CHAPTER 23
Organic Compounds

Launch Lab
Carbon, the Organic Element

The element carbon exists in several forms including dull, black charcoal; slippery, gray graphite; and bright, sparkling diamond. However, this is nothing compared with the millions of different compounds that carbon can form with other elements. In this lab, you will seek out the carbon hidden in two common substances.

For a lab worksheet, use your StudentWorks™ Plus Online.

Make a vocabulary book. Label it with vocabulary from the chapter. Use it to organize your notes on vocabulary for organic compounds.

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THEME FOCUS  Natural Resources
All organisms and many of our natural resources, including crude oil, natural gas, and timber, are made of organic compounds.

BIG Idea  Organic compounds contain the element carbon.

Section 1  Simple Organic Compounds

Section 2  Substituted Hydrocarbons

Section 3  Petroleum—A Source of Organic Compounds

Section 4  Biological Compounds

Chapter 23  Organic Compounds  705
Simple Organic Compounds

**Main Idea** Hydrocarbons are compounds made only of carbon and hydrogen atoms.

**Real-World Reading Link** How many structures could you make with only two types of blocks? Amazingly, a vast number of compounds can be made using only two atomic building blocks—hydrogen and carbon.

**Organic Compounds**

What do you have in common with gasoline, vanilla flavoring, and natural rubber? These items contain carbon compounds, as shown in Figure 1. You also contain carbon compounds. Most compounds containing the element carbon are *organic compounds*.

At one time, scientists thought that only living organisms made organic compounds, which is how they got their name. By 1830, scientists had made organic compounds in laboratories, but they still call them organic compounds. Of the millions of carbon compounds known today, more than 90 percent of them are organic compounds. The others, including carbon dioxide and the carbonates, are inorganic compounds.

**Bonding** You may wonder why carbon can form so many different organic compounds. A carbon atom has four electrons in its outer energy level. Therefore, a carbon atom can form four covalent bonds with atoms of carbon or with other elements. Recall that a covalent bond is formed when two atoms share a pair of electrons. The four available bonding sites allow carbon to form single, double, and triple bonds. As a result, carbon can make many types of compounds, including small compounds used as fuel, complex compounds found in medicines, and the long chains used in plastics.

**Reading Preview**

**Essential Questions**

▷ What is the difference between organic and inorganic compounds?
▷ Why can carbon form so many different compounds?
▷ What is the difference between a saturated and an unsaturated hydrocarbon?
▷ What are isomers and how do their properties vary?

**Review Vocabulary**

covalent bond: attraction formed between atoms when they share electrons

**New Vocabulary**

organic compound hydrocarbon saturated hydrocarbon unsaturated hydrocarbon isomer benzene

**Figure 1** Organic compounds contain carbon. Carbon can form straight chains, branched chains, and rings.

Heptane is a component of gasoline. Isoprene exists in natural rubber. Vanillin is found in vanilla flavoring.
Arrangement  Look back at Figure 1. Notice that carbon atoms can form straight chains, branched chains, and even rings. This variety of arrangements is another reason carbon can form so many compounds.

Representations  Organic compounds are commonly represented in three ways, as shown in Figure 2. The simplest way is with the chemical formula. For example, a main component of natural gas used in homes is the organic compound methane. Methane’s chemical formula is CH₄. The second way to represent the molecule is with the structural formula. The structural formula uses lines to show bonds between atoms. Each line between atoms represents a single covalent bond. The third way, the space-filling model, shows a more realistic picture of the relative size and arrangement of the atoms in the molecule. Most often, however, chemists use chemical and structural formulas to write about reactions.

Reading Check  Identify three ways to represent organic compounds.

Hydrocarbons  Carbon forms an enormous number of compounds with hydrogen alone. A compound composed of only carbon and hydrogen atoms is called a hydrocarbon. The natural gas methane is a hydrocarbon. Another hydrocarbon used as fuel is propane. Some stoves, most outdoor grills, and hot-air balloons burn propane. The structural formulas and space-filling models of propane and methane are shown in Figure 2.

Hydrocarbons produce more than 90 percent of the energy that humans use. Hydrocarbons are also important in medicines, foods, and clothing. To understand how hydrocarbons can play so many roles, you must examine how their structures differ.

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Figure 2  Organic molecules can be represented by their chemical formulas, by their structural formulas, or by space-filling models. Compare and contrast methane and propane.

Vocabulary

Science usage  relating to most carbon-containing compounds

Methane is an organic compound containing carbon and hydrogen.

Common usage  related to a product that was grown or created without using synthetic compounds

The farmer raises organic tomatoes and uses only natural pesticides.
Hydrocarbon lengths The number of carbon atoms in a straight-chain hydrocarbon is indicated by the root of its name. For example, methane has one carbon atom, ethane has two, and propane has three. Table 1 summarizes some of these roots. The length of the carbon chain affects the properties of the compound. For example, Figure 3 shows a graph of the boiling points of some hydrocarbons. Notice the boiling point increases with the addition of carbon atoms.

Bonding in hydrocarbons Hydrocarbons can contain single, double, and triple bonds between carbon atoms. An easy way to know what type of bond that a hydrocarbon has is to look at the last three letters of the compound’s name. The ending –ane indicates a single bonds only, the ending –ene indicates a double bond, and –yne indicates a triple bond.

Single bonds In some hydrocarbons, the carbon atoms are joined by single covalent bonds. Hydrocarbons containing only single-bonded carbon atoms are called saturated hydrocarbons. Saturated means that a compound holds as many hydrogen atoms as possible—it is saturated with hydrogen atoms. Table 2 lists four saturated hydrocarbons. Each carbon atom can be considered a link in a chain connected by single covalent bonds.
Multiple bonds  Hydrocarbons can also have double and triple bonds. Hydrocarbons that contain at least one double or triple bond are called **unsaturated hydrocarbons**. What would happen if the two carbon atoms in ethane (C₂H₆) shared two pairs of electrons and formed a double bond? The resulting compound would be ethene (C₂H₄). Ethene is sometimes called ethylene. Many fruits can form small quantities of ethylene gas, which aids in ripening. The hydrocarbon ethyne (C₂H₂) contains a triple bond in which three pairs of electrons are shared between the two carbon atoms. Ethyne has only two hydrogen atoms and is used in some welding torches. The differences between ethane, ethene, and ethyne are shown in **Figure 4**.

