**9.1 Carbon Compounds**

**Key Concepts**
- What are three forms of carbon?
- What factors determine the properties of a hydrocarbon?
- What are the main fossil fuels and the two primary products of their combustion?
- What are the three types of unsaturated hydrocarbons?
- What are the three main fossil fuels and the two primary products of their combustion?

**Vocabulary**
- organic compound
- network solid
- hydrocarbon
- saturated hydrocarbon
- isomers
- unsaturated hydrocarbon
- aromatic hydrocarbons
- fossil fuels

**Forms of Carbon Compounds**
- Diamond
- Graphite
- Buckminsterfullerene

Until 1828, chemists divided compounds into compounds that chemists could produce and compounds that only organisms could produce. The compounds produced by organisms were called organic compounds. In 1828, a German chemist, Friedrich Wöhler, mixed silver cyanate, AgOCN, with ammonium chloride, NH₄Cl. He expected to make ammonium cyanate. Instead, he produced urea, (NH₂)₂CO, which is a product of reactions that occur in the livers of many organisms. Wöhler had synthesized an organic compound.

An organic compound contains carbon and hydrogen, often combined with a few other elements such as oxygen and nitrogen. There are millions of organic compounds—more than 90 percent of all known compounds. Remember that carbon has four valence electrons. So a carbon atom can form four single covalent bonds, or a double bond and two single bonds, or a triple bond and a single bond. Most of the bonds in organic compounds are carbon-to-carbon bonds or carbon-to-hydrogen bonds.

**Reading Strategy**
- Previewing: Copy the table below. Before you read, use the models in Figure 2 to describe the arrangement of carbon atoms in each form of carbon.

**Build Vocabulary**
- Concept Map: Have students make a concept map with the word hydrocarbons as the starting point. The diagram should include the following terms: saturated hydrocarbons, unsaturated hydrocarbons, alkanes, alkenes, alkydes, aromatic hydrocarbons, branched chain, straight chain, and rings.

**Reading Focus**
- **a.** Rigid three-dimensional network
- **b.** Widely spaced layers
- **c.** Hollow spheres with a surface of carbon atoms arranged in alternating hexagons and pentagons

**Section Resources**
- **Print**
  - Reading and Study Workbook With Math Support, Section 9.1 and Math Skill: Balancing Equations for Organic Reactions
  - Transparencies, Chapter Pretest and Section 9.1
- **Technology**
  - Interactive Textbook, Section 9.1
  - Presentation Pro CD-ROM, Chapter Pretest and Section 9.1
  - Go Online, NSTA SciLinks, Fossil fuels
Forms of Carbon

The element carbon exists in several forms with different properties. Diamond, graphite, and fullerenes are forms of carbon. In each form, there is a different arrangement of bonded carbon atoms.

**Diamond** Cutting, grinding, and drilling tools are often coated with diamond because no substance is harder than diamond. Diamond is an example of a network solid. In a network solid, all the atoms are linked by covalent bonds. A network solid is sometimes described as a single molecule. Figure 2A shows how the carbon atoms are linked in diamond. Covalent bonds connect each carbon atom in diamond to four other carbon atoms. The three-dimensional structure that results is rigid, compact, and strong. Diamond is harder than other substances because cutting a diamond requires breaking many covalent bonds.

**Graphite** A second form of carbon, graphite, has very different properties from diamond. It is extremely soft and slippery. Figure 2B shows how the carbon atoms in graphite are arranged in widely spaced layers. Within each layer, each carbon atom forms strong covalent bonds with three other carbon atoms. Between graphite layers the bonds are weak, which allows the layers to slide easily past one another. Because graphite is soft and slippery, it is a good lubricant for moving metal parts in machinery. Pencil “lead” is a mixture of graphite and clay. The layered structure of graphite explains why you can make pencil marks on paper and why the marks can be erased easily.

**Fullerenes** In 1985, researchers discovered a third form of carbon in the soot produced when some carbon compounds burn. Fullerenes are large hollow spheres, or cages, of carbon. These cages have since been found in meteorites. Figure 2C shows a model of a cage made from 60 carbon atoms. On the surface of the cage, the atoms form alternating hexagons and pentagons, like a soccer ball cover. The C_{60} molecule is called buckminsterfullerene after Buckminster Fuller, an architect who designed domes with similar geometric patterns.

**FYI** Charcoal, carbon black, and lamp black are classified as amorphous carbon because they do not have a regular crystalline structure.

---

**Forms of Carbon**

**Use Visuals**

**Figure 2** Emphasize that the structures shown in A, B, and C all contain only carbon atoms. Ask, What are the differences between the three forms of carbon? (Diamond has a rigid three-dimensional structure, graphite contains widely spaced layers, and fullerenes are hollow cages.) What types of bonds hold carbon atoms together in all three forms of carbon? (Covalent bonds)

**Visual**

When students are asked why a methane molecule has the formula CH₄, a typical response is that carbon needs four bonds. Encourage them to consider a less anthropomorphic view. Have students recall that carbon has four valence electrons and that neon has eight valence electrons. When carbon atoms form four single covalent bonds, as in methane, they achieve the stable electron configuration of neon.

**Logical**

**FYI** Charcoal, carbon black, and lamp black are classified as amorphous carbon because they do not have a regular crystalline structure.
### Saturated Hydrocarbons

Grass contains a compound called cellulose. Most organisms, including the grazing cows in Figure 3, cannot digest cellulose. However, microorganisms in cows’ stomachs break down cellulose into smaller molecules that cows can digest. One of the products of this process is methane, CH₄, which is a hydrocarbon. A hydrocarbon is an organic compound that contains only the elements hydrogen and carbon. Methane is a saturated hydrocarbon. In a saturated hydrocarbon, all of the bonds are single bonds. A saturated hydrocarbon contains the maximum possible number of hydrogen atoms for each carbon atom. Another name for a saturated hydrocarbon is an alkane. Names of alkane compounds end in –ane, as in methane and propane.

Factors that determine the properties of a hydrocarbon are the number of carbon atoms and how the atoms are arranged. A hydrocarbon molecule can contain one carbon atom, as in methane, or more than 30 carbon atoms, as in asphalt. The carbon atoms can be arranged in a straight chain, a branched chain, or a ring.

**Straight Chains** Figure 4 lists the names, molecular formulas, structural formulas, and boiling points for four straight-chain alkanes. Recall that a molecular formula shows the type and number of atoms in a molecule of the compound. A structural formula shows how those atoms are arranged. The number of carbon atoms in a straight-chain alkane affects the size of the alkane at room temperature. Methane and propane are gases. Pentane and octane are liquids. The more carbon atoms, the higher the boiling point is.

### Comparing Models of Molecules

**Purpose** Students compare ball-and-stick models and chemical formulas for methane and propane on the board. Remind students that a structural formula provides more information than a molecular formula because it shows how the atoms are arranged in a molecule. Then, show students ball-and-stick models for methane and propane. Explain that a ball-and-stick model shows the angles between atoms in a molecule and the overall shape of the molecule. (Students may recall methane’s tetrahedral shape from the Quick Lab in Section 6.3.) The bond angle between carbon and hydrogen is 109.5° in methane and propane.

**Expected Outcome** Students observe the similarities and differences between the structures of methane and propane molecules.

