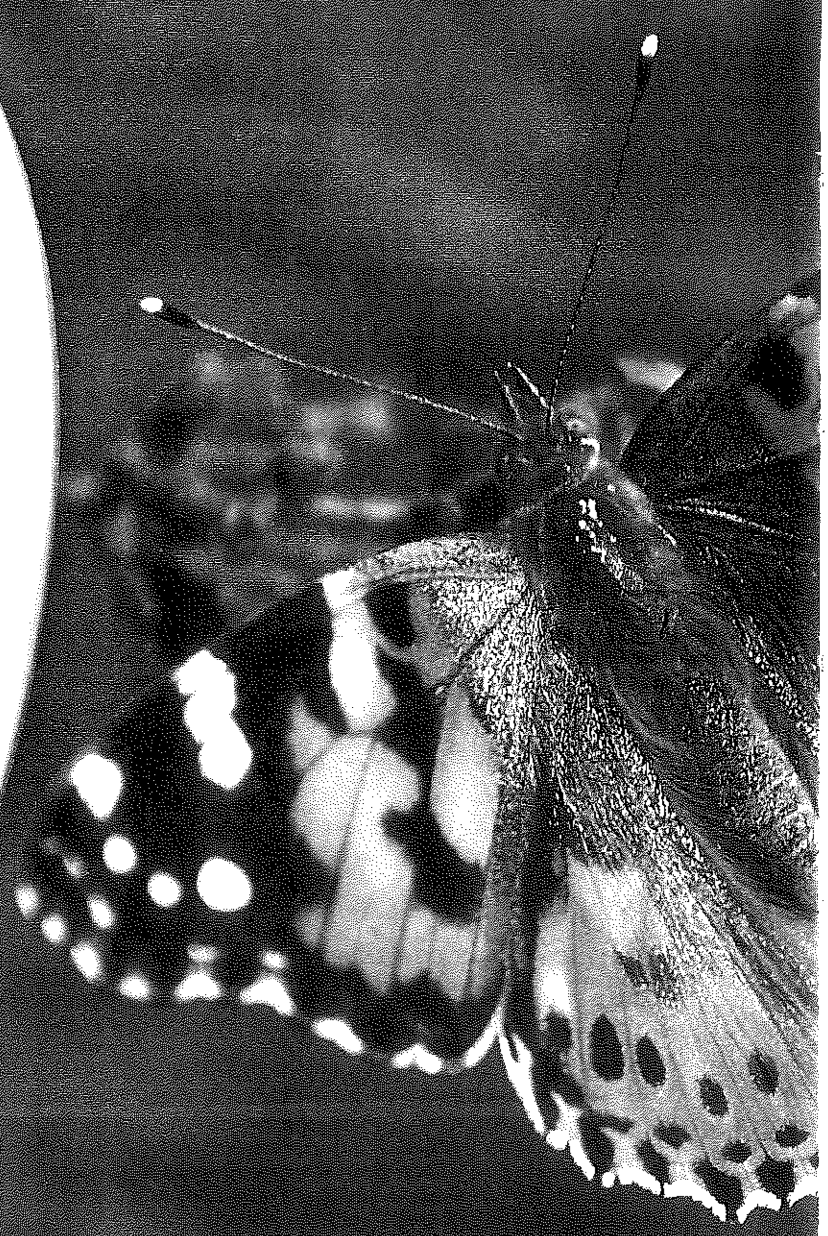
# Chapter 8 Carbon Chemistry

## The BIG Idea
Structure and Function

**Why does carbon have a central role in the chemistry of living things?**





**Butterflies, flowers, and all other living things contain carbon compounds.** ▶

## Lab zone™ Chapter Project

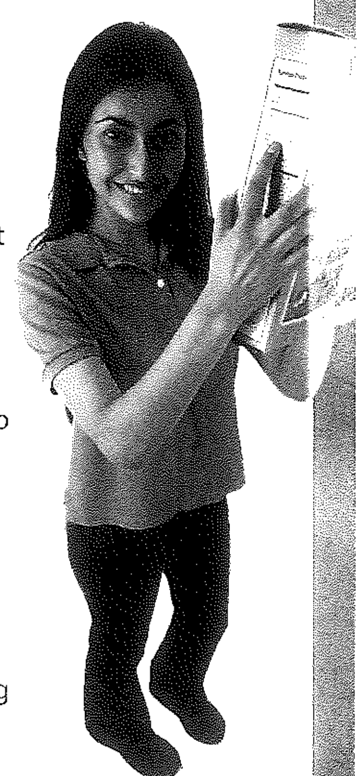
### Check Out the Fine Print

All the foods you eat and drink contain carbon compounds. In this project, you will look closely at the labels on food packages to find carbon compounds.

**Your Goal** To identify carbon compounds found in different foods

To complete the project you must

- collect at least a dozen labels with lists of ingredients and nutrition facts
- identify the carbon compounds listed, as well as substances that do not contain carbon
- interpret the nutrition facts on labels to compare amounts of substances in each food
- classify compounds in foods into the categories of polymers found in living things



**Plan It!** Brainstorm with your classmates about what kinds of packaged foods you want to examine. After your teacher approves your plan, start collecting and studying food labels.

Section 1

# Properties of Carbon

## Reading Preview

### Key Concepts

- How is carbon able to form such a huge variety of compounds?
- What are four forms of pure carbon?

### Key Terms

- diamond
- graphite
- fullerene
- nanotube

### Target Reading Skill

**Using Prior Knowledge** Before you read, look at the section headings and visuals to see what this section is about. Then, write what you know about carbon in a graphic organizer like the one below. As you read, continue to write in what you learn.

| What You Know |
| --- |
| 1. Carbon atoms have 6 electrons.<br>2. |

| What You Learned |
| --- |
| 1.<br>2. |

## Lab zone Discover Activity

### Why Do Pencils Write?

1. Tear paper into two pieces about 5 cm by 5 cm. Rub the two pieces back and forth between your fingers.
2. Now rub pencil lead (graphite) on one side of each piece of paper. Try to get as much graphite as possible on the paper.
3. Rub together the two sides covered with graphite.
4. When you are finished, wash your hands.

**Think It Over**

Observing Did you notice a difference between what you observed in Step 3 and what you observed in Step 1? How could the property of graphite that you observed be useful for purposes other than writing?

Open your mouth and say "aah." Uh-oh, you have a small cavity. Do you know what happens next? Your tooth needs a filling. But first the dentist's drill clears away the decayed part of your tooth.

Why is a dentist's drill hard enough and sharp enough to cut through teeth? The answer has to do with the element carbon. The tip of the drill is covered with diamond chips. Diamond is a form of carbon and the hardest substance on Earth. Because the drill tip is made of diamonds, a dentist's drill stays sharp and useful. To understand why diamond is such a hard substance, you need to take a close look at the carbon atom and the bonds it forms.

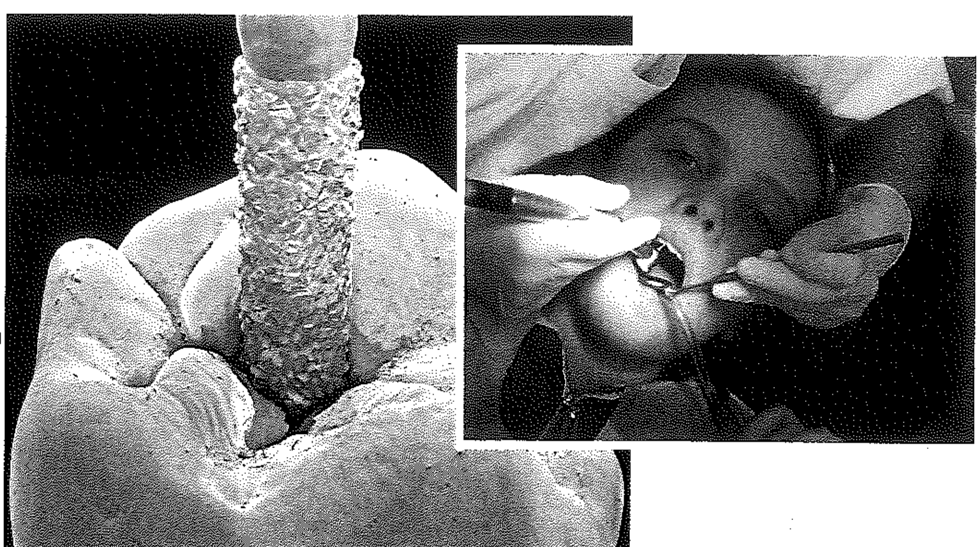
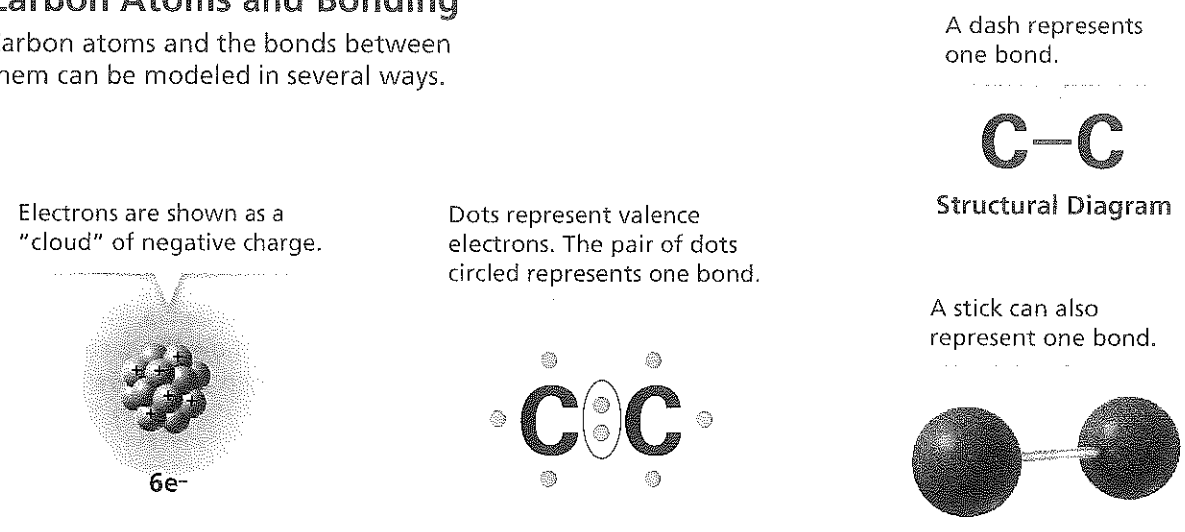


FIGURE 1
**Uses of Carbon**
This colorized photo shows the tip of a dentist's drill (yellow). The tip is made of diamond and is strong enough to bore into a tooth (blue).

FIGURE 2
**Carbon Atoms and Bonding**
Carbon atoms and the bonds between them can be modeled in several ways.




## Carbon Atoms and Bonding

Recall that the atomic number of carbon is 6, which means that the nucleus of a carbon atom contains 6 protons. Surrounding the nucleus are 6 electrons. Of these electrons, four are valence electrons—the electrons available for bonding.

As you have learned, a chemical bond is the force that holds two atoms together. A bond between two atoms results from changes involving the atoms' valence electrons. Atoms gain, lose, or share valence electrons in a way that makes the atoms more stable. A carbon atom can share its valence electrons with other atoms, forming covalent bonds. Figure 2 shows ways that covalent bonds between atoms may be represented.

Atoms of most elements form chemical bonds. Carbon, however, is unique. **Few elements have the ability of carbon to bond with both itself and other elements in so many different ways. With four valence electrons, each carbon atom is able to form four bonds.** So, it is possible to form molecules made of thousands of carbon atoms. By comparison, hydrogen, oxygen, and nitrogen can form only one, two, or three bonds, respectively, and cannot form such long chains.

As you can see in Figure 3, it is possible to arrange the same number of carbon atoms in different ways. Carbon atoms can form straight chains, branched chains, and rings. Sometimes, two or more carbon rings can even join together.

Reading Checkpoint **What happens to a carbon atom's valence electrons when it bonds to other atoms?**

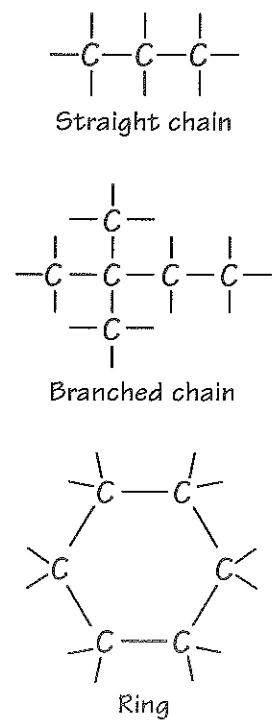
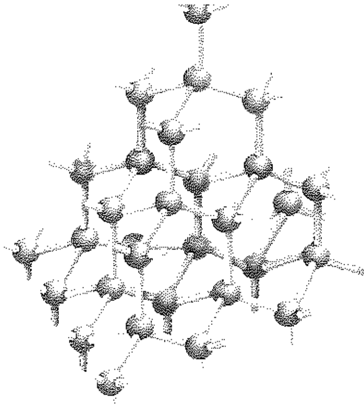
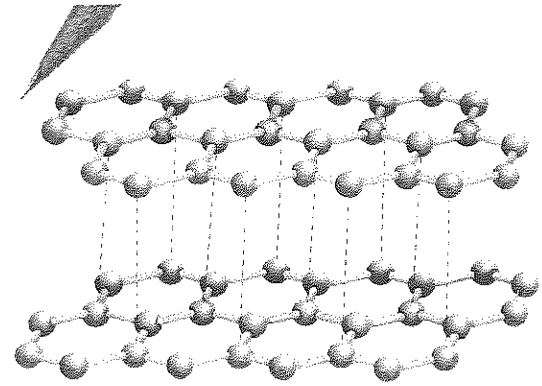



FIGURE 3
**Arrangements of Carbon Atoms** Carbon chains and rings form the backbones for molecules that may contain other atoms.



**Crystal Structure of Diamond** The carbon atoms in a diamond are arranged in a crystal structure.



**Layered Structure of Graphite** The carbon atoms in graphite are arranged in layers. The dashed lines show the weak bonds between the layers.

FIGURE 4
### Forms of Pure Carbon
Pure carbon exists in the form of diamond, graphite, fullerenes, and nanotubes. The properties of each form result from the unique repeating pattern of its carbon atoms. Interpreting Diagrams *Which form of carbon has a crystal structure?*

## Forms of Pure Carbon

Because of the ways that carbon forms bonds, the pure element can exist in different forms. **Diamond, graphite, fullerenes, and nanotubes are four forms of the element carbon.**

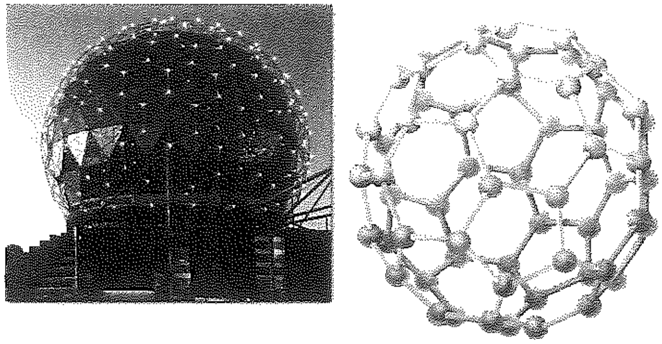
**Diamond** The hardest mineral, **diamond,** forms deep within Earth. At very high temperatures and pressures, carbon atoms form diamond crystals. Each carbon atom is bonded strongly to four other carbon atoms. The result is a solid that is extremely hard and nonreactive. The melting point of diamond is more than 3,500°C—as hot as the surface temperatures of some stars.

Diamonds are prized for their brilliance and clarity when cut as gems. Industrial chemists are able to make diamonds artificially, but these diamonds are not considered beautiful enough to use as gems. Both natural and artificial diamonds are used in industry. Diamonds work well in cutting tools, such as drills.

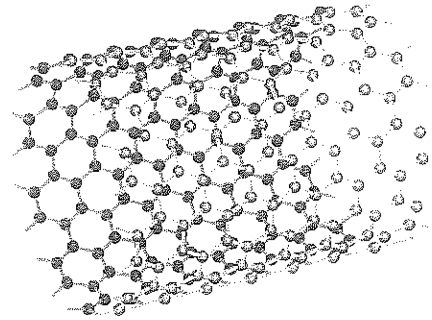
**Graphite** Every time you write with a pencil, you leave a layer of carbon on the paper. The "lead" in a lead pencil is actually mostly **graphite,** another form of the element carbon. In graphite, each carbon atom is bonded tightly to three other carbon atoms in flat layers. However, the bonds between atoms in different layers are very weak, so the layers slide past one another easily.

If you run your fingers over pencil marks, you can feel how slippery graphite is. Because it is so slippery, graphite makes an excellent lubricant in machines. Graphite reduces friction between the moving parts. In your home, you might use a graphite spray to help a key work better in a sticky lock.

Reading Checkpoint **Why is diamond such a hard and nonreactive substance?**



**Spherical Structure of a Fullerene**
The carbon atoms in a fullerene form a sphere that resembles a geodesic dome.



**Cylindrical Structure of a Nanotube**
The carbon atoms in a nanotube are arranged in a cylinder.

**Fullerenes and Nanotubes** In 1985, scientists made a new form of carbon. It consists of carbon atoms arranged in the shape of a hollow sphere. This form of carbon was named a **fullerene** (FUL ur een), for the architect Buckminster Fuller, who designed dome-shaped buildings called geodesic domes. One type of fullerene has been nicknamed "buckyballs."

In 1991, yet another form of carbon was made—the nanotube. In a **nanotube,** carbon atoms are arranged in the shape of a long, hollow cylinder—something like a sheet of graphite rolled into a tube. Only a few nanometers wide in diameter, nanotubes are tiny, light, flexible, and extremely strong. Nanotubes are also good conductors of electricity and heat.

Scientists are looking for ways to use the unique properties of fullerenes and nanotubes. For example, chemists are studying how fullerenes and nanotubes may be used to deliver medicine molecules into cells. Nanotubes may also be used as conductors in electronic devices and as super-strong cables.

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## Section 1 Assessment

**Target Reading Skill** Using Prior Knowledge
Review your graphic organizer and revise it based on what you learned in this section.

### Reviewing Key Concepts

1. a. Identifying How many bonds can a carbon atom form?
   b. Explaining What bonding properties of carbon allow it to form so many different compounds?
2. a. Listing List the four forms of pure carbon.
   b. Describing Describe the carbon bonds in graphite.
   c. Relating Cause and Effect How do the differences in carbon bonds explain why graphite and diamonds have different properties?

### Writing in Science

**Explanation** Draw electron dot diagrams for a straight carbon chain and a branched chain. Then, write an explanation of what you did to show how the carbons are bonded.

Section 2

# Carbon Compounds

## Reading Preview

### Key Concepts

- What are some properties of organic compounds?
- What are some properties of hydrocarbons?
- What kind of structures and bonding do hydrocarbons have?
- What are some characteristics of substituted hydrocarbons, esters, and polymers?

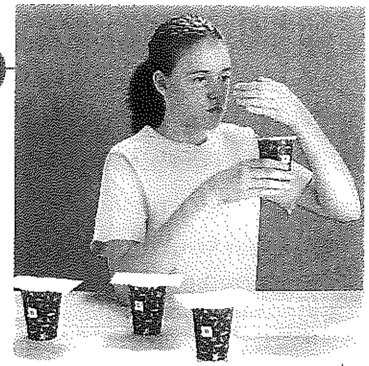
### Key Terms

- organic compound
- hydrocarbon
- structural formula • isomer
- saturated hydrocarbon
- unsaturated hydrocarbon
- substituted hydrocarbon
- hydroxyl group • alcohol
- organic acid • carboxyl group
- ester • polymer • monomer

### Target Reading Skill

**Outlining** As you read, make an outline about carbon compounds. Use the red headings for the main ideas and the blue headings for supporting ideas.

## Lab zone Discover Activity



### What Do You Smell?

1. Your teacher will provide you with some containers. Wave your hand toward your nose over the top of each container.
2. Try to identify each of the odors.
3. After you record what you think is in each container, compare your guesses to the actual substance.

