250 mL beaker with 200 mL water*
- ✔ *balance*
- ✔ *graph paper*

Procedure

1. Make a data table with 3 columns and 12 rows. In the first row, label the columns "Volume of H_2O (mL)," "Mass of cylinder (g) and H_2O (g)," and "Mass of H_2O (g)." In the remaining spaces of the first column, write: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100. All of your data will be entered on this table.
2. Measure the mass of the empty graduated cylinder, and record it in your data table.
3. Pour the amounts of water listed in the first column of your table from the beaker into the graduated cylinder. Then use the balance to find the mass of the graduated cylinder with the water. Record each value in your data table.
4. On the graph paper, make a graph and label the horizontal x-axis "Mass of water (g)." Mark the x-axis in 10 equal increments for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 g. Label the vertical y-axis "Volume of water (mL)." Mark the y-axis in 10 equal increments for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 mL.
5. Plot a graph of your data either on paper, on a graphing calculator, or by using a graphing/spreadsheet computer program.

COMPUTER SKILL

Analysis

1. Use your graph to predict the mass of 55 mL of water and 100 mL of water.
2. Use your graph to predict the volume of 25 g of water and 75 g of water.
3. How could you use your data table to calculate the density of water? How could you use your graph to calculate the density of water? Which method do you think gives better results? Why?

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REAL WORLD APPLICATIONS

Choosing Materials When you choose materials, you have to make sure their properties are suitable. For example, white acrylic plastic can be used to make false teeth. Sometimes a kind of porcelain is used. Metals are less common, although gold teeth are made sometimes. Fillings usually are made of metal or a special kind of glass.

False teeth have a demanding job to do. They are constantly bathed in saliva, which is corrosive. They must withstand the forces from chewing hard objects, like popcorn or hard candy. The material chosen has to be nontoxic, hard, waterproof, unreactive, tooth-like in appearance, and preferably reasonably priced. Acrylic plastic satisfies these requirements well.

George Washington wore false teeth, but contrary to the legend that they were wood, they were made of hippopotamus bone.

Applying Information

1. Identify some advantages of gold false teeth and Washington's bone teeth.
2. Identify some disadvantages of gold false teeth and Washington's bone teeth.

Chemical and Physical Changes

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SCiLINKS NSTA

TOPIC: Chemical and physical changes
GO TO: www.scilinks.org
KEYWORD: HK1024

Some materials benefit us because they stay in the same state and do not change under normal conditions. Long surgical steel pins are used to reinforce broken bones because surgical steel stays the same even after many years in the human body. Concrete and glass are used as building materials because they change very little under most weather conditions.

Other materials are valued for their ability to change physical states easily. Water is turned into steam to heat homes and factories. Liquid gasoline is changed into a gas so it can burn in car engines.

Still other materials are useful because of their ability to change and combine to form new substances. The compounds in gasoline burn in oxygen to form carbon dioxide and water, releasing energy in the process. This is a **chemical change** because the substances after the change are different from the substances at the beginning.

chemical change a change that occurs when a substance changes composition by forming one or more new substances

You see chemical changes happening more often than you may think. When a battery "dies," the chemicals inside the battery have changed so that the battery can no longer supply energy. The oxygen you inhale is used in a series of chemical reactions in your body. You exhale oxygen in carbon dioxide after it has undergone a chemical change. Chemical changes occur when fruits and vegetables ripen and when the food you eat is digested.