**Reading Check**  State the number of carbon atoms and hydrogen atoms in each molecule in **Figure 4**.

Isomers  Pentane, isopentane, and neopentane have exactly the same chemical formula (C₅H₁₂). However, their carbon atoms are arranged very differently, as shown in **Figure 5**. In a molecule of pentane, the carbon atoms form a continuous chain. Isopentane has one branch, and neopentane has two branches. Pentane, isopentane, and neopentane are isomers. **Isomers** are compounds that have identical chemical formulas but different molecular structures and shapes.

Properties of isomers  The arrangement of carbon atoms in each compound changes the shape of the molecule, which affects its physical properties. Generally, melting points and boiling points lower as the amount of branching in an isomer increases. You can see this pattern in **Figure 5**. You may notice that there is an exception to the pattern—the melting point of neopentane is higher than that of pentane or isopentane. In this case, the high melting point results from the symmetry of the molecule and its globular shape.
There are many other kinds of isomers in organic and inorganic chemistry. Examine the three non-branched isomers of butene shown in Figure 6. Notice that the double bond can be located in different places on the chain and that the chain can bend in different ways.

Another type of isomer differs only slightly in how the atoms are arranged in space. Such isomers form what are often called right-handed and left-handed molecules and look like mirror images. Two such isomers may have nearly identical physical and chemical properties.

**Carbon Rings**

Recall that carbon can also form rings. For example, cyclopropane has three carbon atoms joined into a ring by single bonds, as shown in Figure 7. Cyclo- means circular. Propane and cyclopropane are not isomers. Propane’s chemical formula is \( C_3H_8 \), while cyclopropane’s chemical formula is \( C_3H_6 \). Like straight and branched chains, cyclic carbon chains can have double and triple bonds. For example, cyclopentene (\( C_5H_8 \)) has a double bond and cyclooctyne (\( C_8H_{12} \)) has a triple bond. These molecules are also shown in Figure 7.

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**Model Hexane Isomers**

**Procedure**

1. Read the procedure and safety information, and complete the lab form.
2. To model hexane (\( C_6H_{14} \)), use soft **gumdrops** to represent carbon atoms, **raisins** to represent hydrogen atoms, and **toothpicks** for the chemical bonds. **WARNING:** Never eat any food in the laboratory.
3. Model the unbranched chain structure of hexane and draw its structural formula.
4. Make as many different branched formations of hexane as you can, and draw the structural formula of each.

**Analysis**

1. Explain How do you distinguish one hexane isomer from another?
2. State the total number of different hexane isomers found in your class.
**Benzene** Figure 8 shows a special type of carbon ring called benzene. As you can see, the benzene molecule has six carbon atoms bonded into a ring. **Benzene** \((C_6H_6)\) is a cyclic hydrocarbon with carbon atoms that are joined with alternating single and double bonds. The electrons in the double bonds are shared by all six carbon atoms in the ring. The equal sharing of electrons is represented by the benzene symbol: a circle in a hexagon.

**Fused rings** The sharing of these six electrons causes the benzene molecule to be very stable. The carbon atoms are bound in a rigid, flat structure. Benzene acts as a framework upon which new molecules can be built. Benzene rings can fuse together, like in the naphthalene (NAF thuh leen) molecule in Figure 8. Naphthalene is used in mothballs, which have a distinct odor. Many known compounds contain three or more rings fused together. Tetracycline (teh truh SI kleen) antibiotics are based on a fused ring system containing four fused rings.

**Section 1 Review**

**Section Summary**

- Carbon can form many compounds because it has four electrons in its outer energy level.
- Hydrocarbons can be saturated or unsaturated.
- Isomers are compounds that have identical chemical formulas but different molecular structures.
- Benzene contains six carbon atoms bonded into a ring with alternating double and single bonds.

1. **MAIN IDEA** Define the term *organic compounds* and explain how they got this name.
2. Classify each of the following compounds as organic or inorganic: \(C_4H_{10}\), \(H_2O\), \(FeO\), \(CH_3COOH\), and \(CaS\).
3. Compare and contrast ethane, ethene, and ethyne.
4. Explain the term *saturated* in relation to hydrocarbons. What are these compounds saturated with?
5. Describe how boiling and melting points generally vary as branching in hydrocarbon isomers increases.
6. Think Critically Cyclobutane is a cyclic, saturated hydrocarbon containing four carbon atoms. Draw its structural formula. Are cyclobutane and butane isomers? Explain.

**Apply Math**

7. **Identify Trends** Adding one double bond to octane \((C_8H_{18})\) makes the hydrocarbon octene \((C_8H_{16})\). Write the formulas for adding one, two, and three more double bonds to octane. What is the decrease in the number of hydrogen atoms for each double bond added?
Substituted Hydrocarbons

**MAIN IDEA** Substituted hydrocarbons contain other elements besides carbon and hydrogen.

**Real-World Reading Link** Usually, a cheeseburger is a hamburger covered with melted American cheese and served on a bun. But you can make a cheeseburger with Swiss cheese and serve it on toast. Such substitutions would affect the taste of this cheeseburger. What would happen if you changed the atomic ingredients of a hydrocarbon?

**Replacing Hydrogen**

Chemists often change hydrocarbons into other compounds having different physical and chemical properties. They may include a double or triple bond or add different atoms or groups of atoms to a hydrocarbon. Some of these changed compounds are substituted hydrocarbons. A **substituted hydrocarbon** has one or more of its hydrogen atoms replaced by atoms, or groups of atoms, of other elements. The groups of atoms used in the substitution are called functional groups. Depending on what properties are needed, chemists decide what functional groups to add. Examples of substituted hydrocarbons are shown in Figure 9.

**Substituting Oxygen Groups**

Oxygen is found in the air, in water, and in many substituted hydrocarbons. Oxygen can form single and double bonds with carbon and single bonds with hydrogen. As a result, there are many compounds containing just carbon, hydrogen, and oxygen. These compounds include alcohols, organic acids, and esters.

![Figure 9](image) By substituting elements such as oxygen, nitrogen, and chlorine for hydrogen atoms, a wide variety of organic compounds can be made. These diverse compounds have many uses.
Alcohols Rubbing alcohol, used for rubbing aching muscles, is a substituted hydrocarbon. An alcohol is formed when –OH groups replace one or more hydrogen atoms in a hydrocarbon. Alcohols are an important group of organic compounds. They often serve as solvents and disinfectants and can be used as pieces to assemble larger molecules. Figure 10 shows ethanol, an alcohol produced by the fermentation of sugar in grains and in fruit.

Organic acids Organic acids form when a carboxyl group (–COOH) is substituted for one of the hydrogen atoms in a hydrocarbon. Ethanoic acid, also known as acetic acid, is an organic acid found in vinegar. As shown in Figure 10, the structures of ethanol and ethanoic acid are similar. You know some other organic acids, too—citric acid found in citrus fruits, such as oranges and lemons, and lactic acid found in sour milk.