**Visual, Logical**

### Facts and Figures

**Naming Hydrocarbons** Names of straight- and branched-chain hydrocarbons use prefixes to indicate the number of carbon atoms in the longest continuous chain. Except for meth- (1), eth- (2), and prop- (3), the prefixes used match those shown in Figure 20 on p. 175. For branched-chain hydrocarbons, the carbon atoms in the longest continuous chain are numbered beginning at one end of the chain. Prefixes that combine a numeral and a group designation are used to show the type and location of branches. Using this system, the official name for isobutane (shown in Figure 5) is 2-methylpropane.
Comparing Isomers

Materials
30 marshmallows, 70 raisins, 50 toothpicks

Procedure
1. Use marshmallows to represent carbon atoms, and raisins to represent hydrogen atoms, as in the model of propane shown. CAUTION Do not eat anything in the laboratory. Break the toothpicks in half to represent single bonds. Build models of five different isomers of hexane (C₆H₁₄).
2. For each model, attach all six carbon atoms first. Then attach hydrogen atoms until each carbon atom has four bonds.

Branched Chains Look at the butane and isobutane formulas in Figure 5. Both compounds have a molecular formula of C₄H₁₀, but their structural formulas are different. In isobutane, there is a branch at the point where a carbon atom bonds to three other carbon atoms.

Compounds with the same molecular formula but different structural formulas are isomers. Differences in structure affect some properties of isomers. Butane boils at –0.5°C, but isobutane boils at –11.7°C. The number of possible isomers increases rapidly each time an additional carbon atom is added to the chain. For example, octane (C₈H₁₈) has 18 isomers, while decane (C₁₀H₂₂) has 75.

Rings Figure 5 also shows the structural formula for cyclobutane. The carbon atoms in cyclobutane are linked in a four-carbon ring. Because each carbon atom forms bonds with two other carbon atoms, it can bond with only two hydrogen atoms. So cyclobutane (C₄H₈) molecules have two fewer hydrogen atoms than butane (C₄H₁₀) molecules. Most ring alkanes, or cyclic hydrocarbons, have rings with five or six carbons.

Facts and Figures

Hydrocarbons An isomer with branches often has a lower boiling point than its corresponding straight-chain isomer because less efficient packing results in weaker intermolecular forces. There is a strain on rings with only three or four carbon atoms because of the bond angles between the carbon atoms. In general, unsaturated hydrocarbons are more reactive than saturated hydrocarbons because atoms or groups of atoms can be added to the molecule at the locations of double and triple bonds. Combustion reactions are the exception to this trend.

CAUTION Do not eat anything in the laboratory. Break the toothpicks in half to represent single bonds.

Comparing Isomers

Objective
After completing this activity, students will be able to
• use structural formulas and models to describe the isomers of hexane.

Skills Focus Observing, Predicting, Using Models

Materials 30 marshmallows, 70 raisins, 50 toothpicks

Advance Prep Set out raisins, marshmallows, and toothpicks in a central location.

Class Time 15–20 minutes

Safety Remind students never to eat anything in the laboratory.

Teaching Tips
• Display ball-and-stick models that are initially oriented with the branches at opposite ends. Rotate one model 180° to show that the structural formulas represent the same isomer.

Expected Outcome Students should be able to draw the structural formulas for the isomers of hexane.

Differences in structure affect some properties of isomers. Butane boils at –0.5°C, but isobutane boils at –11.7°C. The number of possible isomers increases rapidly each time an additional carbon atom is added to the chain. For example, octane (C₈H₁₈) has 18 isomers, while decane (C₁₀H₂₂) has 75.

Rings Figure 5 also shows the structural formula for cyclobutane. The carbon atoms in cyclobutane are linked in a four-carbon ring. Because each carbon atom forms bonds with two other carbon atoms, it can bond with only two hydrogen atoms. So cyclobutane (C₄H₈) molecules have two fewer hydrogen atoms than butane (C₄H₁₀) molecules. Most ring alkanes, or cyclic hydrocarbons, have rings with five or six carbons.

Facts and Figures

Hydrocarbons An isomer with branches often has a lower boiling point than its corresponding straight-chain isomer because less efficient packing results in weaker intermolecular forces. There is a strain on rings with only three or four carbon atoms because of the bond angles between the carbon atoms. In general, unsaturated hydrocarbons are more reactive than saturated hydrocarbons because atoms or groups of atoms can be added to the molecule at the locations of double and triple bonds. Combustion reactions are the exception to this trend.
There are three types of unsaturated hydrocarbons. A) Ethene is an alkene that controls the ripening of a tomato. B) Ethyne is an alkyne used in torches that cut metals or weld them together. C) Kekulé figured out the ring structure of the aromatic hydrocarbon benzene.

Unsaturated Hydrocarbons

A hydrocarbon that contains one or more double or triple bonds is an unsaturated hydrocarbon. These hydrocarbons are classified by bond type and the arrangement of their carbon atoms. There are three types of unsaturated hydrocarbons—alkenes, alkynes, and aromatic hydrocarbons.

Alkenes

Many fruit-bearing plants produce ethene (C₂H₄), which controls the rate at which fruits, such as the tomato in Figure 6A, ripen. Hydrocarbons that have one or more carbon-carbon double bonds are alkenes. The names of alkenes end in -ene. Plastics used in trash bags and milk jugs are produced by reactions involving ethene.

Alkynes

In 1895, Henry-Louis Le Châtelier reported that a flame produced when ethyne burned had a temperature about 1000°C higher than a flame produced when hydrogen burns. Ethyne (C₂H₂), also known as acetylene, is an alkyne. Alkynes are straight- or branched-chain hydrocarbons that have one or more triple bonds. Alkyne names end in -yne.

Alkynes are the most reactive hydrocarbon compounds. The welder in Figure 6B is burning a mixture of oxygen and acetylene in an oxyacetylene torch. The temperature of the flame produced approaches 3500°C. At that temperature, most metals can be melted and welded together. The acetylene and oxygen are stored under pressure in tanks.

Aromatic Hydrocarbons

The Belgian stamp in Figure 6C honors Friedrich Kekulé (1829–1896), who figured out that benzene (C₆H₆) is an unsaturated hydrocarbon with a ring structure. Although the formula shows alternating single and double bonds, the six bonds in the ring are identical. Six of the valence electrons are shared by all six carbon atoms. Hydrocarbons that contain similar ring structures are known as aromatic hydrocarbons. The name was chosen because many of these compounds have strong aromas or odors.

What is an unsaturated hydrocarbon?
Fossil Fuels

Some hydrocarbons were formed from plants and animals that lived in Earth's oceans and swamps millions of years ago. After those plants and animals died, they were buried under layers of rock and soil. High temperature and pressure deep in Earth's crust changed those remains into deposits of hydrocarbons called fossil fuels. Fossil fuels are mixtures of hydrocarbons that formed from the remains of plants or animals. Three types of fossil fuels are coal, natural gas, and petroleum. The type of fossil fuel produced depends on the origin of the organic material and the conditions under which it decays.

Coal The ferns in Figure 7A are similar to those that produced the coal in Figure 7B. Coal is a solid fossil fuel that began to form about 300 million years ago in ancient swamps. Giant tree ferns and other plants were buried in those swamps. After millions of years of pressure, the plant remains produced a mixture of hydrocarbons. Most of the hydrocarbons in coal are aromatic hydrocarbons with high molar masses. These compounds have a high ratio of carbon to hydrogen. So burning coal produces more soot than burning other fossil fuels does.

Natural Gas The second main fossil fuel, natural gas, formed from the remains of marine organisms. The main component of natural gas is methane—the same compound produced by cows as they digest grass. Natural gas also contains ethane, propane, and isomers of butane. Natural gas is distributed through a network of underground pipes. It is used for heating and cooking, and to generate some electricity. Deposits of natural gas are found along with deposits of coal and petroleum.

Petroleum The third main fossil fuel, petroleum, also formed from the remains of marine organisms. Petroleum, often known as crude oil, is pumped from deep beneath Earth's surface. It is a complex liquid mixture of hydrocarbons, mainly long-branched alkanes and alkenes. For petroleum to be useful, it must be separated into simpler mixtures, or fractions, such as gasoline and heating oil.