**Think It Over**

Developing Hypotheses Develop a hypothesis to explain the differences between the smell of one substance and another.

Imagine that you are heading out for a day of shopping. Your first purchase is a cotton shirt. Then you go to the drug store, where you buy a bottle of shampoo and a pad of writing paper. Your next stop is a hardware store. There, you buy propane fuel for your camping stove. Your final stop is the grocery store, where you buy olive oil, cereal, meat, and vegetables.

What do all of these purchases have in common? They all are made of carbon compounds. Carbon atoms act as the backbone or skeleton for the molecules of these compounds. Carbon compounds include gases (such as propane), liquids (such as olive oil), and solids (such as cotton). Mixtures of carbon compounds are found in foods, paper, and shampoo. In fact, more than 90 percent of all known compounds contain carbon.

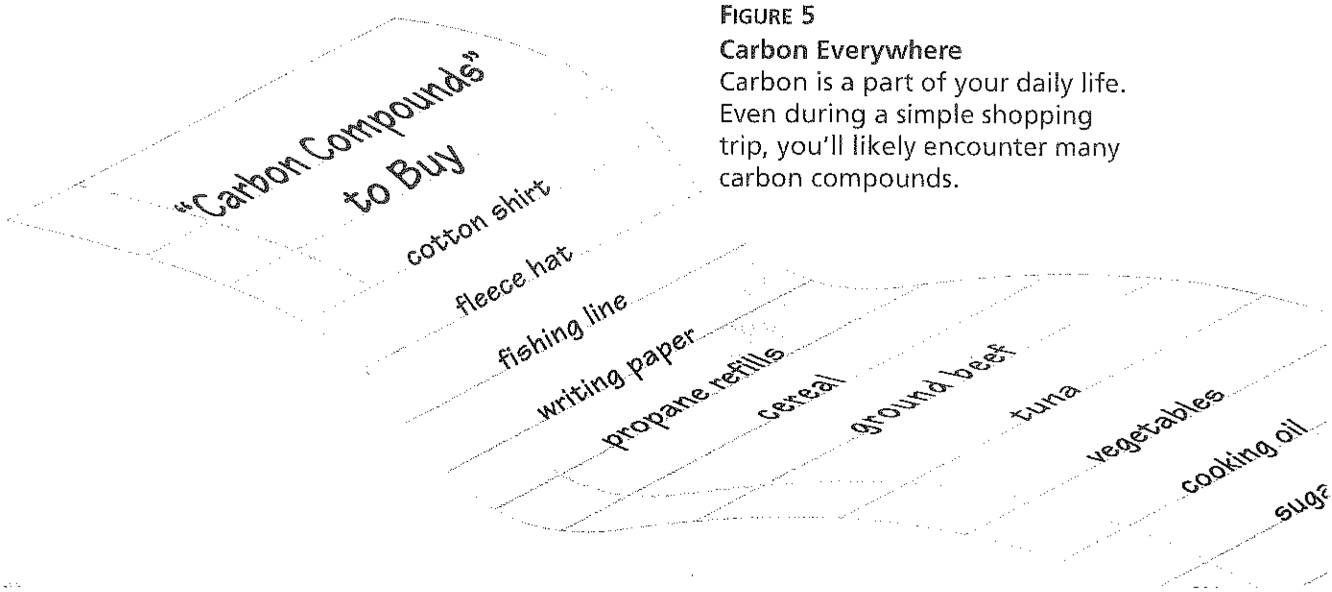
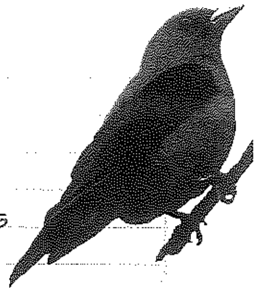



FIGURE 5
**Carbon Everywhere**
Carbon is a part of your daily life. Even during a simple shopping trip, you'll likely encounter many carbon compounds.

**FIGURE 6**
**Where Organic Compounds Are Found**
These three lists represent only a few of the places where organic compounds can be found. Organic compounds are in all living things, in products from living things, and in human-made materials.

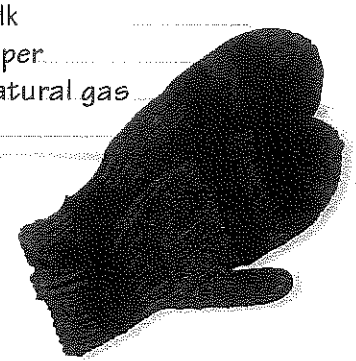
**Part of Living Things**

- Muscle
- Blood
- Seeds
- Leaves
- Feathers
- Skin



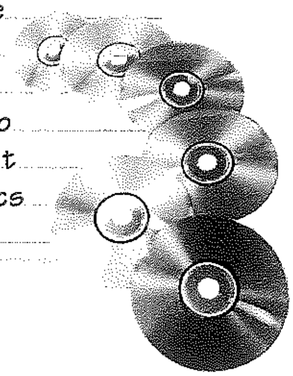
**From Living Things**

- Wool
- Cotton
- Wood
- Silk
- Paper
- Natural gas



**Produced Artificially**

- Gasoline
- Fleece
- Plastics
- Shampoo
- Detergent
- Cosmetics

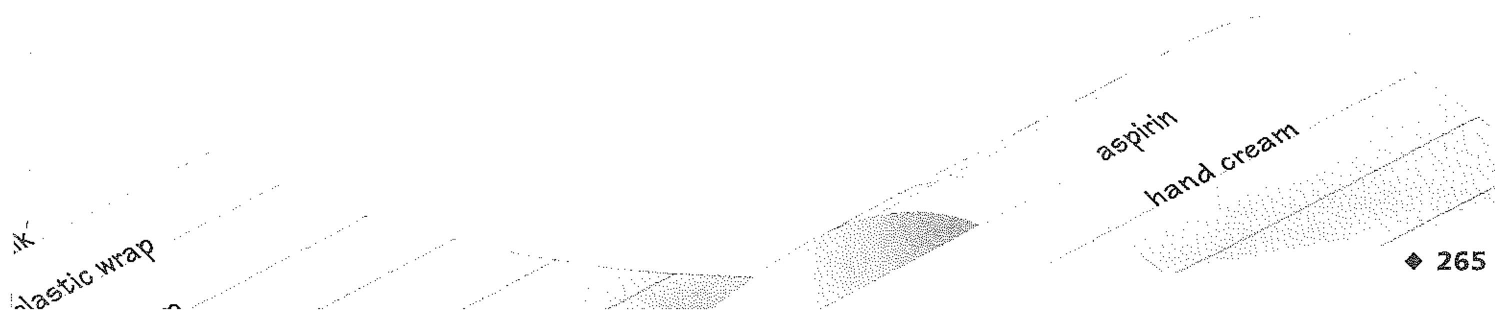


## Organic Compounds

Carbon compounds are so numerous that they are given a specific name. With some exceptions, compounds that contain carbon are called **organic compounds.** This term is used because scientists once thought that organic compounds could be produced only by living things. (The word *organic* means "of living things.") Today, however, scientists know that organic compounds also can be found in products made from living things and in materials produced artificially in laboratories and factories. Organic compounds are part of the solid matter of every organism on Earth. They are part of products that are made from organisms, such as paper made from the wood of trees. Plastics, fuels, cleaning solutions, and many other such products also contain organic compounds. The raw materials for most manufactured organic compounds come from petroleum, or crude oil.

**Many organic compounds have similar properties in terms of melting points, boiling points, odor, electrical conductivity, and solubility.** Many organic compounds have low melting points and low boiling points. As a result, they are liquids or gases at room temperature. Organic liquids generally have strong odors. They also do not conduct electricity. Many organic compounds do not dissolve well in water. You may have seen vegetable oil, which is a mixture of organic compounds, form a separate layer in a bottle of salad dressing.

Reading Checkpoint **What is an organic compound?**



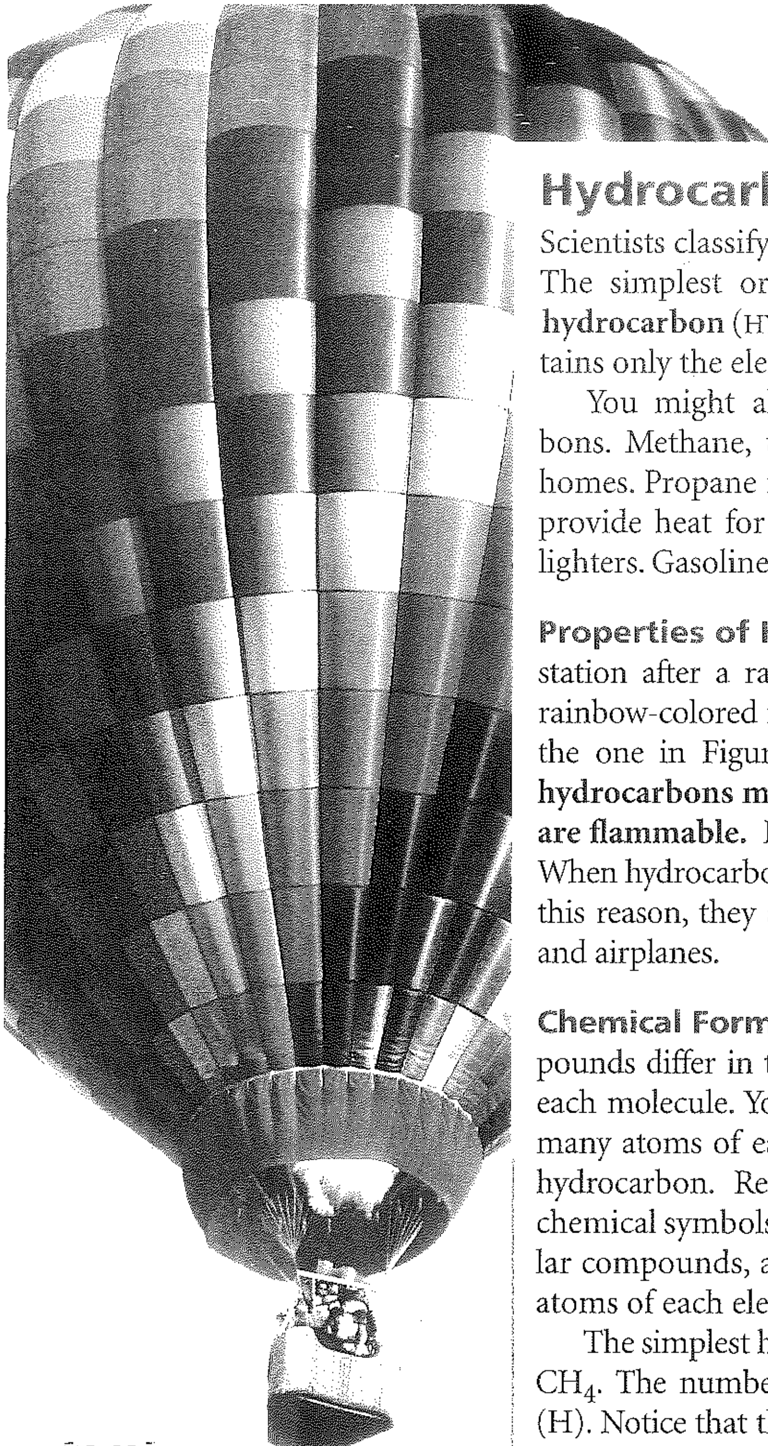


FIGURE 7
Hydrocarbons
Hydrocarbons contain only the elements carbon and hydrogen. From the fuel that heats the air in hot-air balloons (above) to oil slicks (below right), hydrocarbons are all around you.
[illegible]tions *What properties of hydrocarbons do the hot-air balloon and oil slick demonstrate?*

## Hydrocarbons

Scientists classify organic compounds into different categories. The simplest organic compounds are the hydrocarbons. A **hydrocarbon** (HY droh KAHR bun) is a compound that contains only the elements carbon and hydrogen.

You might already recognize several common hydrocarbons. Methane, the main gas in natural gas, is used to heat homes. Propane is used in portable stoves and gas grills and to provide heat for hot-air balloons. Butane is the fuel in most lighters. Gasoline is a mixture of several different hydrocarbons.

**Properties of Hydrocarbons** Have you ever been at a gas station after a rainstorm? If so, you may have noticed a thin rainbow-colored film of gasoline or oil floating on a puddle, like the one in Figure 7. **Like many other organic compounds, hydrocarbons mix poorly with water. Also, all hydrocarbons are flammable.** Being flammable means that they burn easily. When hydrocarbons burn, they release a great deal of energy. For this reason, they are used as fuel for stoves, heaters, cars, buses, and airplanes.

**Chemical Formulas of Hydrocarbons** Hydrocarbon compounds differ in the number of carbon and hydrogen atoms in each molecule. You can write a chemical formula to show how many atoms of each element make up a molecule of a specific hydrocarbon. Recall that a chemical formula includes the chemical symbols of the elements in a compound. For molecular compounds, a chemical formula also shows the number of atoms of each element in a molecule.

The simplest hydrocarbon is methane. Its chemical formula is $CH_4$. The number 4 indicates the number of hydrogen atoms (H). Notice that the 4 is a subscript. Subscripts are written lower and smaller than the letter symbols of the elements. The symbol for carbon (C) in the formula is written without a subscript. This means that there is one carbon atom in the molecule.

A hydrocarbon with two carbon atoms is ethane. The formula for ethane is $C_2H_6$. The subscripts in this formula show that an ethane molecule is made of two carbon atoms and six hydrogen atoms.

A hydrocarbon with three carbon atoms is propane ($C_3H_8$). How many hydrogen atoms does the subscript indicate? If you answered eight, you are right.

**Reading Checkpoint** What is a hydrocarbon?

## Structure and Bonding in Hydrocarbons

The properties of hydrocarbon compounds are related to the compound's structure. **The carbon chains in a hydrocarbon may be straight, branched, or ring-shaped.** If a hydrocarbon has two or more carbon atoms, the atoms can form a single line, that is, a straight chain. In hydrocarbons with four or more carbon atoms, it is possible to have branched arrangements of the carbon atoms as well as straight chains.

**Structural Formulas** To show how atoms are arranged in the molecules of a compound, chemists use a structural formula. A **structural formula** shows the kind, number, and arrangement of atoms in a molecule.

Figure 8 shows the structural formulas for molecules of methane, ethane, and propane. Each dash (—) represents a bond. In methane, each carbon atom is bonded to four hydrogen atoms. In ethane and propane, each carbon atom is bonded to at least one carbon atom as well as to hydrogen atoms. As you look at structural formulas, notice that every carbon atom forms four bonds. Every hydrogen atom forms one bond. There are never any dangling bonds. In other words, both ends of a dash are always connected to something.

**Lab zone Try This Activity**

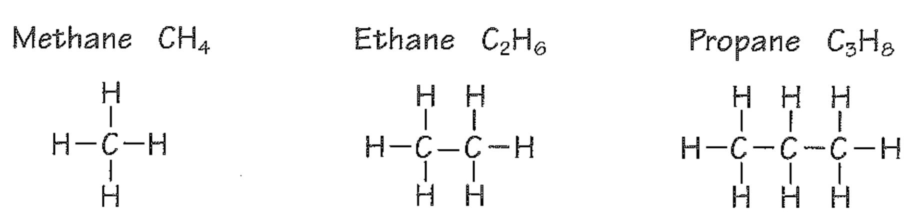
### Dry or Wet?

Petroleum jelly is manufactured from hydrocarbons.

1. Carefully coat one of your fingers in petroleum jelly.
2. Dip that finger in water. Also dip a finger on your other hand in water.
3. Inspect the two fingers, and note how they feel.
4. Use a paper towel to remove the petroleum jelly, and then wash your hands thoroughly.

**Inferring** Compare how your two fingers looked and felt in Steps 2 and 3. What property of hydrocarbons does this activity demonstrate?

**FIGURE 8**
**Structural Formulas**
Each carbon atom in these structural formulas is surrounded by four dashes representing four bonds. **Interpreting Diagrams** *In propane, how many hydrogen atoms is each carbon bonded to?*



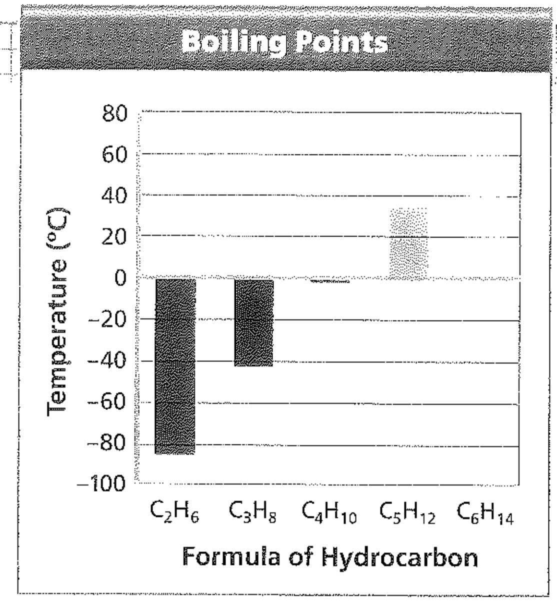
## Math Analyzing Data

### Boiling Points of Hydrocarbons

The graph shows the boiling points of several hydrocarbons. (*Note:* Some points on the *y*-axis are negative.)

Use the graph to answer the following questions.

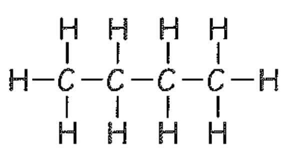
1. Reading Graphs Where is 0°C on the graph?
2. Interpreting Data What is the approximate boiling point of $C_3H_8$? $C_5H_{12}$? $C_6H_{14}$?
3. Calculating What is the temperature difference between the boiling points of $C_3H_8$ and $C_5H_{12}$?
4. Drawing Conclusions At room temperature (about 22°C), which of the hydrocarbons are gases? How can you tell?

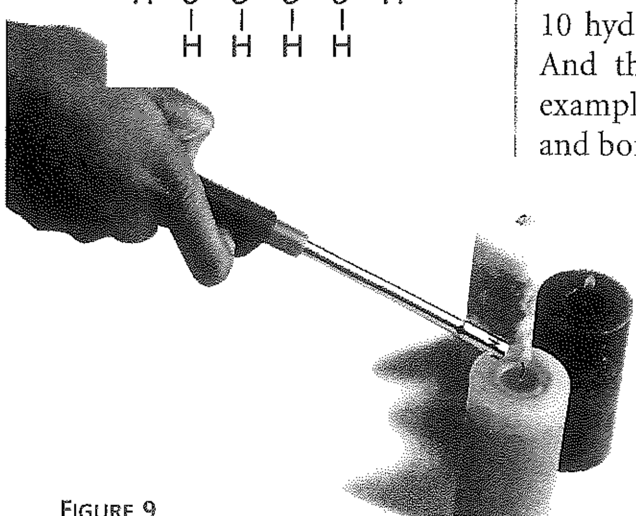


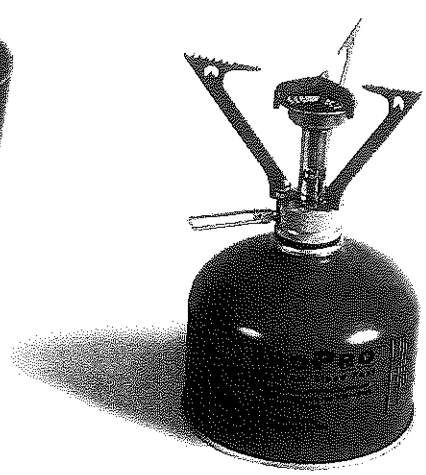

**Isomers** Consider the chemical formula of butane: $C_4H_{10}$. This formula does not indicate how the atoms are arranged in the molecule. In fact, there are two different ways to arrange the carbon atoms in $C_4H_{10}$. These two arrangements are shown in Figure 9. Compounds that have the same chemical formula but different structural formulas are called **isomers** (EYE soh murz). Each isomer is a different substance with its own characteristic properties.

