CHAPTER 13

The Chemistry of Hydrocarbons

Did you know that you have bark from a willow tree in your medicine cabinet at home? The model at the bottom right of the opposite page shows a compound that is found naturally in willow bark. This chemical is called salicin. It is a source of pain relief for moose, deer, and other animals that chew the bark. For thousands of years, Aboriginal people in Canada and around the world have relied on salicin's properties for the same pain-relieving purpose.

The model at the bottom left of the opposite page shows a close relative of salicin. Scientists made, or *synthesized,* this chemical near the end of the nineteenth century. It is called acetyl salicylic acid (ASA). You probably know it better by its brand name, Aspirin™.

Chemists refer to salicin, ASA, and more than ten million other chemicals like them as organic compounds. An **organic compound** is a molecular compound of carbon. Despite the tremendous diversity of organic compounds, nearly all of them share something in common. They are structured from a "backbone" that consists of just two kinds of atoms: carbon and hydrogen.

Compounds that are formed from carbon and hydrogen are called **hydrocarbons**. In this chapter, you will explore the sources, structures, properties, and uses of hydrocarbons—an enormous class of compounds. As well, you will learn how scientists and engineers use the properties of hydrocarbons to produce a seemingly infinite variety of chemicals and products.

How can just two elements, carbon and hydrogen, account for 90% of all the biological matter on Earth?

Chapter Preview

Concepts and Skills You Will Need

Review the following concepts and skills before you begin this chapter:

- identifying characteristics of covalently bonded compounds (Chapter 3, sections 3.1, 3.3, 3.4.)
- relating physical properties to the polarity of molecules and intermolecular forces (Chapter 3, section 3.3; Chapter 8, section 8.2)
- drawing Lewis structures and structural formulas (Chapter 3, sections 3.2, 3.3)

13.1 Introducing Organic Compounds

Section Preview/ Specific Expectations

In this section, you will

- **identify** the origins and major sources of hydrocarbons and other organic compounds
- **communicate** your understanding of the following terms: *organic compound*, *hydrocarbons*, *petroleum*

As stated in the chapter opener, an organic compound is a molecular compound of carbon. There are a few exceptions to this definition, however. For example, scientists classify oxides of carbon, such as carbon dioxide and carbon monoxide, as *in*organic. However, the vast majority of carbon-containing compounds are organic.

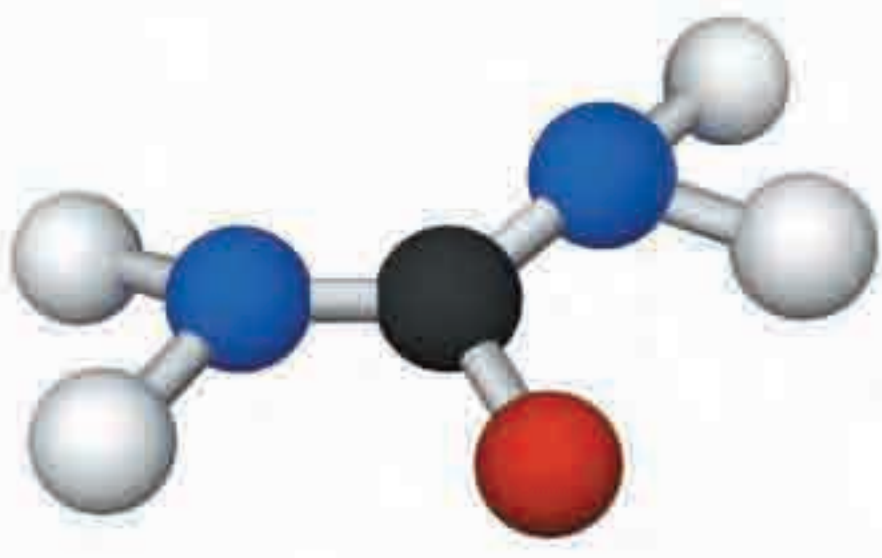
Organic Compounds: Natural and Synthetic

Organic compounds abound in the natural world. In fact, you probably ate sugar or starch at your last meal. Sugars, starches, and other carbohydrates are natural organic compounds. So are fats, proteins, and the enzymes that help you digest your food. Do you wear clothing made from wool, silk, or cotton? These are natural organic compounds, too. So are the molecules of DNA in the nuclei of your cells.

Until 1828, the only organic compounds on Earth were those that occur naturally. In that year, a German chemist named Friedrich Wohler synthesized urea—an organic compound found in mammal urine—from an inorganic compound, ammonium cyanate. (See Figure 13.1.) This was a startling achievement. Until then, chemists had assumed that only living or once-living organisms could be the source of organic compounds. They believed that living matter had an invisible "vital force." According to these early chemists, this vital (life) force made organic matter fundamentally different from inorganic (non-living) matter.

CHECKPOINT

Cyanides (containing carbon bonded to nitrogen, CN) and carbides, (such as calcium carbide, CaC_2) are compounds that contain carbon, but scientists classify them as inorganic. The same is true of carbonates, such as sodium hydrogen carbonate, $NaHCO_3$ (baking soda). Why are carbonate compounds inorganic, rather than organic, compounds?



Urea

Figure 13.1 When Friedrich Wohler (1800–1882) synthesized urea, he wrote a letter to his teacher. In his letter, he said, "I must tell you that I can make urea without the use of kidneys…Ammonium cyanate is urea." About 20 years earlier, Wohler's teacher, Jons Jakob Berzelius (1779–1848), had invented the system that distinguishes organic substances from inorganic substances.

Language LINK

Acetylsalicylic acid (ASA) was first produced commercially under the brand name Aspirin™ by Frederick Bayer and Company in 1897. The word "aspirin" comes from "a," for acetyl, and "spir," for spirea. *Spirea* is a genus of plants that is another natural source of salicylic acid.

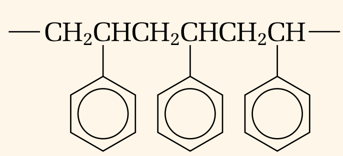
During the mid-1850s, chemists synthesized other organic compounds, such as methane and ethanol, from inorganic chemicals. Eventually chemists abandoned their vital-force ideas. We still use the terms "organic" and "inorganic," however, to distinguish carbon-based compounds from other compounds. For example, sugar is an organic compound since it is carbon based. Salt is inorganic since it contains no carbon.

During the last century, the number of synthetic (human-made) organic compounds has skyrocketed. Chemists invent more than 250 000 new synthetic organic chemicals *each year*. With almost endless variations in properties, chemists can synthesize organic compounds to make products as diverse as life-giving drugs, and toys. Nearly all medicines, such as painkillers, cough syrups, and antidepressants, are based on organic compounds. Perfumes, food flavourings, materials such as rubber and plastic, and fabrics such as nylon, rayon, and polyester are all organic compounds as well.

The next ExpressLab gives you a chance to make one such product. It is up to you to decide what purpose it could have.

ExpressLab: Making Polymer Putty

Polymers are a fundamental part of your life. They also happen to be organic. *Polymers* are long molecular chains that are made up of smaller molecular units called monomers. Natural polymers include cellulose (the "fibre" in your food) and DNA. Synthetic polymers include plastics, polystyrene (see below), and the material you will produce in this activity.



Polystyrene is an example of a polymer.

Safety Precautions

Avoid inhaling the powdered borax. It may cause an allergic reaction. Wash your hands after working with the putty.

Procedure

1. Measure about 45 mL of white glue into a 250 mL beaker. Add an equal amount of warm water and a few drops of food colouring.
2. Measure 15 mL of solid borax into another 250 mL beaker. Add 60 mL of warm water. Stir for about 2 min. **Note:** You may find that not all of the solid borax dissolves. This is all right.
3. Pour 30 mL of the borax solution into the glue mixture. Then quickly and thoroughly stir the mixture.
4. Remove the material from the beaker, and "experiment" with it. Here are a few suggestions. Record your observations.
   - Hold the putty in one hand. Put your other hand below the putty, and let the putty slowly ooze into it.
   - Pull the putty apart slowly.
   - Pull the putty apart quickly.
   - Try bouncing the putty.
5. If time permits, you may wish to try changing the ratio of borax to glue to water. Test your results.
6. Dispose of any excess borax solution as directed by your teacher.

Analysis

1. Compare the properties of the starting materials with the properties of the product. Is the putty a solid or a liquid? Explain.
2. What practical applications for this product can you think of?

COURSE CHALLENGE

Why does society depend on fossil fuels? What are they used for? In the Course Challenge at the end of this book, you will investigate a different type of fossil fuel from an imaginary planet.

The Origins of Hydrocarbons and Other Organic Compounds

Most hydrocarbons and other organic compounds have their origins deep below Earth's present surface. In the past, as now, photosynthetic organisms used energy from the Sun to convert carbon dioxide and water into oxygen and carbohydrates, such as sugars, starches, and cellulose. When these organisms died, they settled to the bottom of lakes, rivers, and ocean beds, along with other organic matter. Bacterial activity removed most of the oxygen and nitrogen from the organic matter, leaving behind mainly hydrogen and carbon.

Over time, the organic matter was covered with layers of mud and sediments. As layer upon layer built up, heat and tremendous pressure transformed the sediments into shale and the organic matter into solid, liquid, and gaseous materials. These materials are the fossil fuels—coal, oil, and natural gas—that society depends on today. (See Figure 13.2.)

Canadians in Chemistry

Dr. Raymond Lemieux

Raymond Lemieux was born into a carpenter's family in 1920 at Lac La Biche, Alberta. He obtained a B.Sc. degree at the University of Alberta and a Ph.D. at McGill University in Montréal. Lemieux then worked briefly at Ohio State University, where he met Dr. Virginia McConaghie. They were married and soon moved to Saskatoon, Saskatchewan. There Lemieux became a senior researcher at a National Research Council (NRC) laboratory.

Raymond Lemieux (1920–2000)

In 1953, while at the NRC lab, Lemieux conquered what some have called "the Mount Everest of organic chemistry." He became the first person to completely synthesize sucrose, or table sugar. Sucrose is a carbohydrate with the chemical formula $C_{12}H_{22}O_{11}$. It is the main sugar in the sap of plants such as sugar beets and sugar cane. Sucrose is related to glucose, $C_6H_{12}O_6$, and other sugars.

Lemieux continued his research at the University of Ottawa, and then at the University of Alberta in Edmonton. He was especially interested in how molecules "recognize" each other and interact in the human body. For example, different blood groups, such as group A and group B, are determined by carbohydrate molecules that differ by only a single sugar. The body is able to recognize these specific sugars and adapt its response to foreign substances, such as bacteria and transplanted organs.

Since it was hard to obtain natural samples of the body sugars that Lemieux wanted to study, he found ways to synthesize them. This was groundbreaking research. Seeing the practical applications of his research, Lemieux was instrumental in starting several chemical companies. Today these companies make products such as antibiotics, blood-group determinants, and immunizing agents that are specific to various human blood groups. They also make complex carbohydrates that absorb antibodies from the blood in order to prevent organ transplant rejection.

Lemieux and his wife had six children and a number of grandchildren. With all that he had accomplished in life, Lemieux said, "My proudest achievement is my family." His autobiography, titled *Explorations with Sugar: How Sweet It Was*, was published in 1990.

Origin of Fossil Fuels

- **Coal** is formed mainly from the remains of land-based plants.
- **Petroleum (crude oil)** is formed mainly from the remains of marine-based microscopic plants, plant-like organisms, and animal-like organisms.
- **Natural gas** may form under the same conditions as petroleum.

Figure 13.2 **Ancient eras that had higher carbon dioxide concentrations, as well as warmer climates, gave rise to abundant plant and animal life on land and under water. Over time, as these organisms died, the organic substances that made up their bodies were chemically transformed into the materials known today as fossil fuels.**

Sources of Hydrocarbons

Sources of hydrocarbons include wood, the products that result from the fermentation of plants, and fossil fuels. However, one fossil fuel—petroleum—is the main source of the hydrocarbons that are used for fuels and many other products, such as plastics and synthetic fabrics.

Petroleum, sometimes referred to as crude oil, is a complex mixture of solid, liquid, and gaseous hydrocarbons. To understand the importance of petroleum in our society, you need to become better acquainted with hydrocarbons. Your introduction begins, in the next section, with carbon—one of the most versatile elements on Earth.

Geology LINK

The origin of fossil fuels, depicted in Figure 13.2, is based on a theory called the *biogenic theory*. Most geologists accept this theory. A small minority of geologists have proposed an alternative theory, called the *abiogenic theory*. Use print and electronic resources to investigate the following:

- the main points of each theory, and the evidence used to support these points
- the reasons why one theory is favoured over the other

Record your findings in the form of a brief report. Include your own assessment of the two theories.

Section Review

1 (a) K/U Name three compounds that you know are organic.
  (b) K/U Name three compounds that you know are inorganic.
  (c) K/U Name three compounds that may be organic, but you do not know for sure.