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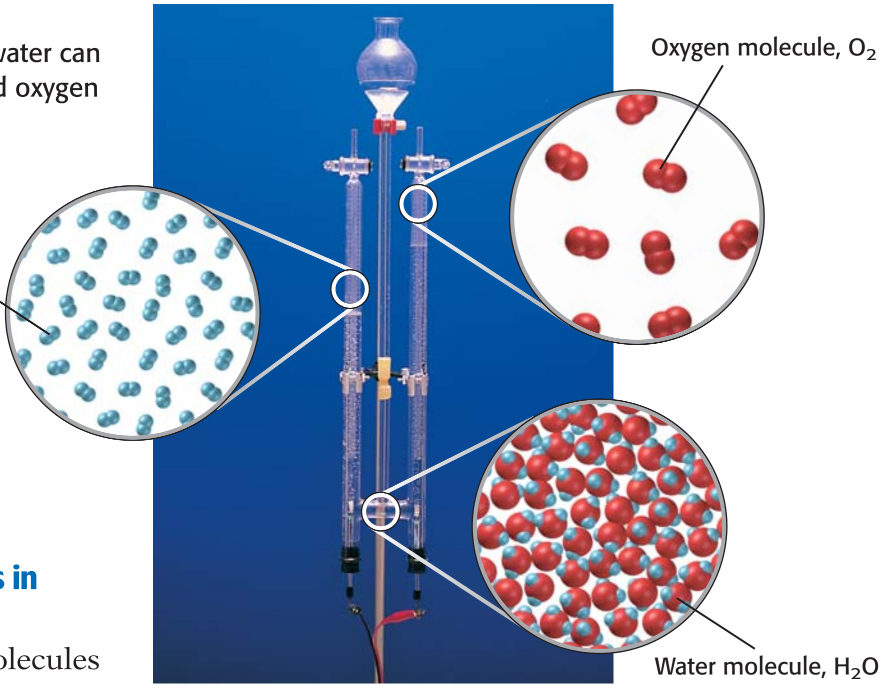

Figure 2-22
Electrolysis is a method by which water can be broken down into hydrogen and oxygen gases.

Chemical changes are changes in composition

When gasoline burns, the molecules involved combine with the oxygen molecules in air to produce new substances. A chemical change also occurs when a compound breaks apart to form at least two other pure substances. When water is broken down, the atoms of oxygen or hydrogen are not destroyed. Rather, these atoms rearrange to form hydrogen gas, H_2, and oxygen gas, O_2, as shown in **Figure 2-22.** The law of conservation of mass applies to all chemical changes. This is because new atoms are not created, and old atoms are not destroyed.

You can learn about the chemical properties of a substance by observing the chemical changes the substance undergoes. A change in odor or color is a good clue that a substance is changing chemically. When food burns, you can often smell the gases given off by the chemical changes that occur. When paint fades, you can see the effects of chemical changes in the paint.

Physical changes do not change composition

Both quartz crystals and sand are made of SiO_2, but they look very different. When quartz crystals are crushed into sand, a physical change takes place. During physical changes, energy always is absorbed or released. After a **physical change,** a substance may look different, but the atoms that make up the substance are not changed or rearranged.

Grinding peanuts into peanut butter or pounding a gold nugget into a ring result in physical changes. But physical changes do not change all the properties of a substance. For example, the color of the gold, its melting point, and its density do not change. Melting, freezing, and evaporating are physical changes, too.

physical change a change in the physical form or properties of a substance that occurs without a change in composition

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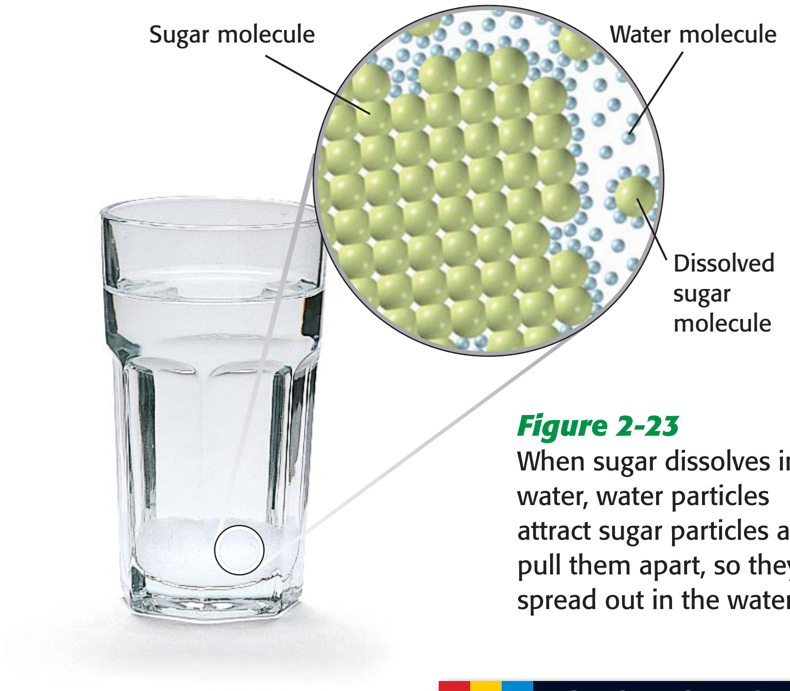