Notice in Figure 9 that a molecule of one isomer, butane, is a straight chain. A molecule of the other isomer, isobutane, is a branched chain. Both molecules have 4 carbon atoms and 10 hydrogen atoms, but the atoms are arranged differently. And these two compounds have different properties. For example, butane and isobutane have different melting points and boiling points.

Butane $C_4H_{10}$







Isobutane $C_4H_{10}$

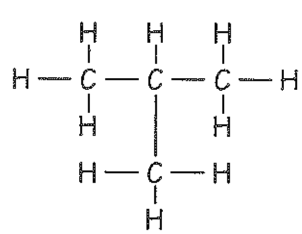


FIGURE 9
**Isomers**
$C_4H_{10}$ has two isomers, butane and isobutane. Applying Concepts *Which isomer is a branched chain?*

**Double Bonds and Triple Bonds** So far in this section, structural formulas have shown only single bonds between any two carbon atoms (C—C). A single dash means a single bond. **In addition to forming a single bond, two carbon atoms can form a double bond or a triple bond.** A carbon atom can also form a single or double bond with an oxygen atom. Structural formulas represent a double bond with a double dash (C=C). A triple bond is indicated by a triple dash (C≡C).

**Saturated and Unsaturated Hydrocarbons** A hydrocarbon can be classified according to the types of bonds between its carbon atoms. If there are only single bonds, it has the maximum number of hydrogen atoms possible on its carbon chain. These hydrocarbons are called **saturated hydrocarbons.** You can think of each carbon atom as being "saturated," or filled up, with hydrogens. Hydrocarbons with double or triple bonds have fewer hydrogen atoms for each carbon atom than a saturated hydrocarbon does. They are called **unsaturated hydrocarbons.**

Notice that the names of methane, ethane, propane, and butane all end with the suffix *-ane*. In general, a chain hydrocarbon with a name ending in *-ane* is saturated, while a hydrocarbon with a name ending in *-ene* or *-yne* is unsaturated.

The simplest unsaturated hydrocarbon with one double bond is ethene ($C_2H_4$). Many fruits produce ethene gas. Ethene gas helps the fruit to ripen. The simplest hydrocarbon with one triple bond is ethyne ($C_2H_2$), which is commonly known as acetylene. Acetylene torches are used in welding.

Reading Checkpoint **What is the difference between saturated and unsaturated hydrocarbons?**

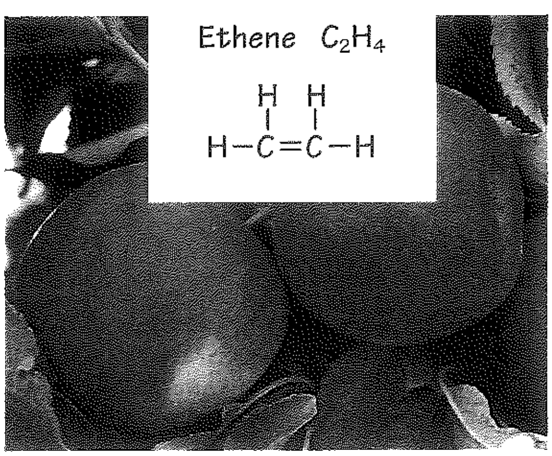
Lab zone **Skills Activity**

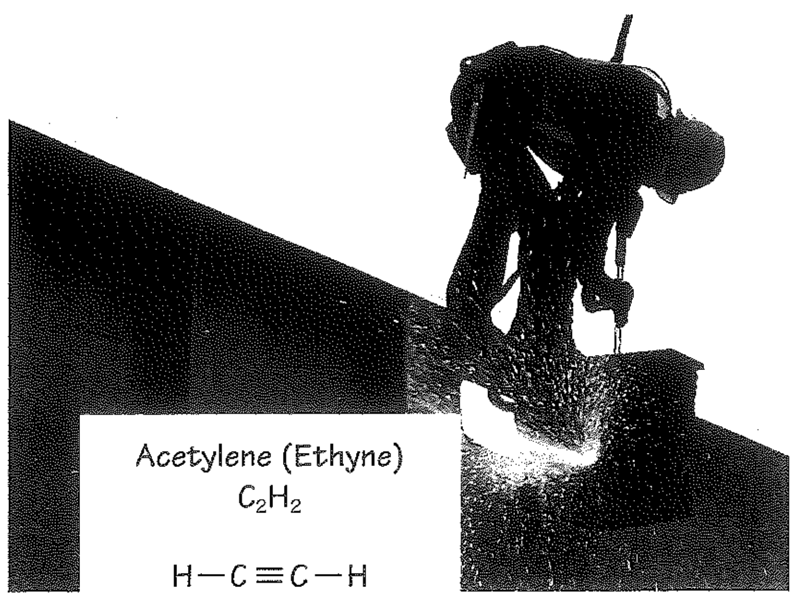
### Classifying

Determine whether each of the following hydrocarbons contains single, double, or triple bonds. (*Hint*: Remember that carbon forms four bonds and hydrogen forms one bond.)

| | |
|---|---|
| $C_2H_6$ | $C_3H_8$ |
| $C_2H_4$ | $C_3H_4$ |
| $C_2H_2$ | $C_4H_{10}$ |

**FIGURE 10**
**Unsaturated Hydrocarbons**
Ethene gas ($C_2H_4$), which causes fruits such as apples to ripen, has one double bond. Acetylene ($C_2H_2$), the fuel in welding torches, has one triple bond.



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## Substituted Hydrocarbons

Hydrocarbons contain only carbon and hydrogen. But carbon can form stable bonds with several other elements, including oxygen, nitrogen, sulfur, and members of the halogen family. **If just one atom of another element is substituted for a hydrogen atom in a hydrocarbon, a different compound is created.** In a **substituted hydrocarbon**, atoms of other elements replace one or more hydrogen atoms in a hydrocarbon. Substituted hydrocarbons include halogen-containing compounds, alcohols, and organic acids.

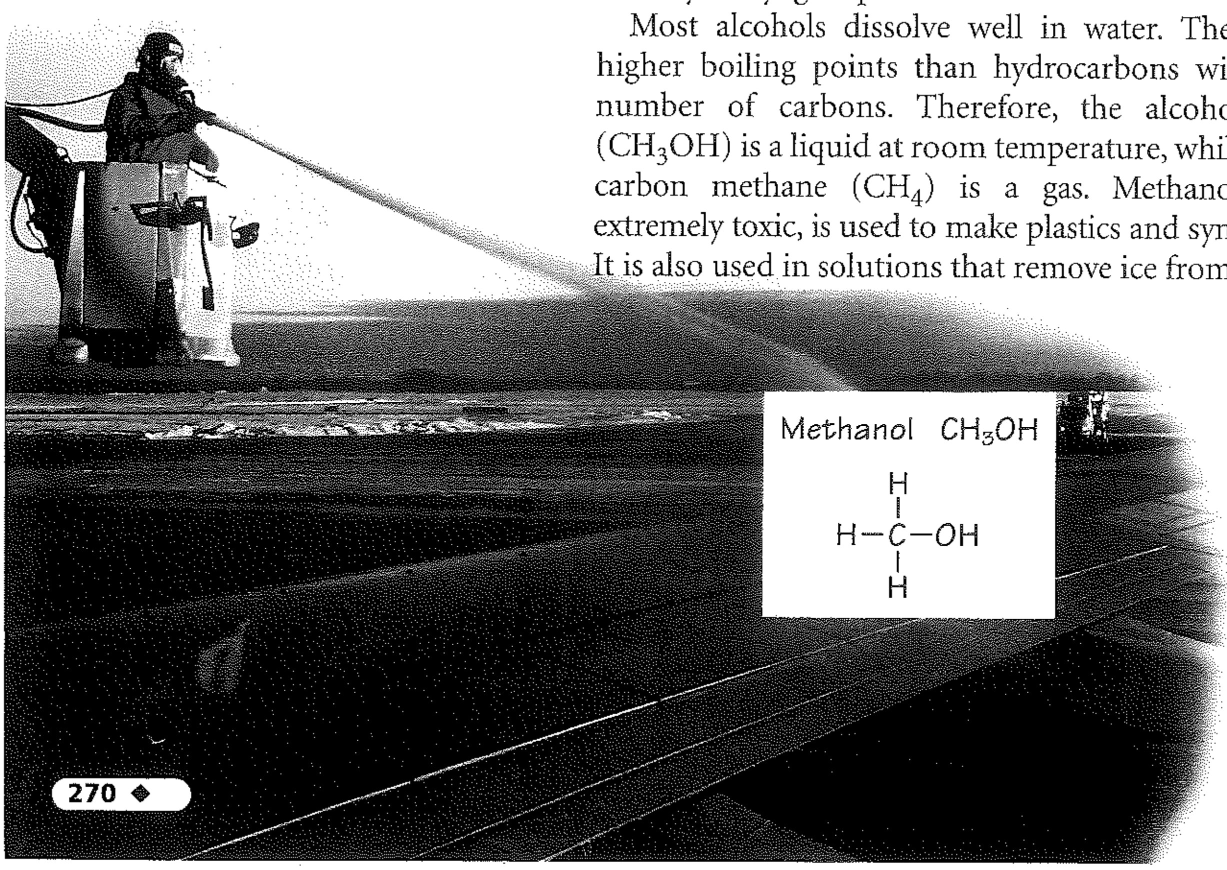
**Compounds Containing Halogens** In some substituted hydrocarbons, one or more halogen atoms replace hydrogen atoms. Recall that the halogen family includes fluorine, chlorine, bromine, and iodine.

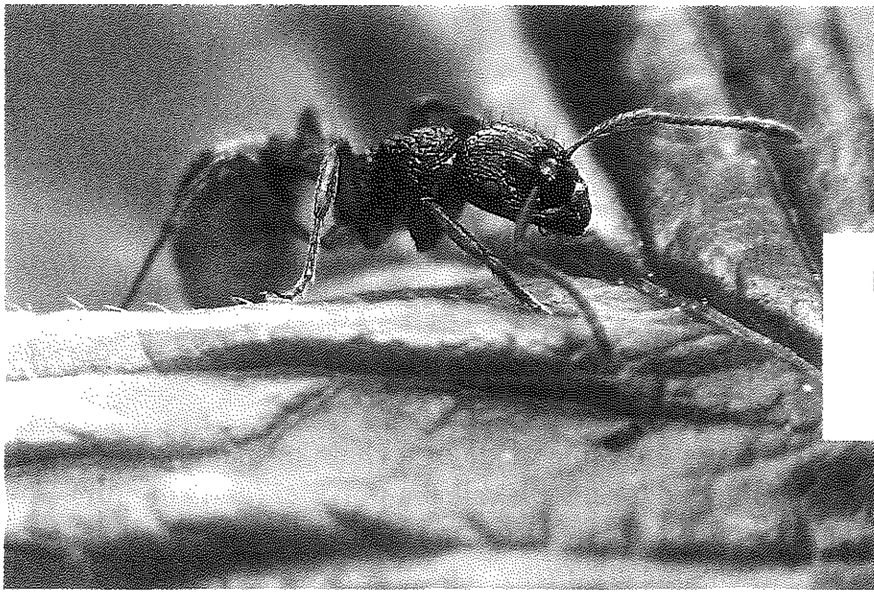
One compound, Freon ($CCl_2F_2$), was widely used as a cooling liquid in refrigerators and air conditioners. When Freon was found to damage the environment, its use was banned in the United States. However, a very hazardous compound that contains halogens, trichloroethane ($C_2H_3Cl_3$), is still used in dry-cleaning solutions. It can cause severe health problems.

**Alcohols** The group —OH can also substitute for hydrogen atoms in a hydrocarbon. Each —OH, made of an oxygen atom and a hydrogen atom, is called a **hydroxyl group** (hy DRAHKS il). An **alcohol** is a substituted hydrocarbon that contains one or more hydroxyl groups.

Most alcohols dissolve well in water. They also have higher boiling points than hydrocarbons with a similar number of carbons. Therefore, the alcohol methanol ($CH_3OH$) is a liquid at room temperature, while the hydrocarbon methane ($CH_4$) is a gas. Methanol, which is extremely toxic, is used to make plastics and synthetic fibers. It is also used in solutions that remove ice from airplanes.

**FIGURE 11**
**Alcohol**
Methanol is used for de-icing an airplane in cold weather.
Classifying *What makes methanol a substituted hydrocarbon?*





Formic acid HCOOH

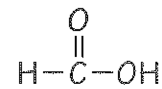


**FIGURE 12**
**Organic Acid**
Formic acid is the simplest organic acid. It is the acid produced by ants and is responsible for the pain caused by an ant bite.

When a hydroxyl group is substituted for one hydrogen atom in ethane, the resulting alcohol is ethanol ($C_2H_5OH$). Ethanol is produced naturally by the action of yeast or bacteria on the sugar stored in corn, wheat, and barley. Ethanol is a good solvent for many organic compounds that do not dissolve in water. It is also added to gasoline to make a fuel for car engines called "gasohol." Ethanol is used in medicines and is found in alcoholic beverages. The ethanol used for industrial purposes is unsafe to drink. Poisonous compounds such as methanol have been added. The resulting poisonous mixture is called denatured alcohol.

**Organic Acids** Lemons, oranges, and grapefruits taste a little tart or sour, don't they? The sour taste of many fruits comes from citric acid, an organic acid. An **organic acid** is a substituted hydrocarbon that contains one or more carboxyl groups. A **carboxyl group** (kahr BAHKS il) is written as —COOH.

You can find organic acids in many foods. Acetic acid ($CH_3COOH$) is the main ingredient of vinegar. Malic acid is found in apples. Butyric acid makes butter smell rancid when it goes bad. Stinging nettle plants make formic acid (HCOOH), a compound that causes the stinging feeling. The pain from ant bites also comes from formic acid.

## Esters

If you have eaten wintergreen candy, then you are familiar with the smell of an ester. An **ester** is a compound made by chemically combining an alcohol and an organic acid. **Many esters have pleasant, fruity smells.** Esters are responsible for the smells of pineapples, bananas, strawberries, and apples. If you did the Discover activity, you smelled different esters. Other esters are ingredients in medications, including aspirin and the local anesthetic used by dentists.

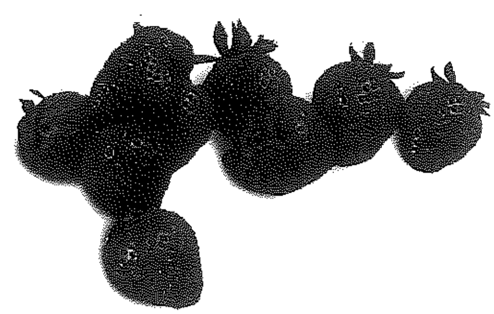


**FIGURE 13**
**Esters**
Strawberries contain esters, which give them a pleasant aroma and flavor.

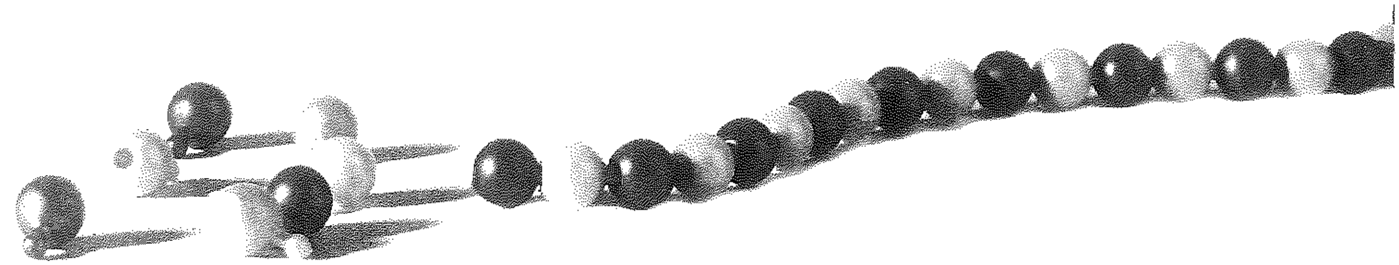


**FIGURE 14**
**Monomers and Polymers**
This chain of plastic beads is somewhat like a polymer molecule. The individual beads are like the monomers that link together to build a polymer.
Comparing and Contrasting *How do polymers differ from monomers?*

## Polymers

A very large molecule made of a chain of many smaller molecules bonded together is called a **polymer** (PAHL ih mur). The smaller molecules are called **monomers** (MAHN uh murz). The prefix *poly-* means "many," and the prefix *mono-* means "one." **Organic compounds, such as alcohols, esters, and others, can be linked together to build polymers with thousands or even millions of atoms.**

Some polymers are made by living things. For example, sheep grow coats of wool. Cotton fibers come from the seed pods of cotton plants. And silkworms make silk. Other polymers, called synthetic polymers, are made in factories. If you are wearing clothing made from polyester or nylon, you are wearing a synthetic polymer. Any plastic item you use is most certainly made of synthetic polymers.

Reading Checkpoint **What is a monomer?**

## Section 2 Assessment

**Target Reading Skill** Outlining Work with a partner to check the answers in your graphic organizer.

### Reviewing Key Concepts

1. a. Listing List properties common to many organic compounds.
   b. Applying Concepts You are given two solid materials, one that is organic and one that is not organic. Describe three tests you could perform to help you decide which is which.
2. a. Identifying What are some properties of hydrocarbons?
   b. Comparing and Contrasting How are hydrocarbons similar? How are they different?
3. a. Reviewing What are three kinds of carbon chains found in hydrocarbons?
   b. Describing Compare the chemical and structural formulas of butane and isobutane.
   c. Problem Solving Draw a structural formula for a compound called butene. In terms of bonding, how does butene differ from butane?
4. a. Defining What is a substituted hydrocarbon?
   b. Classifying What kinds of substituted hydrocarbons react to form an ester?
   c. Drawing Conclusions What do you think the term *polyester fabric* refers to?

### Lab zone At-Home Activity

Mix It Up You can make a simple salad dressing to demonstrate one property of organic compounds. In a transparent container, thoroughly mix equal amounts of a vegetable oil and a fruit juice. Stop mixing, and observe the oil and juice mixture for several minutes. Explain your observations to your family.

Lab zone **Skills Lab**

# How Many Molecules?

## Problem

In this lab you will use gumdrops to represent atoms and toothpicks to represent bonds. How many different ways can you put the same number of carbon atoms together?

## Skills Focus

making models

## Materials

- toothpicks
- multicolored gumdrops
- other materials supplied by your teacher

## Procedure

1. You will need gumdrops of one color to represent carbon atoms and gumdrops of another color to represent hydrogen atoms. When building your models, always follow these rules:
   - Each carbon atom forms four bonds.
   - Each hydrogen atom forms one bond.

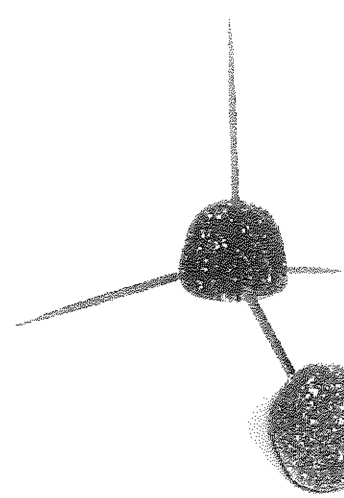
   **CAUTION:** *Do not eat any of the food substances in this experiment.*
2. Make a model of $CH_4$ (methane).
3. Now make a model of $C_2H_6$ (ethane).
4. Make a model of $C_3H_8$ (propane). Is there more than one way to arrange the atoms in propane? (*Hint:* Are there any branches in the carbon chain or are all the carbon atoms in one line?)
5. Now make a model of $C_4H_{10}$ (butane) in which all the carbon atoms are in one line.
6. Make a second model of butane with a branched chain.
7. Compare the branched-chain model with the straight-chain model of butane. Are there other ways to arrange the atoms?
8. Predict how many different structures can be formed from $C_5H_{12}$ (pentane).
9. Test your prediction by building as many different models of pentane as you can.

## Analyze and Conclude

1. Making Models Did any of your models have a hydrogen atom between two carbon atoms? Why or why not?
2. Observing How does a branched chain differ from a straight chain?
3. Drawing Conclusions How many different structures have the formula $C_3H_8$? $C_4H_{10}$? $C_5H_{12}$? Use diagrams to explain your answers.
4. Predicting If you bend a straight chain of carbons, do you make a different structure? Why or why not?
5. Communicating Compare the information you can get from models to the information you can get from formulas like $C_6H_{14}$. How does using models help you understand the structure of a molecule?