2 K/U What are the origins of hydrocarbons and other organic compounds?

3 K/U Identify at least two sources of hydrocarbons and other organic compounds.

4 C Design a concept map (or another kind of graphic organizer) to show the meanings of the following terms and the relationships among them: organic compound, inorganic compound, hydrocarbon, fossil fuels, petroleum, natural gas.

5 K/U Copy the following compounds into your notebook. Identify each carbon as organic or inorganic, and give reasons for your answer. If you are not sure whether a compound is organic or inorganic, put a question mark beside it.

(a) CH_4	(c) CO_2	(e) C_6H_6	(g) CH_3COOH
(b) CH_3OH	(d) HCN	(f) NH_4SCN	(h) $CaCO_3$

13.2 Representing Hydrocarbon Compounds

Section Preview/ Specific Expectations

In this section, you will

- **demonstrate** an understanding of the bonding characteristics of the carbon atom in hydrocarbons
- **draw** structural representations of aliphatic hydrocarbon molecules
- **demonstrate** the arrangement of atoms in isomers of hydrocarbons using molecular models
- **communicate** your understanding of the following terms: *expanded molecular formula, isomers, structural model, structural diagram*

Examine the three substances in Figure 13.3. It is hard to believe that they have much in common. Yet each substance is composed entirely of carbon atoms. Why does the carbon atom lead to such diversity in structure? Why do carbon compounds outnumber all other compounds so dramatically? The answers lie in carbon's atomic structure and behaviour.

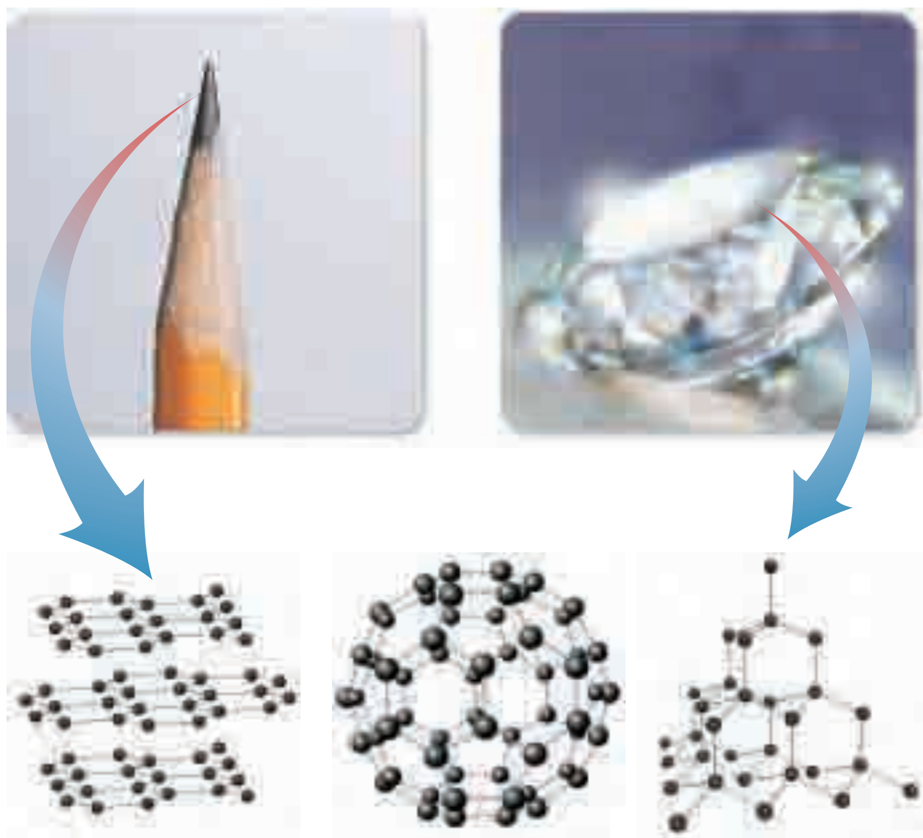


Figure 13.3 Each of these substances is pure carbon. What makes carbon a "chemical chameleon?"

Figure 13.4 outlines three key properties of carbon. Throughout this section and the next, you will explore the consequences of each of these properties.

Properties of Carbon

- **Carbon has four bonding electrons.** This electron structure enables carbon to form four strong covalent bonds. As a result, carbon may bond to itself, as well as to many different elements (mainly hydrogen, oxygen, and nitrogen, but also phosphorus, sulfur, and halogens such as chlorine).
- **Carbon can form strong single, double, and triple bonds with itself.** This allows carbon to form long chains of atoms—something that very few other atoms can do. In addition, the resulting compounds are fairly stable under standard conditions of temperature and pressure.
- **Carbon atoms can bond together to form a variety of geometrical structures.** These structures include straight chains, branched chains, rings, sheets, tubes, and spheres. No other atom can do this.

Figure 13.4 Three key properties of carbon

Representing Structures and Bonding

You have written chemical formulas for inorganic compounds such as ammonia, NH_3, and calcium carbonate, $CaCO_3$. As well, you have represented these compounds using Lewis diagrams, and perhaps other models. Such compounds are fairly small, so they are easy to represent using these methods. Many organic compounds—such as methane, CH_4, and ethanol, C_2H_6O—are also fairly small. With patience, you might even figure out how to draw a Lewis diagram for cholesterol, $C_{27}H_{46}O$! Most hydrocarbons and other organic compounds are quite large, however. They are also structurally complex. Therefore chemists have devised other methods to represent them, as explained below.

Using Expanded Molecular Formulas to Represent Hydrocarbons

One method that chemists use to represent a large molecule is the **expanded molecular formula**. This type of formula shows the groupings of atoms, and it often gives an idea of molecular structure. For example, the chemical formula for propane is C_3H_8. This formula tells you that propane contains three carbon atoms and eight hydrogen atoms. It gives no clue, though, about the way in which the atoms are bonded together.

Propane's expanded molecular formula is $CH_3CH_2CH_3$. As you can see from this formula, the expanded molecular formula gives a clearer idea of atomic arrangement. It implies that a CH_3 group is attached to a CH_2 group, which is attached to another CH_3 group.

Writing expanded molecular formulas becomes more helpful when you are dealing with larger hydrocarbons. For example, C_6H_{14} is a component of gasoline. It is also used as a solvent for extracting oils from soybeans and other edible oil seeds. Depending on how the carbon and hydrogen atoms are bonded together, C_6H_{14} can have any of the five structural arrangements shown in Figure 13.5. Each arrangement has a different name.

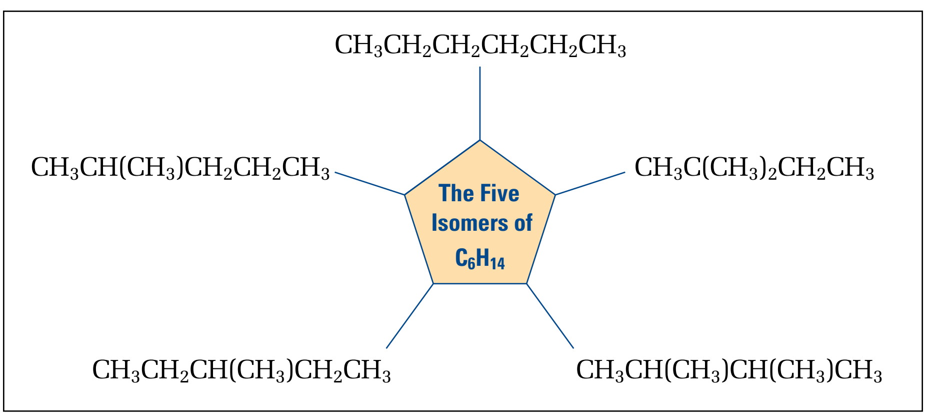


Figure 13.5 **Expanded molecular formulas for five structural arrangements of C_6H_{14}**

Keep in mind that all five of these arrangements have the same chemical formula: C_6H_{14}. Compounds that have the same formula, but different structural arrangements, are called **isomers**. Hexane, for example, is one isomer of C_6H_{14}. You will learn more about isomers as you study this chapter.

Math LINK

Graph the data in the table below. **Note:** Bond energy is the amount of energy that is needed to break a chemical bond.

Some Average Bond Energies

Bond	Bond energy (kJ/mol)
C—C	346
C═C	610
C≡C	835
Si—Si	226
Si═Si	318 (estimate)
C—H	413
Si—H	318

Infer a relationship between the stability of a compound and bond energy. Then suggest a reason why there are many more carbon-based compounds than silicon-based compounds.

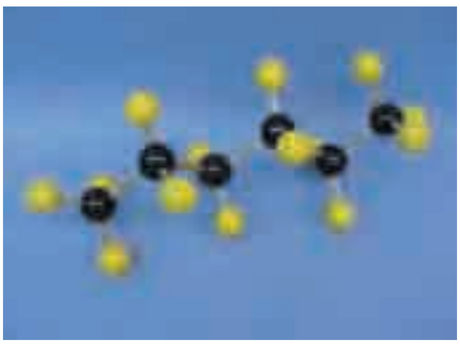
CHEM FACT

The number of isomers of an organic compound increases greatly as the number of carbon atoms increases. For example, C_5H_{12} has three isomers, C_6H_{14} has five isomers, and C_8H_{18} has 18 isomers. $C_{30}H_{62}$, a large hydrocarbon, has over four billion isomers!

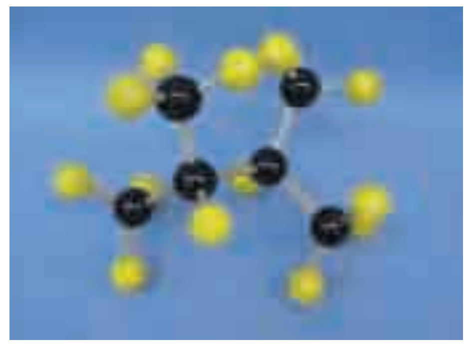
The expanded molecular formulas of C_6H_{14} give you a better idea of the arrangement of the carbon and hydrogen atoms in its five possible isomers. You can use other methods as well, however, to represent hydrocarbons and other organic compounds. These methods are outlined below.

Using Structural Models to Represent Hydrocarbons

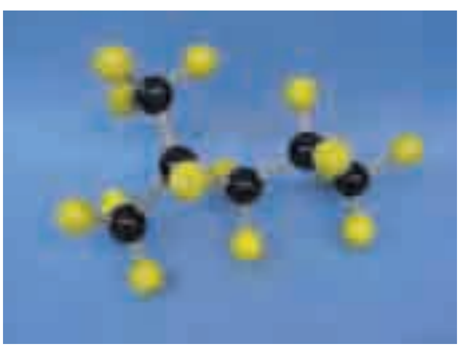
A **structural model** is a three-dimensional representation of the structure of a compound. There are two kinds of structural models: *ball-and-stick models* and *space-filling models*. Figure 13.6 shows ball-and-stick models for the five isomers of C_6H_{14}. Notice that they show how the carbon and hydrogen atoms are bonded within the structures.



$CH_3CH_2CH_2CH_2CH_2CH_3$



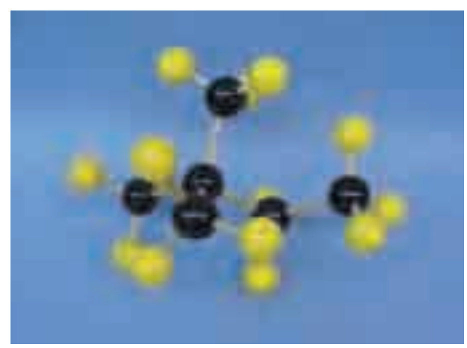
$CH_3CH(CH_3)CH(CH_3)CH_3$



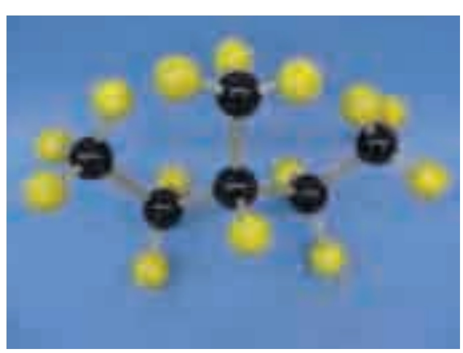
$CH_3CH(CH_3)CH_2CH_2CH_3$

The Five Isomers of

C_6H_{14}



$CH_3C(CH_3)_2CH_2CH_3$



$CH_3CH_2CH(CH_3)CH_2CH_3$

Figure 13.6 C_6H_{14} can have any one of these five structural arrangements. How do the ball-and-stick models compare with the expanded molecular formulas for C_6H_{14}? How does each isomer differ from the rest?

A space-filling model, such as the one in Figure 13.7, also shows the arrangement of the atoms in a compound. As well, it represents the molecular shape and the amount of space that each atom occupies within the structure.

Electronic Learning Partner

To see an animation comparing structural diagrams with molecular formulas, go to your Chemistry 11 Electronic Partner now.