Fractional Distillation
Purpose Students will observe fractional distillation of a mixture of organic compounds.

Materials distillation apparatus with stand, 50 mL water, 50 mL ethanol, 60 mL mineral oil, hot plate, 60-mL beakers (6), concave glass beaker covers (3), shield, dropper pipets (5)

Procedure Explain that fractional distillation is a method of separating mixtures using differences in boiling points. Measure 50 mL of water and 50 mL of ethanol in two different beakers and mix them together in the distillation chamber. Heat the mixture, keeping the temperature at about 85°C, just above the boiling point of ethanol and below the boiling point of water. Three times during the process, collect the distilled liquid (distillate) in a separate beaker, and cover the beaker. After you complete the distillation, place a drop of pure ethanol and a drop of pure water in a beaker of mineral oil. Next, place a drop from each beaker of distilled liquid into the mineral oil. Have students notice whether the drops float or how quickly they sink.

Safety Place a blast shield between the equipment and students. Use mitts or tongs to handle hot glass.

Expected Outcome The ethanol will collect more rapidly in the catch beaker. Pure ethanol floats in mineral oil, and pure water sinks. Students can infer the relative concentrations of ethanol and water in each distillate sample by the behavior of the drops in the mineral oil.

Visual
Section 9.1 (continued)

Build Science Skills

Problem Solving Tell students that they are given an unknown alkane. Have them use Figure 8 to answer the following question. Ask, How could you determine if the alkane is one of the components of gasoline? (If its boiling point is between 40°C and 100°C, then the alkane may be a component of gasoline.) Visual, Logical FYI

In industry documents that describe fractional distillation, there is variation in the names of the fractions collected, the length of the carbon chains in a fraction, and the temperature range at which a fraction is collected. There is agreement on how the process separates the numerous substances in petroleum into fractions.

Combustion of Fossil Fuels

Build Math Skills Balancing Equations Remind students that only the coefficients in front of the formulas, and not the subscripts in the formulas, may be changed when they balance an equation. Have students practice balancing the equation for the complete combustion of ethane:

\[ C_2H_6 + O_2 \rightarrow CO_2 + H_2O \]

(2C_2H_2 + 7O_2 \rightarrow 4CO_2 + 6H_2O)

Then, have students determine the balanced equation for incomplete combustion of ethane:

(2C_2H_2 + 5O_2 \rightarrow 4CO + 6H_2O)

Logical Direct students to the Math Skills in the Skills and Reference Handbook at the end of the student text for additional help.

Figure 8 The petroleum pumped from underground deposits is a complex mixture of hydrocarbons. A At a refinery, petroleum is separated into mixtures called fractions. B The diagram shows some of the fractions that can be collected from a distillation tower. The labels provide data on the compounds within a fraction. For example, compounds in kerosene have from 12 to 16 carbon atoms and condense at temperatures between 200°C and 250°C. Interpreting Diagrams How many carbon atoms are there in the compounds in the petroleum gas fraction?

Combustion of Fossil Fuels

The energy released from fossil fuels through combustion is used to heat buildings, cook food, or for transportation. Recall that energy from the combustion of propane heats the air in a hot-air balloon.

\[ C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \text{ (complete combustion)} \]

The primary products of the complete combustion of fossil fuels are carbon dioxide and water. Burning fossil fuels increases the amount of carbon dioxide in the atmosphere. This increase may affect temperatures, amounts of rain, and sea levels worldwide. Some sulfur and nitrogen are in fossil fuels, and air contain nitrogen. So nitrogen oxides and sulfur dioxide are produced during the combustion of fossil fuels.

Incomplete Combustion In stoves and furnaces, there may not be enough oxygen available for complete combustion of all the fuel. So a deadly gas, carbon monoxide, is produced. This colorless, odorless gas can be inhaled and absorbed by blood. It keeps hemoglobin from carrying oxygen to cells. Safety experts recommend that homes heated with natural gas or heating oil have carbon monoxide detectors.

\[ 2C_3H_8 + 7O_2 \rightarrow 6CO + 8H_2O \text{ (incomplete combustion)} \]

When fossil fuels undergo incomplete combustion in factories or power plants, they also produce tiny particles of carbon. Inhaling these particles can cause heart and lung problems.

Facts and Figures

Octane Number Octane ratings are used to compare blends of gasoline. Two substances found in gasoline are used as reference fuels: n-heptane and isooctane (2,2,4-trimethylpentane). Because n-heptane self-ignites when compressed, it burns too rapidly, causing a knocking sound in a poorly performing engine. Isooctane will not self-ignite if it is compressed before sparking. The octane rating describes a blend as though it contained only n-heptane and isooctane. With an octane rating of 89, gasoline performs as if it contained 89% isooctane and 11% n-heptane. With a higher octane rating, the possibility of knocking is lower.
Acid Rain  The combustion of fossil fuels causes the acidity of rain to increase. Rain is always slightly acidic, with a pH of about 5.6, because carbon dioxide dissolves in water droplets and forms carbonic acid, $\text{H}_2\text{CO}_3$. Sulfur dioxide and nitrogen oxides released into the atmosphere also dissolve in water, forming sulfuric acid, $\text{H}_2\text{SO}_4$, and nitric acid, $\text{HNO}_3$. The pH of rain containing sulfuric acid and nitric acid can be as low as 2.7. These acids damage stone structures like the statue in Figure 9. They also damage metal and concrete.

Critical Thinking
7. **Classifying** Why isn’t carbon dioxide considered an organic compound? 
8. **Applying Concepts** Draw structural formulas for the two branched-chain isomers of pentane, $\text{C}_5\text{H}_{12}$.

### Section 9.1 Assessment

**Reviewing Concepts**
1. Name three forms of carbon.
2. What two factors can affect the properties of a hydrocarbon?
3. Name the three categories of unsaturated hydrocarbons.
4. Name the three main fossil fuels.
5. What are the two primary products of the complete combustion of fossil fuels?
6. What are three ways that carbon atoms can be arranged in hydrocarbon molecules?

**Connecting Concepts**

**Saturation** Compare the way saturated and unsaturated are used in describing hydrocarbons to how they were used in describing solutions in Section 8.2.

**Build Math Skills**

**Interpreting Equations** Write the equations for the complete and incomplete combustion of propane on the board. Ask, Why are there 5 moles of oxygen in the equation for the complete combustion, but 7 moles of oxygen in the equation for the incomplete combustion? Let students figure out that the number of moles of methane is not the same in the two equations. Then, multiply the coefficients in the first equation by 2 to show that the amount of oxygen used is greater.

**Logical**

Direct students to the Math Skills in the Skills and Reference Handbook at the end of the student text for additional help.

### ASSESS

**Evaluate Understanding**

Have students make flashcards for the key concepts and vocabulary in this section. For example, for each type of unsaturated hydrocarbon, they can make a card that has an example and a definition. Students can use the flashcards to quiz one another.

**Reteach**

Use the structural formulas in the text on pp. 265 and 266 to review each type of hydrocarbon.

In a saturated solution, the solvent contains the maximum amount of solute at a given temperature. A saturated hydrocarbon contains the maximum number of hydrogen atoms for each carbon atom. More solute can be added to an unsaturated solution. More hydrogen atoms can be added to an unsaturated hydrocarbon.