## More to Explore

Use a third color of gumdrops to model an oxygen atom. An oxygen atom forms two bonds. Use the rules in this lab to model as many different structures for the formula $C_4H_{10}O$ as possible.



Section 3 • Tech & Design •

# Polymers and Composites

## Reading Preview

### Key Concepts

- How do polymers form?
- What are composites made of?
- What benefits and problems relate to the use of synthetic polymers?

### Key Terms

- protein
- amino acid
- plastic
- composite

### Target Reading Skill

**Asking Questions** Before you read, preview the red headings. In a graphic organizer like the one below, ask a *how* or *why* question for each heading. As you read, write the answers to your questions.

| Question | Answer |
|---|---|
| How do polymers form? | Polymers form when chemical bonds link . . . |
| | |

## Lab zone Discover Activity

### What Did You Make?

1. Look at a sample of borax solution and write down the properties you observe. Do the same with white glue.
2. Put about 2 tablespoons of borax solution into a paper cup.
3. Stir the solution as you add about 1 tablespoon of white glue.
4. After 2 minutes, record the properties of the material in the cup. Wash your hands when you are finished.

**Think It Over**

Observing What evidence of a chemical reaction did you observe? How did the materials change? What do you think you made?

Delectable foods and many other interesting materials surround you every day. Have you ever wondered what makes up these foods and materials? You might be surprised to learn that many are partly or wholly polymers. Recall that a polymer is a large, complex molecule built from smaller molecules joined together in a repeating pattern.

The starches in pancakes and the proteins in meats and eggs are natural polymers. Many other polymers, however, are manufactured or synthetic. These synthetic polymers include plastics and polyester and nylon clothing. Whether synthetic or natural, most polymers rely on the element carbon for their fundamental structures.

**FIGURE 15**
**Polymers**
The clothing, boots, goggles, and helmet worn by this climber are all made of polymers.

# Forming Polymers

Food materials, living things, and plastic have something in common. All are made of organic compounds. Organic compounds consist of molecules that contain carbon atoms bonded to each other and to other kinds of atoms. Carbon is present in several million known compounds, and more organic compounds are being discovered or invented every day.

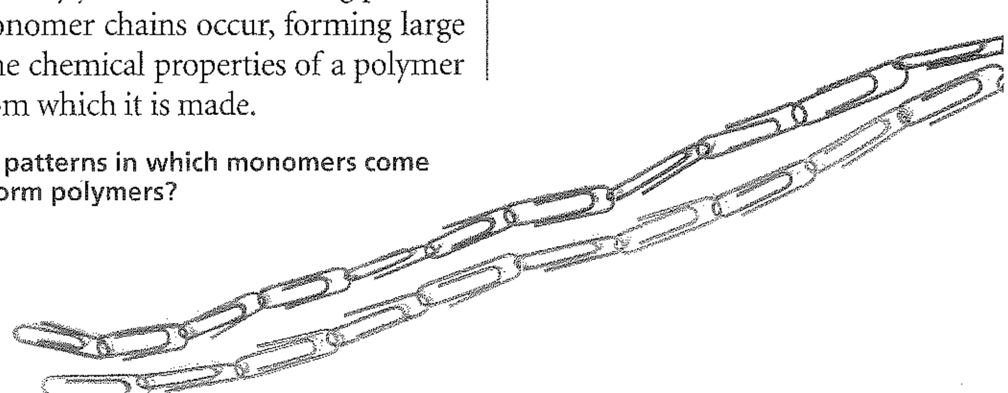
**Carbon's Chains and Rings** Carbon's unique ability to form so many compounds comes from two properties. First, carbon atoms can form four covalent bonds. Second, as you have learned, carbon atoms can bond to each other in straight and branched chains and ring-shaped groups. These structures form the "backbones" to which other atoms attach.

Hydrogen is the most common element found in compounds with carbon. Other elements include oxygen, nitrogen, phosphorus, sulfur, and the halogens—especially chlorine.

**Carbon Compounds and Polymers** Molecules of some organic compounds can bond together, forming larger molecules, such as polymers. Recall that the smaller molecules from which polymers are built are called monomers. **Polymers form when chemical bonds link large numbers of monomers in a repeating pattern.** A polymer may consist of hundreds or even thousands of monomers.

Many polymers consist of a single kind of monomer that repeats over and over again. You could think of these monomers as linked like the identical cars of a long passenger train. In other cases, two or three monomers may join in an alternating pattern. Sometimes links between monomer chains occur, forming large webs or netlike molecules. The chemical properties of a polymer depend on the monomers from which it is made.

**Reading Checkpoint** What are the patterns in which monomers come together to form polymers?



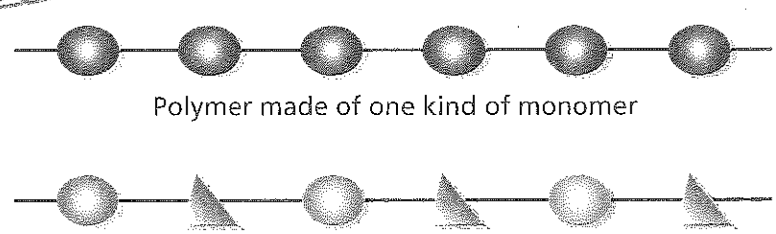
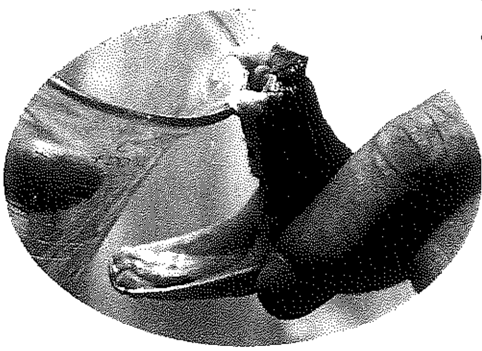


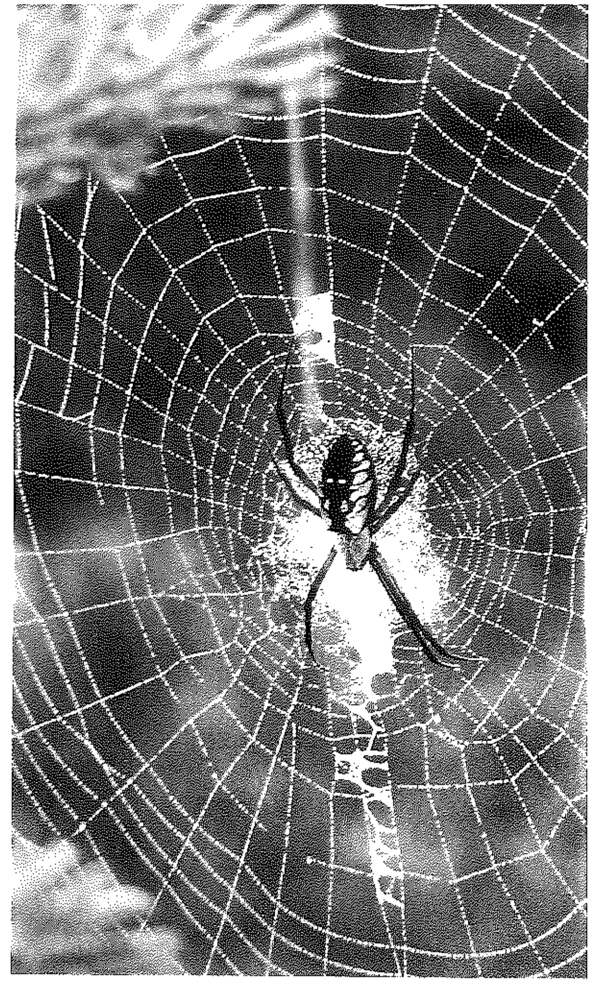

**FIGURE 16**
**Building Polymers**
Like chains made of similar or different paper clips, polymers can form from similar or different kinds of monomers.

FIGURE 17
### Natural Polymers
Cellulose, the proteins in snake venom, and spider's silk are three examples of natural polymers.

▲ The cellulose in fruits and vegetables serves as dietary fiber that keeps the human digestive system healthy.



▲ Snake venom is a mixture containing approximately 90 percent proteins.



A spider's web is a silken polymer that is one of the strongest materials known. ▶

## Polymers and Composites

Polymers have been around as long as life on Earth. Plants, animals, and other living things produce many natural materials made of large polymer molecules.

**Natural Polymers** Cellulose (SEL yoo lohs) is a flexible but strong natural polymer found in the cell walls of fruits and vegetables. Cellulose is made in plants when sugar molecules are joined into long strands. Humans cannot digest cellulose. But plants also make digestible polymers called starches, formed from sugar molecules that are connected in a different way. Starches are found in pastas, breads, and many vegetables.

You can wear polymers made by animals. Silk is made from the fibers of the cocoons spun by silkworms. Wool is made from sheep's fur. These polymers can be woven into thread and cloth. Your own body makes polymers, too. For example, your fingernails and muscles are made of polymers called proteins. Within your body, **proteins** are formed from smaller molecules called amino acids. An **amino acid** is a monomer that is a building block of proteins. The properties of a protein depend on which amino acids are used and in what order. One combination builds the protein that forms your fingernails. Yet another combination forms the protein that carries oxygen in your blood.

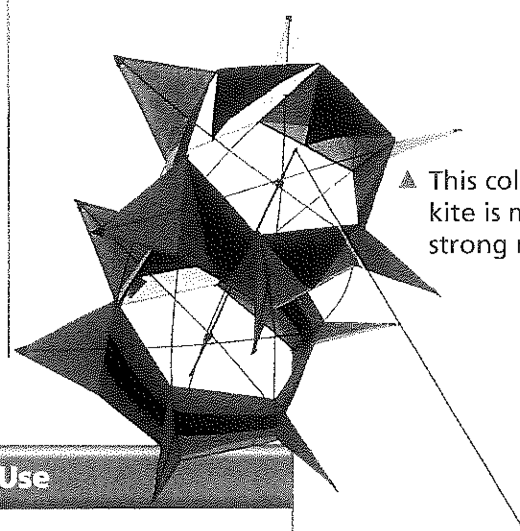
Lab zone **Skills Activity**

### Calculating
Sit or stand where you have a clear view of the room you are in. Slowly sweep the room with your eyes, making a list of the objects you see. Do the same sweep of the clothes you are wearing. Check off those items on your list made (completely or partly) of natural or synthetic polymers. Calculate the percent of items that were *not* made with polymers.

**Synthetic Polymers** Many polymers you use every day are synthesized—or made—from simpler materials. The starting materials for many synthetic polymers come from coal or oil. **Plastics,** which are synthetic polymers that can be molded or shaped, are the most common products. But there are many others. Carpets, clothing, glue, and even chewing gum can be made of synthetic polymers.

Figure 18 lists just a few of the hundreds of polymers people use. Although the names seem like tongue twisters, see how many you recognize. You may be able to identify some polymers by their initials printed on the bottoms of plastic bottles.

Compare the uses of polymers shown in the figure with their characteristics. Notice that many products require materials that are flexible, yet strong. Others must be hard or lightweight. When chemical engineers develop a new product, they have to think about how it will be used. Then they synthesize a polymer with properties to match.



▲ This colorful kite is made of strong nylon.

**Some Synthetic Polymers You Use**

| Name | Properties | Uses |
|---|---|---|
| Low-density polyethylene (LDPE) | Flexible, soft, melts easily | Plastic bags, squeeze bottles, electric wire insulation |
| High-density polyethylene (HDPE) | Stronger than LDPE; higher melting temperatures | Detergent bottles, gas cans, toys, milk jugs |
| Polypropylene (PP) | Hard, keeps its shape | Toys, car parts, bottle caps |
| Polyvinyl chloride (PVC) | Tough, flexible | Garden hoses, imitation leather, plumbing pipes |
| Polystyrene (PS) | Lightweight, can be made into foam | Foam drinking cups, insulation, furniture, "peanut" packing material |
| Nylon | Strong, can be drawn into flexible thread | Stockings, parachutes, fishing line, fabric |
| Teflon (polytetrafluoroethylene) | Nonreactive, low friction | Nonstick coating for cooking pans |

**FIGURE 18**
The properties of synthetic polymers make them ideal starting materials for many common objects.
Applying Concepts *Which synthetic polymer would you use to make a cover for a picnic table?*

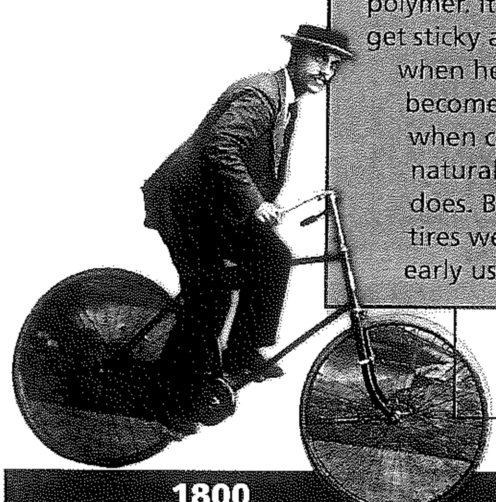
**Comparing Polymers** Synthetic polymers are often used in place of natural materials that are too expensive or wear out too quickly. Polyester and nylon fabrics, for example, are frequently used instead of wool, silk, and cotton to make clothes. Laminated countertops and vinyl floors replace wood in many kitchens. Other synthetic polymers have uses for which there is no suitable natural material. Compact discs, computer parts, artificial heart valves, and even bicycle tires couldn't exist without synthetic polymers.

**Composites** Every substance has its desirable and undesirable properties. What would happen if you could take the best properties of two substances and put them together? A **composite** combines two or more substances in a new material with different properties.

## • Tech & Design in History •

### The Development of Polymers

The first synthetic polymers were made by changing natural polymers in some way. Later, crude oil and coal became the starting materials. Now, new polymers are designed regularly in laboratories.



**1839**
**Synthetic Rubber**
Charles Goodyear invented a process that turned natural rubber into a hard, stretchable polymer. It did not get sticky and soft when heated or become brittle when cold, as natural rubber does. Bicycle tires were an early use.

**1869**
**Celluloid**
Made using cellulose, celluloid became a substitute for ivory in billiard balls and combs and brushes. It was later used to make movie film. Because celluloid is very flammable, other materials have replaced it for almost all purposes.

**1909**
**Bakelite**
Bakelite was the first commercial polymer made from compounds in coal tar. Bakelite doesn't get soft when heated, and it doesn't conduct electricity. These properties made it useful for handles of pots and pans, for telephones, and for parts in electrical outlets.

1800 1850 1900

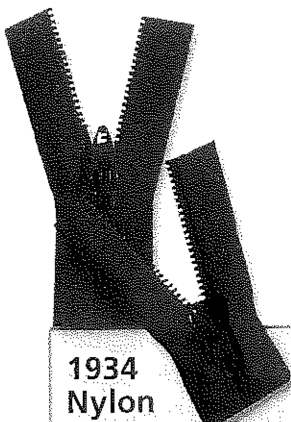
By combining the useful properties of two or more substances in a composite, chemists can make a new material that works better than either one alone. **Many composite materials include one or more polymers.** The idea of putting two different materials together to get the advantages of both was inspired by the natural world. Many synthetic composites are designed to imitate a common natural composite—wood.

Wood is made of long fibers of cellulose, held together by another plant polymer called lignin. Cellulose fibers are flexible and can't support much weight. Lignin is brittle and would crack under the weight of the tree branches. But the combination of the two polymers makes a strong tree trunk.

**Reading Checkpoint** Why is wood a composite?

## Writing in Science

**Research and Write** Find out more about the invention of one of these polymers. Write a newspaper headline announcing the invention. Then write the first paragraph of the news report telling how the invention will change people's lives.



**1934**
**Nylon**
A giant breakthrough came with a synthetic fiber that imitates silk. Nylon replaced expensive silk in women's stockings and fabric for parachutes and clothing. It can also be molded to make objects like buttons, gears, and zippers.


**1971**
**Kevlar**
Kevlar is five times stronger than steel. Kevlar is tough enough to substitute for steel ropes and cables in offshore oil rigs but light enough to use in spacecraft parts. It is also used in protective clothing for firefighters and police officers.

**2002**
**Light-Emitting Polymers**
Discovered accidentally in 1990, light-emitting polymers (LEPs) are used commercially in products such as MP3 audio players and electric shavers with display screens. LEPs give off light when exposed to low-voltage electricity. Newer, more colorful LEPs may be useful as flexible monitors for computers, TV screens, and watch-sized phones.

1950 2000 2050

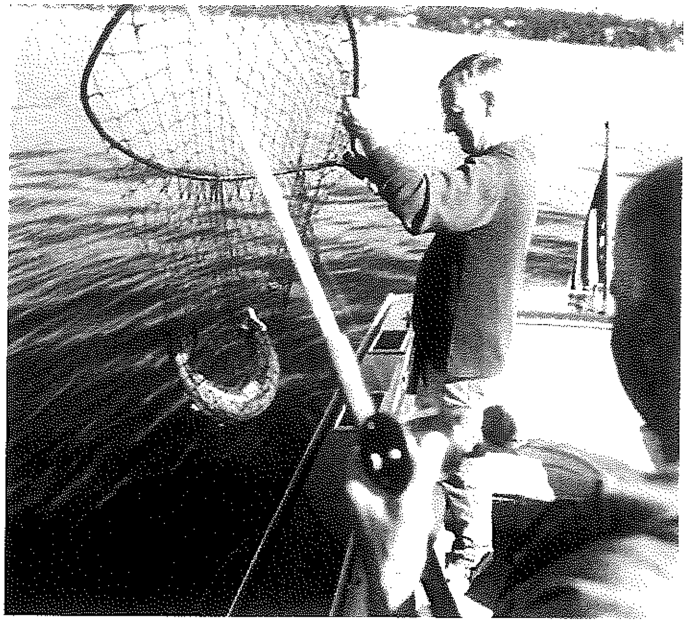


**FIGURE 19**
**Synthetic Composites**
The composites in the fishing rod above make it flexible so that it will not break when reeling in a fish. Fiberglass makes the snowboard at right both lightweight and strong.

**Uses of Composites** The idea of combining the properties of two substances to make a more useful one has led to many new products. Fiberglass composites are one example. Strands of glass fiber are woven together and strengthened with a liquid plastic that sets like glue. The combination makes a strong, hard solid that can be molded around a form to give it shape. These composites are lightweight but strong enough to be used as a boat hull or car body. Also, fiberglass will not rust as metal does.

Many other useful composites are made from strong polymers combined with lightweight ones. Bicycles, automobiles, and airplanes built from such composites are much lighter than the same vehicles built from steel or aluminum. Some composites are used to make fishing rods, tennis rackets, and other sports equipment that needs to be flexible but strong.

Reading Checkpoint **What are two examples of composites?**

## Too Many Polymers?

You can hardly look around without seeing something made of synthetic polymers. They have replaced many natural materials for several reasons. **Synthetic polymers are inexpensive to make, strong, and last a long time.**

But synthetic polymers have caused some problems, too. Many of the disadvantages of using plastics come from the same properties that make them so useful. **For example, it is often cheaper to throw plastics away and make new ones than it is to reuse them. As a result, plastics increase the volume of trash.**

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One of the reasons that plastics last so long is that most plastics don't react very easily with other substances. As a result, plastics don't break down—or degrade—into simpler materials in the environment. In contrast, natural polymers do. Some plastics are expected to last thousands of years. How do you get rid of something that lasts that long?

Is there a way to solve these problems? One solution is to use waste plastics as raw material for making new plastic products. You know this idea as recycling. Recycling has led to industries that create new products from discarded plastics. Bottles, fabrics for clothing, and parts for new cars are just some of the many items that can come from waste plastics. A pile of empty soda bottles can even be turned into synthetic wood. Look around your neighborhood. You may see park benches or "wooden" fences made from recycled plastics. Through recycling, the disposal problem is eased and new, useful items are created.