Figure 2-23
When sugar dissolves in water, water particles attract sugar particles and pull them apart, so they spread out in the water.

Dissolving is a physical change

When you stir sugar into water, the sugar dissolves and seems to disappear. But the sugar is still there; you can taste the sweetness when you drink the water. **Figure 2-23** shows how the kinetic theory describes this. When sugar dissolves, it seems to disappear because the sugar particles get spread out between the particles of the water. The molecules of the sugar haven't changed because dissolving is a physical change. Dissolving a solid in a liquid, a gas in a liquid, or a liquid in a liquid are all physical changes.

SECTION 2.3 REVIEW

SUMMARY

- Chemical properties can be observed when one substance reacts with another.
- Physical properties can be observed or measured without changing the composition of matter.
- The density of a substance is equal to its mass divided by its volume.
- New substances are formed in chemical changes.
- Physical changes do not affect all properties because physical changes do not change composition.
- Changes of state, including melting, subliming, evaporating, boiling, condensing, and freezing, are physical changes.

CHECK YOUR UNDERSTANDING

1. **Classify** the following as either chemical or physical properties:
   - **a.** is shiny and silvery
   - **b.** melts easily
   - **c.** burns in air
   - **d.** has a density of 2.3 g/cm^3
   - **e.** tarnishes in moist air
2. **Describe** several uses for plastic, and explain why plastic is a good choice for these purposes.
3. **Classify** the following as either a chemical or a physical change:
   - **a.** ice melting in a drink
   - **b.** sugar added to lemonade
   - **c.** mixing vinegar and baking soda to generate bubbles
   - **d.** plants using CO_2 and H_2O to form O_2 and sugar
4. **Explain** why changes of state are physical changes.
5. **Categorize** the following as either absorbing or releasing energy:
   - **a.** solid carbon dioxide going to CO_2 gas
   - **b.** rubbing alcohol evaporating
   - **c.** aluminum solidifying in a mold
   - **d.** chocolate melting
6. **Calculate** the density of a rock that has a mass of 454 g and a volume of exactly 100 cm^3.
7. **Critical Thinking** You need to build a raft. Write a paragraph describing the physical and chemical properties of the raft that would be important to ensure your safety. You are not limited to the properties discussed in this chapter.

WRITING SKILL

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CHAPTER 2 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found on pages 44, 52, and 60. The key vocabulary terms are listed on pages 38, 45, and 53.

UNDERSTANDING CONCEPTS

1. "Anything that takes up space and has mass" is the definition of ______.

a. a solid **c.** matter
b. a liquid **d.** a gas

2. Which of the following is a compound?

a. sodium **c.** iodine
b. chlorine **d.** water

3. What is the chemical formula for iron(III) oxide?

a. H_2O **c.** H_2O_2
b. NaCl **d.** Fe_2O_3

4. Which of the following is a mixture?

a. air **c.** water
b. salt **d.** sulfur

5. Most of the hot flavor in peppers comes from capsaicin, $C_{18}H_{27}NO_3$. Capsaicin is a(n) ______.

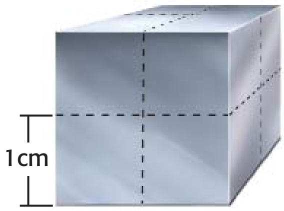
a. element **c.** pure substance
b. mixture **d.** atom

6. Which of the following assumptions is not part of the kinetic theory?

a. All matter is made up of tiny, invisible particles.
b. The particles are always moving.
c. Particles move faster at higher temperatures.
d. Particles are smaller at lower pressure.