**Answer to . . .**

**Figure 8** Molecules of compounds in petroleum gas contain one to four carbon atoms.
Breathing Easy

Background
The Department of Energy began The Clean Coal Technology Program in response to concerns about acid rain. The diagram illustrates some of the methods used to reduce emissions of nitrogen oxides and sulfur dioxide. (1) Sulfur that is not bonded to carbon is removed when coal is crushed and washed. (2) Jets of air keep limestone and crushed coal suspended so that the limestone can react with the sulfur dioxide. Because the temperature in the furnace is low and the amount of air is limited, most of the oxygen reacts with fuel, not nitrogen. (3) Smokestacks may contain electrostatic precipitators and scrubbers. As particles of ash pass through the precipitator, they gain a charge. They can be collected on a plate with an opposite charge. In one type of scrubber, limewater is sprayed into the stream of waste gases. The calcium hydroxide reacts with sulfur dioxide and forms solid calcium sulfate.

Build Science Skills

Observing
Purpose: In this activity, students will use physical properties to separate a mixture of coal and sulfur.
Materials: 100-mL beaker containing a 1:1 mixture of sulfur powder and coal dust, 100-mL graduated cylinder, stir rod, distilled water, plastic pipet, 100-mL beaker
Class Time: 10–15 minutes
Procedure: Provide each group with a beaker containing 10 g of the sulfur-coal mixture. Have them add 30 mL of water to the beaker and mix using a stir rod. Allow layers to form in the mixture. Next have students use a pipet to transfer the layer of water containing coal dust to a second beaker. Stir the mixture and allow layers to form again. Have students compare their activity to the process described in Step 1 of the diagram.
Safety: Students should wear safety goggles and aprons.

Facts and Figures

Catalytic Converters: The combustion of petroleum products in internal combustion engines produces emissions that contribute to air pollution. In a vehicle’s exhaust system, there is a catalytic converter. This device contains a mixture of catalysts for the oxidation of carbon monoxide and unburned hydrocarbons to carbon dioxide and water and the reduction of nitrogen oxides to nitrogen. The catalysts may be transition metals, such as platinum, palladium, and rhodium; or oxides of transition metals, such as CuO and Cr₂O₃.
Most of the sulfur will settle to the bottom of the first beaker while the coal dust floats. Any remaining sulfur will settle to the bottom of the second beaker. This activity demonstrates what happens when coal is crushed and washed prior to burning.

Visual, Kinesthetic

Expected Outcome

The United States Department of Energy has funded research into coal gasification. They are encouraging the development of methods for converting solid coal into gases that can be used to generate power. During gasification, coal reacts with steam and oxygen at a high temperature and pressure. The methods produce a mixture of gases. Hydrogen and carbon monoxide are typical products. The hydrogen can be separated from the raw mixture and used directly as fuel or it can be combined with carbon monoxide to produce methane. Any carbon dioxide produced is captured for commercial applications or sequestered to prevent its release into the atmosphere.

If students search the Internet, they will find descriptions of multiple methods for coal gasification, and information on the advantages and drawbacks of the methods. The main advantages of coal gasification are a reduction in air pollution and an increase in efficiency (more energy produced from the same amount of coal). For now, drawbacks include the cost of equipment and a higher cost per kilowatt for power generation. Other drawbacks are the amount of water required and the amount of wastewater produced.

Verbal, Portfolio

Going Further

- Research the process of coal gasification. Write a paragraph describing one of the methods used to convert coal into flammable gases. What gases are produced? What are the benefits of coal gasification? Are there any problems with the technology?
- Take a Discovery Channel Video Field Trip by watching "Clean Energy."
9.2 Substituted Hydrocarbons

The electric drill in Figure 10 can be used to drill holes, tighten a screw, or sand a rough surface. To change the function of the drill, you replace, or substitute, an attachment. A carbon atom in an organic compound can have four attachments. In a methane molecule (CH₄), the carbon atom has four identical attachments—its hydrogen atoms. When methane reacts with chlorine, chlorine atoms replace hydrogen atoms.

\[
\text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl}
\]

Chloromethane and hydrogen chloride are products of the reaction between methane and chlorine. So are compounds with two, three, or four chlorine atoms. Organic compounds containing chlorine or other halogens are halocarbons. Almost all the halocarbons found on Earth were released from refrigerators, air conditioners, or aerosol sprays. Researchers have established that halocarbons containing chlorine and fluorine deplete Earth’s protective ozone layer. The manufacture of chlorofluorocarbons has been restricted since 1990.

A hydrocarbon in which one or more hydrogen atoms have been replaced by an atom or group of atoms is a substituted hydrocarbon. The substituted atom or group of atoms is called a functional group because it determines the properties of the compound. Alcohols, organic acids, organic bases, and esters are substituted hydrocarbons.

### Key Concepts
- What functional groups are found in alcohols, organic acids, and organic bases?
- How are esters formed?

### Vocabulary
- substituted hydrocarbon
- functional group

### Reading Strategy
- Monitoring Your Understanding
  - Copy the table. As you read, complete the table by connecting each functional group with the type of compound that contains the functional group.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Type of Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>-OH</td>
<td>a. alcohol</td>
</tr>
<tr>
<td>-COOH</td>
<td>b. organic acid</td>
</tr>
<tr>
<td>-NH₂</td>
<td>c. organic base</td>
</tr>
</tbody>
</table>

Figure 10: Hydrocarbons in which some hydrogen atoms have been replaced can be compared to an electric drill with attachments.

Infering: What determines the function of the drill, the drill itself or the attachments?

The electric drill in Figure 10 can be used to drill holes, tighten a screw, or sand a rough surface. To change the function of the drill, you replace, or substitute, an attachment. A carbon atom in an organic compound can have four attachments. In a methane molecule (CH₄), the carbon atom has four identical attachments—its hydrogen atoms. When methane reacts with chlorine, chlorine atoms replace hydrogen atoms.

\[
\text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl}
\]

Chloromethane and hydrogen chloride are products of the reaction between methane and chlorine. So are compounds with two, three, or four chlorine atoms. Organic compounds containing chlorine or other halogens are halocarbons. Almost all the halocarbons found on Earth were released from refrigerators, air conditioners, or aerosol sprays. Researchers have established that halocarbons containing chlorine and fluorine deplete Earth’s protective ozone layer. The manufacture of chlorofluorocarbons has been restricted since 1990.

A hydrocarbon in which one or more hydrogen atoms have been replaced by an atom or group of atoms is a substituted hydrocarbon. The substituted atom or group of atoms is called a functional group because it determines the properties of the compound. Alcohols, organic acids, organic bases, and esters are substituted hydrocarbons.
Alcohols
Methanol, CH₃OH, is used as a fuel in some motorcycles. Ethanol, CH₃CH₂OH, is often mixed with gasoline to help the gasoline burn more completely. Methanol and ethanol are alcohols. The name of an alcohol ends in -anol. The functional group in an alcohol is a hydroxyl group, -OH. When a halocarbon reacts with a base, the products are an alcohol and salt.

CH₃Cl + NaOH → CH₃OH + NaCl

An alcohol can also be made by reacting an alkene with water.

Ethene Water Ethanol

Organic Acids and Bases
The sharp, sour taste of a lemon comes from citric acid, an organic acid. The functional group in organic acids is a carboxyl group, -COOH. Names of organic acids end in -oic. Organic acids tend to have sharp tastes and strong odors. The simplest organic acid is methanoic acid, which is also known as formic acid. Vinegar is a solution of water and the organic acid ethanoic acid, which is usually referred to as acetic acid. If the ants in Figure 11 sprayed the formic acid they produce on your skin, your skin would itch or burn.

Methanoic acid Ethanoic acid

Exploring Boiling Points of Chlorocarbons
Use the data given to construct a graph with Number of Chlorine Atoms, from 0 to 4, on the horizontal axis and Boiling Point on the vertical axis. Draw a smooth curve connecting the points.
1. Using Graphs Predict the boiling point of dichloromethane.
2. Relating Cause and Effect What effect does increasing the number of chlorine atoms have on the boiling point?