**Reading Checkpoint** **Why do plastic materials often increase the volume of trash?**

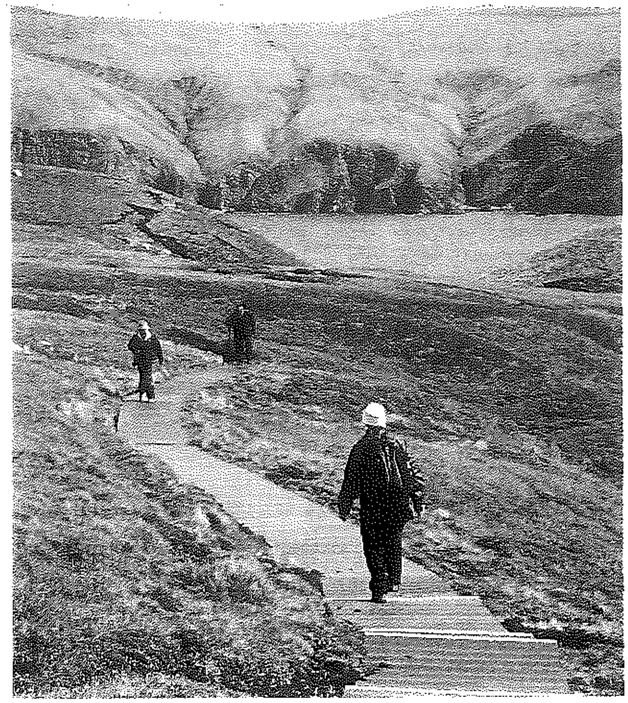


FIGURE 20
**Recycling Plastics**
Plastics can be recycled to make many useful products. This boardwalk, for example, is made of recycled plastics. Making Judgments *What advantages or disadvantages does this material have compared to wood?*

## Section 3 Assessment

**Target Reading Skill** Asking Questions Use your graphic organizer about the section headings to help answer the questions below.

### Reviewing Key Concepts

1. a. Defining What are polymers made of?
   b. Identifying What properties enable carbon atoms to form polymers and so many other compounds?
   c. Interpreting Diagrams How do the two kinds of polymers modeled in Figure 16 differ?
2. a. Reviewing Distinguish between natural polymers, synthetic polymers, and composites.
   b. Classifying Make a list of polymers you can find in your home. Classify them as natural or synthetic.
   c. Drawing Conclusions Why are composites often more useful than the individual materials from which they are made?
3. a. Listing List two benefits and two problems associated with the use of synthetic polymers.
   b. Making Judgments Think of something plastic that you have used today. Is there some other material that would be better than plastic for this use?

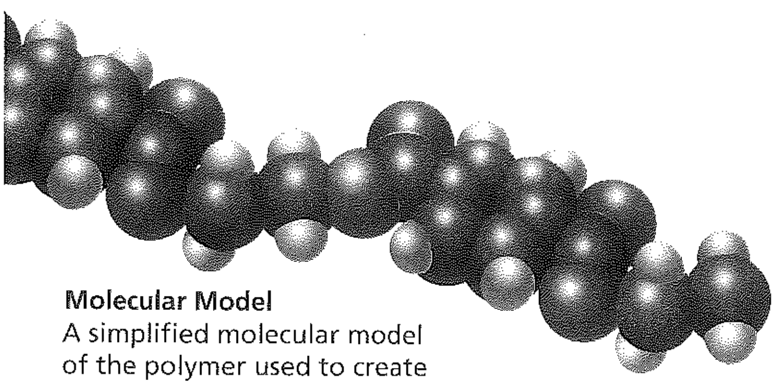
### Writing in Science

**Advertisement** You are a chemist. You invent a polymer that can be a substitute for a natural material such as wood, cotton, or leather. Write an advertisement for your polymer, explaining why you think it is a good replacement for the natural material.

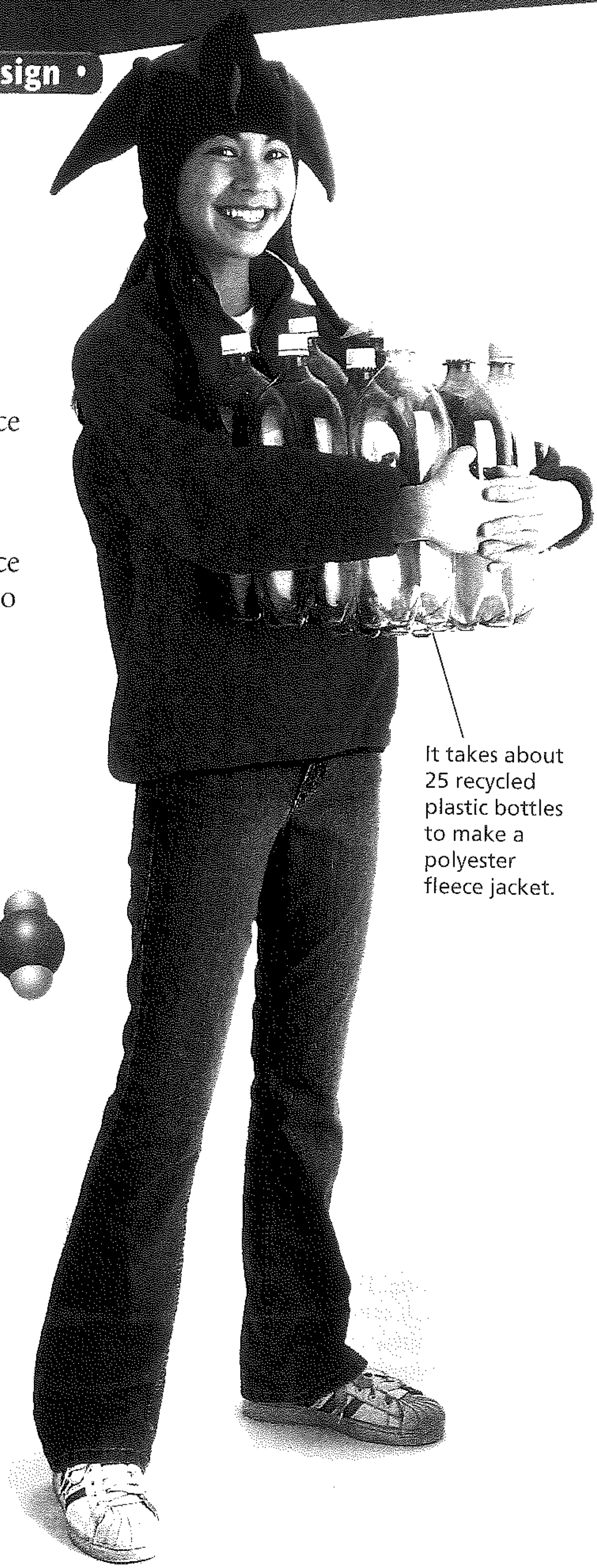
# Technology and **Society** • Tech & Design •

## Polyester Fleece

Would you go hiking in the freezing Antarctic wearing a bunch of plastic beverage bottles? If you are like most serious hikers, you would. Polyester fleece is a lightweight, warm fabric made from plastic, including recycled soda bottles. The warmth of the fabric is due to its ability to trap and hold air. Polyester fleece is easy to wash and requires less energy to dry than wool or goose down.



**Molecular Model**
A simplified molecular model of the polymer used to create polyester fleece is shown here. The molecules form long, straight chains.

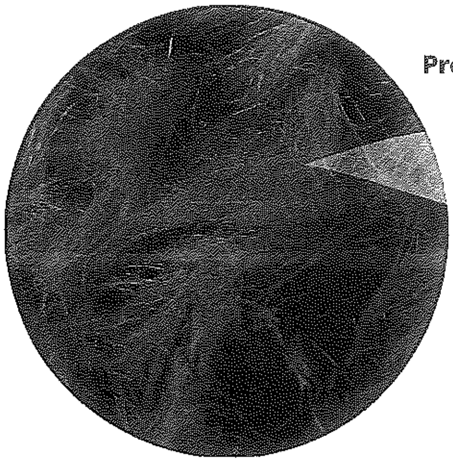


It takes about 25 recycled plastic bottles to make a polyester fleece jacket.

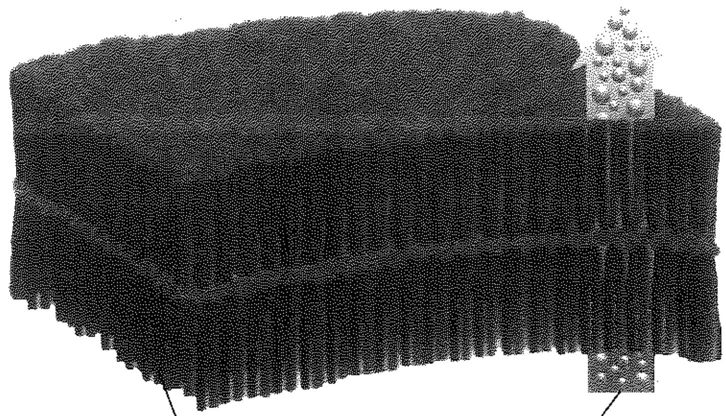
### Making Polyester Fleece

Polyethylene terephthalate, or PET, is the polymer that is used to make polyester fleece. The first step in the process is creating the polyester fiber or thread. It can be made from raw materials or recycled PET plastic. The thread is then knit into fabric, which can be dyed or printed. It is then dried and "napped." In the napping process, the fibers are first raised and then clipped to an even height. This process increases the amount of air the fabric can hold, which helps keep you warm in cold weather.

Properties of Polyester Fleece



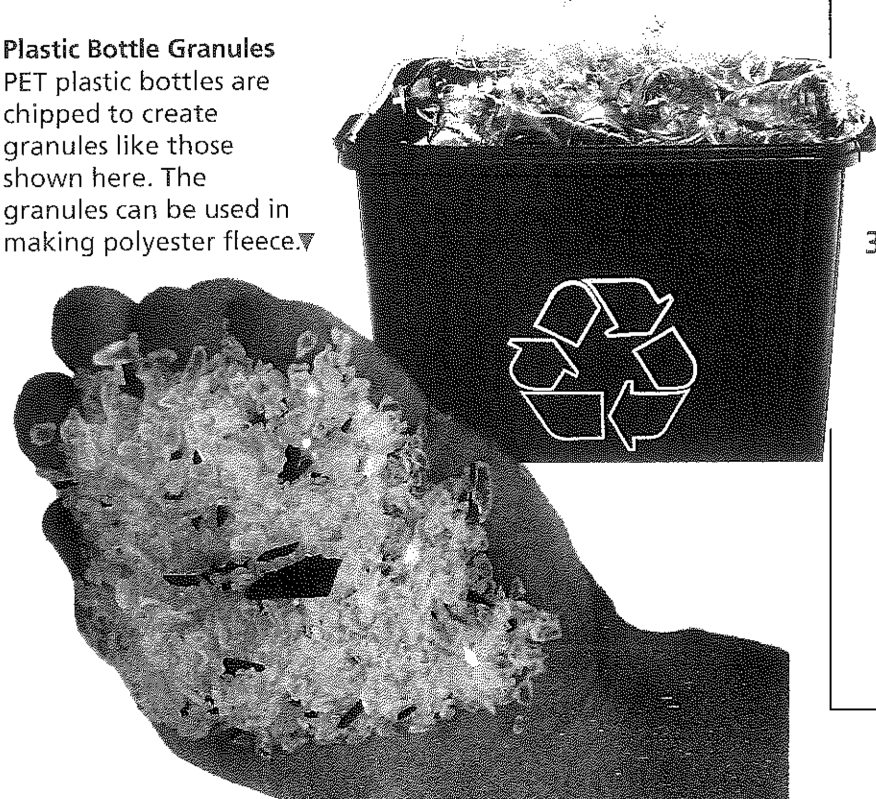
▲ **Fleece Fabric**
Similar to yarn in a sweater, fleece fibers are knit together to create a stretchy, dense fabric that is soft, lightweight, and durable.




## Polyester Fleece and the Environment

Making polyester fleece fabric uses water and energy, like other fabric-making processes. Using recycled materials to create polyester fleece saves energy and reduces wastes. One trade-off involves the safety of workers in the fleece factories. The clipping process creates dust particles in the air that workers then breathe. Some companies that produce fleece are developing technology that should reduce dust in the workplace, as well as technologies that conserve and reuse energy and water.

**Plastic Bottle Granules**
PET plastic bottles are chipped to create granules like those shown here. The granules can be used in making polyester fleece.▼



### Weigh the Impact

1. **Identify the Need**
   What are some benefits of using polyester fleece to make clothing and blankets?
2. **Research**
   Use the Internet to find companies that make or sell polyester fleece made from recycled plastic. Identify ways in which this form of recycling helps the environment.
3. **Write**
   Create a pamphlet to encourage your classmates to recycle plastics. Describe how PET plastic can be used to create polyester fleece.

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**Visit:** PHSchool.com
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Section 4

Integrating Life Science

# Life With Carbon

## Reading Preview

### Key Concepts

- What are the four main classes of organic compounds in living things?
- How are the organic compounds in living things different from one another?

### Key Terms

- carbohydrate
- glucose
- complex carbohydrate
- starch
- cellulose
- lipid
- fatty acid
- cholesterol
- nucleic acid
- DNA
- RNA
- nucleotide

### Target Reading Skill

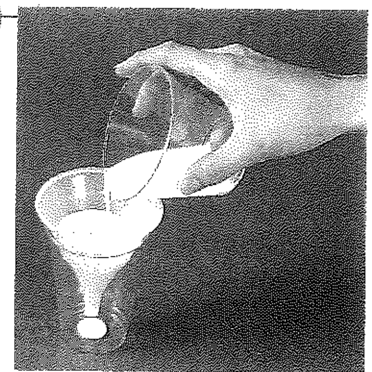
**Asking Questions** Before you read, preview the red headings. In a graphic organizer like the one below, ask a *what* question for each heading. As you read, write the answers to your questions.

Life With Carbon

| Question | Answer |
|---|---|
| What is a carbohydrate? | A carbohydrate is . . . |
| | |

## Lab zone Discover Activity

### What Is in Milk?



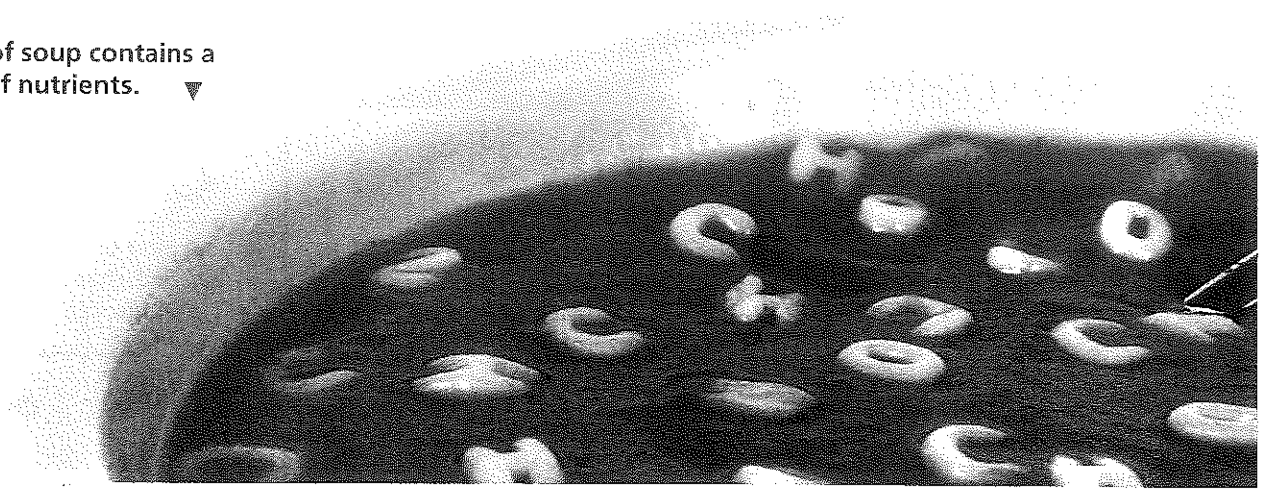
1. Pour 30 mL of milk into a plastic cup.
2. Pour another 30 mL of milk into a second plastic cup. Rinse the graduated cylinder. Measure 15 mL of vinegar and add it to the second cup. Swirl the two liquids together and let the mixture sit for a minute.
3. Set up two funnels with filter paper, each supported in a narrow plastic cup.
4. Filter the milk through the first funnel. Filter the milk and vinegar through the second funnel.
5. What is left in each filter paper? Examine the liquid that passed through each filter paper.

**Think It Over**

Observing Where did you see evidence of solids? What do you think was the source of these solids?

Have you ever been told to eat all the organic compounds on your plate? Have you heard how eating a variety of polymers and monomers contributes to good health? What? No one has ever said those things to you? Well, maybe what you really heard was something about eating all the vegetables on your plate, or eating a variety of foods to give you a healthy balance of carbohydrates, proteins, fats, and other nutrients. All these nutrients are organic compounds, which are the building blocks of all living things.

A bowl of soup contains a variety of nutrients. ▼



Foods provide organic compounds, which the cells of living things use, change, or store. **The four classes of organic compounds required by living things are carbohydrates, proteins, lipids, and nucleic acids.** Carbohydrates, proteins, and lipids are nutrients. Nutrients (NOO tree unts) are substances that provide the energy and raw materials the body needs to grow, repair worn parts, and function properly.

## Carbohydrates

A **carbohydrate** (kahr boh HY drayt) is an energy-rich organic compound made of the elements carbon, hydrogen, and oxygen. The word *carbohydrate* is made of two parts: *carbo-* and *-hydrate*. *Carbo-* means "carbon" and *-hydrate* means "combined with water." If you remember that water is made up of the elements hydrogen and oxygen, then you should be able to remember the three elements in carbohydrates.

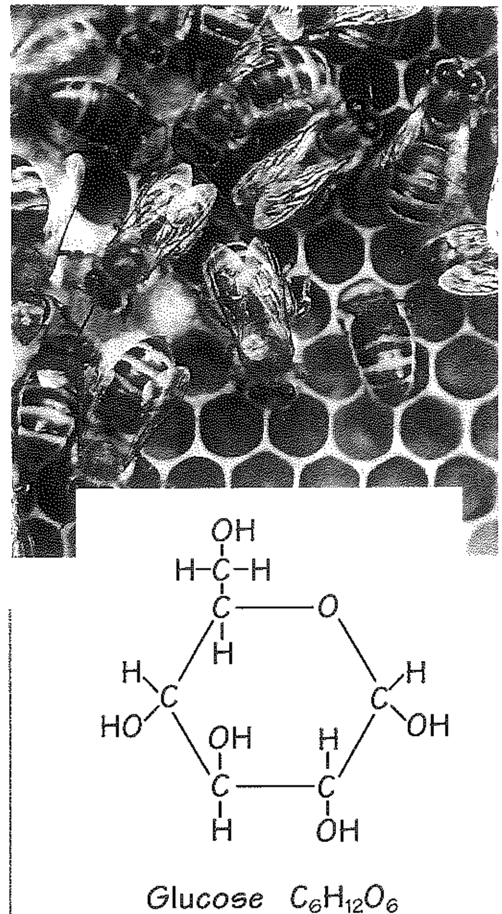
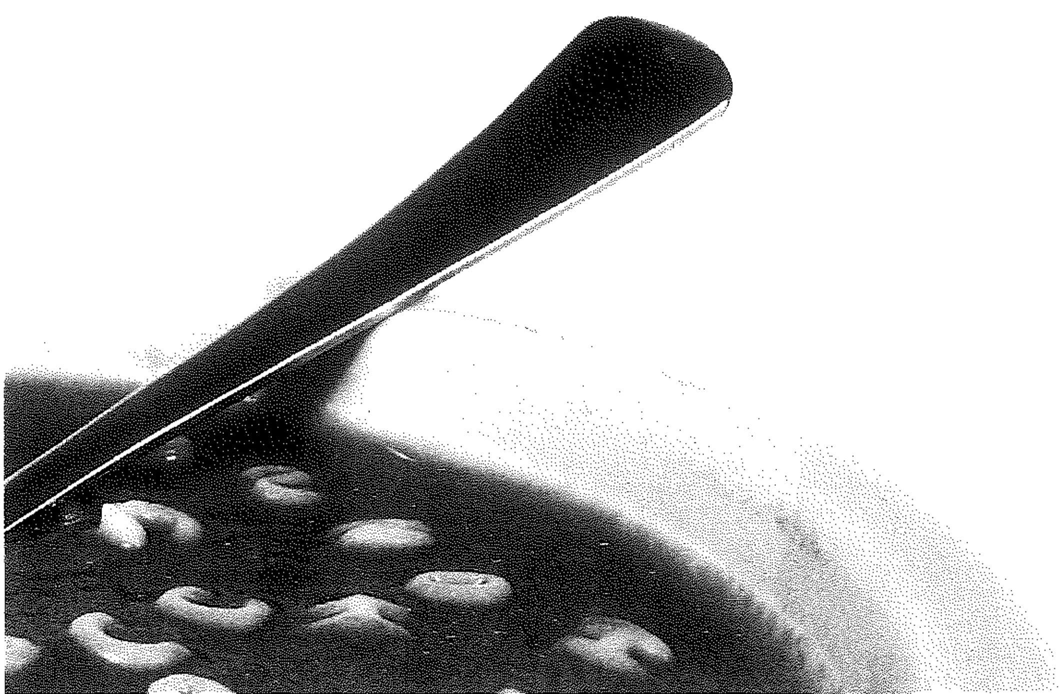



**FIGURE 21**
**Carbohydrates**
The honey made by honeybees contains glucose, a simple carbohydrate. **Applying Concepts** *What are some other examples of foods that contain carbohydrates?*

**Simple Carbohydrates** The simplest carbohydrates are sugars. You may be surprised to learn that there are many different kinds of sugars. The sugar listed in baking recipes, which you can buy in bags or boxes at the grocery store, is only one kind. Other sugars are found naturally in fruits, milk, and some vegetables.