7. The cube of metal shown below has a mass of 64 g. The density of the metal is ______.

a. 2.0 g/cm^3
b. 4.0 g/cm^3
c. 8.0 g/cm^3
d. 21 g/cm^3



8. Three common states of matter are ______.

a. solid, water, gas
b. ice, water, gas
c. solid, liquid, gas
d. solid, liquid, air

9. Which of the following is a physical change?

a. melting ice cubes
b. burning paper
c. rusting iron
d. burning gasoline

10. In the figure below, the particles above the cup have ______.

a. lost enough energy to sublime
b. gained enough energy to sublime
c. lost enough energy to evaporate
d. gained enough energy to evaporate

Using Vocabulary

WRITING SKILL

11. In an alcohol thermometer, the height of a constant amount of liquid alcohol in a thin glass tube increases or decreases as temperature changes. Using what you have learned about the kinetic theory, explain the behavior of the alcohol using the following terms: *lose energy, gain energy, volume (or space), movement, molecules (or particles).*

12. The figure at right shows magnesium burning in the presence of oxygen. Give some evidence that the figure shows signs that a chemical change is occurring.

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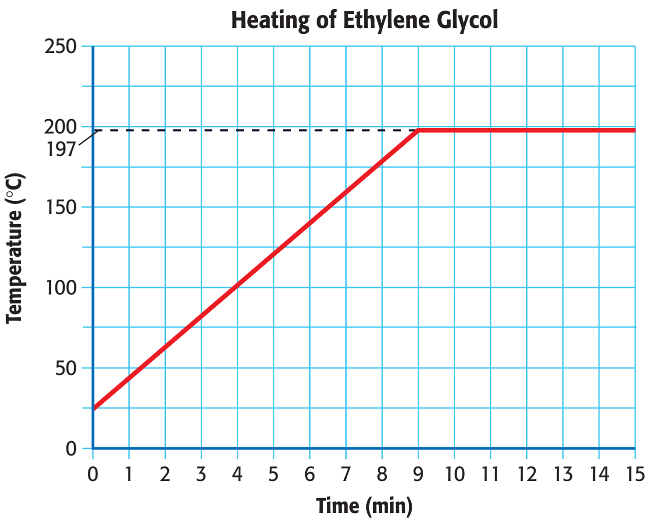
CHAPTER 2 REVIEW

13. Make a table with two columns. Label one column "Physical properties" and the other "Chemical properties." Put each of the following terms in the proper column: *viscosity, density, reactivity, buoyancy, melting point, corrosion, flammability, dissolving, conducting electricity, tarnishing*.

14. When a candle is burned, the wax seems to disappear, and heat and light are given off. Does this violate the laws of conservation of mass and energy? Explain why or why not.

BUILDING MATH SKILLS

15. **Graphing** The graph below shows some effects of heating on ethylene glycol, the liquid commonly used as antifreeze. Until the temperature is 197°C, is the temperature increasing or decreasing? What physical change is taking place when the ethylene glycol is at 197°C? Describe what is happening to the ethylene glycol molecules at 197°C. How can you tell?



16. **Density** A piece of titanium metal has a mass of 67.5 g and a volume of 15 cm^3. What is the density of titanium?

17. **Density** If a liquid has a volume of 620 cm^3 and a mass of 480 g, what is its density?

18. **Density** A sample of a substance with a mass of 85 g occupies a volume of 110 cm^3. What is the density of the substance? Will it float in water?