Reading Check Explain why organic acids are considered substituted hydrocarbons.
Esters Recall that mixing an acid and a base will yield water and a salt. In a similar way, alcohols and organic acids combine to form water and an ester. An ester is a substituted hydrocarbon with a −COOC− group. Figure 11 shows the reaction of butyric (byew THIR ihk) acid and ethyl alcohol to produce water and the ester ethyl butyrate, which is a component in pineapple flavor. Esters have many different applications. Esters of the alcohol glycerine are used to make commercial soaps. Other esters can be made into fibers for clothing, and still others are used in flavors and perfumes.

Esters for flavor and odors Many fruit-flavored soft drinks and desserts taste like real fruit. If you look at the label, you might be surprised to find that no fruit was used, only artificial flavor. Most likely, this artificial flavor contains esters.

The odor of some individual esters immediately makes you think of particular fruits, as shown in Figure 12. For example, octyl ethanoate smells like oranges, and both isopentyl ethanoate and butyl ethanoate smell like bananas. But many natural and artificial flavors contain a blend of many esters. Strawberry flavor, for example, may contain several esters. Making realistic synthetic flavors is an art in which chemists vary the blends of esters to achieve the desired taste.
Substituting Other Elements

Other functional groups can be added to hydrocarbons. Each group has unique properties. Three common groups are amines, mercaptans, and halocarbons.

**Amines**  An amine forms when an amine group (−NH₂) replaces a hydrogen atom in a hydrocarbon. For example, aniline is formed when −NH₂ replaces a hydrogen atom on a benzene ring. Aniline, shown in Figure 13, is used to make dyes. Amines are also essential for life.

**Mercaptans**  When the group −SH replaces a hydrogen atom in a hydrocarbon, the resulting compound is a thiol. Thiols are commonly called mercaptans. Most mercaptans have unpleasant odors. This can be useful to animals such as skunks. Strangely, small concentrations of foul-smelling mercaptans are often found in pleasant-smelling substances. For example, the odor of grapefruits is due to the mercaptan shown in Figure 13.

Mercaptan odors are also powerful. You can smell skunk spray in concentrations as low as 0.5 parts per million. Such a powerful stink can be an asset to people, too. Natural gas has no odor of its own so it is impossible to smell a gas leak. For this reason, gas companies add small amounts of a mercaptan to the gas to make people aware of leaks.

**Halocarbons**  A substituted hydrocarbon with a halogen, such as chlorine or bromine, in place of a hydrogen atom is called a halocarbon. For example, when four chlorine atoms replace four hydrogen atoms in ethene, the result is tetrachloroethene (teh truh klor uh eh THEEN), a solvent used in dry cleaning. Adding four fluorine atoms to ethene makes a compound that is a starting material for making nonstick coatings on cookware, as shown in Figure 14.

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**Figure 13**  Amines and mercaptans are two types of substituted hydrocarbons.

**Figure 14**  Tetrafluoroethene is a halocarbon used to make non-stick coatings on pans.
Aromatic Compounds

Recall that benzene is very stable and makes a good building block for compounds. All compounds that contain a benzene structure are aromatic compounds. Benzene's hydrogen atoms can be replaced with various functional groups to make many different aromatic compounds.

Aromatic compounds and smell Aromatic compounds are so named because most of them have a distinctive smell. They contribute to the smell of cloves, cinnamon, and vanilla. Some aromatic compounds produce pleasant odors or tastes. For example, methyl salicylate, shown in Figure 15, produces a fresh wintergreen fragrance. Other aromatic compounds have less pleasant flavors and smells. Aspirin, also shown in Figure 15, is a sour-tasting aromatic compound. The different flavors are due to the different functional groups.

Section 2 Review

Section Summary

- In alcohols, the –OH group is substituted for a hydrogen atom.
- Organic acids contain the group –COOH.
- Esters are prepared by combining an alcohol and an organic acid.
- Amines contain the –NH₂ group and mercaptans contain the –SH group.
- Substituted hydrocarbons containing a halogen are called halocarbons.
- Many aromatic compounds have distinct odors.

8. **MAIN IDEA** Classify each of the following as a hydrocarbon or a substituted hydrocarbon: ethyne, tetrachloroethene, ethanol, benzene, propane, and acetic acid.

9. **Identify** the structure that is present in all aromatic compounds.

10. **Explain** why chemists might want to prepare substituted hydrocarbons. Give two examples of possible substitutions.

11. **Identify** possible uses for each of the following types of substituted hydrocarbons: alcohols, esters, and halocarbons.

12. **Think Critically** Chloroethane (C₂H₅Cl) can be used as a spray-on anesthetic for localized injuries. How does chloroethane fit the definition of a substituted hydrocarbon? Diagram its structure.

Apply Math

13. **Use Percentages** The odor of mercaptans can be detected in concentrations as low as 0.5 parts per million. Express this concentration as a percent.
Objectives
- **Initiate** a chemical reaction to produce a specific compound.
- **Gather** evidence to form conclusions about the identity of a new compound formed from a chemical reaction.

**Background:** Have you ever wondered how chemists change one substance into another? You have learned that changing the bonding between atoms holds the key to that process.

**Question:** How can an alcohol change into an organic acid?

**Preparation**

**Materials**
- large test tube and stopper
- 0.01 M potassium permanganate solution (1 mL)
- 6 M sodium hydroxide solution (1 mL)
- ethanol (3 drops)
- 10-mL graduated cylinder
- universal indicator strips

**Safety Precautions**

**WARNING:** Always handle chemicals carefully. Immediately flush any spill with water.

**Procedure**

1. Read the procedure and the safety information and complete the lab form.
2. Pour 1 mL of 0.01 M potassium permanganate solution and 1 mL of 6 M sodium hydroxide solution into a test tube.
   **WARNING:** Potassium permanganate is an irritant. Sodium hydroxide is caustic.
3. Add 3 drops of ethanol to the test tube.
4. Stopper the test tube. Gently shake it for 1 minute. Observe and record any changes in the solution for 5 minutes.
5. Use a strip of universal indicator paper to determine the pH of the solution.

**Conclude and Apply**

1. **Draw** the structural formula of ethanol, and identify the part of the compound that makes it an alcohol.
2. **Identify** the part of a molecule that identifies a compound as an organic acid.
3. **Explain** how you know that a chemical change took place in the test tube.
4. **Predict** the formula of the acid produced when ethanol undergoes a chemical reaction in the presence of potassium permanganate.
5. **Identify** the acid produced by this reaction. (Hint: This acid is found in vinegar.)