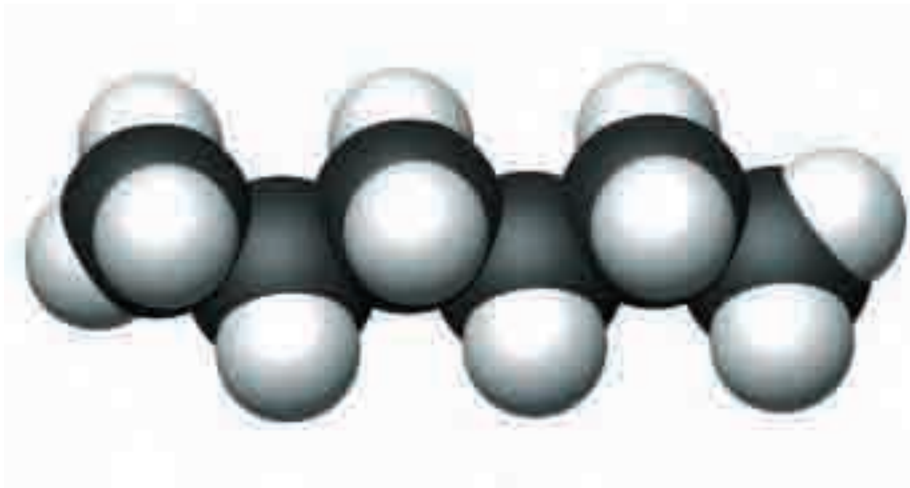
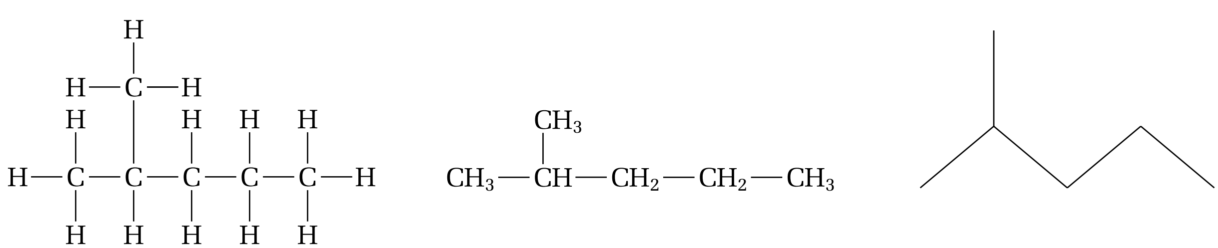


Figure 13.7 A space-filling model for hexane, one of the isomers of C_6H_{14}

Using Structural Diagrams to Represent Hydrocarbons

A **structural diagram** is a two-dimensional representation of the structure of a compound. (In some chemistry textbooks, structural diagrams are called structural formulas.) There are three kinds of structural diagrams: *complete structural diagrams*, *condensed structural diagrams*, and *line structural diagrams*. As you can see in Figure 13.8, each serves a specific purpose in describing the structure of a compound.

In the next investigation, you will have an opportunity to make your own models of the isomers of several organic compounds.



A **complete structural diagram** shows all the atoms in a structure and the way they are bonded to one another. Straight lines represent the bonds between the atoms.

A **condensed structural diagram** simplifies the presentation of the structure. It shows the bonds between the carbon atoms but not the bonds between the carbon and hydrogen atoms. Chemists assume that these bonds are present. Notice how much cleaner and clearer this diagram is, compared with the complete structural diagram.

A **line structural diagram** is even simpler than a condensed structural diagram. The end of each line, and the points at which the lines meet, represent carbon atoms. This kind of diagram gives you a sense of the three-dimensional nature of a hydrocarbon. **Note:** Line structural diagrams are used only for hydrocarbons, not for other organic compounds.

Figure 13.8 Comparing complete, condensed, and line structural diagrams

SKILL FOCUS

Predicting

Analyzing and interpreting

Communicating results

Modelling concepts

Investigation 13-A

Modelling Organic Compounds

Figure 13.6 showed you that an organic compound can be arranged in different structural shapes, called isomers. All the isomers of a compound have the same molecular formula. In this investigation, you will make two-dimensional and three-dimensional models of isomers. Your models will help you explore the arrangements of the atoms in organic compounds.

Question

How do models help you visualize the isomers of organic compounds?

Predictions

Predict the complete, condensed, and line structural diagrams for the three isomers of C_5H_{12}. Then predict the complete and condensed structural diagrams for the four isomers of C_3H_9N.

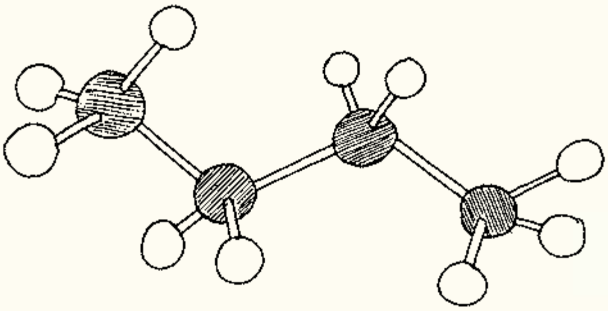
Materials

paper and pencil
molecular modelling kit

These representations of the hydrocarbon ethane, C_2H_6, were made using different modelling kits. Your school may have one or more of these kits available.

Procedure

1. Construct three-dimensional models of the three isomers of C_5H_{12}. Use your predictions to help you. As you complete each model, draw a careful diagram of the structure. Your diagram might be similar to the one below.



2. Repeat step 1 for each isomer of C_3H_9N.

Analysis

1. In what ways were your completed models similar to your predictions? In what ways were they different?
2. How do the models of each compound help you understand the concept of isomers?

Conclusion

3. How accurately do you think your models represent the real-life structural arrangements of C_5H_{12} and C_3H_9N?

Applications

4. In earlier units, you considered how the structure and polarity of molecules can affect the boiling point of a compound. For each compound you studied in this investigation, predict which isomer has the higher boiling point. Explain your prediction.
5. Construct models for C_7H_{16}. How many isomers are possible?

Section Wrap-up

The names of the isomers of hydrocarbons and other organic compounds are quite different from the names of inorganic compounds. For example, go back to the structural diagrams shown in Figure 13.8. They all represent the same isomer of C_6H_{14}. Its name is 2-methylpentane. Now look at Figure 13.9. It shows the names and condensed structural diagrams for the four other isomers of C_6H_{14}. Why do these names look so different from the names of inorganic compounds? Scientists have devised a systematic way to communicate all the possible atoms and structures for each organic compound—all in its name! In the next section, you will learn the rules for naming hydrocarbons. You will also learn how to interpret the information that hydrocarbon names communicate.

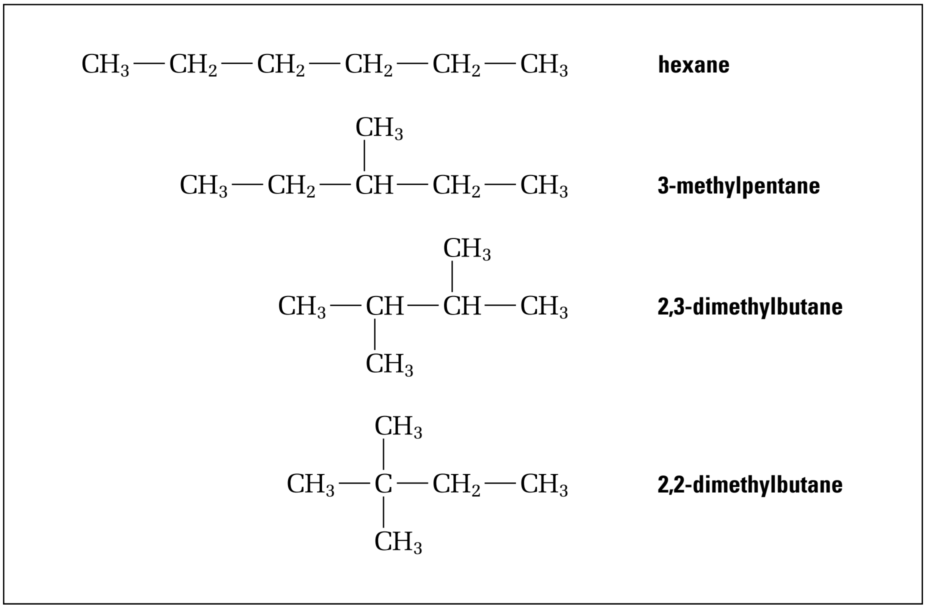
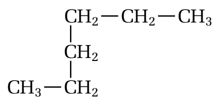


Figure 13.9 Four of the five isomers of C_6H_{14}

CHEM FACT

When is an isomer not an isomer? When it is *exactly* the same compound! The hydrocarbon C_6H_{14} has only five isomers. Examine these two representations for one of them, hexane.

$CH_3-CH_2-CH_2-CH_2-CH_2-CH_3$



You might think that these are different isomers, but they are actually the same. The structure on the bottom is just a bent version of the structure on the top. Think about a length of chain. You can lay it out straight, or you can bend it. The chain is still a chain in either case. It just looks different. Naming a compound helps you recognize the difference between a true isomer and a structure that just looks like an isomer.

Section Review

1. K/U Identify the three properties of carbon that allow it to form such a great variety of compounds.
2. I Chose one of the hydrocarbon molecules in this section to represent, using as many different kinds of models as you can. Identify each model you used.
3. C You have seen the expanded molecular formulas and condensed structural diagrams for the five isomers of C_6H_{14}. Draw the complete and line structural diagrams for each of these isomers.
4. C Draw the complete, condensed, and line structural diagrams for the isomers of C_5H_{12}. How many *true* isomers did you draw? (See the ChemFact above to help you interpret this question.)
5. C Many organic compounds contain elements such as oxygen, nitrogen, and sulfur, as well as carbon and hydrogen. For example, think about ethanol, CH_3CH_2OH. Draw complete and condensed structural diagrams for ethanol. Can you draw a line structural diagram for ethanol? Explain your answer.

13.3 Classifying Hydrocarbons

Section Preview/ Specific Expectations

In this section, you will

- **demonstrate** an understanding of the carbon atom by classifying hydrocarbons and by analyzing the bonds that carbon forms in aliphatic hydrocarbons
- **name** alkanes, alkenes, and alkynes, and **draw** structural representations for them
- **describe** some of the physical and chemical properties of hydrocarbons
- **determine** through experimentation some of the characteristic properties of saturated and unsaturated hydrocarbons
- **communicate** your understanding of the following terms: *alkanes, aliphatic hydrocarbons, saturated hydrocarbons, homologous series, alkenes, unsaturated hydrocarbons, cis-trans isomer, alkynes, cyclic hydrocarbons*

Chemists group hydrocarbons and other organic compounds into the categories shown in Figure 13.10. The International Union of Pure and Applied Chemistry (IUPAC) has developed a comprehensive set of rules for naming the compounds within each category. Using these rules, you will be able to classify and name all the hydrocarbon compounds that you will encounter in this unit.

The names that are based on the IUPAC rules are called *systematic names*. During your study of organic chemistry, you will also run across many common names for organic compounds. For example, the systematic name for the organic acid CH_3CO_2H is ethanoic acid. You are probably more familiar with its common name: vinegar.

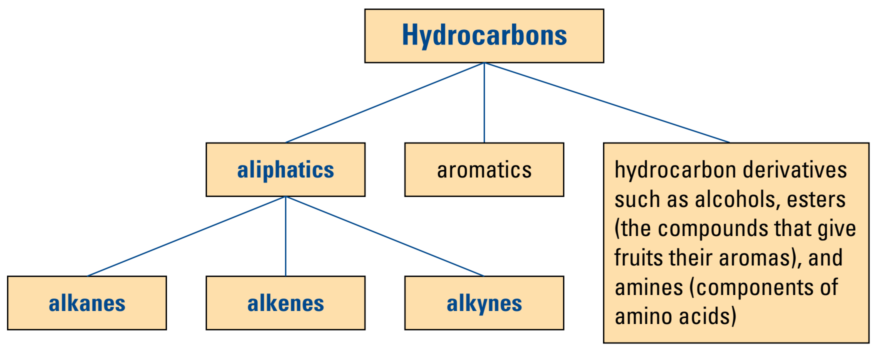


Figure 13.10 **This concept map illustrates a system for classifying organic compounds. In this chapter, you will explore only part of the family of organic compounds—the aliphatic hydrocarbons shown by the boldface type.**

Alkanes

Alkanes are hydrocarbon molecules that are joined by *single* covalent bonds. They are the simplest hydrocarbons. Methane, CH_4, is the simplest alkane. It is the main component of natural gas. Alkanes are **aliphatic hydrocarbons:** organic compounds in which carbon atoms form chains and non-aromatic rings.