19. **Density** The density of a piece of brass is 8.4 g/cm^3. If its mass is 510 g, find its volume.

20. **Density** What mass of water in grams will fill a tank 100 cm long, 50 cm wide, and 30 cm high?

21. **Density** A graduated cylinder is filled with water to a level of 40.0 mL. When a piece of copper is lowered into the cylinder, the water level rises to 63.4 mL. Find the volume of the copper sample. If the density of the copper is 8.9 g/cm^3, what is its mass?

THINKING CRITICALLY

22. **Creative Thinking** Suppose you are planning a journey to the center of the Earth in a self-propelled tunneling machine. List properties of the special materials that would be needed to build the machine.

23. **Applying Knowledge** In the early history of the United States, people would search out sandy stream beds in which small particles of gold were mixed with the sand. The particles were separated by "panning." What properties of the two substances, gold and sand, made panning possible?

24. **Acquiring and Evaluating Data** The air in the Earth's atmosphere is a mixture. Research the atmosphere's contents. What are the main components of the Earth's atmosphere? What is the most abundant substance in the mixture? Is air or nitrogen more dense?

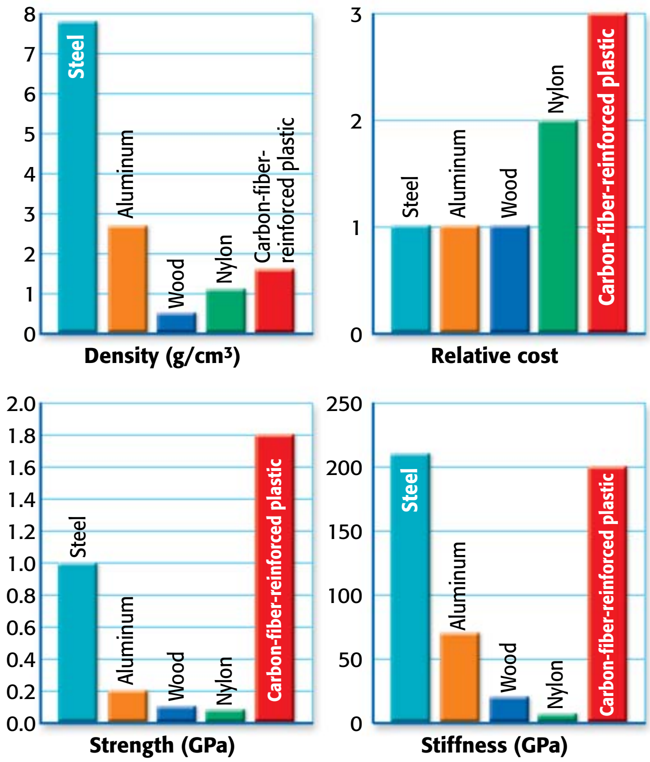
DEVELOPING LIFE/WORK SKILLS

25. Applying Technology Use a computer art program to illustrate a chemical change in which one atom and one molecule interact to form two molecules.

COMPUTER SKILL

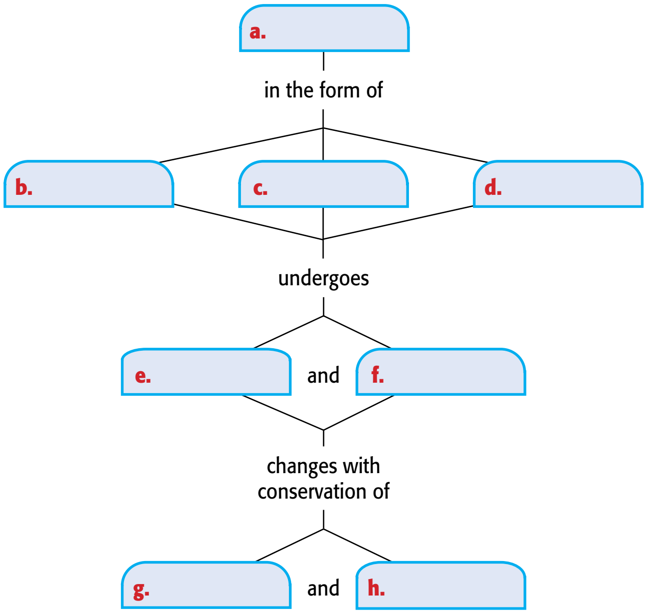
26. Working Cooperatively Suppose you are given a piece of a material that is painted black so you cannot tell its normal appearance. Working in groups of three, plan tests you would do on the material to decide whether it is metal, glass, plastic, or wood.