One of the most important sugars in your body is **glucose.** Its chemical formula is $C_6H_{12}O_6$. Glucose is sometimes called "blood sugar" because the body circulates glucose to all body parts through blood. The structural formula for a glucose molecule is shown in Figure 21.

The white sugar that sweetens cookies, candies, and many soft drinks is called sucrose. Sucrose is a more complex molecule than glucose and has a chemical formula of $C_{12}H_{22}O_{11}$.



Lab zone **Try This Activity**

### Alphabet Soup

Here's how you can model the rearrangement of amino acids in your body.

1. Rearrange the letters of the word *proteins* to make a new word or words. (Don't worry if the new words don't make sense together.)
2. Choose three other words with ten or more letters. Repeat the activity.

**Making Models** What words did you make from *proteins*? What new words did you make from the words you chose? How does this activity model the way your body uses proteins in food to make new proteins?

**Complex Carbohydrates** When you eat plants or food products made from plants, you are often eating complex carbohydrates. Each molecule of a simple carbohydrate, or sugar, is relatively small compared to a molecule of a complex carbohydrate. A **complex carbohydrate** is a polymer made of smaller molecules that are simple carbohydrates bonded to one another. As a result, just one molecule of a complex carbohydrate may have hundreds of carbon atoms.

Two of the complex carbohydrates assembled from glucose molecules are starch and cellulose. **Starch and cellulose are both polymers built from glucose, but the glucose molecules are arranged differently in each case.** Having different arrangements means that starch and cellulose are different compounds. They serve different functions in the plants that make them. Your body also uses starch very differently from the way it uses cellulose.

**Starch** Plants store energy in the form of the complex carbohydrate **starch.** You can find starches in food products such as bread, cereal, pasta, rice, and potatoes.

The process of breaking large molecules, such as starch, into smaller ones involves chemical reactions that occur during digestion. The body digests the large starch molecules from these foods into individual glucose molecules. The body then breaks apart the glucose molecules, releasing energy in the process. This energy allows the body to carry out its life functions.

**Cellulose** Plants build strong stems and roots with the complex carbohydrate **cellulose** and other polymers. Most fruits and vegetables are high in cellulose. So are foods made from whole grains. Even though the body can break down starch, it cannot break down cellulose into individual glucose molecules. Therefore the body cannot use cellulose as an energy source. In fact, when you eat foods with cellulose, the molecules pass through you undigested. However, this undigested cellulose helps keep your digestive tract active and healthy. Cellulose is sometimes called fiber.

**Reading Checkpoint** What foods are high in cellulose?

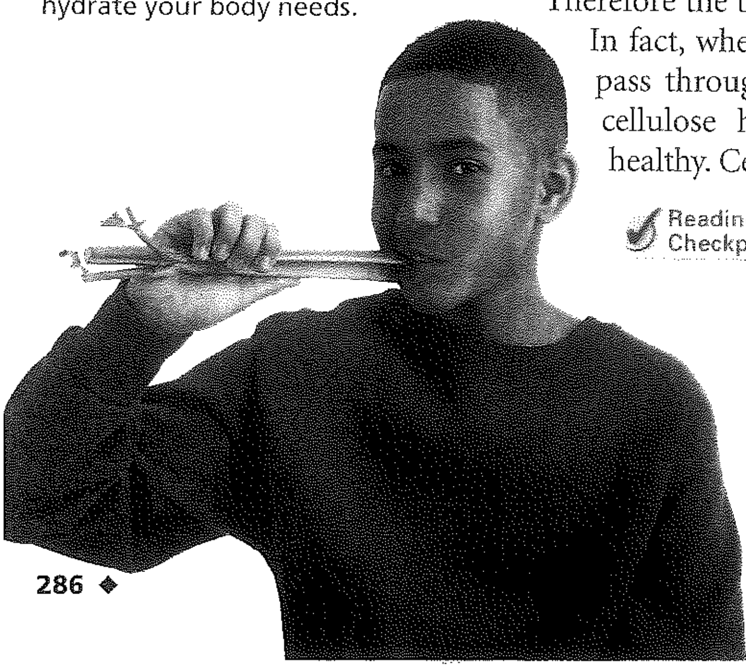


FIGURE 22
**Cellulose**
Cellulose, found in celery and other vegetables, is a carbohydrate your body needs.

## Proteins

If the proteins in your body suddenly disappeared, you would not have much of a body left! Your muscles, hair, skin, and fingernails are all made of proteins. A bird's feathers, a spider's web, a fish's scales, and the horns of a rhinoceros are also made of proteins.

**Chains of Amino Acids** As you have learned, proteins are polymers formed from combinations of monomers called amino acids. There are 20 kinds of amino acids found in living things. **Different proteins are made when different sequences of amino acids are linked into long chains.** Since proteins can be made of combinations of amino acids in any order and number, a huge variety of proteins is possible.

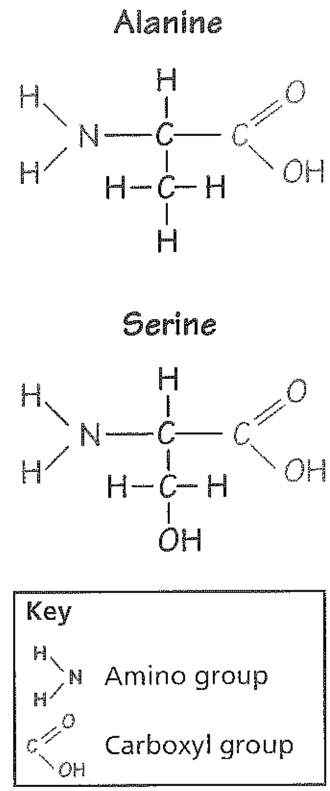
The structure of an amino acid is shown in Figure 23. Each amino acid molecule has a carboxyl group (—COOH). The *acid* in the term *amino acid* comes from this part of the molecule. An amino group, with the structure —$NH_2$, is the source of the *amino* half of the name. The remaining part of the molecule differs for each kind of amino acid.

**Food Proteins Become Your Proteins** Some of the best sources of protein include meat, fish, eggs, and milk or milk products. If you did the Discover activity, you used vinegar to separate proteins from milk. Some plant products, such as beans, are good sources of protein as well.

The body uses proteins from food to build and repair body parts and to regulate cell activities. But first the proteins must be digested. Just as starch is broken down into glucose molecules, proteins are broken down into amino acids. Then the body reassembles those amino acids into thousands of different proteins that can be used by cells.

**Reading Checkpoint** What are good sources of dietary protein?

FIGURE 23
**Amino Acids**
Alanine and serine are two of the 20 amino acids in living things. Each amino acid has a carboxyl group (—COOH) and an amino group (—$NH_2$).



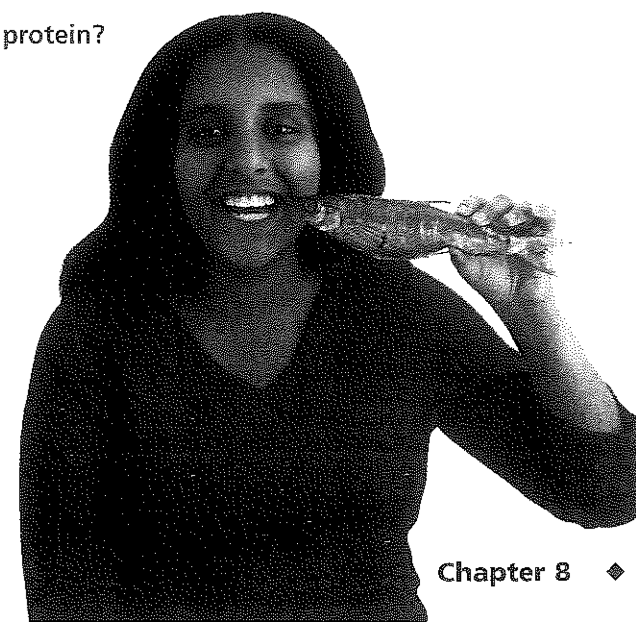



FIGURE 24
**Proteins**
Your body needs proteins, which are available in fish and meat. Drawing Conclusions *How are amino acids related to proteins?*

**Lab zone** **Try This Activity**

### Like Oil or Water?

Oils mix poorly with water. They also do not evaporate very quickly when exposed to air.

1. Obtain a piece of brown paper and some samples of liquids provided by your teacher.
2. Using a dropper, place one drop of liquid from each sample on the paper.
3. Wait 5 minutes.
4. Note which of the liquids leaves a spot.

**Inferring** Which of the liquids is a fat or oil? How can you tell?

## Lipids

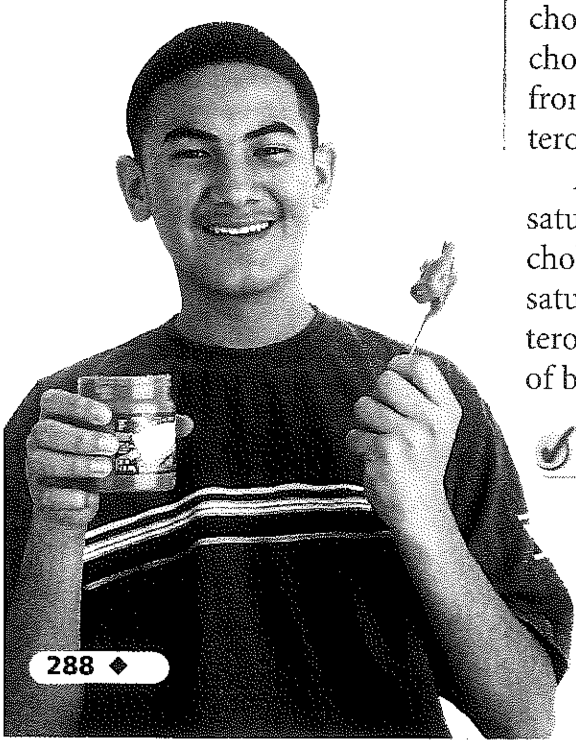
The third class of organic compounds in living things is lipids. Like carbohydrates, **lipids** are energy-rich compounds made of carbon, oxygen, and hydrogen. Lipids include fats, oils, waxes, and cholesterol. **Gram for gram, lipids release twice as much energy in your body as do carbohydrates.** Like hydrocarbons, lipids mix poorly with water.

**Fats and Oils** Have you ever gotten grease on your clothes from foods that contain fats or oils? Fats are found in foods such as meat, butter, and cheese. Oils are found in foods such as corn, sunflower seeds, peanuts, and olives.

Fats and oils have the same basic structure. Each fat or oil is made from three **fatty acids** and one alcohol named glycerol. There is one main difference between fats and oils, however. Fats are usually solid at room temperature, whereas oils are liquid. The temperature at which a fat or an oil becomes a liquid depends on the chemical structure of its fatty acid molecules.

You may hear fats and oils described as "saturated" or "unsaturated." Like saturated hydrocarbons, the fatty acids of saturated fats have no double bonds between carbon atoms. Unsaturated fatty acids are found in oils. Monounsaturated oils have fatty acids with one double bond. Polyunsaturated oils have fatty acids with many double bonds. Saturated fats tend to have higher melting points than unsaturated oils have.

**FIGURE 25**
**Fats and Oils**
Foods that contain fats and oils include peanut butter, butter, cheese, corn, and olives.

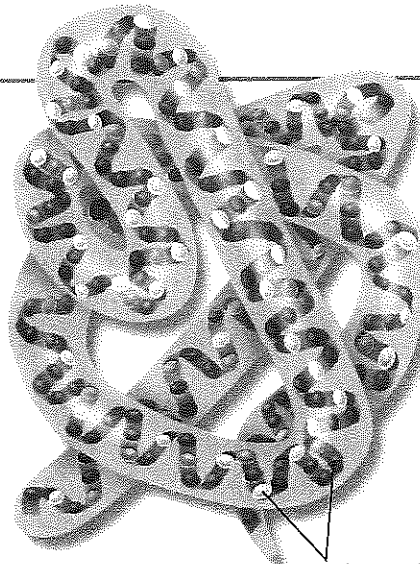


**Cholesterol** Another important lipid is **cholesterol** (kuh LES tuh rawl), a waxy substance found in all animal cells. The body needs cholesterol to build cell structures and to form compounds that serve as chemical messengers. Unlike other lipids, cholesterol is not a source of energy. The body produces the cholesterol it needs from other nutrients. Foods that come from animals—cheese, eggs, and meat—also provide cholesterol. Plants do not produce cholesterol.

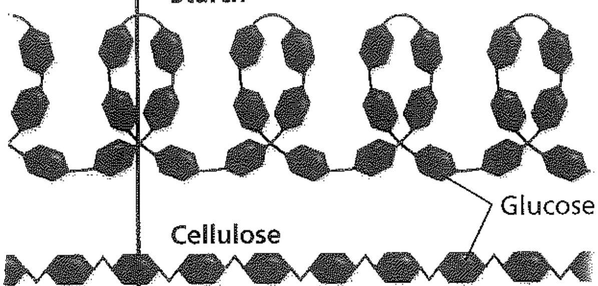
Although cholesterol is often found in the same foods as saturated fats, they are different compounds. An excess level of cholesterol in the blood can contribute to heart disease. So can saturated fats. And saturated fats can affect the level of cholesterol in the blood. For this reason it is wise to limit your intake of both nutrients.

**Reading Checkpoint** What are sources of cholesterol in the diet?

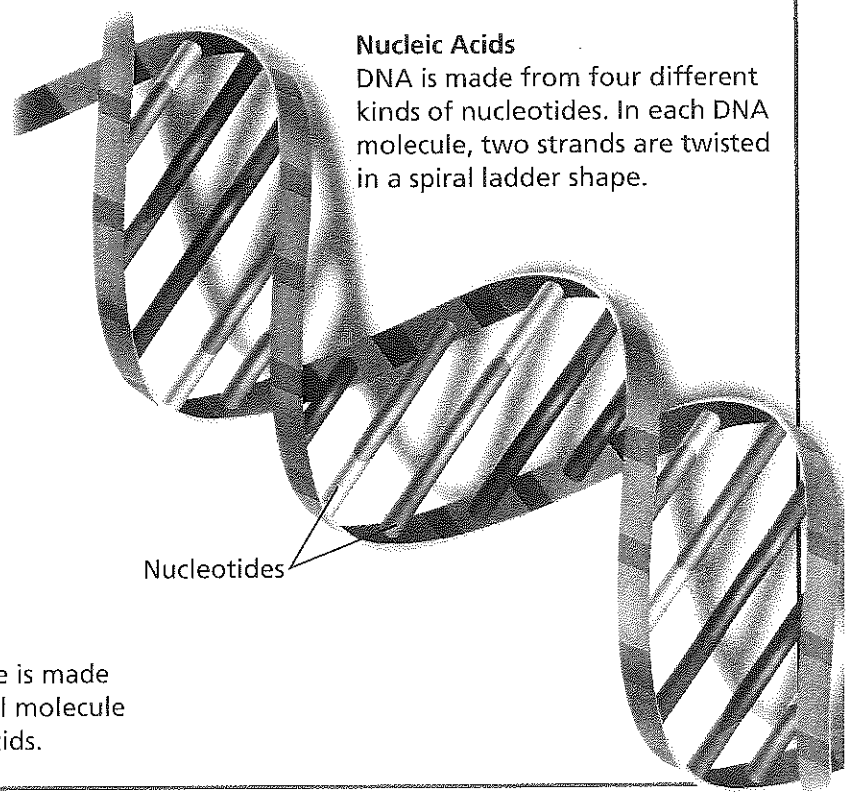
FIGURE 26
### The Molecules of Life
Complex carbohydrates, proteins, lipids, and nucleic acids are all large organic molecules. They are built of smaller molecules linked in different patterns. Applying Concepts *What are the building blocks of proteins?*



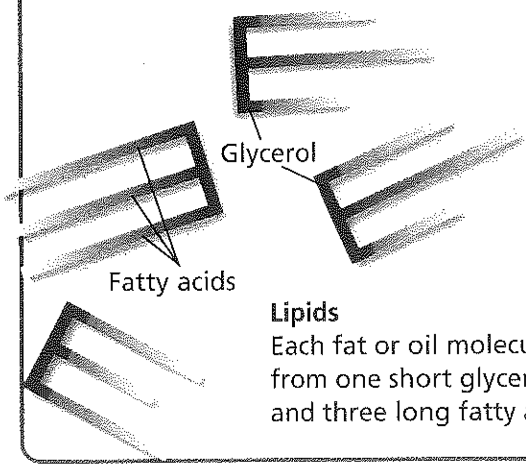

**Proteins**
The building blocks of proteins are amino acids. Although protein chains are never branched, each chain can twist and bend, forming complex three-dimensional shapes.




**Complex Carbohydrates**
Complex carbohydrates are polymers of simple carbohydrates. Starch and cellulose, both made of glucose, differ in how their molecules are arranged.




**Nucleic Acids**
DNA is made from four different kinds of nucleotides. In each DNA molecule, two strands are twisted in a spiral ladder shape.




**Lipids**
Each fat or oil molecule is made from one short glycerol molecule and three long fatty acids.

## Nucleic Acids
The fourth class of organic compounds in living things is nucleic acids. **Nucleic acids** (noo KLEE ik) are very large organic molecules made up of carbon, oxygen, hydrogen, nitrogen, and phosphorus. You have probably heard of one type of nucleic acid—**DNA,** deoxyribonucleic acid (dee ahk see ry boh noo KLEE ik). The other type of nucleic acid, ribonucleic acid (ry boh noo KLEE ik), is called **RNA.**

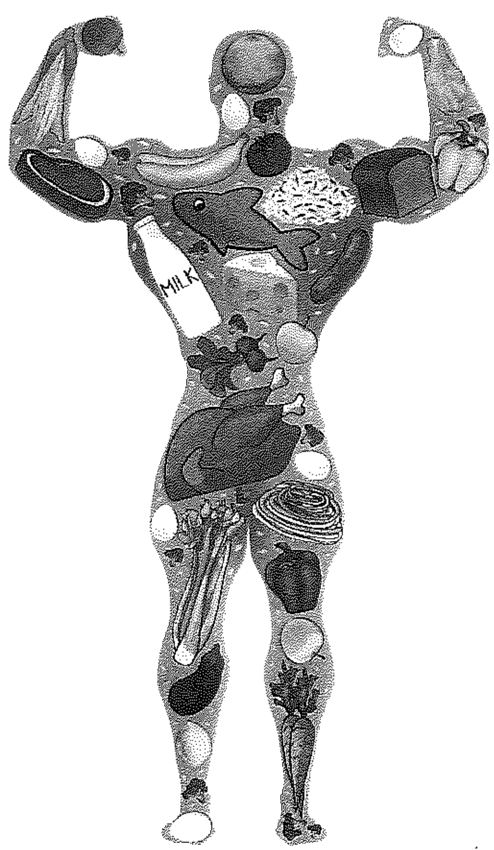
**Nucleotides** DNA and RNA are made of different kinds of small molecules connected in a pattern. The building blocks of nucleic acids are called **nucleotides** (NOO klee oh tydz). In even the simplest living things, the DNA contains billions of nucleotides! There are only four kinds of nucleotides in DNA. RNA is also built of only four kinds of nucleotides, but the nucleotides in RNA differ from those in DNA.