Figure 13.11 on the next page compares the structural formulas of methane and the next three members of the alkane family. Notice three facts about these alkanes:

1. Each carbon atom is bonded to the maximum possible number of atoms (either carbon or hydrogen atoms). As a result, chemists refer to alkanes as **saturated hydrocarbons**.
2. Each molecule differs from the next molecule by the structural unit $–CH_2–$. A series of molecules like this, in which each member increases by the same structural unit, is called a **homologous series**.
3. A mathematical pattern underlies the number of carbon and hydrogen atoms in each alkane. All alkanes have the general formula C_nH_{2n+2}, where n is the number of carbon atoms. For example, propane has 3 carbon atoms. Using the general formula, we find that

$$2n + 2 = 2(3) + 2 = 8$$

Thus propane should have the formula C_3H_8, which it does.

Language LINK

The name "aliphatic" comes from the Greek word *aleiphatos*, meaning "fat." Early chemists found these compounds to be less dense than water and insoluble in water, like fats. "Aliphatic" now refers to the classes of hydrocarbons called alkanes, alkenes, and alkynes.

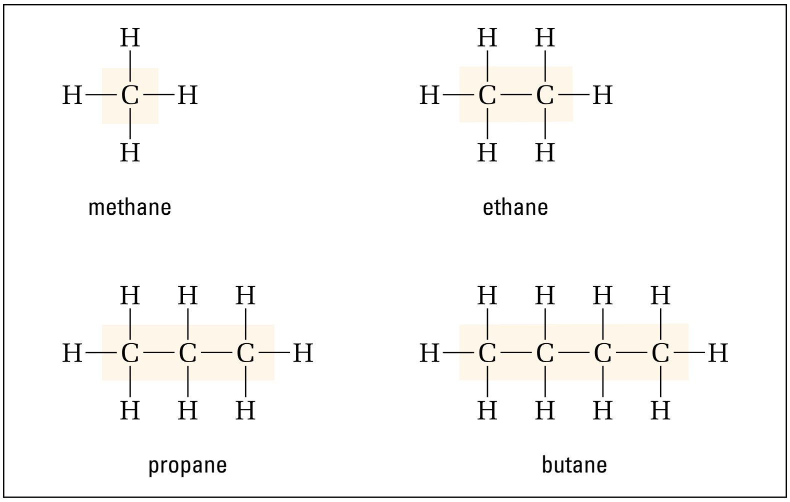


Figure 13.11 **Carefully examine these four molecules. They are the first four alkanes. In what ways are they similar? In what ways are they different?**

CHECKPOINT

Why is methane the simplest of all the millions of hydrocarbons? **Hint:** Recall what you know about chemical bonding and the common valences of elements.

Figure 13.12 illustrates these three important facts about alkanes. Study the two alkanes, then complete the Practice Problems that follow.

$CH_3—CH_3$ + -$\mathbf{CH_2}$- → $CH_3—\mathbf{CH_2}—CH_3$

ethane **propane**

Figure 13.12 **How are these two alkanes similar? How are they different? Use the ideas and terms you have just learned to help you answer these questions.**

Practice Problems

1. Heptane has 7 carbon atoms. What is the chemical formula of heptane?
2. Nonane has 9 carbon atoms. What is its chemical formula?
3. An alkane has 4 carbon atoms. How many hydrogen atoms does it have?
4. Candle wax contains an alkane with 52 hydrogen atoms. How many carbon atoms does this alkane have?

Properties of Alkanes

Alkanes (and all other aliphatic compounds) have an important physical property. They are non-polar. As you know from Chapter 8, non-polar molecules have fairly weak intermolecular forces. As a result, hydrocarbons such as alkanes have relatively low boiling points. As the number of atoms in the hydrocarbon molecule increases, the boiling point increases. Because of this, alkanes exist in a range of states under standard conditions.

Table 13.1 compares the sizes (number of atoms per molecule) and boiling points of alkanes. Notice how the state changes as the size increases.

Table 13.1 Comparing the Sizes and Boiling Points of Alkanes

Size (number of atoms per molecule)	Boiling point range (°C)	Examples of products
1 to 5	below 30	gases: used for fuels to cook and heat homes
5 to 16	30 to 275	liquids: used for automotive, diesel, and jet engine fuels; also used as raw materials for the petrochemical industry
16 to 22	over 250	heavy liquids: used for oil furnaces and lubricating oils; also used as raw materials to break down more complex hydrocarbons into smaller molecules
over 18	over 400	semi-solids: used for lubricating greases and paraffin waxes to make candles, waxed paper, and cosmetics
over 26	over 500	solid residues: used for asphalts and tars in the paving and roofing industries

CHECKPOINT

Many industries rely on alkane hydrocarbons. The states of these hydrocarbons can affect how they are stored at industrial sites. For example, methane is a gas under standard conditions. In what state would you expect a large quantity of methane to be stored? What safety precautions would be necessary?

Naming Alkanes

The IUPAC system for naming organic compounds is very logical and thorough. The rules for naming alkanes are the basis for naming the other organic compounds that you will study. Therefore it is important that you understand how to name alkanes.

Naming Straight-Chain Alkanes

Recall that carbon can bond to form long, continuous, chain-like structures. Alkanes that bond in this way are called *straight-chain alkanes*. (They are also called *unbranched alkanes*.) Straight-chain alkanes are the simplest alkanes. Table 13.2 lists the names of the first ten straight-chain alkanes.

Table 13.2 The First Ten Straight-Chain Alkanes

Name	Number of carbon atoms	Expanded molecular formula
methane	1	CH_4
ethane	2	CH_3CH_3
propane	3	$CH_3CH_2CH_3$
butane	4	$CH_3(CH_2)_2CH_3$
pentane	5	$CH_3(CH_2)_3CH_3$
hexane	6	$CH_3(CH_2)_4CH_3$
heptane	7	$CH_3(CH_2)_5CH_3$
octane	8	$CH_3(CH_2)_6CH_3$
nonane	9	$CH_3(CH_2)_7CH_3$
decane	10	$CH_3(CH_2)_8CH_3$

The root of each name (highlighted in colour) serves an important function. It tells you the number of carbon atoms in the chain. The suffix -ane tells you that these compounds are alkane hydrocarbons. Thus the root and the suffix of one of these simple names provide the complete structural story of the compound.

Naming Branched-Chain Alkanes

The naming rules for straight-chain alkanes can, with a few additions, help you recognize and name other organic compounds. You now know that the name of a straight-chain alkane is composed of a root (such as meth-) plus a suffix (-ane). Earlier in the chapter, you saw the isomers of C_6H_{14}. Figure 13.13 shows one of them, called 2-methylpentane.

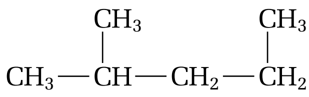


Figure 13.13 **2-methylpentane**

Notice four important facts about 2-methylpentane:

1. Its structure is different from the structure of a straight-chain alkane. Like many hydrocarbons, this isomer of C_6H_{14} has a branch-like structure. Alkanes such as 2-methylpentane are called *branched-chain alkanes*. (The branch is sometimes called a *side-chain*.)
2. The name of this alkane has a prefix (2-methyl-) as well as a root and a suffix. Many of the hydrocarbons you will name from now on have a prefix.
3. This alkane has a single CH_3 unit that branches off from the main (parent) chain of the compound.
4. There is another CH_3 unit bonded to a CH_2 unit at the right end of the chain. *This is not another branch*. It is a bend in the parent chain. Before continuing, refer to the ChemFact on page 543. Make sure that you understand why the CH_3 unit is not another branch.

Rules for Naming Alkanes

The names of branched-chain alkanes (and most other aliphatic compounds) have the same general format, as shown in Figure 13.14. This format will become clearer as you learn and practise the rules for naming hydrocarbons. To start, read the steps on the next page to see how 2-methylpentane gets its name.

2-methylpentane is a simple example of a branched hydrocarbon. Later you will see more complicated examples.

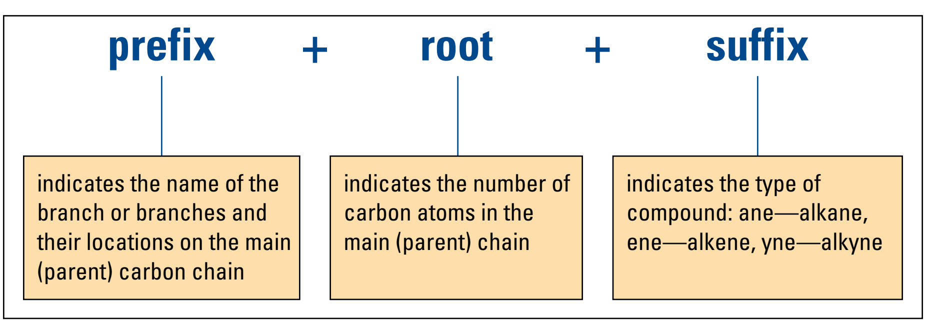


Figure 13.14 **Parts of a hydrocarbon name**

CHECKPOINT

The root and the suffix of an alkane name do not tell you directly about the number of hydrogen atoms in the compound. If you did not know the molecular formula of heptane, for example, how would you still know that heptane contains 16 hydrogen atoms?

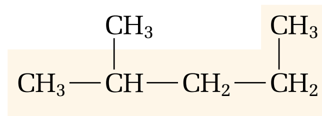
Language LINK

You are probably familiar with the origins of some of the roots that are used for naming organic compounds, especially the roots for naming alkanes with five or more carbons. The roots for the first four alkanes may be unfamiliar, however. Use a comprehensive dictionary (one that gives information about word origins) to find out the meanings of the roots meth- through dec-.

Naming 2-Methylpentane

Step 1

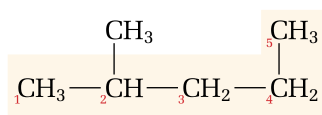
Find the longest continuous chain (the parent chain). It does not have to be straight. The number of carbons in the parent chain forms the root of the name.



- The parent chain for 2-methylpentane is not straight. It is bent.
- There are five carbons in the longest chain, as highlighted. Therefore the root of the name is -pent-.
- Since the compound contains only single carbon-carbon bonds, the suffix of the name is -ane.
- So far, then, you have pentane as part of the name.

Step 2

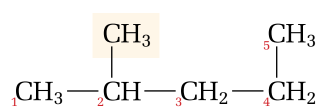
Identify any branches that are present. Then number the main chain from the end that gives the lowest number to the first location at which branching occurs.



- There is only one branch here. Since the branch is closer to the left end of the molecule, you number the carbon at the left end "1." Then you number the other main chain carbons consecutively.

Step 3

Identify the location of any branches with numbers. Use the number of carbons in each branch to name it.



- You name a branch based on the appropriate root name for the number of carbons it contains. You change the ending to –yl, however. (IUPAC rules identify branches by using the -yl ending.)
- Here there is only one carbon. Instead of calling the branch methane, you replace the -ane ending with -yl. So the name for this branch is methyl.
- You also give the branch name a number. The number indicates which carbon in the main chain it is bonded with. Here the branch is bonded with the number 2 carbon in the main chain. So the numeral 2 is added to the prefix.
- You now have the full prefix name for the compound: 2-methyl.

Step 4

Put the complete compound name together in this general form: prefix + root + suffix. The name of the compound is 2-methyl + pent + ane = 2-methylpentane.

The structure of an alkane can be much more complex than the structure of 2-methylpentane. For instance, there can be many branches bonded to the main chain, and the branches can be quite long. As a result, you need to know several other IUPAC rules for naming branched-chain alkanes and other aliphatic compounds.

Additional IUPAC Rules for Naming Branched-Chain Alkanes and Other Aliphatic Compounds

1. If there are two or more of the same type of branch, give each branch a position number. Also, use multiplying prefixes such as di- (meaning 2), tri- (meaning 3), and tetra- (meaning 4) to indicate the number of branches.

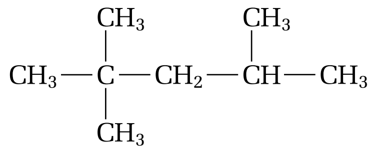


Figure 13.15 **This compound is 2,2,4-trimethylpentane, an isomer of C_8H_{18}. It is one of the main ingredients in gasoline.**

2. Put commas between numbers, and hyphens between numbers and letters.

3. When possible, put numbers in ascending order. (For example, the compound in Figure 13.15 compound is 2,2,4-trimethylpentane, not 4,2,2-trimethylpentane.)

4. If there is more than one type of branch, name the branches in alphabetical order. Determine the alphabetical order by using the first letter of the root (for example, -methyl-or-ethyl-), not the multiplying prefix (for example, di- or tri-).

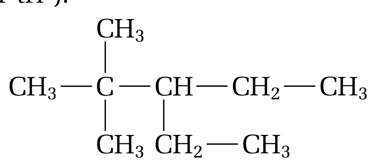


Figure 13.16 **3-ethyl-2,2-dimethylpentane**

5. If more than one chain could be the main chain (because they are the same length), choose the chain that has the most branches attached.