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>–161</td>
</tr>
<tr>
<td>Chloromethane</td>
<td>ClCH₂</td>
<td>–24</td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>Cl₂CH₂</td>
<td></td>
</tr>
<tr>
<td>Trichloromethane</td>
<td>Cl₃CH</td>
<td>61</td>
</tr>
<tr>
<td>Tetrachloromethane</td>
<td>Cl₄</td>
<td>77</td>
</tr>
</tbody>
</table>

3. Formulating Hypotheses Why is the boiling point of CH₃Br higher than the boiling point of CH₃Cl? (Hint: Compare the atomic masses for bromine and chlorine.)

Exploring Boiling Points of Chlorocarbons
1. Acceptable answers include temperatures between –24°C and 61°C. (The boiling point of dichloromethane is 40°C.)
2. As the number of chlorine atoms increases, the boiling point increases.
3. Bromine is more massive than chlorine.

For Extra Help
Demonstrate how to use a curve on a graph to estimate the value of an unknown data point. Find the appropriate value on the horizontal axis. Use a ruler to intersect the curve above that value. Turn the ruler 90° and read the vertical value for the intersection point. Visual

Alcohols
Build Science Skills
Applying Concepts Ask students to predict the products for the complete combustion of methanol and ethanol. Then, have them write balanced equations for these reactions.

2CH₃OH + 3O₂ → 2CO₂ + 4H₂O
C₂H₅OH + 3O₂ → 2CO₂ + 3H₂O

Logical
FYI
There are multiple methods for the formation of alcohols, including fermentation and reduction of aldehydes and ketones.

Organic Acids and Bases
Build Reading Literacy
Compare and Contrast Refer to page 226D in Chapter 8, which provides guidelines for comparing and contrasting. Have students read the text on pp. 273–274 related to organic acids and bases. Ask, How do organic acids and bases differ? (Organic acids have a carboxyl group, while organic bases have an amino group.) How are organic acids and bases similar? (They are substituted hydrocarbons with strong odors.)

Verbal

Answer to . . .
Figure 10 The attachments determine the specific function of the drill.

Carbon Chemistry 273
Section 9.2 (continued)

Esters

Address Misconceptions

Students may not know that an object has an odor because molecules from substances in the object interact with chemoreceptors in the nose. Studying esters is a good way to challenge this misconception. Have students smell some fragrant objects, such as apples, bananas, or flowers. Explain that some of the compounds responsible for the odors are esters.

Logical, Kinesthetic

Use Community Resources

Have a pharmacist speak to the class about how functional groups determine the effect of a medicine. Have students ask how to find information on the chemical composition of active ingredients in prescription and over-the-counter drugs.

Interpersonal

ASSESS

Evaluate Understanding

Have students design and play a matching game that uses cards that identify the formulas and characteristics of each functional group described in the section.

Reteach

Use short phrases to summarize the characteristics of functional groups. For example, say that amines smell like rotten fish and esters have pleasant smells, like some flowers. Review other characteristics, such as chemical structure, for each functional group.

Connecting Concepts

Replacing a halogen with a hydroxyl group is a double-replacement reaction because the hydroxyl group and the halogen exchange places. The reaction of alkenes with water to produce an alcohol is a synthesis reaction because two reactants join to form one product.

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 9.2.

Reviewing Concepts

1. What functional groups are found in alcohols, organic acids, and organic bases?
2. Which types of compounds can react to produce esters?
3. What is a substituted hydrocarbon?
4. When a halocarbon reacts with a base, what products are produced?
5. What are two properties of organic acids?

Critical Thinking

6. Classifying An unknown compound has no noticeable odor. Explain why the compound is unlikely to be an organic acid, an organic base, or an ester.

Connecting Concepts Types of Reactions

Alcohols can be made by reacting halocarbons with bases, or alkenes with water. Review the general types of reactions presented in Section 7.2. Which types best describe the two methods for producing an alcohol? Explain your choices.

Section 9.2 Assessment

Esters

Do you know the smell of rotten fish? Then you’ve encountered a type of substituted hydrocarbon called an amine. Amines are organic bases. The functional group in an amine is an amino group, –NH₂. Amines are found in paints, dyes, and disinfectants. In Section 9.3 you will study the role organic bases play in the formation of organic compounds that are essential for life.

Esters

One group of substituted hydrocarbons accounts for the flavors of many foods and the pleasant odor of many flowers. These compounds are known as esters. Esters form when organic acids react with alcohols. The second product of the reaction is water. For example, ethanoic acid can react with methanol to produce methyl ethanoate (methyl acetate). The reaction is reversible.

\[
\text{H}_2\text{C}=\text{O} + \text{HO-CH}_2\text{H} \rightleftharpoons \text{H}_2\text{C}=\text{O-CH}_2\text{H} + \text{H}_2\text{O}
\]

Ethanoic acid Methanol Methyl ethanoate Water

Esters are used in many processed foods to produce flavors such as strawberry, banana, and grape. Flowers like the roses in Figure 12 produce esters and other compounds with distinctive odors that attract insects for pollination. Sometimes, the compounds produced by the plant mimic compounds produced by the insect.

Figure 12 Many compounds in rose petals contribute to the fragrance of a rose. Some of these compounds are esters, which tend to have pleasant, sweet odors.

274 Chapter 9
Freight trains, like those in Figure 13, use different types of cars to transport goods. A flatcar with no sides or roof is used to haul steel beams. Grain is carried in covered hoppers, which have a hatch at the top and a chute at the bottom. Liquids travel in tank cars. The cars on a train may be all the same type or a mixture of different types. On average, about 100 cars are linked together behind the locomotive on a freight train.

Like freight trains, some molecules are built up from smaller units linked together. A polymer is a large molecule that forms when many smaller molecules are linked together by covalent bonds. The smaller molecules that join together to form a polymer are monomers. Poly- means “many.” Mono- means “one.” In some polymers, there is only one type of monomer. Other polymers have two or more kinds of monomers. Polymers can be classified as natural polymers or synthetic polymers. Many important types of biological molecules are natural polymers. Organisms produce these polymers in their cells. Synthetic polymers are developed by chemists in research laboratories and manufactured in factories. Both types of polymers have industrial uses. For example, silk and cotton fabrics are woven from natural polymer fibers, while polar fleece is made from a synthetic polymer.

## 9.3 Polymers

### Key Concepts
- What is one way that polymers can be classified?
- What are three examples of synthetic polymers?
- What are four types of polymers that organisms can produce?

### Reading Focus

#### Vocabulary
- polymer
- monomers
- carbohydrates
- nucleic acids
- amino acid
- protein

#### Reading Strategy

**Identifying Main Ideas** Before you read, copy the concept map. As you read, complete the map to summarize two main ideas about polymers.

---

**Figure 13** Couplers that interlock like the fingers of your hands connect one railroad car to another. Many cars can be joined together to form a train, because there is a coupler on both ends of a car. How is a polymer like a train?

---

**Section Resources**

#### Print
- *Laboratory Manual*, Investigations 9A and 9B
- *Reading and Study Workbook With Math Support*, Section 9.3
- *Transparencies*, Section 9.3

#### Technology
- *Interactive Textbook*, Section 9.3
- *Presentation Pro CD-ROM*, Section 9.3
- *Go Online*, NSTA Scilinks, Polymers

---

**Answer to . . .**

*Figure 13* Like a train, a polymer is made up of single units that are joined together.
Rubber, nylon, and polyethylene are three examples of synthetic polymers that have properties not found in natural polymers. The sap collected from rubber trees in tropical regions contains rubber. So why would a chemist make synthetic rubber? The supply of natural rubber is limited. During World War II, the allies could not obtain natural rubber. Chemists worked hard to produce a synthetic rubber, using hydrocarbons from petroleum. Natural rubber and synthetic rubbers contain different monomers and have different properties. The tires in Figure 14A will resist wear and be less likely to leak if they are made of synthetic rubber. Rubber is used as an adhesive. The How It Works box on page 277 explains how adhesives work.