**Write an Article** Suppose you are submitting a description of your investigation to a scientific journal. Write an article summarizing your procedure, your results, and your conclusions. Exchange articles with a classmate and peer review each other’s articles.
Petroleum—A Source of Organic Compounds

**MAIN Idea**  Petroleum is the source of organic compounds used to make fuels, polymers, and many other products.

**Real-World Reading Link**  Suppose you fill your car’s gas tank and buy a bottle of water. What do your purchases have in common? Both gasoline and plastic contain organic compounds that came from petroleum.

**What is petroleum?**

Do you carry a plastic comb in your pocket or purse? Do you know where that plastic originated? Chances are, it came from petroleum, a mixture of hydrocarbons and small amounts of other substances found deep within Earth. Because it is formed from the remains of fossilized material, it is a fossil fuel. The liquid part of petroleum is called crude oil. Crude oil is dark, flammable, and foul-smelling.

How can a thick, dark liquid like crude oil be transformed into a hard, brightly colored, useful object like a comb? The answer lies in the nature of crude oil. Crude oil is a mixture of thousands of organic compounds. To make items such as combs, specific compounds are refined from this mixture and then processed into consumer products.

**Processing Crude Oil**

The first step is to extract the crude oil from its underground source, as shown in Figure 16. Once the crude oil is obtained, chemists and engineers separate the crude oil into fractions containing compounds with similar boiling points. The separation process is known as fractional distillation and takes place in oil refineries.
**The tower** If you have ever driven past a refinery, you may have seen big, metal towers called fractionating towers. These towers, like the one shown in Figure 17, can rise as high as 35 m and be 18 m wide. Inside the tower is a series of metal plates arranged like the floors of a building. These plates have small holes through which vapors can pass. On the outside is a maze of scaffolding and pipes at various levels.

**Separating organic compounds** The tower separates crude oil into fractions containing compounds having a range of boiling points. Within a fraction, boiling points may range more than 100°C.

At the base of the tower, the crude oil is heated to more than 350°C. At this temperature, most hydrocarbons in the mixture become vapor and start to rise. A few compounds, such as those in asphalt, remain as liquids and are drained from the bottom of the tower. Compounds with higher boiling points condense on the lower plates, drain off through pipes on the sides of the tower, and are collected.

Fractions with lower boiling points may rise to the middle plates before condensing. Those with the lowest boiling points condense on the topmost plates. A few compounds never condense at all and are collected as gases at the top of the tower.

Figure 17 shows some typical fractions. Larger carbon chains have higher boiling points. They generally condense at the bottom of the tower, and smaller compounds condense at the top.

**Reading Check** Compare the masses of compounds collected at the top of the tower to those collected at the bottom.

Why do the condensed liquids not fall back through the holes? The reason is that pressure from the rising vapors prevents this. In fact, the separation of the fractions is improved by the interaction of rising vapors with condensed liquid. The exact processes involved vary. For example, some towers add steam at the bottom to aid vaporization. The design and process used depend on the type of crude oil and on the fractions desired.
Figure 18 Crude oil provides the organic compounds used in many common products. After crude oil has been refined, the organic compounds can be used to make various types of fuel, plastics, and synthetic fibers, as well as paint, dyes, and medicines.

Figure 19 Both paper chains and polymers are long chains made up of smaller units. Paper chains are made of loops of paper and polymers are made of monomers.

Uses for Petroleum Compounds

The lightest fractions from the top of the tower include butane and propane, which are used for fuel. The fractions that condense on the upper plates and contain from five to ten carbons are used for gasoline and solvents. Below these are fractions with 12 to 18 carbons that are used for kerosene and jet fuel. The bottom fractions go into lubricating oil, and the residue is used for paving asphalt.

Other petroleum products are obtained by further purifying crude oil fractions using different techniques to isolate individual compounds. After these are separated, they can be converted into substituted hydrocarbons. Chemists use these to make products ranging from medicines such as aspirin to insecticides, printers’ ink, and flavorings, as shown in Figure 18. Aromatic dyes from crude oil have almost completely replaced natural dyes, such as indigo (a deep blue) and alizarin (a deep red). The first synthetic dye was a bright purple called mauve that was accidentally discovered in coal tar compounds.

Polymers

Did you ever loop together strips of paper to make paper chains for decorations, or have you ever strung paper clips together? A paper chain can represent the structure of a polymer, as shown in Figure 19. Some of the smaller molecules from petroleum are monomers that act like links in a chain. Mono- means one. A monomer is a small molecule that can combine with itself repeatedly to form a long chain. When these links are hooked together, they make new, extremely large molecules known as polymers. Polymers are long chains of monomers. Often, two or more different monomers, known as copolymers, combine to make one polymer molecule.

Reading Check Explain how polymers are similar to paper chains.
Polymer properties The properties of polymers depend mostly on which monomers are used to make them. The amount of branching and the shape of the polymer also greatly affect its properties. Because of this diversity, polymers can be made light and flexible or strong enough to make plastic pipes, boats, and even some auto bodies. Other polymers can be spun into threads for use in clothing, suitcases, and backpacks.

Hydrocarbon polymers Some polymers are made entirely of carbon and hydrogen, as shown in Table 3. When ethene combines with itself repeatedly, it forms the common polymer polyethylene (pah lee EH thuh leen). Polyethylene is used widely in shopping bags and plastic bottles, as shown in Table 3. Another common polymer, polypropylene (pah lee PRO puh leen), is made of propene monomers and has many uses.