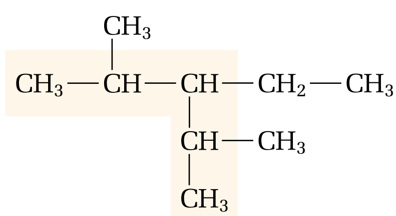


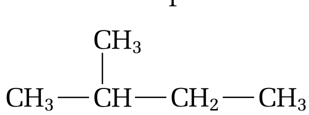
Figure 13.17 **3-ethyl-2,4-dimethylpentane**

Now practise naming the compounds in the Practice Problem below. Work slowly and patiently. The names become more challenging as you proceed.

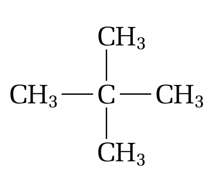
Practice Problems

5. Name each compound.

(a)



(b)



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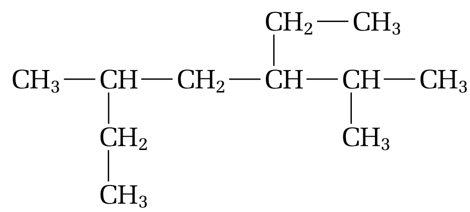
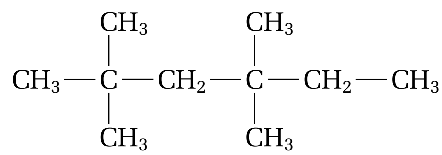
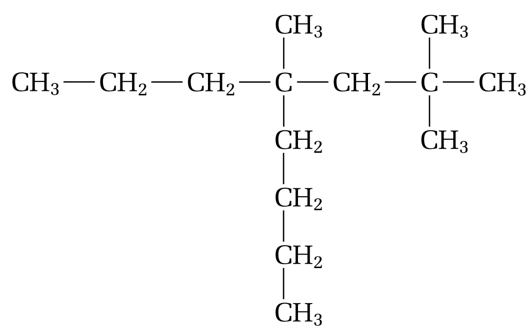
(c)



(d)



(e)



Drawing Alkanes

As you learned earlier in this chapter, three kinds of diagrams can be used to represent the structure of a hydrocarbon. The easiest kind is probably the condensed structural diagram. When you are asked to draw a condensed structural diagram for an alkane, such as 2,3-dimethylhexane, you can follow several simple rules. These rules are listed below. After you have studied the rules, use the Practice Problems to practise your alkane-drawing skills.

Rules for Drawing Condensed Structural Diagrams

1. Identify the root and the suffix of the name. In 2,3-dimethylhexane, for example, the root and suffix are -hexane. The *-hex-* tells you that there are six carbons in the main chain. The *-ane* tells you that the compound is an alkane. Therefore this compound has single carbon-carbon bonds only.
2. Draw the main chain first. Draw it straight, to avoid mistakes caused by a fancy shape. Do not include any hydrogen atoms. You will need to add branches before you finalize the number of hydrogen atoms on each carbon. Leave space beside each carbon on the main chain to write the number of hydrogen atoms later.

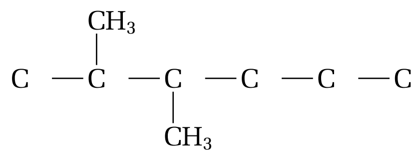
$$C - C - C - C - C - C$$

3. Choose one end of your carbon chain to be carbon number 1. Then locate the carbon atoms to which the branches must be added. Add the appropriate number and size of branches, according to the prefix in the name of the compound. In this example, *2,3-dimethyl* tells you that there is one methyl (single carbon-containing) branch on the second

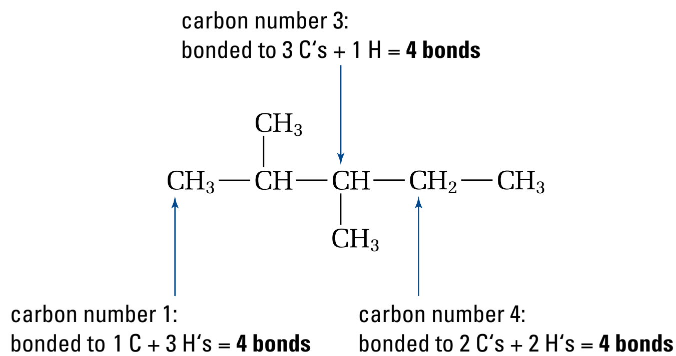
CHEM FACT

You have learned how the non-polar nature of alkanes affects their boiling point. This non-polarity also affects another physical property: the solubility of alkanes in water. For example, the solubility of pentane in water is only 5.0×10^{-3} mol/L at 25°C. Hydrocarbon compounds, such as those found in crude oil, do not dissolve in water. Instead they float on the surface. This physical property helps clean-up crews minimize the devastating effects of an oil spill.

carbon of the main chain, and another methyl branch on the third carbon of the main chain. It does not matter whether you place both branches above the main chain, both below, or one above and one below. The compound will still be the same.



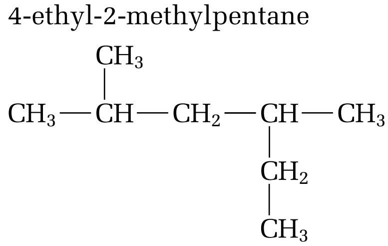
4. Finish drawing your diagram by adding the appropriate number of hydrogen atoms beside each carbon. Remember that each carbon has a valence of four. So if a carbon atom has one other carbon atom bonded to it, you need to add three hydrogen atoms. If a carbon atom has two other carbon atoms bonded to it, you need to add two hydrogen atoms, and so on.



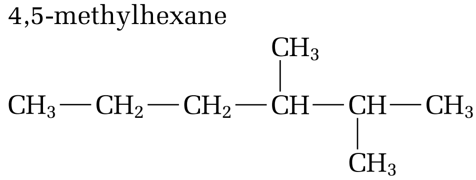
Practice Problems

6. Draw a condensed structural diagram for each alkane.
   (a) 3-ethyl-3,4-dimethylhexane
   (b) 2,3,4-trimethylpentane
   (c) 5-ethyl-3,3-dimethylheptane
   (d) 4-butyl-6-ethyl-2,5-dimethylnonane

7. One way to assess how well you have learned a new skill is to identify mistakes. Examine the following compounds and their names. Identify any mistakes, and correct the names.
   (a) 4-ethyl-2-methylpentane



   (b) 4,5-methylhexane



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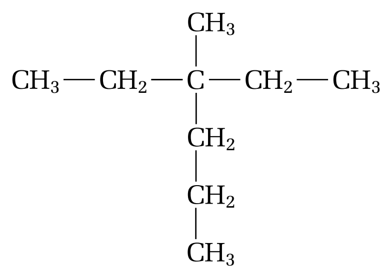
(c) 3-methyl-3-ethylpentane



Alkenes

Did you know that bananas are green when they are picked? How do they become yellow and sweet by the time they reach your grocer's produce shelf or your kitchen? Food retailers rely on a hydrocarbon to make the transformation from bitter green fruit to delicious ripe fruit. The hydrocarbon is ethene. It is the simplest member of the second group of aliphatic compounds: the alkenes.

Alkenes are hydrocarbons that contain one or more double bonds. Like alkanes, alkenes can form continuous chain and branched-chain structures. They also form a homologous series. As well, they are non-polar, which gives them physical properties similar to those of alkanes.

Alkenes are different from alkanes, however, in a number of ways. First, their bonds are different, as indicated by their suffixes. As you will recall, the -ane ending tells you that alkane compounds are joined by single bonds. *The -ene ending for alkenes tells you that these compounds have one or more double bonds*. A double bond involves four bonding electrons between two carbon atoms, instead of the two bonding electrons in all alkane bonds. Examine Figure 13.18 to see how the presence of a double bond affects the number of hydrogen atoms in an alkene.

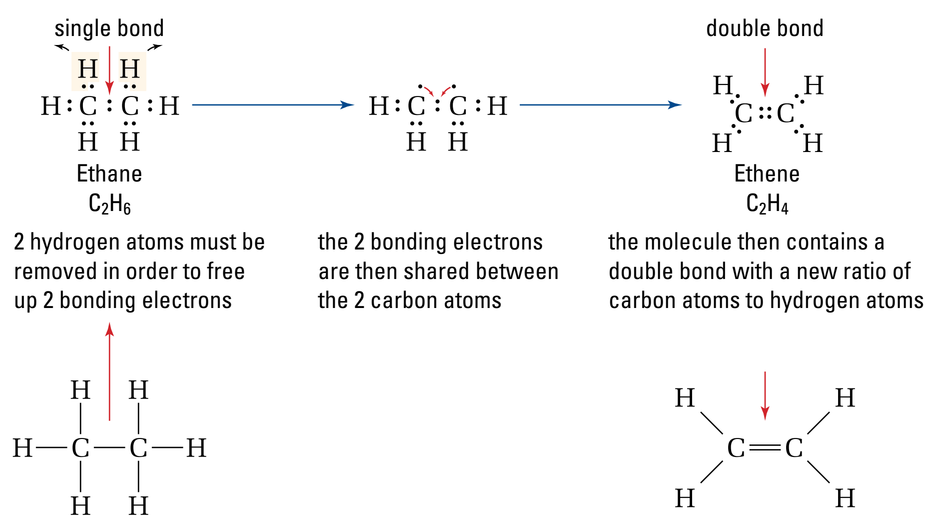


Figure 13.18 **This diagram shows how an ethane molecule can become an ethene molecule. The two hydrogen atoms that are removed from ethane often form hydrogen gas, $H_{2(g)}$.**

The general formula for an alkene is C_nH_{2n}. You can check this against the next two members of the alkene series. Propene has three carbon atoms, so you would expect it to have six hydrogens. Butene has four carbon atoms, so it should have eight hydrogens. The formulas for propene and butene are C_3H_6 and C_4H_8, so the general formula is accurate. Note, however, that the general formula applies only if there is one double bond per molecule. You will learn about alkenes with multiple double bonds in future chemistry courses.

Figure 13.19 Plastics made from ethene

Properties of Alkenes

The general formula for alkenes implies that at least two carbon atoms in any alkene compound have fewer than four bonded atoms. As a result, chemists refer to alkenes as unsaturated compounds. Unlike saturated compounds, **unsaturated hydrocarbons** contain carbon atoms that can potentially bond to additional atoms.

Unsaturated compounds have physical and chemical properties that differ from those of saturated compounds. For example, the boiling points of alkenes are usually slightly less than the boiling points of similar-sized alkanes (alkanes with the same number of carbon atoms). This difference reflects the fact that the forces between molecules are slightly less for alkenes than for alkanes. For example, the boiling point of ethane is –89˚C, whereas the boiling point of ethene is –104˚C. On the other hand, both alkenes and alkanes have a low solubility in water. Alkenes, like all aliphatic compounds, are non-polar.

The double bond in alkenes has important consequences for their chemical properties. Alkenes are much more reactive than alkanes. For example, alkenes react with halogens in the absence of light, but alkanes do not.

PROBEWARE

If you have access to probeware, do the Properties of Hydrocarbons lab, or a similar lab available from a probeware company.

The chemical reactivity of alkenes makes them a popular choice among chemical engineers. For example, nearly half of the ethene used industrially is in the plastics industry. Beverage containers, boil-in-the-bag food pouches, milk bottles, motor oil bottles, many toys, shrink-wrap, and plastic bags are all based on the small ethene molecule. (See Figure 13.19.) The ethene in these products undergoes a process called *polymerization*. In polymerization, hundreds of ethene molecules are reacted and strung together to make long chains of molecules. Another alkene, propene, undergoes a similar process and thus increases the variety of possible polymers.

On the previous page, you learned that ethene is used to ripen fruit. How does this work? When a fruit ripens, enzymes in the fruit begin to produce ethene gas. The ethene is responsible for the colour change, as well as the softening and sweetening that occur as the fruit ripens. Food chemists have learned that they can suppress ethene production (and delay ripening) by keeping fruits at a low temperature as they are transported. Once the fruits reach their final destination, ethene can be pumped into the fruit containers to hasten the ripening process. No wonder you can get such a variety of fresh fruit at the supermarket!

In the next investigation, you will use reactivity to identify saturated and unsaturated compounds in some everyday products. Saturated and unsaturated compounds play an important part in healthy eating, as you will discover.