27. Making Decisions The frame of a tennis racket needs to be strong and stiff, yet light. Tennis racket frames were once made of wood. But to be strong and stiff, the frame had to be thick and heavy. Now rackets can be made from different materials. Make a table of the advantages and disadvantages of each of the materials described in the graphs below.



INTEGRATING CONCEPTS

28. Concept Mapping Copy the unfinished concept map below onto a sheet of paper. Complete the map by writing the correct word or phrase in the lettered boxes.



29. Connection to Biology Your body uses the food you eat to do work. However, some of the food energy is lost as heat. How does your body give off this heat?

30. Connection to Language Arts An element is sometimes named for one of its properties, an interesting fact about the element, or for the person who first discovered the element. Research the origin of the name of each of the following elements: promethium, oxygen, iridium, fermium, curium, tantalum, silver, polonium, ytterbium, and hafnium.

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SCILINKS NSTA

TOPIC: Kinetic theory
GO TO: www.scilinks.org
KEYWORD: HK1025

Design Your Own Lab

Testing the Conservation of Mass

Introduction

How can you show that mass is conserved in a chemical reaction between two household substances—vinegar and baking soda?

Objectives

- ***Measure*** the masses of reactants and products in a chemical reaction.
- ***Design*** an experiment to test the law of conservation of mass.

Materials

baking soda (sodium bicarbonate)
vinegar (acetic acid solution)
400 mL beaker (optional)
100 mL graduated cylinder
2 clear plastic cups (capable of holding at least 150 mL each)
balance (with standard masses, if necessary)
2 weighing papers
plastic sandwich bag with zipper-type closure
twist tie

Safety Needs

safety goggles
lab apron
polyethylene gloves
rimmed tray with paper lining

▶ Observing the Reaction Between Vinegar and Baking Soda

1. On a blank sheet of paper, prepare a table like the one shown below.

	Initial mass (g)	Final mass (g)	Change in mass (g)
Trial 1			
Trial 2			

SAFETY CAUTION Put on a lab apron, safety goggles, and gloves. If you get a chemical on your skin or clothing, wash it off at the sink while calling to your teacher. If you get a chemical in your eyes, immediately flush it out at the eyewash station while calling to your teacher. When mixing chemicals, use a rimmed tray with a paper lining to catch and absorb spills.

2. Place a piece of weighing paper on the balance. Place about 4–5 g of baking soda on the paper. Carefully transfer the baking soda to a plastic cup.
3. Using the graduated cylinder, measure about 50 mL of vinegar. Pour the vinegar into the second plastic cup.
4. Place both cups on the balance, and determine the combined mass of the cups, baking soda, and vinegar to the nearest 0.01 g. Record the combined mass in the first row of your table under "Initial mass."
5. Take the cups off the balance. Carefully and slowly pour the vinegar into the cup that contains the baking soda. To avoid splattering, add only a small amount of vinegar at a time. Gently swirl the cup to make sure the reactants are well mixed.
6. When the reaction has finished, place both cups back on the balance. Determine the combined mass to the nearest 0.01 g. Record the combined mass in the first row of your table under "Final mass."

7. Subtract the final mass from the initial mass, and record the result in the first row of your table under "Change in mass."