Versatile polystyrene Some polymers can take two completely different forms. Polystyrene (pah lee STI reen) forms brittle, transparent cases for CDs. But if a gas such as carbon dioxide is blown into the melted polystyrene as it is molded, bubbles will remain within the polymer when it cools. These bubbles make polystyrene the efficient insulator used in foam cups.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Hydrocarbon Polymers</th>
<th>Interactive Table</th>
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<tbody>
<tr>
<td>Polymer</td>
<td>Monomer</td>
<td>Uses</td>
</tr>
</tbody>
</table>
| Polyethylene | [CH₂ — CH₂] | • plastic bags  
• plastic bottles |
| Polypropylene | [CH₂ — CH | • glues  
• carpets  
• high-performance outdoor clothing |
| Polystyrene | [CH — CH₂] | • foam packing  
• disposable food containers  
• CD cases |

VOCABULARY

WORD ORIGIN
Polymer
from the Greek poly—meaning “many” and –mer meaning “part or segment”  
Polymers are used to make plastic bags and foam cups.
### Table 4: Substituted Hydrocarbon Polymers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Monomer</th>
<th>Uses</th>
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<tbody>
<tr>
<td>Polyurethane</td>
<td><img src="image1" alt="Polyurethane Monomer" /></td>
<td>• foam&lt;br&gt;• waterproof coatings&lt;br&gt;• shoe parts</td>
</tr>
<tr>
<td>Polyvinyl chloride</td>
<td><img src="image2" alt="Polyvinyl Chloride Monomer" /></td>
<td>• pipes&lt;br&gt;• hoses&lt;br&gt;• house siding</td>
</tr>
<tr>
<td>Polyester</td>
<td><img src="image3" alt="Polyester Monomer" /></td>
<td>• fabric&lt;br&gt;• rope</td>
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**Substituted hydrocarbon polymers** Polymers can contain elements other than carbon and hydrogen, as shown in Table 4. Polyurethane has functional groups that contain oxygen and nitrogen. The monomers of polyvinyl chloride, also known as PVC, are ethene monomers with chlorine substituted for one hydrogen atom. This substitution makes PVC harder and more heat resistant than polyethylene.

**Polyesters** Synthetic fibers called polyesters are made from an organic acid that has two −COOH groups and an alcohol that has two −OH groups, as shown in Figure 20. Polyester is strong because these chains are closely packed together. Many varieties of polyesters can be made, depending on what alcohols and acids are used. Polyesters can be woven or knitted into durable fabrics.

![Figure 20](image4) Polyesters are formed when an organic acid with two −COOH groups combines with an alcohol that has two −OH groups.

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Organic acid + Alcohol → Polyester (1 unit) + H₂O
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![Diagram](image5)
**Depolymerization** Disposing of polymers has become a problem because polymers have been used so widely and many polymers do not decompose. One way to combat this is by recycling, which recovers clean plastics for reuse in new products, such as the bench in Figure 21. Many communities recycle plastics.

Another approach is depolymerization. **Depolymerization** is a process that uses heat or chemicals to break the long polymer chain into its monomer fragments. These monomers can then be reused. However, each polymer requires a different depolymerization process and much research is needed to make this type of recycling economical.

**Section 3 • Review**

**Section Summary**

- Crude oil is a dark, flammable liquid formed from fossilized materials.
- Organic compounds in crude oil can be separated using fractional distillation.
- Polymers are long chains of repeating chemical units called monomers.
- Polymers can be designed with specific properties.
- Depolymerization is the process of breaking a polymer into its components.

14. **Main Idea** Identify several items around your home that are made from organic compounds obtained from crude oil.

15. **Name** some of the fuels obtained from crude oil by fractional distillation.

16. **Describe** the process of fractional distillation.

17. **Explain** why polymers made from the same monomer can have physical properties that vary greatly.

18. **Describe** why depolymerization can be an expensive process.

19. **Think Critically** Based on the names of the polymers in this section, what do you think the polymer made from the monomer terpene is called?

**Apply Math**

20. **Calculate** If the mass of a monomer is 105 atomic mass units, find the mass of a polymer containing 122 monomers.

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**Figure 21** Plastics can be recycled into many structures, such as decks, gazebos, and this bench.
Biological Compounds

**MAIN Idea** Proteins, carbohydrates, lipids, and nucleic acids are large, organic molecules made by plants and animals.

**Real-World Reading Link** You may have had cereal for breakfast this morning. Cereals, like all foods, contain biological compounds such as proteins and carbohydrates.

**Biological Polymers**

Like all polymers, biological polymers are huge molecules made of many monomers linked together. The monomers of biological polymers are usually larger and more complex in structure than those used to make plastics. Many of the important biological compounds in your body are polymers. Among them are the proteins and starches.

**Proteins**

Proteins are large organic polymers formed from organic monomers called amino acids. Even though only 20 amino acids are commonly found in nature, they can be arranged in so many ways that millions of different proteins exist. Proteins come in numerous forms and make up many of the tissues in your body, such as muscles, tendons, hair, and fingernails. In fact, proteins account for 15 percent of your total body weight.

**Protein formation** Amino acids, like glycine and cysteine, are the monomers that combine to form proteins. As shown in Figure 22, the amine group (–NH$_2$) of one amino acid combines with the carboxylic acid group (–COOH) of another amino acid to form a compound called a peptide. The bond joining them is known as a peptide bond. Peptides with about 50 or more amino acids are called proteins.
**Protein structure**  Long protein molecules tend to twist and coil in a manner unique to each protein. For example, hemoglobin, which carries oxygen in your blood, has four chains that coil around each other, as shown in Figure 23. Each chain contains an iron atom that carries the oxygen. If you look closely, you can see all four iron atoms in hemoglobin.

When you eat foods that contain proteins, such as meat, dairy products, and some vegetables, your body breaks down the proteins into their amino acid monomers. Then your body uses these amino acids to make new proteins that form muscles, blood, and other body tissues.

**Carbohydrates**  
If you hear the word carbohydrate, you may think of bread, cookies, or pasta. You may know someone who is on a low-carbohydrate diet to control weight. Or, you may have heard of carbohydrate loading by athletes. Runners, for example, often prepare for a long-distance race by eating, or loading up on, carbohydrates in foods such as vegetables and pasta. Carbohydrates are compounds containing carbon, hydrogen, and oxygen that have twice as many hydrogen atoms as oxygen atoms. Carbohydrates include the sugars and starches.

---

**Test for Starch**

**Procedure**  
**WARNING:** Use caution when using iodine solution. Iodine solution can be a skin and eye irritant and is toxic if ingested or inhaled. Never eat any foods in the lab.
1. Read the procedure and safety information, and complete the lab form.
2. Collect a variety of materials, including cotton balls, paper, potato pieces, wood, apple pieces, laundry spray starch, bread, and metal. Predict which items contain starch.
3. Use a dropper to place one or two drops of iodine solution on each material. For each item, record any color change.

**Analysis**
1. **Infer** What color indicates the presence of starch? (Hint: Bread contains starch.)
2. **Evaluate** How do your results compare with your predictions?
**Figure 24** Fruits contain glucose and another simple sugar called fructose. Sucrose, commonly called table sugar, consists of a glucose molecule and a fructose molecule bonded together.

**Explain why sugars are carbohydrates.**

**Sugars** Sugars form a major group of carbohydrates. The sugar glucose, shown in Figure 24, is found in your blood and also in many sweet foods, such as grapes and honey. Common table sugar, known as sucrose, is broken down by digestion into two simpler sugars—fructose, often called fruit sugar, and glucose. Unlike starches, sugars provide energy soon after eating.