Investigation 13-B

SKILL FOCUS
- Predicting
- Performing and recording
- Analyzing and interpreting
- Conducting research

Comparing the Reactivity of Alkanes and Alkenes

Because of differences in reactivity, you can use aqueous potassium permanganate, $KMnO_{4(aq)}$, to distinguish alkanes from alkenes. When the permanganate ion comes in contact with unsaturated compounds, such as alkenes, a reaction occurs. The permanganate ion changes to become manganese dioxide. This is shown by a colour change, from purple to brown. When the permanganate ion comes in contact with saturated compounds, such as alkanes, that have only single bonds, no reaction occurs. The colour of the permanganate does not change.

$$MnO_4{}^-{}_{(aq)} \xrightarrow[\text{compounds}]{\text{unsaturated}} MnO_{2(s)}$$

$$MnO_4{}^-{}_{(aq)} \xrightarrow[\text{compounds}]{\text{saturated}} \text{no change}$$

Aqueous potassium permanganate was added to the two test tubes on the left. One test tube contains an alkane compound. The other test tube contains an alkene compound. Which is which?

Question

How can you use aqueous potassium permanganate in a test to identify unsaturated compounds in fats and oils?

Predictions

Predict whether each substance to be tested will react with aqueous potassium permanganate. (In part, you can base your predictions on what you know about saturated and unsaturated fats from the media, as well as from biology and health classes.)

Safety Precautions

Do not spill any $KMnO_{4(aq)}$ on your clothing or skin, because it will stain. If you do accidentally spill $KMnO_{4(aq)}$ on your skin, remove the stain using a solution of sodium bisulfite.

Materials

test tubes (13 × 100 mm)
test tube rack
stoppers
medicine droppers
hot plate
5.0 mmol/L $KMnO_{4(aq)}$
water bath
samples of vegetable oils, such as varieties of margarine, corn oil, and coconut oil
samples of animal fats, such as butter and lard

Procedure

1. Read steps 2 and 3. Design a table to record your predictions, observations, and interpretations. Give your table a title.
2. Place about two full droppers of each test substance in the test tubes. Use a different dropper for each substance, or clean the dropper each time. Melt solids, such as butter, in a warm water bath (40°C to 50°C). Then test them as liquids.
3. Use a clean dropper to add one dropper full of potassium permanganate solution to each substance. Record your observations.

4. Dispose of the reactants as directed by your teacher.

Analysis

1. On what basis did you make your predictions? How accurate were they?
2. Did any of your results surprise you? Explain your answer.

Conclusion

3. Is there a connection between your results and the unsaturated or saturated compounds in the substances you tested? Explain your answer.

Application

4. Investigate the possible structures of some of the compounds (fatty acids) that are contained in various fats and oils. Use both print and electronic resources. See if you can verify a link between the tests you performed and the structures of these fats and oils. Check out compounds such as trans-fats (trans-fatty acids) and cis-fats (cis-fatty acids). Record your findings, and compare them with your classmates' findings.

Naming Alkenes

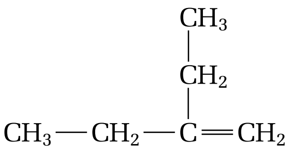


Figure 13.20

The names of alkenes follow the same format as the names of alkanes: **prefix + root + suffix**. The prefixes and the steps for locating and identifying branches are the same, too. The greatest difference involves the double bond. The suffix -ene immediately tells you that a compound has at least one double bond. The rest of the necessary information—the location of the double bond, and the number of carbon atoms in the main chain—is communicated in the root. Follow the steps below to find out how to name the compound in Figure 13.20.

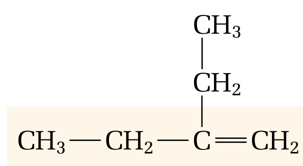
Biology LINK

According to many nutrition scientists, foods that contain double or triple bonds (unsaturated compounds) are healthier for us than foods that contain single bonds (saturated compounds). Research the implications of including unsaturated and saturated fats and oils in your diet. Use a library, the Internet, or any other sources of information. Decide on a suitable format in which to present your findings.

Naming 2-Ethyl-1-Butene

Step 1

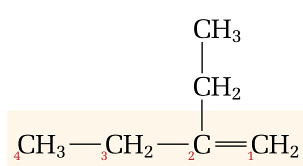
Find the longest continuous chain that contains the double bond. (This step represents the main difference from naming alkanes.)



- The main chain must contain the double bond, even though it may not be the longest chain.
- Here it is possible to have a main chain of five carbons. However, this chain would not include the double bond. Instead, choose the shorter chain with only four carbons. This chain includes the double bond. We now have part of the root, along with the suffix: -butene.

Step 2

Number the main chain from the end that is closest to the double bond.

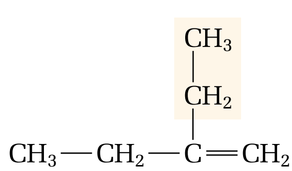


- Here you number the main chain from the right side of the chain. This ensures that the double bond gets the lowest possible position number.

- You need the number that locates the double bond. Here the double bond is between carbon number 1 and carbon number 2. Which should you use? Logic and the IUPAC rules suggest that you should use the lowest possible number. Therefore the double bond is located with the number 1. So the root and suffix of the name are -1-butene.

Step 3

To create the prefix, identify and locate the branches with numbers.



- If there is more than one branch, remember to put the branches in alphabetical order.
- There are two carbons in the branch that is attached to the number 2 carbon of the main chain. Therefore the prefix is 2-ethyl-. (Make sure that you understand why -ethyl is used.)

Step 4

Use the formula prefix + root + suffix to put the name together. The full name of this compound is 2-ethyl-1-butene. Remember that a hyphen is placed between numbers and letters, and commas are placed between consecutive numbers.

In 2-ethyl-1-butene, the double bond and the branch are near each other on the carbon chain. What happens if the double bond is close to one end of the carbon chain, but the branches are close to the other end? For example, how would you name the compound in Figure 13.21?

The methyl branch is close to the right end of the main chain. The double bond is close to the left end of the main chain. Therefore you need to follow the rule in step 2: *the double bond has the lowest possible position number*. Now you can combine the name as follows:

- The 5-carbon main chain is numbered from the left. The double bond is given the number 2 (because 2 is lower than 3). The root and the suffix are -2-pentene.
- The prefix is 4-methyl- since there is a 1-carbon branch on the fourth carbon of the main chain.
- The complete name is 4-methyl-2-pentene.

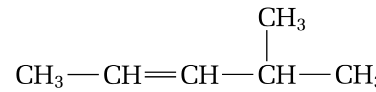


Figure 13.21

Although the compounds you have just named have different structural formulas, they both have the same molecular formula: C_6H_{12}. These compounds are both isomers of C_6H_{12}! You worked with structural isomers earlier in this chapter. You have seen that isomers can be made by rearranging carbon and hydrogen atoms and creating new branches. Now you will learn that isomers can also be made by rearranging double bonds.

Drawing Alkenes

You draw alkenes using the same method you learned for drawing alkanes. There is only one difference: you have to place the double bond in the main chain. Remember the valence of carbon, and be careful to count to four for each carbon atom on the structure. (Figure 13.22 gives an example of another alkene, 2-methyl-2-butene.) Be especially careful with the carbon atoms on each side of the double bond. The double bond is worth two for each carbon! Now complete the Practice Problems to reinforce what you have learned about naming and drawing alkenes.

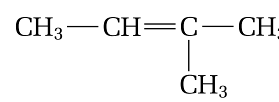


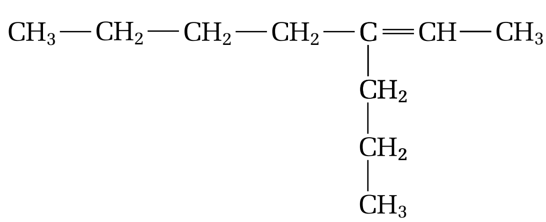
Figure 13.22 **Each carbon atom is bonded four times, once for each valence electron.**

Practice Problems

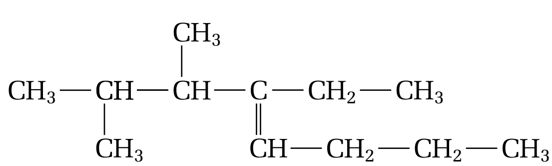
8. Name each hydrocarbon.

(a) $CH_3—CH_2—CH═CH—CH_2—CH_3$

(b)



(c)



Continued ...

PROBLEM TIP

The easiest way to tell whether or not isomers are true isomers is to name them. Two structures that look different may turn out to have the same name. If this happens, they are not true isomers.

Continued ...
FROM PAGE 557

9. Draw a condensed structural diagram for each compound.

(a) 2-methyl-1-butene

(b) 5-ethyl-3,4,6-trimethyl-2-octene

10. You have seen that alkenes, such as C_6H_{12}, can have isomers. Draw condensed structural formulas for the isomers of C_4H_8. Then name the isomers.

cis-2-Butene

trans-2-Butene

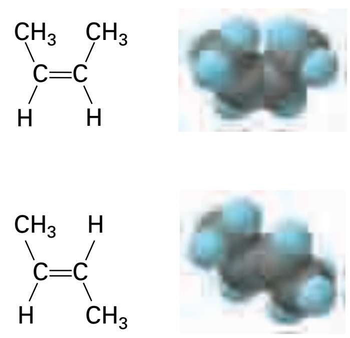


Figure 13.23 **These diagrams show the cis and trans isomers of 2-butene. Notice that the larger methyl groups are on the same side of the double bond (both above) in the cis isomer. They are on opposite sides (one above and one below) in the trans isomer.**

Cis-Trans (Geometric) Isomers

You have seen that isomers result from rearranging carbon atoms and double bonds in alkenes. Another type of isomer results from the presence of a double bond. It is called a **cis-trans isomer** (or **geometric isomer**). Cis-trans isomers occur when different groups of atoms are arranged around the double bond. Unlike the single carbon-carbon bond, which can rotate, the double carbon-carbon bond remains fixed. Figure 13.23 shows one of the compounds you have worked with already: 2-butene.

Remember these general rules:

- To have a cis-trans (geometric) isomer, each carbon in the $C{=}C$ double bond must be attached to two different groups.
- In a cis isomer, the two larger groups are attached to each $C{=}C$ double bond on the same side.
- In a trans isomer, the two larger groups are attached to each $C{=}C$ double bond on opposite sides.

Like all isomers, cis-trans isomers have different physical and chemical properties. For example, the cis-2-butene isomer has a boiling point of 3.7°C, while the trans-2-butene isomer has a boiling point of 0.9°C.

Practice Problems

11. Draw and name the cis-trans isomers for C_5H_{10}.

12. Why can 1-butene not have cis-trans isomers? Use a structural diagram to explain.

13. Like other isomers, two cis-trans isomers have the same atomic weight. They also yield the same elements when decomposed. How might you distinguish between two such isomers in the lab?

14. C_6H_{12} has four possible pairs of cis-trans isomers. Draw and name all four pairs.

Electronic Learning Partner

Go to the Electronic Learning Partner to find out more about cis-trans isomers.

Chemistry Bulletin

Science | Technology | Society | Environment

Elastomer Technology: Useful or Harmful?

What do tires and chewing gum have in common? They are both made of *elastomers*: any substance you can pull or flex. Elastomer molecules can be *crosslinked*, or chemically linked, to produce rubber that retains its shape. You can find elastomers and/or rubber in many everyday products, such as running shoes, tires, underwear, and bubble gum.

Elastomers are a type of polymer, or giant molecule. To form a polymer such as an elastomer, many small molecules are connected to form a chain with thousands of repeating units.

Elastomer technology is useful in medicine. Muscles and arteries contain giant molecules, called *elastin*, that make muscles and arteries contract. Doctors can give artificial arteries to people with severe heart problems or other diseases. Unfortunately these artificial arteries do not last long enough. Can they be replaced by a new type of elastomer?

Judit Puskas

Dr. Judit Puskas holds Canada's first Industrial Research Chair in Elastomer Technology at the University of Western Ontario in London, Ontario. She thinks that an elastomer called *polyisobutylene*, along with some of its derivatives, looks promising. In the future, it may be used to make better artificial arteries. It may also be useful for other implants, since it can imitate the rubber-like properties of elastin.

Although elastomers and rubber have many helpful and useful properties, they can also cause problems. For example, rubber is used to make safe tires for cars, trucks, and other vehicles. These tires wear out and must be changed regularly. As a result, Canada and the United States accumulate 275 million used tires every year! What can be done with these used tires?

Scrap tires that are left in piles may catch on fire. Since tires usually burn with incomplete combustion, many dangerous and polluting gases are emitted into the environment. In addition, burning tires can leak oil and aromatic hydrocarbons into the soil. Thus they can contaminate drinking water in the area.

Tire manufacturers try to reduce waste by making tires that last longer. Unfortunately, when these durable radial tires break down, they disintegrate into small airborne particles, instead of large pieces as older tires do. This "tire dust" contains latex rubber, which is an allergen. As well, tire dust is small enough to be breathed deeply into the lungs. Tire dust may be one reason why asthma is becoming more common in North America.

Since tires are made of hydrocarbons, scrap tires can be used as a fuel source. Tire derived fuel (TDF) is used in power plants, paper mills, and cement kilns. Environmentalists are concerned, however, that incomplete combustion may result in the release of toxins.