**DNA and Proteins** **The differences among living things depend on the order of nucleotides in their DNA.** The order of DNA nucleotides determines a related order in RNA. The order of RNA nucleotides, in turn, determines the sequence of amino acids in proteins made by a living cell.

Remember that proteins regulate cell activities. Living things differ from one another because their DNA, and therefore their proteins, differ from one another. The cells in a hummingbird grow and function differently from the cells in a flower or in you. When living things reproduce, they pass DNA and the information it carries to the next generation.

**Reading Checkpoint** **What are the building blocks of nucleic acids?**

FIGURE 27
**Vitamins and Minerals**
Sources of vitamins and minerals include fruits, vegetables, nuts, meats, and dairy products.
Observing *Which of these foods can you identify in the picture?*




## Other Compounds in Foods

Carbohydrates, proteins, and lipids are not the only compounds your body needs. Your body also needs vitamins, minerals, water, and salts. **Unlike the nutrients discussed so far, vitamins and minerals are needed only in small amounts.** They do not directly provide you with energy or raw materials.

**Vitamins** Vitamins are organic compounds that serve as helper molecules in a variety of chemical reactions in your body. For example, vitamin C, or ascorbic acid, is important for keeping your skin and gums healthy. Vitamin D helps your bones and teeth develop and keeps them strong.

**Minerals** Minerals are elements in the form of ions needed by your body. Unlike the other nutrients discussed in this chapter, minerals are not organic compounds. Minerals include calcium, iron, iodine, sodium, and potassium. They are important in many body processes.

If you eat a variety of foods, you will probably get the vitamins and minerals you need. Food manufacturers add some vitamins and minerals to packaged foods to replace vitamins and minerals that are lost in food processing. Such foods say "enriched" on their labels.

Sometimes manufacturers add extra vitamins and minerals to foods to "fortify," or strengthen, the nutritional value of the food. For example, milk is usually fortified with vitamin A and vitamin D.

**Water** Although water, $H_2O$, is not an organic compound, it is a compound that your body needs to survive. In fact, you would be able to survive only a few days without fresh water. Water makes up most of your body's fluids, including about 90 percent of the liquid part of your blood.

Nutrients and other important substances are dissolved in the watery part of the blood and carried throughout the body. Many chemical reactions, such as the breakdown of nutrients, take place in water. Wastes from cells dissolve in the blood and are carried away.

Reading Checkpoint **What is a vitamin?**

Go Online SCI LINKS NSTA

**For:** Links on organic compounds
**Visit:** www.SciLinks.org
**Web Code:** scn-1243

## Section 4 Assessment

**Target Reading Skill** Asking Questions Review your graphic organizer and revise it based on what you just learned in the section.

### Reviewing Key Concepts

1. a. Naming What are the four main classes of organic compounds required by living things?
   b. Classifying To what class of organic compounds does each of the following belong: glucose, RNA, cholesterol, cellulose, and oil?
   c. Making Generalizations How is each class of organic compounds used by the body?
2. a. Identifying What are the building blocks of complex carbohydrates?
   b. Comparing and Contrasting Compare the building blocks found in complex carbohydrates with those found in proteins.
   c. Making Judgments Would it matter if you ate foods that provided only carbohydrates but not proteins? Explain your reasoning.

### Writing in Science

**Advertisement** Collect several food advertisements from magazines and watch some TV commercials. What do the ads say about nutrients? What do they emphasize? What do they downplay? Choose one ad and rewrite it to reflect the nutritional value of the product.

Lab zone **Consumer Lab**

# Are You Getting Your Vitamins?

## Problem

Fruit juices contain vitamin C, an important nutrient. Which juice should you drink to obtain the most vitamin C?

## Skills Focus

controlling variables, interpreting data, inferring

## Materials

- 6 small cups
- 6 plastic droppers
- starch solution
- iodine solution
- vitamin C solution
- samples of beverages (orange juice, apple juice, sports drink, fruit-flavored drink)

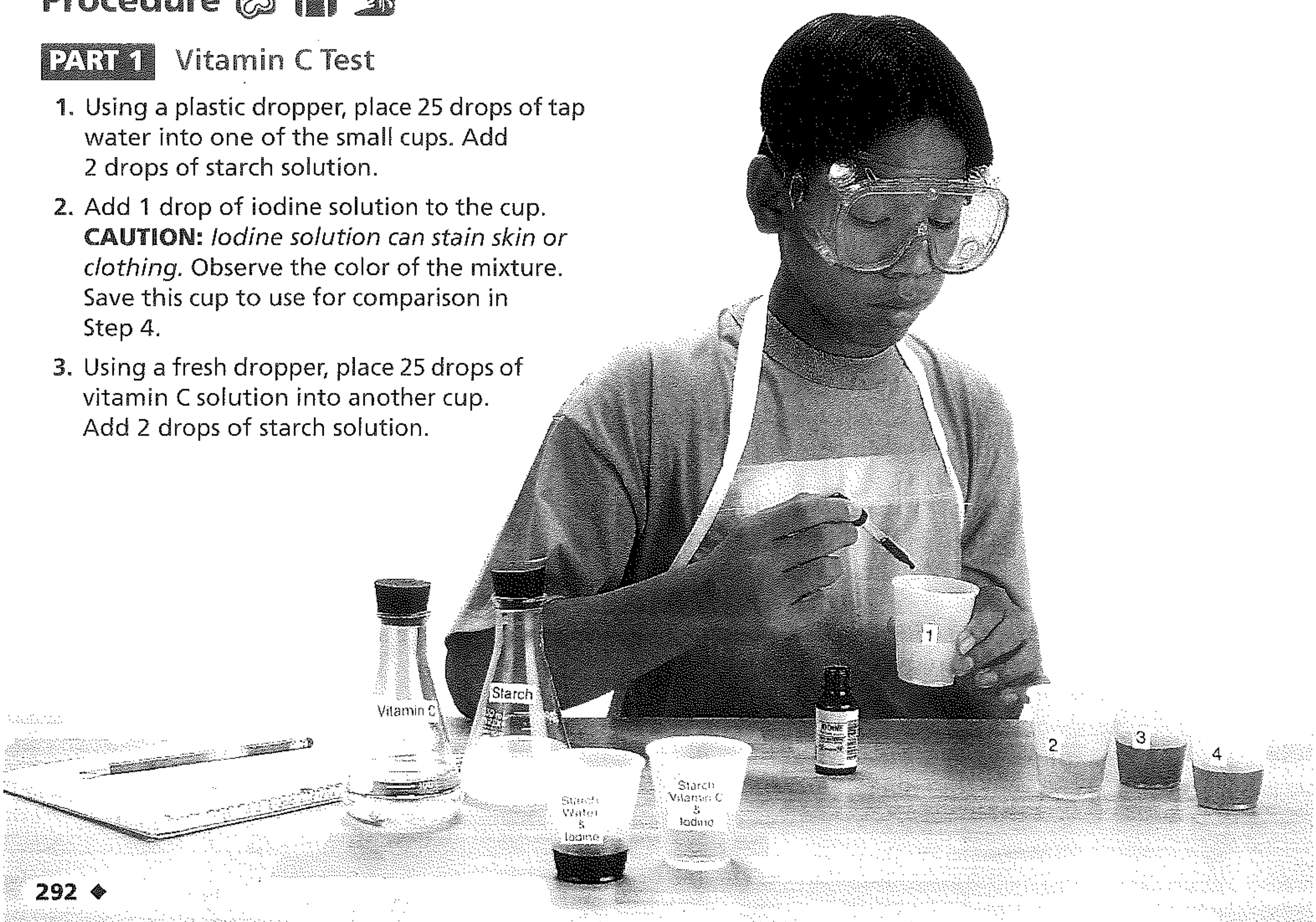
## Procedure

### PART 1 Vitamin C Test

1. Using a plastic dropper, place 25 drops of tap water into one of the small cups. Add 2 drops of starch solution.
2. Add 1 drop of iodine solution to the cup. **CAUTION:** *Iodine solution can stain skin or clothing.* Observe the color of the mixture. Save this cup to use for comparison in Step 4.
3. Using a fresh dropper, place 25 drops of vitamin C solution into another cup. Add 2 drops of starch solution.
4. Add 1 drop of iodine solution to the cup and swirl. Continue adding iodine a drop at a time, swirling after each drop, until you get a dark blue color similar to the color obtained in Step 2. Record the number of iodine drops.
5. Save the cup from Step 4 and use it for comparison during Part 2.

### PART 2 Comparison Test

6. Make a data table in your notebook similar to the one on the next page.
7. Which beverage sample do you think has the most vitamin C? Which do you think has the least? Rank your beverage samples according to your predictions.




| Data Table | | | |
|---|---|---|---|
| Test Sample | Drops of Iodine | Predicted Rank | Actual Rank |
| Vitamin C | | | |
| Orange juice | | | |
| Apple juice | | | |
| Sports drink | | | |
| Fruit-flavored drink | | | |

8. Adapt the procedure from Part 1 so you can compare the amount of vitamin C in your beverage samples to the vitamin C solution.
9. Carry out your procedure after your teacher approves.

## Analyze and Conclude

1. Controlling Variables What was the purpose for the test of the mixture of starch and water in Step 2?
2. Controlling Variables What was the purpose for the test of the starch, water, and vitamin C in Step 4?
3. Drawing Conclusions What do you think caused differences between your data from Step 2 and Step 4?
4. Controlling Variables Why did you have to add the same amount of starch to each of the beverages?
5. Predicting What would happen if someone forgot to add the starch to the beverage before they began adding iodine?
6. Measuring Of the four drinks you tested, which took the most drops of iodine before changing color? Which took the fewest?
7. Interpreting Data Which beverage had the most vitamin C? Which had the least? How do you know?
8. Inferring When you tested orange juice, the color of the first few drops of the iodine faded away. What do you think happened to the iodine?
9. Communicating If a beverage scored low in your test for vitamin C, does that mean it isn't good for you? Write a paragraph in which you explain what other factors might make a beverage nutritious or take away from its nutrient value.

## Design an Experiment

Foods are often labeled with expiration dates. Labels often also say to "refrigerate after opening." Design an experiment to find out if the vitamin C content of orange juice changes over time at different temperatures. *Obtain your teacher's permission before carrying out your investigation.*

# Chapter 8 Study Guide

**The BIG Idea** **Structure and Function** Carbon has the ability to combine in many ways with itself and other elements. Carbon molecules serve many different functions in living things.

## 1 Properties of Carbon

### Key Concepts

- Few elements have the ability of carbon to bond with both itself and other elements in so many different ways. With four valence electrons, each carbon atom is able to form four bonds.
- Diamond, graphite, fullerenes, and nanotubes are four forms of the element carbon.

### Key Terms

• diamond • graphite • fullerene • nanotube

## 2 Carbon Compounds

### Key Concepts

- Many organic compounds have similar properties in terms of melting points, boiling points, odor, electrical conductivity, and solubility.
- Hydrocarbons mix poorly with water. Also, all hydrocarbons are flammable.
- The carbon chains in a hydrocarbon may be straight, branched, or ring-shaped. In addition to forming a single bond, two carbon atoms can form a double bond or a triple bond.
- If just one atom of another element is substituted for a hydrogen atom in a hydrocarbon, a different compound is created.
- Many esters have pleasant, fruity smells.
- Organic compounds, such as alcohols, esters, and others, can be linked to build polymers with thousands or even millions of atoms.

### Key Terms

organic compound
hydrocarbon
structural formula
isomer
saturated hydrocarbon
unsaturated hydrocarbon
substituted hydrocarbon
hydroxyl group
alcohol
organic acid
carboxyl group
ester
polymer
monomer

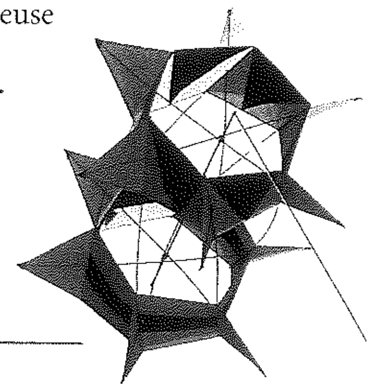
## 3 Polymers and Composites

### Key Concepts

- Polymers form when chemical bonds link large numbers of monomers in a repeating pattern.
- Many composite materials include one or more polymers.
- Synthetic polymers are inexpensive to make, strong, and last a long time.
- It is often cheaper to throw plastics away and make new ones than it is to reuse them. As a result, plastics increase the volume of trash.

### Key Terms

protein
amino acid
plastic
composite



## 4 Life With Carbon

### Key Concepts

- The four classes of organic compounds required by living things are carbohydrates, proteins, lipids, and nucleic acids.
- Starch and cellulose are both polymers built from glucose, but the glucose molecules are arranged differently in each case.
- Different proteins are made from different sequences of amino acids.
- Gram for gram, lipids release twice as much energy in your body as do carbohydrates.
- The differences among living things depend on the order of nucleotides in their DNA.
- Vitamins and minerals are needed only in small amounts.

### Key Terms

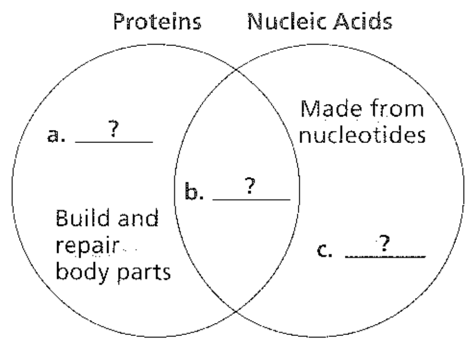
• carbohydrate • glucose • complex carbohydrate
• starch • cellulose • lipid • fatty acid
• cholesterol • nucleic acid • DNA • RNA
• nucleotide

# Review and Assessment

Go Online
PHSchool.com
For: Self-Assessment
Visit: PHSchool.com
Web Code: cka-1080

## Organizing Information

**Comparing and Contrasting** Copy the Venn Diagram comparing proteins and nucleic acids onto a separate sheet of paper. Then complete it and add a title. (For more on Comparing and Contrasting, see the Skills Handbook.)




## Reviewing Key Terms

**Choose the letter of the best answer.**

1. A form of carbon in which the carbon bonds are arranged in a repeating pattern similar to a geodesic dome is
   a. a fullerene.
   b. graphite.
   c. diamond.
   d. a nanotube.
2. A compound that contains only hydrogen and carbon is defined as
   a. a monomer.
   b. an isomer.
   c. a hydrocarbon.
   d. a polymer.
3. Fiberglass is a type of
   a. polymer.
   b. alloy.
   c. ceramic.
   d. composite.
4. The smaller molecules from which cellulose is made are
   a. glucose.
   b. amino acids.
   c. nucleotides.
   d. fatty acids.
5. Cholesterol is a type of
   a. nucleic acid.
   b. carbohydrate.
   c. lipid.
   d. cellulose.

**If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.**

6. Because the bonds between layers of carbon atoms are weak, layers of fullerenes slide easily past one another.
7. Hydrocarbons that contain only single bonds are said to be unsaturated hydrocarbons.
8. An organic acid is characterized by one or more hydroxyl groups.
9. Plastics are synthetic polymers that can be molded or shaped.
10. Proteins are made up of long chains of amino acids.

## Writing in Science

**Web Site** You are writing a feature article on carbon for a chemistry Web site. In your article, describe four forms of the element carbon. Include in your descriptions how the carbon atoms are arranged and how the bonds between the carbon atoms affect the properties of the substance. Include any helpful illustration.

# Review and Assessment

## Checking Concepts

**11.** What does a dash written between two carbon symbols in a structural diagram represent?

**12.** What do diamonds, graphite, fullerenes, and nanotubes have in common?

**13.** How would you notice the presence of esters in a fruit such as a pineapple?

**14.** Name some polymers that are produced in nature. Tell where they come from.

**15.** Starch and cellulose are both complex carbohydrates. How does your body treat these compounds differently?

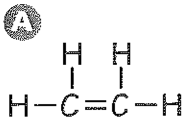
**16.** Compare and contrast the fatty acids in fats that are solid at room temperature with fatty acids in oils that are liquids.

## Thinking Critically

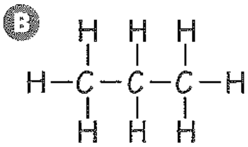
**17.** Relating Cause and Effect What features of the element carbon allow it to form the "backbone" of such a varied array of different compounds?

**18.** Applying Concepts Which of the diagrams below represents a saturated hydrocarbon? Which represents an unsaturated hydrocarbon? Explain your answer.

A



B



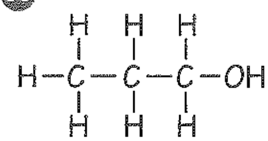
**19.** Making Judgments The plastic rings that hold beverage cans together are sometimes hazardous to living things in the ocean. Do you think companies that make soft drinks should be allowed to continue using plastic rings? Consider what could replace them.

**20.** Posing Questions Glucose and fructose are both simple carbohydrates with the formula $C_6H_{12}O_6$. What else do you need to know about glucose and fructose to decide if they should be considered different compounds?

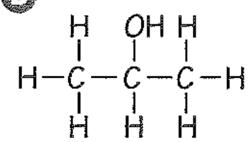
## Applying Skills

**Use the following structural formulas to answer Questions 21–25.**

A



B



**21.** Classifying Which type of substituted hydrocarbons are compounds A and B? What information in the structural formulas did you use to decide your answer?

**22.** Observing What is the correct subscript for the carbon atoms (C) in the chemical formula that corresponds to each structural formula?

**23.** Inferring Are compounds A and B isomers? How can you tell?

**24.** Predicting Would you expect these two compounds to have identical properties or different properties? Explain.

**25.** Problem Solving What kind of compound would result if an organic acid were chemically combined with compound A? What properties would you expect the new compound to have?

## Lab zone Chapter Project

Performance Assessment Display your data table classifying compounds in foods, along with the labels from which you collected your data. Point out the nutrients that are found in almost all foods and the nutrients found in only a few.

# Standardized Test Prep

### Test-Taking Tip

Choosing Among Similar Answers

Sometimes two or more answer choices in a multiple choice question are almost identical. If you do not read each choice carefully, you may select an incorrect answer. In the sample question below, the four chemical formulas given as answer choices are very similar. Examine each formula carefully before selecting your answer. Drawing a diagram of each formula may also help you see the differences between the answer choices.

***Sample Question***

Which chemical formula represents a saturated hydrocarbon with 2 carbon atoms?

**A** $C_2H_2$
**B** $C_2H_4$
**C** $C_2H_6$
**D** $CH_4$

***Answer***

The correct answer is **C**. A saturated hydrocarbon has only single bonds and, thus, has the maximum number of hydrogen atoms on its carbon chain. Only choices **C** and **D** represent saturated hydrocarbons. $CH_4$, however, has only one carbon atom while $C_2H_6$ has two.

**Choose the letter of the best answer.**

1. The formula $C_5H_{11}OH$ represents an
   **A** amino acid.
   **B** organic acid.
   **C** alcohol.
   **D** ester.

2. Material X is a synthetic polymer that is strong, flexible, and can be made into thread. Of the following choices, material X is most likely
   **F** cellulose.
   **G** fiberglass.
   **H** silk.
   **J** nylon.