Nylon In the 1930s, Wallace Carothers was trying to produce a synthetic polymer to replace silk. The polymer he produced was nylon, which has properties not found in natural polymers. Nylon fibers are very strong, durable, and shiny. Nylon is used in parachutes, windbreakers, fishing line, carpets, and ropes like the one in Figure 14B.

Polyethylene Plastic milk bottles, plastic wrap, and the plastic shapes in Figure 14C are made of polyethylene. This polymer forms when ethene (or ethylene) molecules link head to tail. The number of carbon atoms in a polyethylene chain affects the properties of the polymer. The more carbon atoms in the chain, the harder the polymer is.

The hardness of polyethylene is determined by the number of carbon atoms in the chain. The more carbon atoms there are, the harder the polymer is.
Synthetic Adhesives

Adhesion is the force of attraction between molecules of different substances whose surfaces are in contact. These forces are rarely strong enough to bind two surfaces together. An adhesive placed between the surfaces binds them together. Most adhesives are synthetic polymers. The diagram illustrates how some adhesives work. The adhesive remains liquid until the surfaces are in position. Then the adhesive sets.

Interpreting Diagrams Explain the purpose of a stabilizer in an adhesive.

1. Liquid adhesive
   - In a typical adhesive, monomer molecules and a stabilizer are in a solvent. The stabilizer stops the monomers from forming a solid polymer.

2. Applying the adhesive
   - Some of the liquid is squeezed onto one of the surfaces to be joined.

3. The adhesive sets
   - Contact with water in the air and on the surfaces being joined makes the stabilizer inactive. The monomers then begin to join together to form a polymer. As the chain lengthens, the adhesive changes from a liquid to a solid.

Types of adhesion
- Adhesive can work in three ways. Molecules of the polymer may fill crevices in the surfaces being connected. The molecules may also be attracted to one another by intermolecular forces, or they may react by forming covalent bonds.

Permanent adhesion
- An epoxy resin was used to attach the automobile to the billboard. Epoxy resins are often stored in two parts that are mixed just before the epoxy is used. Strong binding forces in these adhesives make them heat- and water-resistant.

Temporary adhesion
- The sticky strip on a reusable note is an adhesive containing tiny spheres. The spheres limit the amount of surface area that makes contact, so the note sticks lightly and repositions easily.

Permanent adhesion

Permanent adhesion

Synthetic Adhesives

The invention of reusable notes began in 1966 when Dr. Spencer Silver was attempting to make a strong adhesive. One of the adhesives he produced was just strong enough to hold papers together, but it was weak enough that the papers could be separated without damage. Silver tried to develop a use for the weak adhesive, but it was his colleague, Art Fry, who realized the adhesive’s potential. While singing in a choir, Fry was bothered by bookmarks slipping out of pages. By applying some of the weak adhesive to paper, Fry developed a reusable bookmark that could stick to pages without harming them. The adhesive is now used to produce the familiar, multi-colored reusable notes.

Interpreting Diagrams Stabilizers are used to prevent the adhesive monomers from forming a solid polymer.

Logical

For Enrichment

Have students work in pairs and devise an experiment to compare two types of commercially-available adhesives. Remind them to start by forming a hypothesis and writing a plan for their experiment. Suggest that they develop a number scale for reporting how well each adhesive binds two surfaces together. Materials may include paper, metal foil, or wooden craft sticks.

Kinesthetic, Logical

FYI

Although the terms are used interchangeably, glue refers to natural products and adhesives refers to synthetics.
Section 9.3 (continued)

Natural Polymers

Distinguishing Sugars From Starches

Objective
After completing this activity, students will be able to
• use iodine to test for the presence of starch in foods.

Skills Focus Observing, Formulating Hypotheses, Inferring

Prep Time 15 minutes

Materials
1 slice each of potato, ripe apple, bread; 15 mL cornstarch; 15 mL table sugar; iodine in a dropper bottle; 6 small paper plates

Advance Prep Cut apples, potatoes, and bread into small cubes (about 1 cm³). Place iodine solution in labeled dropper bottles.

Class Time 10–15 minutes

Safety Students should wear safety goggles and aprons. Remind students not to eat anything in the lab. If students slice their own apples and potatoes, remind them to be careful when handling sharp objects.

Teaching Tips
• Do not slice the apples and potatoes until right before class. Oxidation will cause them to turn brown, making it difficult to observe the results.
• Make sure that the apples are very ripe, but not rotten. In an unripe apple, all of the starch may not be converted to sugar, and students may get a positive result. Test one apple in advance.

Expected Outcome Iodine solution changes color in the presence of starch. Iodine will change from orange-rust to brown or blue-black with the cornstarch, potato, and bread. Iodine will not change color with the sugar or the apple.

Analyze and Conclude
1. Iodine will change color with starch, but not with a sugar.
2. The cornstarch, potato, and bread contain starch.
3. Possible answers include corn, flour, cereals, or any of the foods shown in Figure 15.

Visual, Logical

Natural Polymers

Almost all of the large molecules produced by organisms are polymers.

Four types of polymers produced in plant and animal cells are starches, cellulose, nucleic acids, and proteins.

Starches
Many animals are attracted to sweet-tasting foods. The compounds responsible for this sweetness are often sugars. Simple sugars have the formula C₆H₁₂O₆. They can exist as straight chains or rings. The simple sugars glucose and fructose can react to form sucrose (table sugar). Glucose monomers join to form starches as shown below.

Typically, a starch contains hundreds of glucose monomers. Plants store starches for food and to build stems, seeds, and roots. Flour for the bread, pasta, and tortillas shown in Figure 15 is made by grinding the seeds of grains, such as wheat and corn. Simple sugars, slightly more complex sugars such as sucrose, and polymers built from sugar monomers are all classified as carbohydrates.

Cellulose
The carbohydrate cellulose is the main component of cotton and wood. It is the most abundant of all organic compounds found in nature. Cellulose molecules contain 3000 or more glucose monomers. Cellulose gives strength to plant stems and tree trunks. Most animals cannot digest cellulose.

Facts and Figures

Starchy Root Cassava is a starchy tuber that is a food staple for many people in South America, West Africa, and the Caribbean. Cassava is similar to the sweet potato, except that some varieties contain prussic acid. If not prepared by grating, pressing, and heating, cassava is toxic. Tapioca is a product of cassava roots.
There are molecules in each cell of a plant or animal that store information about its structures and functions. These molecules are nucleic acids. **Nucleic acids** are large nitrogen-containing polymers found mainly in the nuclei of cells. There are two types of nucleic acid, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

The monomers in a nucleic acid are nucleotides. Figure 16A shows the three parts of a DNA nucleotide. The yellow circle represents a phosphate group. The green pentagon represents deoxyribose sugar, which has a five-atom ring. The purple rectangle represents an organic base. The bases in DNA are adenine, thymine, cytosine, and guanine.

When two strands of DNA line up as shown in Figure 16B, an adenine base always pairs up with a thymine base, and a cytosine base always pairs up with a guanine base. These pairs of bases are arranged like the rungs of a ladder. The strands are held together by strong intermolecular attractions between hydrogen atoms on one strand and nitrogen or oxygen atoms on the other strand. Figure 16C shows how the strands twist around each other in a structure called a double helix. The order of the base pairs in a strand is a code that stores information that is used to produce proteins.

**Nucleic Acids**

**Figure 16** Nucleic acids are polymers that store the genetic information that gives the girls in the photograph their distinct physical characteristics.