**Starches** Starch, shown in Figure 25, is a carbohydrate that is also a polymer. It is made of monomers of the sugar glucose. During digestion, the starch is broken down into similar sugars, which releases energy in your body cells. Athletes, especially long-distance runners, use starches to provide high-energy, long-lasting fuel for the body. The energy from starches can be stored in liver and muscle cells in the form of a compound called glycogen.

**Reading Check** Describe the difference between sugars and starches.

**Lipids**

Fats, oils, and related compounds make up a group of organic compounds known as lipids. Lipids include animal fats, such as butter, and vegetable oils, such as corn oil. Lipids contain the same elements as carbohydrates but in different proportions. For example, lipids have fewer oxygen atoms and contain carboxylic acid groups. Lipids are long hydrocarbon chains, but they are not polymers.
**Fats and oils** Lipids are similar in structure to hydrocarbons. They can be classified as saturated or unsaturated according to the types of bonds in their carbon chains. Saturated fats, like saturated hydrocarbons, are saturated with hydrogen and contain only single bonds between carbon atoms. Unsaturated fats are like unsaturated hydrocarbons and have double or triple bonds. Unsaturated fats with one double bond are called monounsaturated, and those with two or more double bonds are called polyunsaturated.

Animal lipids, called fats, tend to be saturated and are solids at room temperature. Plant lipids, called oils, are unsaturated and are usually liquids, as shown in Figure 26. Sometimes, hydrogen is added to vegetable oils to form more saturated solid compounds called hydrogenated vegetable shortenings.

Have you heard that eating too much fat can be unhealthy? Evidence shows that too much saturated fat and cholesterol in the diet may contribute to some heart disease and that unsaturated fats may help to prevent heart disease. It appears that saturated fats are more likely to be converted to substances that can block the arteries leading to the heart. A balanced diet includes some fats, just as it includes proteins and carbohydrates.

---

**Which foods should you choose?**

What do you like to eat? You probably choose your foods by how good they taste. A better way might be to look at their nutritional values. Your body needs nutrients, such as proteins, carbohydrates, and fats, to give it energy and to help it build cells. Almost every food has some of these nutrients in it. The trick is to choose your foods so you do not get too much of one thing and not enough of another.

**Identify the Problem**

The table shows some basic nutrients for a variety of foods. The amount of the protein, carbohydrate, and fat is recorded as the number of grams in 100 g of the food. By examining these data, select the foods that best provide each nutrient.

<table>
<thead>
<tr>
<th>Nutritional Values for Some Common Foods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food (100 g)</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td>Cheddar cheese</td>
</tr>
<tr>
<td>Hamburger</td>
</tr>
<tr>
<td>Soybeans</td>
</tr>
<tr>
<td>Wheat</td>
</tr>
<tr>
<td>Potato chips</td>
</tr>
</tbody>
</table>

**Solve the Problem**

1. Using the table, list the foods that supply the most protein and carbohydrates. What might be the problem with eating too many potato chips?
2. In countries where meat and dairy products are not plentiful, people eat a lot of food made from soybeans. Give several reasons why people might wish to substitute meat and dairy products with soybean-based products.
**Cholesterol**  Cholesterol is another lipid that is often in the news. It is found in meats, eggs, butter, cheese, and fish. Like fats and oils, cholesterol can be both helpful and harmful to your body. Some cholesterol is produced by the body to build cell membranes. It is also found in bile, a digestive fluid. However, too much cholesterol may cause serious damage to heart and blood vessels, similar to the damage caused by saturated fats.

**Nucleic Acids**

The nucleic acids are another important group of organic polymers that are essential for life. A **nucleic acid** is an organic polymer that controls the activities and reproduction of cells. You may have heard about DNA, which is one type of nucleic acid. **Deoxyribonucleic** (dee AHK sih ri boh noo klay ihk) **acid**, also called DNA, is an essential biological polymer found in the nuclei of cells that codes and stores genetic information. This information is known as the genetic code.

**Nucleic acid monomers**  The monomers that make up DNA are called nucleotides. **Nucleotides** are complex molecules that make up DNA and that contain one of four organic bases, a sugar, and a phosphate unit. **Figure 27** shows the structure of DNA, along with a closer look at a nucleotide. DNA nucleotides form chains that are unique to an organism. Two nucleotide chains twist around each other, forming what resembles a twisted ladder called a double helix. The rungs of the ladder are paired organic bases. Your genetic code gives instructions for making other nucleotides and proteins needed by your body. Which proteins are made depends on the order of the bases in the DNA.

**Reading Check**  Identify the three components of a nucleotide.
DNA fingerprinting  Human DNA contains more than five billion base pairs. The DNA of each person differs in some way from that of everyone else. The unique nature of DNA offers crime investigators a way to identify criminals from hair or fluids left at a crime scene. First, DNA from bloodstains or cells in saliva found on a soda bottle can be extracted in the laboratory. Then, chemists can break up the DNA into its nucleotide components and use radioactive and X-ray methods to obtain a picture of the nucleotide pattern. Figure 28 shows a DNA profile similar to those used by investigators. Comparing this pattern to one made from the DNA of a suspect can link that suspect to the crime scene.
Objectives

- **Prepare** an ester from an alcohol and an acid.
- **Detect** the results of the reaction by the odor of the product.

**Background:** Organic compounds known as acids and alcohols react to form another type of organic compound called an ester. Esters frequently produce a recognizable and often pleasant fragrance. Esters are responsible for many fruit flavors, such as apple, pineapple, pear, and banana. However, esters are not always aromatic in the chemical sense—they might not contain a benzene ring.

**Question:** How do an acid and an alcohol react to produce a compound with different characteristics? Can the presence of the new compound formed be detected by its odor?

**Preparation**

**Materials**
- medium-size test tube
- test-tube holder
- 250-mL beaker
- 10-mL graduated cylinder
- water
- hot plate
- ring stand
- thermometer
- salicylic acid (1.0 g)
- amyl alcohol (2 mL)
- concentrated sulfuric acid (1 mL to be added by teacher)

**Safety Precautions**

1. Read the procedure and safety information, and complete the lab form.
2. Add about 150 mL of water to the beaker, and heat it on the hot plate to 70°C.
3. Place approximately 1 g of salicylic acid in a test tube. Does this material have an odor? See the warning and illustration below for the proper way to detect odors in the laboratory.

**WARNING:** To detect an aroma safely, hold the container about 10 cm in front of your face and wave your hand over the opening to direct air currents to your nose.