Making Connections

A large company is proposing to build a cement kiln to produce cement. It will use scrap tires as fuel. Divide the class into various stakeholders, such as

- local citizens
- an environmental group
- the company
- the provincial ministry of the environment
- the owners of a scrap tire storage facility

Debate the proposal.

Alkynes

Carbon and hydrogen atoms can be arranged in many ways to produce a great variety of compounds. Yet another way involves triple bonds in the structure of compounds. This bond structure creates a class of aliphatic compounds called alkynes. **Alkynes** are aliphatic compounds that contain one or more triple bonds.

Naming and Drawing Alkynes

Both double and triple bonds are multiple bonds. Therefore alkynes are unsaturated hydrocarbons, just as alkenes are. To name alkynes and draw their structures, you follow the same rules that you used for alkenes. The only difference is the suffix -yne, which you need to use when naming alkyne compounds. Also, remember to count the number of bonds for each carbon. An alkyne bond counts as three bonds.

As you might expect, the presence of a triple bond in alkynes makes their physical and chemical properties different from those of alkanes and alkenes. A structure with a triple bond must be linear around the bond. (See Figure 13.24.) This means that the shapes of alkynes are different from the shapes of alkanes and alkenes. As well, the triple bond makes the molecule much more reactive—even more so than the double bond. In fact, few alkynes occur naturally because they are so reactive.

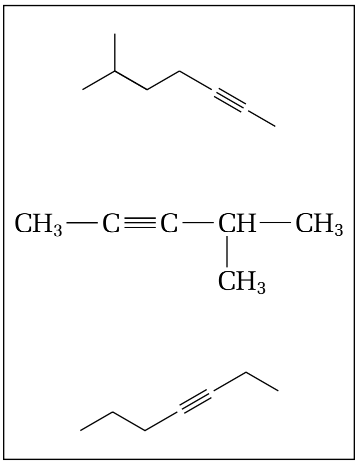


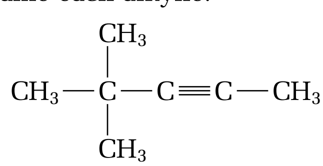
Figure 13.24 **Alkynes are linear around the triple bond, as these examples show.**

Alkynes are similar to both alkanes and alkenes because they form a homologous series. Alkynes have the general formula of C_nH_{2n-2}. So, for example, the first member of the alkyne series, ethyne, has the formula C_2H_2. (You may know this compound by its common name: acetylene.) The next member, propyne, has the formula C_3H_4.

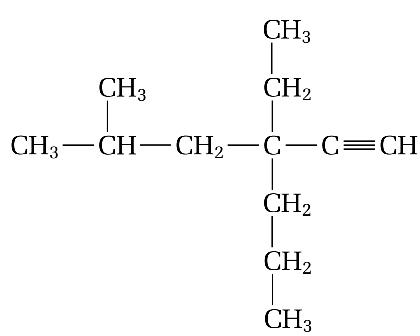
Practice Problems

15. Name each alkyne.

(a)



(b)



16. Draw a condensed structural diagram for each compound.

(a) 2-pentyne

(b) 4,5-dimethyl-2-heptyne

(c) 3-ethyl-4-methyl-1-hexyne

(d) 2,5,7-trimethyl-3-octyne

Cyclic Hydrocarbons

You have probably heard the term "steroid" used in the context of athletics. (See Figure 13.25.) Our bodies contain steroids, such as testosterone (a male sex hormone) and estrone (a female sex hormone). Steroids also have important medicinal uses. For example, budesonide is a steroid that is used to treat asthma. One of the most common steroids is cholesterol. This compound is essential to your normal body functions, but it has been linked to blocked artery walls and heart disease, as well.

Steroids have also been associated with misuse, especially at the Olympics and other sporting events. Some athletes have tried to gain an advantage by using steroids to increase their muscle mass.

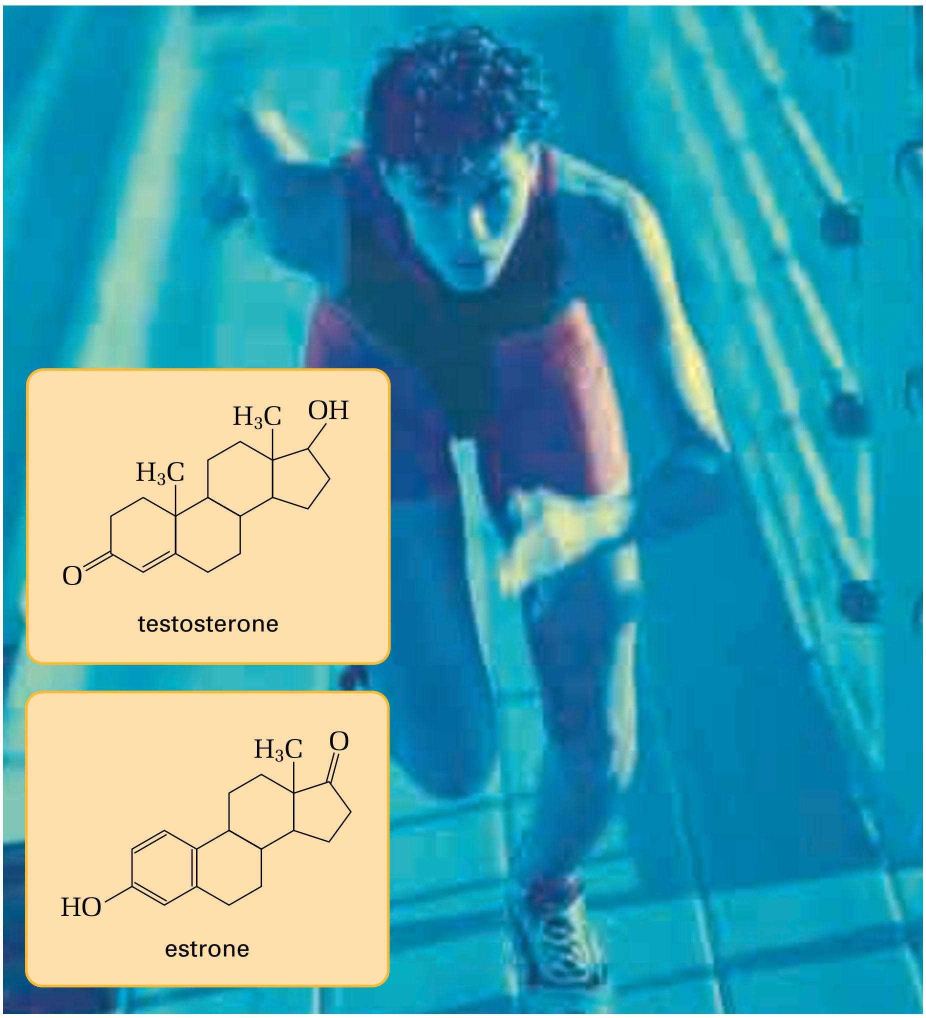


Figure 13.25 Steroids are organic compounds. Our bodies make steroids naturally. Steroids may also be synthesized in chemical laboratories. What do the structures of these steroids have in common?

What do steroids have to do with hydrocarbons? Steroids are unsaturated compounds. Although they are complex organic molecules, their basic structure centres on four rings of carbon atoms. In other words, steroids are built around ring structures of alkanes and alkenes.

Hydrocarbon ring structures are called **cyclic hydrocarbons**. They occur when the two ends of a hydrocarbon chain join together. In order to do this, a hydrogen atom from each end carbon must be removed, just as in the formation of a multiple bond. (See Figure 13.26 on the next page.)

You should have no trouble recognizing cyclohexane as a member of the alkane family. Notice, however, that cycloalkanes, such as cyclohexane, have two fewer hydrogen atoms compared with other alkanes. Thus they have the general formula C_nH_{2n}. (This is the same as the general formula for alkenes.)

Naming and Drawing Cyclic Hydrocarbons

To draw the structure of a cyclic hydrocarbon, use a line diagram in a ring-like shape, such as the one shown in Figure 13.26. Each carbon-carbon bond is shown as a straight line. Each corner of the ring represents a carbon atom. Hydrogen atoms are not shown, but they are assumed to be present in the correct numbers.

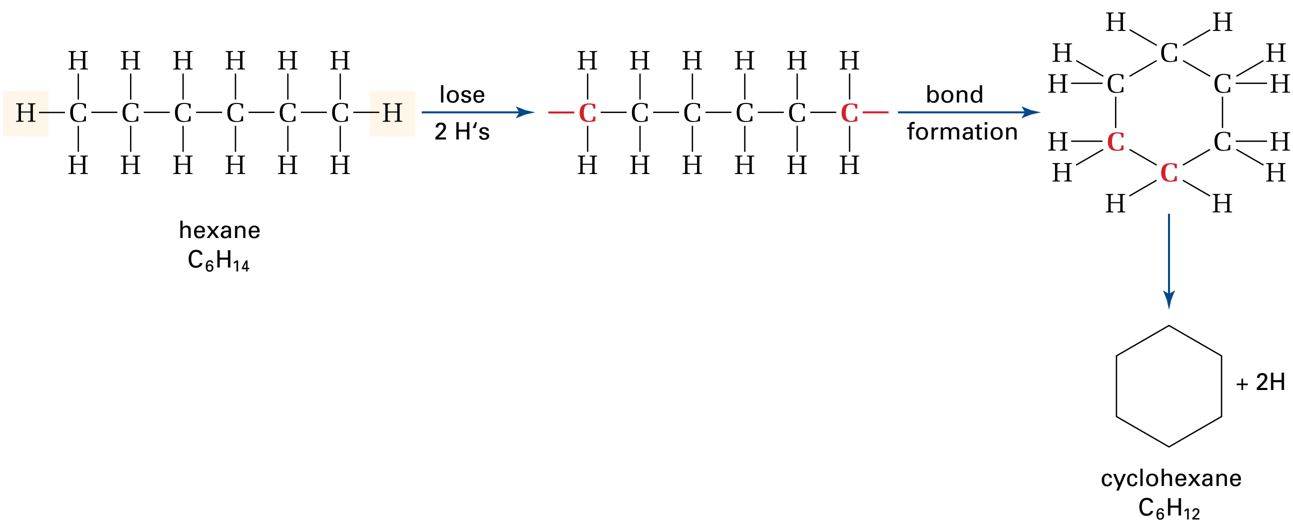


Figure 13.26 How hexane, C_6H_{14}, can become cyclohexane, C_6H_{12}

Because of the ring structure, the naming rules for cyclic hydrocarbons, including cycloalkanes and cycloalkenes, are slightly different from those for alkanes and alkenes. Below are four examples to illustrate the naming rules.

To draw cyclic hydrocarbons, start with the rules you learned for drawing other types of compounds. To place multiple bonds and branches, you have the option of counting in either direction around the ring.

Naming Cyclic Hydrocarbons

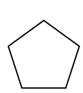


Figure 13.27

Example 1: You can still use the general formula: prefix + root + suffix. In Figure 13.27, there are only single carbon-carbon bonds. There are also five corners (carbon atoms) in the ring, which is the main chain. Since there are no branches, the name of this compound is cyclopentane. Notice the addition of cyclo- to indicate the ring structure.

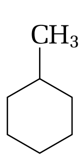


Figure 13.28

Example 2: When naming cyclic compounds, all carbon atoms in the ring are treated as equal. This means that any carbon can be carbon number 1. In Figure 13.28, only one branch is attached to the ring. Therefore the carbon that the branch is attached to is carbon number 1. Because this branch automatically gets the lowest possible position number, no position number is required in the name. Thus the name of this compound is methylcyclohexane.

Example 3: When two or more branches are on a ring structure, each must have the lowest possible position number. Which way do you count the carbons around the ring? You can count in either direction around the ring. In Figure 13.29, a good choice is to make the ethyl branch carbon number 1 and then count counterclockwise. This allows you to sequence the branches in alphabetical order and to add the position numbers in ascending order. So the name of this structure is 1-ethyl-3-methylcyclohexane.

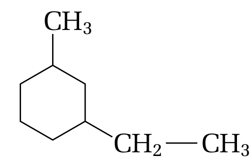


Figure 13.29

Example 4: In Figure 13.30, there is a double bond, represented by the extra vertical line inside the ring structure. You must follow the same rules as for alkenes. That is, the double bond gets priority for the lowest number. This means that one of the carbon atoms, on either end of the double bond, must be carbon number 1. The carbon atom at the other end must be carbon number 2. Next you have to decide in which direction to count so that the branch gets the lowest possible position number. In this compound, the carbon atom on the bottom end of the double bond is carbon number 1. Then you can count clockwise so that the methyl group on the top carbon of the ring has position number 3. (Counting in the other direction would give a higher locating number for the branch.) The name of this structure is 3-methyl-1-cyclohexene.