*Use the structural diagrams below and your knowledge of science to answer Questions 3–5.*

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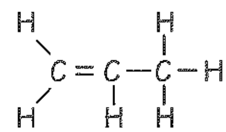

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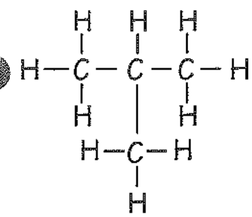

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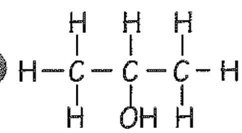

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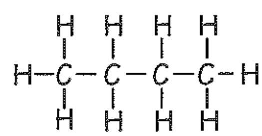


3. Isomers are organic compounds having the same chemical formula, but different structural formulas. Which pair of compounds are isomers?
   **A** 1 and 2 **B** 1 and 3
   **C** 2 and 3 **D** 2 and 4

4. Which structural diagram represents an unsaturated hydrocarbon?
   **F** 1 **G** 2
   **H** 3 **J** 4

5. What is the ratio of carbon atoms to hydrogen atoms in the compound represented by 1?
   **A** 1 to 9
   **B** 9 to 1
   **C** 3 to 6
   **D** 6 to 3

## Constructed Response

6. Explain why carbohydrates, lipids, and proteins are important parts of a well-balanced diet.

# Interdisciplinary **Exploration**

# Soap—The Dirt Chaser

## What slippery substance

- makes things cleaner, fresher, brighter?
- can you put on your head and on your floors?
- rids your hands of germs?

It's soap, which is a cleaner made from materials that are found in nature. People figured out how to make soap by heating natural fats or oils, alkali (a chemical they got from wood ashes), and water. Detergent is also a cleaner. It's similar to soap, but made from manufactured materials.

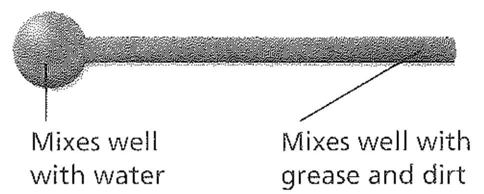
In a year, the average American uses about 11 kilograms of soap just to keep clean! Some of that soap is used for baths and showers. Soap is also used by medical experts to clean wounds and prevent infection.

In your home you use soaps and detergents to clean dishes, laundry, windows, floors, and much more. Even factories use soaps in the process of making products such as rubber, jewelry, aluminum, antifreeze, leather, and glossy paper.

So, if you lived without soap, you and your surroundings would be a lot dirtier! You would look and feel quite different. You may just owe your way of life to soap!

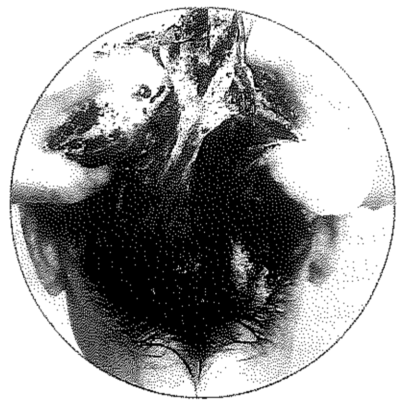
**Car Wash**
Young workers apply soap to this car.

**Soap Molecule**

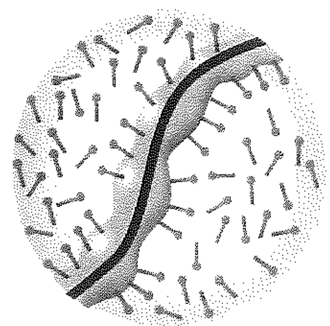



**Soap Molecules**
These molecules help loosen dirt. Water washes away the dirt.

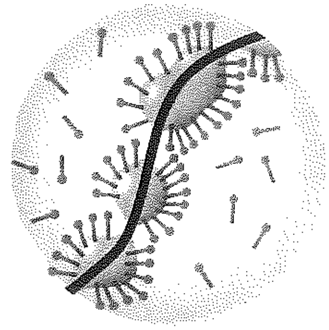
**How Soap Works**



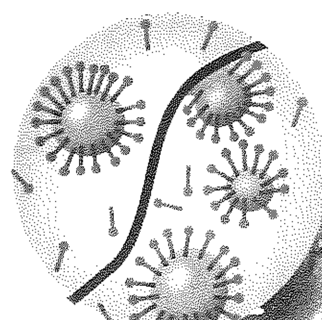
1. You rub shampoo and water into your hair.



2. Soap molecules in shampoo loosen the grease and dirt on your hair.



3. Soap molecules break the dirt into tiny pieces.



4. Water carries away the dirt surrounded by soap molecules.

## Wash the Dirt Away

Soap manufacturers claim that their products can wash away the dirt from the dirtiest clothes. How does that work? First, you need to wet the clothes with water that contains soap. The soap then spreads out and soaks into the material.

Each molecule of soap is shaped like a tiny tadpole. The tail-like end is similar to a hydrocarbon molecule. It mixes poorly with water, but it mixes well with dirt and grease. The large end, on the other hand, mixes well with water. When you wash, the soap molecules surround the dirt and break it up into tiny pieces that water can wash away.

Some dirt is difficult to dissolve. It takes longer for the soap molecules to loosen it. In these cases, rubbing, scrubbing, and squeezing may help to lift the dirt.

Some water, called hard water, has minerals dissolved in it—calcium, magnesium, and iron. In hard water, soap forms deposits, called scum. Scum doesn't dissolve and is difficult to wash away. It keeps clean hair from being shiny and leaves a "bathtub ring."

The invention of detergents helped solve the problem of scum and stubborn stains. For many cleaning tasks, detergent is more effective than soap. Detergent also dissolves in cold water more easily than soap.

# Chemistry of Soap

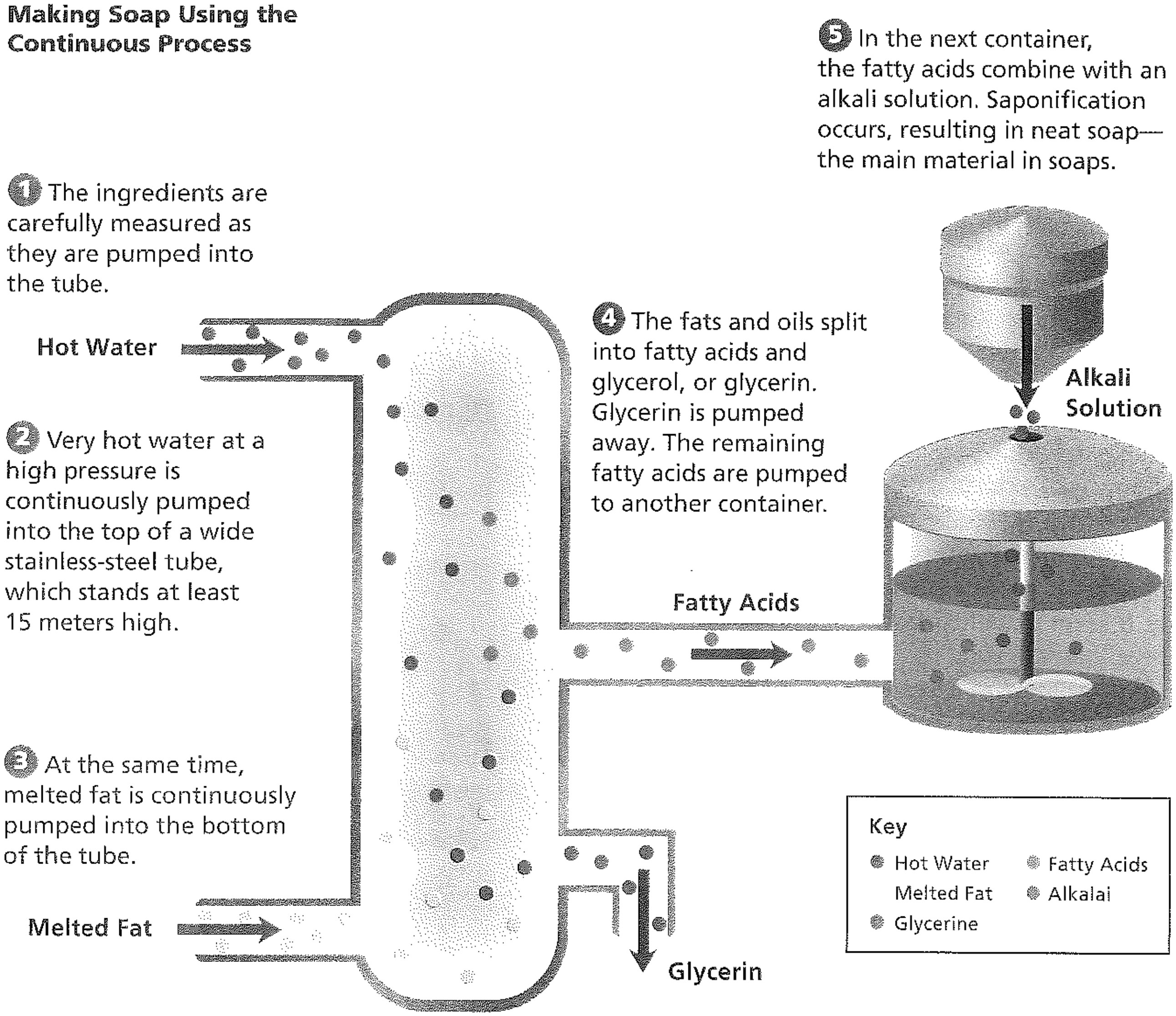
How is soap made? It's the product of heating two types of compounds—an acid and a base. Acids and bases are compounds that have physical and chemical properties opposite to each other. An acid tastes sour. Grapefruits, pickles, and vinegar have acids in them. A base has properties that make it taste bitter and feel slippery. Bases and acids combine to neutralize each other.

Natural fats and oils are the source of the acids in soapmaking. Fats and oils are polymers, made of three fatty acid monomers and an alcohol called glycerol.

In soapmaking, the fatty acids combine with an alkali solution (made of bases). The mixture is processed using water and heat. The resulting chemical reaction is called *saponification*. Saponification produces the main material of soaps, called "neat" soap. The glycerol left over, also called glycerin, is pumped away.

The difference between solid and liquid soaps depends on the alkali that's added. In a solid soap, the alkali solution is the base sodium hydroxide. In liquid soaps, the alkali solution is the base potassium hydroxide.

**Making Soap Using the Continuous Process**



## Soapmaking

After saponification occurs, neat soap is poured into molds. Other ingredients are sometimes added at this stage. Then the bars are stamped with a brand name or design and wrapped for shipment.

To make cosmetic soaps, an additional process called milling is needed. The neat soap is poured into large slabs instead of into molds. When the slab cools, several sets of rollers press and crush it. This process makes finer, gentler soaps that people can use on their face and hands.

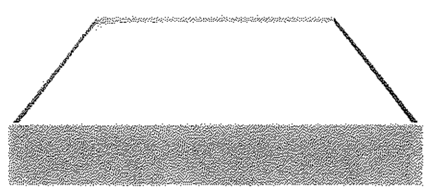
At this stage, a variety of other ingredients can be added, such as scents, colors, or germicides (to kill bacteria). Air can be whipped into soap to make it float. Soapmakers compete to find the combination of ingredients that will be most attractive and smell pleasant to customers.

### Science Activity

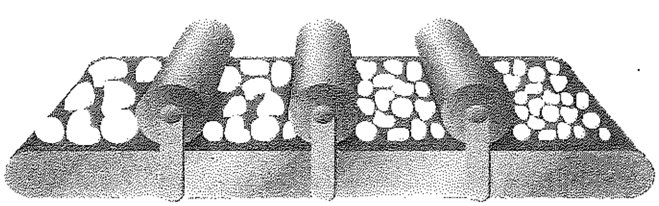
Make your own soap, using lard, baking soda, water, and salt.

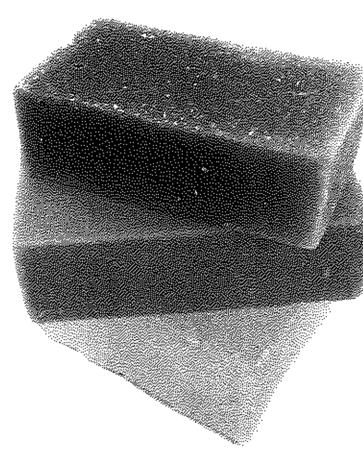
- Prepare a solution of baking soda by dissolving 5 grams in 10 milliliters of water.
- Mix the baking soda solution with 20 grams of lard in a 400-milliliter glass beaker.
- Boil gently on a hot plate for 20 minutes. Stir continuously while the mixture is boiling.
- Let the mixture cool. Transfer to a plastic beaker. Place in an ice water bath for 5–10 minutes. Stir.
- Make a saturated salt solution by dissolving 20 grams in 25 milliliters of water. Add to the mixture. Stir.
- Remove soap curdles by pouring through cheesecloth. Drain any liquid. Put soap into a dish to dry and harden.
- Put a portion of soap into warm water and stir. Observe the bubbles.
- Test with litmus paper to see if it is acid or base. (Blue litmus paper turns red in an acid. Red litmus paper turns blue in a base.)

6 Neat soap is poured into molds and allowed to harden. Before neat soap is made into bars, flakes, or powdered soap, other optional ingredients such as abrasives (scrubbing agents) can be added.



7 Cosmetic soaps require an additional process. After the neat soap cools, it goes through the milling process. The soap is fed through rollers that crush it. Perfumes and other ingredients can be added at this stage.





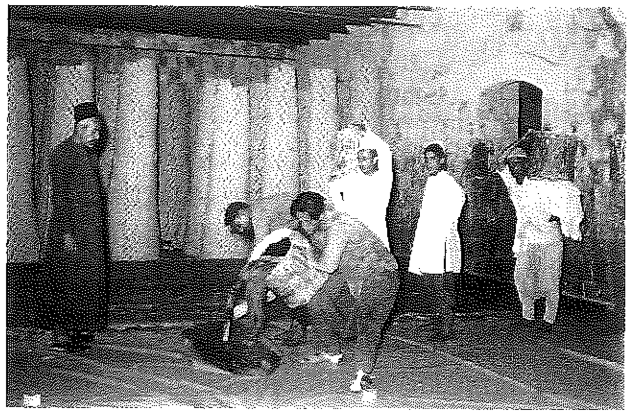
8 The finished soap is pressed, cut, stamped, and wrapped for shipment.

# The Development of Soap

People have made soap for at least 2,300 years. The ancient Babylonians, Arabs, Greeks, Romans, and Celts made soap and sometimes traded it. The English word comes from "saipo," the Celts' name for soap. But these early cultures used soap primarily as a hair dye or a medicine, not as a cleaner! Only in the period from A.D. 100–199 did soap become known as a cleaning agent.

Soapmaking in Western Europe began about A.D. 100. First France was a leading producer, then Italy by 700, and Spain by 800. England didn't begin making soap until about 1200. But even then, most people didn't use soap for bathing.

Around 1790, Nicolas Leblanc, a French scientist, discovered that alkali could be made from common table salt and water. After that, soap could be made more easily and sold for profit.



**Liquid Soap**
Liquid soap being poured out to harden in Nablus, Palestine, 1940.

**Soap Ad**
This Ivory Soap advertisement is from 1898.


In North America beginning around 1650, colonists made their own soap. Families would make up to a year's supply for their own use. Then around 1800, some people started collecting waste fats and ashes from their neighbors and making soap in large quantities. Soon bars of soap were sold from door to door.

In 1806, William Colgate, a soap and candle maker, started a business called Colgate and Company. His company produced soap and another cleaner, toothpaste. Today, nearly all soap is made in factories using large machinery.

The first detergent was produced in Germany around 1916, during World War I. Because fats were in short supply, detergent was meant to be a substitute for fat-based soap. However, people found that detergent was a better cleaner than soap for many purposes. The first household detergents appeared in the United States in 1933.

## Social Studies Activity

Create a time line of important events in the history of soapmaking. Find photos or make illustrations for the time line. Include the following events:

- early uses and users of soap
- beginning of the soapmaking industry
- early North American soapmaking
- first detergent

Before they discovered soap, what do you think people in earlier times used as a cleaner?

## Colonial Soapmaking

Making soap in North America in the 1600s was an exhausting, unpleasant process. For months, colonists saved barrels of ashes from their wood fires. Then they poured hot water over the ashes. An alkali solution, called lye, dripped out of a spigot in the bottom of the barrel.

In a large kettle over a roaring outdoor fire, they boiled the alkali solution with fat, such as greases, which they had also saved. They had to keep the fire high and hot and stir the mixture for hours. When it was thick, they ladled the liquid soap into shallow boxes. Families made soap in the spring and sometimes again in the fall.

In the novel *The Iron Peacock,* Mary Stetson Clarke describes the arduous process. The story takes place in 1650 in Massachusetts Bay Colony.

Two men and two women work together on the task. The men light a fire and hang a pot over it on a huge structure consisting of two large supports and a crossbar. The women add the ingredients and spend the entire morning stirring liquid soap with a homemade tool. Hours later, the men return to help lift the pot off the fire.

The women then ladle the thick brown liquid into boxes lined with cloth. It cools into cream-colored slabs that they cut into cakes several days later.

Through the ages, depending upon the customs of the locale, bathing rituals have varied greatly. While the Americans Clarke described considered soap a necessity for hygiene and went to great lengths to make it, other cultures did not agree. According to Katherine Ashenburg, author of *The Dirt on Clean: An Unsanitized History,* aristocratic seventeenth century Frenchmen never used soap on their bodies at all. Likewise, first century Romans, who spent two hours a day steaming, soaking, and oiling, never touched their bodies with soap.

### Language Arts Activity

Reread the passage and list the steps for making soap. Think of a process or activity that you know well. It can be packing for a trip or preparing for a party. Jot down the steps and number them. Then, write a description of the process. Include steps and details so that a reader unfamiliar with your activity would know how to do it.

# Mathematics

## A Year's Supply of Soap

What would you do if you had to make a year's supply of your own soap, using modern ingredients? You probably buy the soap you use from a store. But it is still possible to make soap yourself by using the right ingredients and following specific instructions.

Soap recipes are as varied and numerous as food recipes. You can make soap using the oil from avocados, hazelnuts, or sunflower seeds. To add natural scents, you might include rose, cinnamon, cloves, lavender, lemon, mint, grapefruit, pine, rose, vanilla, or something else.

Colors might come from beetroot, cocoa, goldenrod, licorice, paprika, or even seaweed. You can even include "scrubbers" such as cornmeal, oatmeal, or poppy seeds!

### Math Activity

Here is the ingredient list for one bar of soap with a mass of 141.8 grams.

#### List of Ingredients

16.8 grams alkali

45.4 grams water

42.2 grams olive oil

36.2 grams coconut oil

42.2 grams palm oil

Use the list to find the answers to these questions:

- What is the ratio of alkali to oil in this recipe? Round to the nearest tenth.
- If you made a large batch with a total mass of 1.7 kg, about how many bars of soap would you get in that batch?
- How much of each ingredient would you need to make this batch?
- If your family used two bars of soap per month, how many batches of soap would you make to provide one year's supply?
- How many batches would you make if your family used four bars of soap per month through the summer (June, July, and August), two bars per month through the winter (December, January, and February), and three bars per month during the rest of the year?

## Tie It Together

### Soap Study

Organize a class project to survey and test soaps and soap products that are on the market today. Work in small groups. Choose one kind of cleaner to study, such as bar soaps, dishwashing detergents, laundry detergents, or another cleaner.

As your group investigates one kind of product, answer these questions:

- Look at the labels. What kinds of oils and other ingredients are listed?
- What do the makers claim these ingredients do? What language do they use to make these claims?
- How many kinds of surfaces can you clean with this product?

Next, collect several brands. Design an experiment to help you decide which brand works best.

- Decide what you will test for, such as how well the brand cleans grease.
- Develop a grading scale for rating the products.
- Before you begin, predict what your results will be.
- Keep all variables the same except for the brand.
- Perform the tests, collect data, and take careful notes.

Decide how to present your results to the class. You might include photographs of the test results, create a graph, or write a report describing and summarizing the results.