▶ Designing Your Experiment

8. Examine the plastic bag and the twist ties. With your lab partners, develop a procedure that will test the law of conservation of mass more accurately than Trial 1 did. Which products' masses were not measured? How can you be sure you measure the masses of all of the reaction products?
9. In your lab report, list each step you will perform in your experiment.
10. Before you carry out your experiment, your teacher must approve your plan.

▶ Performing Your Experiment

11. After your teacher approves your plan, perform your experiment using approximately the same quantities of baking soda and vinegar you used in Trial 1.
12. Record the initial mass, final mass, and change in mass in your table.

▶ Analyzing Your Results

1. Compare the changes in mass you calculated for the first and second trials. What value would you expect to obtain for a change in mass if both trials validated the law of conservation of mass?
2. Was the law of conservation of mass violated in the first trial? Explain your reasoning.
3. If the results of the second trial were different from those of the first trial, explain why.

▶ Defending Your Conclusions

4. Suppose someone performs an experiment like the one you designed and finds that the final mass is much less than the initial mass. Would that prove that the law of conservation of mass is wrong? Explain your reasoning.

Back

viewpoints

Paper or Plastic at the Grocery Store?

As people focus more on the environment, there is a debate raging at the grocery store. It begins with a simple question asked at the checkout counter: "Paper or plastic?"

Some say that paper is a bad choice because making paper bags requires cutting down trees. Yet these bags are naturally biodegradable, and they recycle easily.

Others say that plastic is not a good choice because plastic bags are made from nonrenewable petroleum products. But recent advances have made plastic bags that can break down when exposed to sunlight. Many stores collect used plastic bags and recycle them to make new ones.

How should people decide which bags to use? What do you think?

> FROM: Jaclyn M., Chicago, IL

I think people should choose paper bags because they can be recycled and reused. There should be a mandatory law that makes sure each community has a weekly recycling service for paper bags.

PAPER!

> FROM: Eric S., Rochester, MN

When it comes down to it, both types of bags can be recycled. However, as we know, not everybody recycles bags. Therefore, paper is a better choice because it is a renewable resource.

> FROM: Christy M., Houston, TX.

I believe we should use more plastic bags in grocery stores. By using paper we are chopping down not only trees but also the homes of animals and plants.

PLASTIC!

> FROM: Ashley A., Dyer, IN

Plastic is not necessarily better, but is a lot more convenient. You can reuse plastic bags as garbage bags or bags to carry anything you need to take with you. Plastic is also easier to carry when you leave the store. Plastic bags don't get wet in the rain and break, causing you to drop your groceries on the ground.

> FROM: Andrew S., Bowling Green, KY

People should be able to use the bags they want. People that use paper bags should try to recycle them. People that use plastic bags should reuse them. We should be able to choose, as long as we recycle the bags in some way.

> FROM: Alicia K., Coral Springs, FL

Canvas bags would be a better choice than the paper or plastic bags used in stores. Canvas bags are made mostly of cotton, a very renewable resource, whereas paper bags are made from trees, and plastic bags are made from nonrenewable petroleum products.

BOTH or NEITHER!

Your Turn

1. **Critiquing Viewpoints** Select one of the statements on this page that you *agree* with. Identify and explain at least one weak point in the statement. What would you say to respond to someone who brought up this weak point as a reason you were wrong?
2. **Critiquing Viewpoints** Select one of the statements on this page that you *disagree* with. Identify and explain at least one strong point in the statement. What would you say to respond to someone who brought up this point as a reason they were right?
3. **Creative Thinking** Make a list of at least 12 additional ways for people to reuse their plastic or paper bags.
4. **Life/Work Skills** Imagine that you are trying to decrease the number of bags being sent to the local landfill. Develop a presentation or a brochure that you could use to convince others to reuse or recycle their bags.

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TOPIC: Paper vs. plastic
GO TO: go.hrw.com
KEYWORD: HK1Grocery bag

Which kind of bag do you think is best to use? Why? Share your views on this issue and learn about other viewpoints at the HRW Web site.