A. The monomers in DNA have three components—a phosphate group, a sugar, and one of four organic bases. 
B. Two strands of DNA are held together by intermolecular attractions between the organic bases. 
C. The shape of DNA is like a twisted ladder. Phosphate-sugar chains form the sides of the ladder. The rungs of the ladder are pairs of bases.

**Use Visuals**

Figure 16 Have students examine the three-part diagram of DNA. Ask, **Which part of the diagram (A, B, or C) shows a single monomer of a nucleic acid?**

**How are Parts B and C of the diagram related?** (Part B shows two strands of the polymer, each containing many monomer units. Part C shows how the strands in Part B twist to form a double helix.) Explain that the strands of DNA need to separate when DNA replicates (makes copies of itself). Ask, **If the strands were held together by covalent bonds instead of intermolecular attractions, how might this affect DNA replication?** (Because covalent bonds are stronger than intermolecular attractions, more energy would be required to separate the strands.)

**FYI**

RNA is different from DNA in several ways. The sugar in RNA is ribose instead of deoxyribose. RNA contains the base uracil instead of thymine. RNA has only one strand.

**Answer to . . .**

**Figure 15** Answers may include waffles, bread, pasta, oats, tortillas, rice, and cereal.

**RNA and DNA**
Section 9.3 Assessment

Proteins Recall that organic acids contain a \(-\text{COOH}\) group and organic bases, or amines, contain an \(-\text{NH}_2\) group. There is one substituted hydrocarbon that contains both groups. An amino acid is a compound that contains both carboxyl and amino functional groups in the same molecule. There are about 20 amino acids that your body needs to function.

Your cells can manufacture some, but not all, of the amino acids. For example, your body can make glycine, but not phenylalanine. The essential amino acids that your body cannot make must come from foods like those in Figure 17.

Your cells use amino acids as the monomers for constructing protein polymers. A protein is a polymer in which at least 100 amino acid monomers are linked through bonds between an amino group and a carboxyl group. The instructions for making proteins are stored in DNA. Proteins make up the fibers of your muscles, your hair and fingernails, and the hemoglobin in your blood. Your body may contain as many as 300,000 different proteins.

Section 9.3 Assessment

Reviewing Concepts

1. Describe a way that polymers can be classified.
2. Name three synthetic polymers.
3. What are four types of polymers that can be found in the cells of organisms?
4. What are the three parts of a nucleotide?
5. What holds the bases together in DNA?
6. What two functional groups are found in amino acids?
7. Using Analogies Which natural polymers are like a train with identical freight cars and which are like a train with a mixture of different cars?
8. Inferring There is another system for classifying carbohydrates that uses the categories monosaccharides, disaccharides, and polysaccharides. Where would you place glucose, sucrose, and cellulose in this classification system? Give a reason for your answer.

Critical Thinking

7. Using Analogies Which natural polymers are like a train with identical cars, and proteins and nucleic acids are like trains with a mixture of different cars?
8. Glucose is a monosaccharide because its molecules are single sugar units. Sucrose is a disaccharide because its molecules contain a glucose unit and a fructose unit linked together. Cellulose is a polysaccharide because it contains many glucose units linked together.

Figure 17 The foods shown are all good protein sources. Classifying Group the foods into three or four categories.

**Glycine**

**Phenylalanine**

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 9.3.
Should People Conserve Fossil Fuels?

Many people depend on fossil fuels such as petroleum, or crude oil. Nearly 28 billion barrels of oil were consumed in 2002. More than 14 billion barrels was used to supply energy for automobiles, airplanes, and other means of transportation. Fractions of crude oil are also used to produce plastics, dyes, fertilizers, solvents, aerosols, explosives, paints, soaps, and medicines.

Scientists estimate that annual consumption of oil will increase to 38.6 billion barrels by 2020. Scientists disagree about how much of the fossil fuels remaining than predicted and that there is no crisis. Others suggest that scientists must quickly develop alternative sources of energy for transportation, such as solar power, hydrogen fuel cells, or fuels made from plants. Alternative energy sources would reduce the use of fossil fuels and limit the amount of pollution during their combustion.

Fossil fuels are still abundant.

People can continue to use the known supply of fossil fuels at current rates for many years. New technology makes finding and extracting oil, coal, and natural gas easier. For example, in 1978 scientists thought there was about 648 billion barrels of oil remaining worldwide. However, with new discoveries and improved technology, optimists now think there may be as much as 3 trillion barrels remaining. Even if the use of oil increased, scientists would still have several hundred years to develop alternative fuels and new refining processes. In addition, technologies are reducing the amount of sulfur dioxide and nitrogen oxides released when fossil fuels are burned.

Fossil fuels must be conserved.

Advances in technology will serve only to speed up the rate at which oil is extracted from oil reserves. The amount of oil available for consumers will rise, and people will feel no need to conserve. At some point, production will decrease as supplies dwindle. The emissions produced when fossil fuels burn put society at a whole at risk. Despite more efficient methods of combustion, more than 6 billion tons of carbon dioxide was released into the atmosphere in 1997. Developing alternative sources of energy now will reduce pollution in the future. These alternatives also free fossil fuels for use in the production of plastics, paints, medicines, and other essential materials.

The Viewpoints

1. Defining the Issue In your own words, describe the issue that needs to be resolved about the use of fossil fuels.
2. Analyzing the Viewpoints List three arguments made by those who think that fossil fuels do not need to be conserved. List three arguments made by people who think that fossil fuels must be conserved.
3. Forming Your Opinion Should people conserve fossil fuels? Did you find any convincing argument for or against conservation?
4. Role-Playing You manufacture a product that has parts made from synthetic polymers. The polymers are made from compounds found in oil. Your costs would increase without the polymers. Write a letter to your senator stating your point of view on funding alternative energy research.

Research and Decide

Visit: PHSchool.com Web Code: cch-1090

Go Online

Should People Conserve Fossil Fuels?

Background

Industrialized societies are highly dependent on fossil fuels. These fuels provide the energy for heating, cooling, and lighting commercial and residential buildings; operating industrial machinery and home appliances; and transporting goods and people. A reduction in the supply of fossil fuels or an increase in their cost would have a major impact on the economy of an industrialized society. In these countries the availability and use of fossil fuels is an important domestic and foreign policy issue. The effect on the environment of the combustion of fossil fuels is also an important issue.

So is the extraction, refining, and transporting of fossil fuels.

Answers

1. Should fossil fuels be conserved?
2. Acceptable answers against conservation include: Reserves are greater than previously thought; technology makes finding and extracting fuels easier; scientists have time to develop alternative technologies; technologies have reduced the emission of sulfur and nitrogen oxides when fossil fuels are burned. Acceptable answers in favor of conservation include: Advances in technology will increase the rate of consumption; eventually production will decrease; despite more efficient methods of combustion, tons of carbon dioxide are still released into the atmosphere.
3. Students should present arguments to support their decisions.
4. Acceptable answers will include persuasive reasoning to explain the chosen point of view.

Web Code: cch-1090

Have students further research the issues related to this topic.

Go Online
For thousands of years, people used whale oil and other animal fats as fuels for their lamps. As fats burn, they combine with oxygen and produce carbon dioxide and water. They also release energy in the form of heat and light. In a lamp, combustion takes place rapidly. In the cells of organisms, a more controlled version of the process releases energy stored in molecules. Some of the energy released helps maintain your internal body temperature at or close to 37°C.

Reactions that take place in cells follow the same rules as reactions that take place in a research laboratory or classroom. Some reactions go to completion and some reach an equilibrium point. Many reactions occur in solution and catalysts are often needed. Energy is transferred and energy is converted from one form to another.

Photosynthesis and cellular respiration are two processes that allow organisms to meet their energy needs.