**Procedure**

1. Read the procedure and safety information, and complete the lab form.
2. Add about 150 mL of water to the beaker, and heat it on the hot plate to 70°C.
3. Place approximately 1 g of salicylic acid in a test tube. Does this material have an odor? See the warning and illustration below for the proper way to detect odors in the laboratory.

**WARNING:** To detect an aroma safely, hold the container about 10 cm in front of your face and wave your hand over the opening to direct air currents to your nose.
4. Check to see if amyl alcohol has an odor. If so, try to remember what it smells like.
5. Add 2 mL of amyl alcohol to the test tube.
6. Ask your teacher to carefully add 1 mL of concentrated sulfuric acid. **WARNING:** Sulfuric acid is caustic. Avoid all contact. Do not inhale fumes.
7. Place the test tube in the hot water, and leave it untouched for about 12 to 15 minutes.
8. Remove the tube from the hot water using a test-tube holder, and allow it to cool. Check to see if you can detect a new aroma.

**Conclude and Apply**

1. **Predict** This reaction formed the ester amyl salicylate. What esters would form if amyl alcohol were replaced by the following alcohols: methyl, ethyl, propyl, and isobutyl?
2. **Predict** Look at the equation for the reaction at the bottom of the page. One product is given. What do you think is the second product formed in this reaction? Explain.
3. **Design an Experiment** How might you modify the experiment to produce a different ester?

**Analyze Your Data**

1. **Identify** What did you smell after the reaction was complete?
2. **Infer** Look closely at the surface of the liquid in the test tube. Do you see any small droplets of an oily substance? What do you think it is?

**Communicate Your Data**

**Poster** Make a poster showing the reaction that took place. Use the poster to explain the formation of esters to students from another class.
Molecular Clock Forensics

The case was as tragic as it was bizarre. A doctor injected his former girlfriend with a substance he claimed was vitamin B. Later, when she tested positive for HIV, the virus that causes AIDS, she was certain she had been the victim of a terrible crime. But, how could it be proven?

Evolution on the clock Investigators used the science of the molecular clock to examine the evidence. The genetic material of HIV, shown in Figure 1, mutates at a rate of around one percent per year. Measuring and tracking these mutations can tell scientists when two strains of HIV last shared a common ancestor. The genetic material itself acts as a type of clock.

The investigators examined two genes from the virus’s genome. The first gene contains information for the protein coat and evolves rapidly. The second gene is involved in the genetic copying process and evolves more slowly.

Figure 1 HIV is a virus that consists of a protein coat surrounding genetic material.

The rapidly-evolving gene showed that the HIV strain from the victim was closely related to that from a blood sample found in the doctor’s refrigerator. The slowly-evolving gene proved that the viruses in the victim’s body had evolved from those in the sample. With this evidence, the doctor was convicted of attempted murder.

Calibrating the clock The accuracy of molecular clocks depends on a controversial question: Just how regularly does the clock “tick”? Some parts of a genome may evolve more rapidly than others, particularly if the change increases fitness. Fortunately, there are many mutations that are neutral or nearly neutral to the survival of the organism. By locating these mutations, scientists can calibrate their molecular clocks and discover unanticipated sequences of events.

Million year clocks The molecular clock can also be applied to much longer intervals. For example, it was once believed that many mammals first evolved soon after the extinction of the dinosaurs around 65 million years ago (mya). Molecular clock measurements put their emergence at around 100 mya, firmly in the time of the dinosaurs. Many scientists thought this number had to be wrong. Later, more fossils were found that showed the molecular clock had been correct.

WebQuest Model Molecular Clocks

Have one person (the common ancestor) create two copies of a phrase (the genome). Pass each copy to a classmate, who flips a coin. On heads, make a random change to one letter. Pass copies to two other classmates. After everyone has a turn, count the mutations in each genome and find the average rate of your molecular clock.
**Section 1 Simple Organic Compounds**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>benzene</td>
<td>711</td>
</tr>
<tr>
<td>hydrocarbon</td>
<td>707</td>
</tr>
<tr>
<td>isomer</td>
<td>709</td>
</tr>
<tr>
<td>organic compound</td>
<td>706</td>
</tr>
<tr>
<td>saturated hydrocarbon</td>
<td>708</td>
</tr>
<tr>
<td>unsaturated hydrocarbon</td>
<td>709</td>
</tr>
</tbody>
</table>

**Main Idea**

Hydrocarbons are compounds made only of carbon and hydrogen atoms.

- Carbon can form many compounds because it has four electrons in its outer energy level.
- Hydrocarbons can be saturated or unsaturated.
- Isomers are compounds that have identical chemical formulas but different molecular structures.
- Benzene contains six carbon atoms bonded into a ring with alternating double and single bonds.

**Section 2 Substituted Hydrocarbons**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>alcohol</td>
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<tr>
<td>amine</td>
<td>715</td>
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<tr>
<td>aromatic compound</td>
<td>716</td>
</tr>
<tr>
<td>ester</td>
<td>714</td>
</tr>
<tr>
<td>substituted hydrocarbon</td>
<td>712</td>
</tr>
</tbody>
</table>

**Main Idea**

Substituted hydrocarbons contain other elements besides carbon and hydrogen.

- In alcohols, the −OH group is substituted for a hydrogen atom.
- Organic acids contain the group −COOH.
- Esters are prepared by combining an alcohol and an organic acid.
- Amines contain the −NH₂ group and mercaptans contain the −SH group.
- Substituted hydrocarbons containing a halogen are called halocarbons.
- Many aromatic compounds have distinct odors.

**Section 3 Petroleum—A Source of Organic Compounds**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>depolymerization</td>
<td>723</td>
</tr>
<tr>
<td>monomer</td>
<td>720</td>
</tr>
<tr>
<td>polymer</td>
<td>720</td>
</tr>
</tbody>
</table>

**Main Idea**

Petroleum is the source of organic compounds used to make fuels, polymers, and many other products.

- Crude oil is a dark, flammable liquid formed from fossilized materials.
- Organic compounds in crude oil can be separated using fractional distillation.
- Polymers are long chains of repeating chemical units called monomers.
- Polymers can be designed with specific properties.
- Depolymerization is the process of breaking a polymer into its components.

**Section 4 Biological Compounds**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbohydrate</td>
<td>725</td>
</tr>
<tr>
<td>deoxyribonucleic acid (DNA)</td>
<td>728</td>
</tr>
<tr>
<td>lipid</td>
<td>726</td>
</tr>
<tr>
<td>nucleic acid</td>
<td>728</td>
</tr>
<tr>
<td>nucleotide</td>
<td>728</td>
</tr>
<tr>
<td>protein</td>
<td>724</td>
</tr>
</tbody>
</table>

**Main Idea**

Proteins, carbohydrates, lipids, and nucleic acids are large, organic molecules made by plants and animals.