**Photosynthesis**
The sun is the primary source of energy for most plants and animals. During photosynthesis, plants chemically combine carbon dioxide and water into carbohydrates. The process requires light and chlorophyll, a green pigment in plants. This equation summarizes the process:

\[
6\text{H}_2\text{O} + 6\text{CO}_2 + \text{Energy (light)} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]

During photosynthesis, energy from sunlight is converted into chemical energy. Photosynthesis involves a complex series of chemical reactions. When all the reactions are complete, the energy from sunlight has been stored in the covalent bonds of molecules.

**Cellular Respiration**
Cellular respiration is the process by which organisms use oxygen to release energy from food and transport it to the cell’s organelles. This process involves a series of reactions that release energy stored in the chemical bonds of food molecules. The energy is then used to power the cell’s activities.

**Key Concepts**
- What energy conversion takes place during photosynthesis?
- How are photosynthesis and cellular respiration related?
- What molecules help cells function efficiently?

**Vocabulary**
- photosynthesis
- enzymes
- vitamins

<table>
<thead>
<tr>
<th>Heading</th>
<th>Main Idea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthesis</td>
<td>a. ?</td>
</tr>
<tr>
<td>Cellular Respiration</td>
<td>b. ?</td>
</tr>
<tr>
<td>Enzymes and Vitamins</td>
<td>c. ?</td>
</tr>
</tbody>
</table>

**Reading Focus**

**Objective**
9.4.1 Compare photosynthesis and cellular respiration.
9.4.2 Explain how enzymes and vitamins help reactions take place in cells.

**Reading Strategy**

a. During photosynthesis, energy from sunlight is converted into chemical energy.

b. During cellular respiration, the energy stored in products of photosynthesis is released.

c. Enzymes and vitamins are compounds that help cells function efficiently at normal body temperature.

**Reading Focus**

**Objectives**
9.4.1 Compare photosynthesis and cellular respiration.
9.4.2 Explain how enzymes and vitamins help reactions take place in cells.

**Reading Strategy**

a. During photosynthesis, energy from sunlight is converted into chemical energy.

b. During cellular respiration, the energy stored in products of photosynthesis is released.

c. Enzymes and vitamins are compounds that help cells function efficiently at normal body temperature.

**Instruct**

**Photosynthesis**

**Build Reading Literacy**

**Sequence** Refer to page 290D in Chapter 10, which provides guidelines for using a sequence.

Have students create a flowchart that follows a carbon atom through photosynthesis and cellular respiration. Have students mark where oxygen, water, and energy enter and exit the overall process.

**Integrate Biology**

In green plants, chlorophyll a and b are the dominant light-absorbing pigments. These pigments and others contribute to the color of leaves and allow plants to absorb the energy of sunlight.

Have interested students research chlorophyll’s structure. (Chlorophyll has a flat, star-shaped structure with a Mg^{2+} ion in the center.)

**Logical**

**Technology**

- Interactive Textbook, Section 9.4
- Presentation Pro CD-ROM, Section 9.4
- Go Online, Science News, Organic chemistry and biochemistry
because starch is a polymer of glucose. During digestion, starch breaks down into simple sugars or starches, which can be used by the body as energy sources.

Carbon dioxide and water are reactants in cellular respiration and products of photosynthesis. Carbon dioxide and water are reactants in photosynthesis and products of cellular respiration. Carbohydrates and oxygen are reactants in cellular respiration and products of photosynthesis.

In the equation for cellular respiration, glucose is reacting with oxygen. The glucose can come from simple sugars or from starches, because starch is a polymer of glucose. During digestion, starch breaks down into glucose. This process is an example of depolymerization.

Fats are also a good source of energy. One gram of fat produces twice the energy of one gram of a carbohydrate.

Cellular Respiration

What does your body need energy for, besides maintaining a constant body temperature? Everything! It takes energy to laugh or cry, to heal a bone or a paper cut, to climb a rope or a staircase, or even to sleep. During cellular respiration, the energy stored in the products of photosynthesis is released. Like photosynthesis, cellular respiration is a complex series of reactions. This equation is a summary of the overall process.

\[ C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + \text{Energy (heat)} \]

Figure 19 summarizes the relationship between photosynthesis and cellular respiration. Each process produces the reactants for the other process. Carbon dioxide and water are reactants in photosynthesis and products of cellular respiration. Carbohydrates and oxygen are reactants in cellular respiration and products of photosynthesis.

In the equation for cellular respiration, glucose is reacting with oxygen. The glucose can come from simple sugars or from starches, because starch is a polymer of glucose. During digestion, starch breaks down into glucose. This process is an example of depolymerization.

Fats are also a good source of energy. One gram of fat produces twice the energy of one gram of a carbohydrate.

Which produces more energy per gram, a carbohydrate or a fat?
**Section 9.4 Assessment**

**Enzymes and Vitamins**

Without some help, many of the reactions that take place in your cells would not happen fast enough to keep the cells alive. Your internal temperature should not vary more than a few degrees from 37°C. So you cannot increase the temperature to speed up a reaction in your cells. **Enzymes and vitamins are compounds that help cells function efficiently at normal body temperature.**

**Enzymes** Without enzymes, cells could not digest food or extract energy from food. **Enzymes** are proteins that act as catalysts for reactions in cells. Enzymes allow reactions to proceed faster at much lower temperatures than would normally happen. Your body uses thousands of enzymes to control reactions within your cells. Pepsin, for example, is an enzyme that breaks apart proteins. It works only in the acidic environment of the stomach. Some enzymes require a co-enzyme to function, often a metal ion or a water-soluble vitamin.

**Vitamins** In the 1800s, British sailors ate limes on long sea voyages. The limes were protection against scurvy, which causes severe pain and weakness. Limes contain vitamin C. **Vitamins** are organic compounds that organisms need in small amounts, but cannot produce. A vitamin that dissolves in water, such as vitamin C, gets eliminated from the body and must be replaced daily. A vitamin that dissolves in fats, such as vitamin A, can build up over time in body tissues. Taking excess amounts of fat-soluble vitamins may be harmful.

**Critical Thinking**

6. **Formulating Hypotheses** Why must combustion in cells take place in multiple steps?

**Visual**

**Denaturing an Enzyme**

**Purpose** Students will observe how enzyme activity is affected by temperature.

**Materials** potato, sharp knife, cutting surface, 3% hydrogen peroxide solution, water, 500-mL beakers (2), hot plate

**Procedure** Fill a beaker halfway with water and use the hot plate to boil the water. Cut a potato into small cubes (about 1 cm³). Place some of the cubes in the boiling water and allow them to cook for several minutes. Fill a second beaker halfway with hydrogen peroxide solution. Place some of the raw cubes in the hydrogen peroxide solution. Have students observe the gas bubbles that form on the surface of the potato cubes. Explain that an enzyme in the potato is speeding up the reaction that decomposes hydrogen peroxide into water and oxygen. Explain that enzymes lose their ability to speed up reactions when they are damaged by an increase in temperature. Place some of the cooked potato cubes in the hydrogen peroxide and have students note that gas bubbles do not form (or form at a much slower rate). **Visual**

**Evaluate Understanding**

- **Assess** Have groups of students write four review questions with answers.

- **Reteach** Have students use Figure 19 to review the relationships between photosynthesis and cellular respiration.

**Writing in Science**

The masses of the vitamins in the pills are small (micrograms) compared to the masses of the minerals (milligrams).

**If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 9.4.**

**Figure 20** Soluble in water

**Critical Thinking**

6. Multiple steps allow the cells to release the energy stored in chemical bonds in smaller amounts, rather than all at once, which could cause the temperature in a cell to rise. 7. It’s likely that these bacteria would not be affected because they do not require the oxygen that plants produce during photosynthesis. 8. Without these essential amino acids, the body would not be able to produce enzymes needed for cellular reactions.