- Proteins are large, organic polymers that form muscles, blood, and other body tissues.
- Carbohydrates contain carbon, hydrogen, and oxygen.
- Sugars and starches are carbohydrates that provide energy to your body.
- Lipids include fats and oils.
- DNA is a nucleic acid that is found in the cell nucleus.

**Review**

Vocabulary eGames
Use Vocabulary

Complete each statement with the correct term from the Study Guide.

27. **BIG Idea** __________ are most compounds that contain the element carbon.

28. Amino acids combine to form large organic polymers known as __________.

29. __________ is the nucleic acid that contains your genetic information.

30. A(n) __________ is a compound containing the benzene-ring structure.

31. Sugars and starches are part of the group of organic compounds called __________.

32. Fats and oils are part of the group of organic compounds called __________.

33. __________ are compounds with identical chemical formulas but different structures.

Check Concepts

34. How would you describe a benzene ring?
   A) rare
   B) stable
   C) unstable
   D) saturated

35. What are the small units that make up polymers called?
   A) monomers
   B) isomers
   C) plastics
   D) carbohydrates

36. What type of compound is hemoglobin?
   A) carbohydrate
   B) lipid
   C) nucleic acid
   D) protein

37. What type of compounds form the DNA molecule?
   A) amino acids
   B) nucleotides
   C) polymers
   D) carbohydrates

38. Glucose and fructose both have the formula C₆H₁₂O₆. What are such compounds called?
   A) amino acids
   B) alcohols
   C) isomers
   D) polymers

39. If a carbohydrate has 16 oxygen atoms, how many hydrogen atoms does it have?
   A) 4
   B) 8
   C) 16
   D) 32

40. **THEME FOCUS** Which crude oil fractions are collected at the top of a fractionating tower?
   A) high boiling point, few carbon atoms
   B) high boiling point, many carbon atoms
   C) low boiling point, few carbon atoms
   D) low boiling point, many carbon atoms

Interpret Graphics

41. Copy and complete the following concept map about types of hydrocarbons.
42. Write the chemical formula of each of these hydrocarbons, and identify which two are isomers.

43. Look at the fiber content of ten items of your clothing. Note the percentages of synthetic or natural fibers. Make a circle graph to compare the average percentages of natural and synthetic fibers. (Hint: cotton, linen, wool, and silk are natural fibers.)

44. Infer A healthy diet contains a variety of nutrients, including fats. However, saturated fats have some drawbacks. Based on this knowledge, how would you modify your diet to make it healthier? What general rule would you apply in making your choices?

45. Classify the following compounds as saturated, unsaturated, or substituted hydrocarbons: hexane (C6H14), isopropyl alcohol (C3H7OH), 2-chlorobutane (C4H9Cl), pentene (C5H10), and butyric acid (C3H7COOH).

46. Explain why the toughness and durability of many plastic polymers can be both an asset and a liability.

47. Describe how the structures of propyl alcohol and isopropyl alcohol might differ, although both have the formula C3H8O.

48. Draw a substituted hydrocarbon that has the following: six carbon atoms; single, double, and triple bonds; a hydroxyl group; and an amine group.

49. Solve One-Step Equations Although physicians disagree about what is a healthy level of blood cholesterol, many feel that levels above 200 mg/dL are harmful. A patient’s blood cholesterol level measured 228 mg/dL. After two months on a low-fat diet, it dropped to 210 mg/mL. By what percent did the patient’s cholesterol level decrease?

50. Use Percentages The label on a 500-mL bottle of vinegar states that it contains 6 percent acid by volume. How many milliliters of acid does this bottle contain?

51. Calculate Percent The U.S. Food and Drug Administration recommends a maximum intake of 65 g of fat per day. What percent of the daily fat allowance is a 30 g serving of potato chips?
Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

1. What atoms make up a hydrocarbon molecule?
   A. oxygen, carbon, and hydrogen  
   B. nitrogen and carbon  
   C. carbon and hydrogen  
   D. oxygen and hydrogen

2. What is the chemical formula of the compound shown above?
   A. C$_3$H$_3$  
   B. CH$_8$  
   C. C$_6$H$_6$  
   D. C$_3$H$_8$

3. What is the name of this compound?
   A. propane  
   B. heptane  
   C. isoprene  
   D. methane

4. Which of these contains carbon, hydrogen, and oxygen, and has twice as many hydrogen atoms as oxygen atoms?
   A. hydrocarbon  
   B. carbohydrate  
   C. alcohol  
   D. isomer

5. Which of the following is not a polymer derived from petroleum?
   A. polypropylene  
   B. acetylene  
   C. polyethylene  
   D. polystyrene

6. Which of the following is a type of recycling that breaks up the polymers into their original monomers?
   A. fractionation  
   B. depolymerization  
   C. isomerization  
   D. saturation

7. What is true of all three of these compounds?
   A. Their basic structural unit is a benzene ring.  
   B. They are inorganic compounds.  
   C. They are substituted hydrocarbons.  
   D. They are polymers.

8. Which of these compounds is an alcohol that is often obtained from corn?
   A. ethanol  
   B. acetic acid  
   C. tetrachloroethene  
   D. ethane

9. Which of these best shows the shape of the nucleic acid DNA?
   A.  
   B.  
   C.  
   D.
10. Describe the bonds between carbon atoms found in an organic compound.

Use the figure below to answer question 11.

11. These hydrocarbons are isomers. Write their chemical formulas.

12. Describe the general relationship between melting point, boiling point, and the amount of branching in an isomer.

13. Describe some properties and uses of alcohols.

14. Diagram the process used to separate petroleum compounds. On what physical property is this process based?

15. How are alcohols and organic acids similar? How are they different?

16. Describe useful properties of polymers. Name several objects made of polymer material that would likely have been made of wood or metal in the past.

17. Identify the polymer material used to make CD cases and foam drinking cups. Explain the processes used to make these two different products.

Use the figure below to answer question 18.

18. How is this a good representation of a protein? Describe the importance of proteins in the human body.

19. When you read or hear about cholesterol in the news, it is usually associated with negative effects on the heart and blood vessels. Why does the body make a substance that can potentially damage the circulatory system?

20. Plastic polymers are inexpensive, but they do not decompose readily in landfills. Describe two ways to solve this problem.