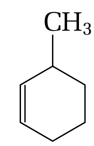
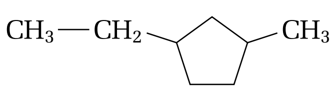
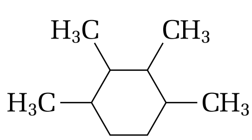


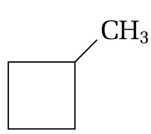
Figure 13.30

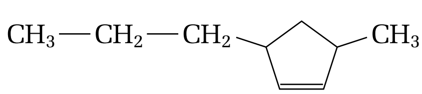
Practice Problems

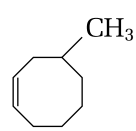
17. Name each compound.

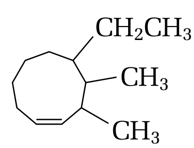
(a) 

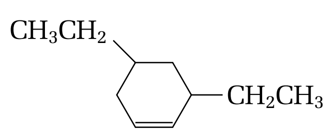
(b) 

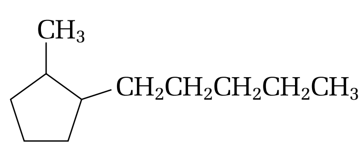
(c) 

(d) 

(e) 

(f) 

(g) 

(h) 

18. Draw a condensed structural diagram for each compound.

(a) 1,2,4-trimethylcycloheptane

(b) 2-ethyl-3-propyl-1-cyclobutene

(c) 3-methyl-2-cyclopentene

(d) cyclopentene

(e) 1,3-ethyl-2-methylcyclopentane

(f) 4-butyl-3-methyl-1-cyclohexene

(g) 1,1-dimethylcyclopentane

(h) 1,2,3,4,5,6-hexamethyl cyclohexane

You have now had some experience naming and drawing aliphatic compounds. In the next investigation, you will develop a more thorough understanding of them by examining their structural and physical properties.

SKILL FOCUS

Predicting

Modelling concepts

Analyzing and interpreting

Investigation 13-C

Structures and Properties of Aliphatic Compounds

To compare the properties of alkanes, alkenes, and alkynes, you will be working with compounds that have the same number of carbon atoms. First, you will construct and compare butane, trans-2-butene, 2-butyne, and cyclobutane. You will use a graph to compare the boiling points of each compound. Next, you will use what you have just observed to predict the relative boiling points of pentane, trans-2-pentene, 2-pentyne, and cyclopentane. You will construct and compare these structures and graph their boiling points.

Question

How can constructing models of butane, trans-2-butene, 2-butyne, and cyclobutane help you understand and compare their physical properties?

Predictions

Predict the structural formula for each compound. After completing steps 1 to 4, predict what the graph of the boiling points of pentane, trans-2-pentene, 2-pentyne, and cyclopentane will look like.

Materials

molecular model kits
reference books

Procedure

1. Construct models of butane, trans-2-butene, 2-butyne, and cyclobutane.
2. Examine the structure of each model. Draw a diagram of it in your notebook.
3. If possible, rotate the molecule around each carbon-carbon bond to see if this changes the appearance of the structure.
4. Look up the boiling points of these four compounds in the table below. Draw a bar graph to compare the boiling points.
5. Repeat steps 1 to 3 for pentane, trans-2-pentene, 2-pentyne, and cyclopentane.
6. Predict the relative boiling points for these four compounds. Use a reference book to find and graph the actual boiling points.

Comparing the Boiling Points of Four-Carbon Compounds

Compound	Boiling point (°C)
butane	–0.5
trans-2-butene	0.9
2-butyne	27
cyclobutane	12

Analysis

1. What are the differences between the multiple-bond compounds and the alkanes?
2. What type of compound has the highest boiling point? What type has the lowest boiling point?

Conclusion

3. Identify possible reasons for the differences in boiling points between compounds.

Application

4. Compare the boiling points of cyclopentane and cyclobutane. Use this information to put the following compounds in order from highest to lowest boiling point: cyclohexane, cyclobutane, cyclopropane, cyclopentane. Use a reference book to check your order.

Summary: Rules for Naming and Drawing Aliphatic Compounds

Naming Alkanes

- Find the longest continuous chain. This is the parent (main) chain. Number the parent chain so that the branches have the lowest possible position numbers.
- Locate any branches. Use the number of carbons in each branch to name it (for example, ethyl). Give it a position number.
- When writing the parts of the name, separate two numbers by a comma. Separate a number from a word by a hyphen.
- Write the prefix. Each branch has a position number. Write the branches in alphabetical order. More than one of each type of branch is shown by di-, tri-, and so on.
- Write the root. This depends on the number of carbons in the main chain.
- Write the suffix -ane. (See Figure 13.31 for practice.)

Drawing Alkanes

- In a straight line, draw the carbon atoms in the parent (main) chain. The number of carbon atoms is indicated by the root of the name.
- Give position numbers to the carbon atoms in the parent chain. Attach all the branches to their appropriate parent chain carbon atoms.
- Add enough hydrogen atoms and bonds for each carbon atom to have four bonds.

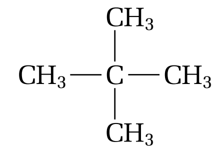


Figure 13.31 Can you name this alkane?

Naming Alkenes and Alkynes

- Find the longest continuous chain containing the multiple bond. This is the parent chain. Number the parent chain so that the multiple bond has the lowest possible position number.
- Locate any branches. Identify the position number and number of carbons for each branch.
- When writing the parts of the name, separate two numbers by a comma. Separate a number from a word by a hyphen.
- Write the prefix. Each branch has a position number. Write the branches in alphabetical order. More than one of each type of branch is shown by di-, tri-, and so on.
- Write the root. This includes the position number of the multiple bond and the name for the number of carbon atoms in the parent chain.
- Write the suffix -ene for alkenes and -yne for alkynes. (See Figure 13.32 for practice.)

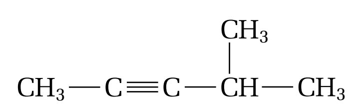


Figure 13.32 Can you name this alkyne?

Drawing Alkenes and Alkynes

- In a straight line, draw the carbon atoms in the parent chain. The number of carbon atoms is indicated by the root of the name. Place the multiple bond between two carbon atoms in the chain, as indicated by the number in the name.
- Give position numbers to the carbon atoms in the parent chain. Attach all the branches to their appropriate parent chain carbon atoms.
- Add enough hydrogen atoms and bonds for each carbon atom to have four bonds.

Naming Cycloalkanes

- Identify the branches.
- Number the carbons in the ring, in either direction, so that the branches have the lowest possible position numbers.
- Write the prefix, as for naming alkanes.
- Write the root -cyclo- plus the name for the number of carbon atoms in the ring. For example, a five-carbon ring would have the root -cyclopent-.
- Write the suffix -ane.

Drawing Cycloalkanes

- Draw the ring, according to the root of the name.
- Choose one of the ring carbon atoms as carbon number 1. Place each branch accordingly.

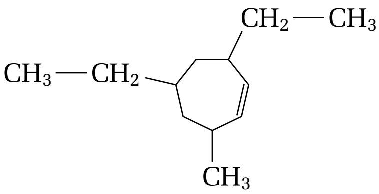


Figure 13.33 Can you name this cycloalkene?

Naming Cycloalkenes and Cycloalkynes

- Identify the branches.
- Number the carbons in the ring, in either direction, so that the multiple bond is between the two lowest numbers, and the branches get the lowest possible position numbers.
- Write the prefix and root, as for cycloalkanes.
- Write the suffix -ene for cycloalkenes or -yne for cycloalkynes. (See Figure 13.33 for practice.)

Drawing Cycloalkenes and Cycloalkynes

- Draw the ring, according to the root of the name.
- Choose one of the ring carbon atoms as carbon number 1. Place the multiple bond accordingly.
- Add each branch according to its type and position number.

Section Wrap-up

Now you know how to name and draw alkanes, alkenes, alkynes, and ring compounds. In the next section, you will discover how petroleum, the source of most hydrocarbons, can be separated into its components.

Section Review

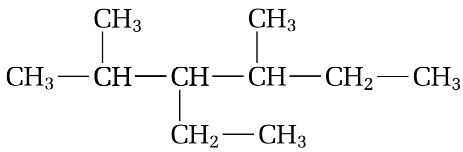
1. **(a)** K/U What are the names of the three types of aliphatic compounds that you studied in this section?

   (b) K/U Which of these are saturated compounds, and which are unsaturated compounds? How does this difference affect their properties?

2. K/U List the roots used to name the first ten members of the alkane homologous series. Indicate the number of carbon atoms that each represents.

3. C If water and octane are mixed, does the octane dissolve in the water? Explain.

4 **(a)** K/U Name each compound.



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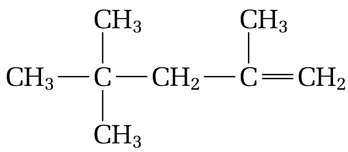

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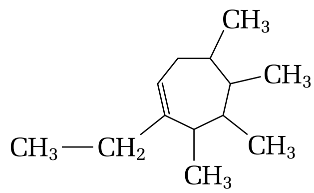

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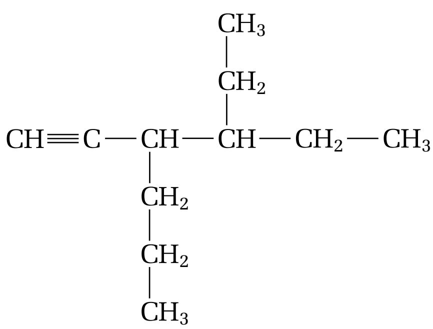


5 C Draw a condensed structural diagram for each compound.

(a) 2,4-dimethyl-3-hexene

(b) 5-ethyl-4-propyl-2-heptyne

(c) 3,5-diethyl-2,4,7,8-tetramethyl-5-propyldecane

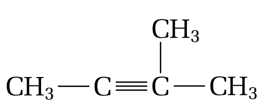
(d) trans-4-methyl-3-heptene

6 C Draw and name all the isomers that are represented by each molecular formula.

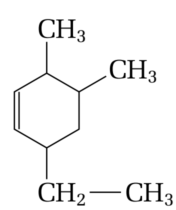
(a) C_3H_4 **(b)** C_5H_{12} **(c)** C_5H_{10}

7 K/U Identify any mistakes in the name and/or structure of each compound.

(a) 3-methyl-2-butene



(b) 2-ethyl-4,5-methyl-1-hexene



8 C What happens when there is more than one double bond or more than one ring? Try to draw a condensed structural diagram for each of the following compounds.

(a) propadiene

(b) 2-methyl-1,3-butadiene

(c) 1,3,5-cycloheptatriene

(d) cyclopentylcyclohexane

13.4 Refining and Using Hydrocarbons

Section Preview/ Specific Expectations

In this section, you will

- **describe** the steps involved in refining petroleum to obtain gasoline and other useful fractions
- **explain** the importance of hydrocarbons in the petrochemical industry
- **communicate** your understanding of the following terms: *petrochemicals, fractional distillation, cracking, reforming*

Is it possible to take hydrocarbons straight out of the ground and use them as they are? Since the earliest recorded history, people have done just that. In the past, people used crude oil that seeped up to Earth's surface to waterproof boats and buildings. They also used it to grease wheels and even dress the wounds of animals and humans. As well, people burned natural gas, mainly to supply lighting for temples and palaces.

Today hydrocarbons are extracted from the ground at well sites, then processed further at refineries. (See Figure 13.34.) The first commercial oil well in North America was located in southern Ontario's Enniskillen Township. It began production in 1858. At that time, kerosene (which was used to fuel lamps) was the principal focus of the young petroleum industry. Paraffin (for making candles) and lubricating oils were also produced, but there was little demand for other hydrocarbon materials, such as gasoline.

Figure 13.34 This oil refinery is in Clarkson, Ontario.

Reliance on hydrocarbons has increased substantially since the nineteenth century. Our society now requires these compounds for fuel, as well as for the raw materials that are used to synthesize petrochemicals. **Petrochemicals** are basic hydrocarbons, such as ethene and propene, that are converted into plastics and other synthetic materials. Petroleum is the chief source of the petrochemicals that drive our cars and our economy. Petroleum is not a pure substance, however. Rather, petroleum is a complex mixture of hydrocarbons—mainly alkanes and alkenes—of varying molecular sizes and states. Because petroleum is a mixture, its composition varies widely from region to region in the world. An efficient process is essential for separating and collecting the individual, pure hydrocarbon components. Read on to learn about this process in greater detail.

Using Properties to Separate Petroleum Components

Fractional distillation is a process for separating petroleum into its hydrocarbon components. This process relies on a physical property—boiling point. Each of the hydrocarbon components, called *fractions*, has its own range of boiling points. At an oil refinery, the separating (refining) of petroleum begins in a large furnace. The furnace vaporizes the liquid components. The fluid mixture then enters a large fractionation tower. Figure 13.35 outlines how the various hydrocarbon fractions are separated in the tower. (**Note:** The temperatures shown are approximate boiling points for the hydrocarbon fractions.)

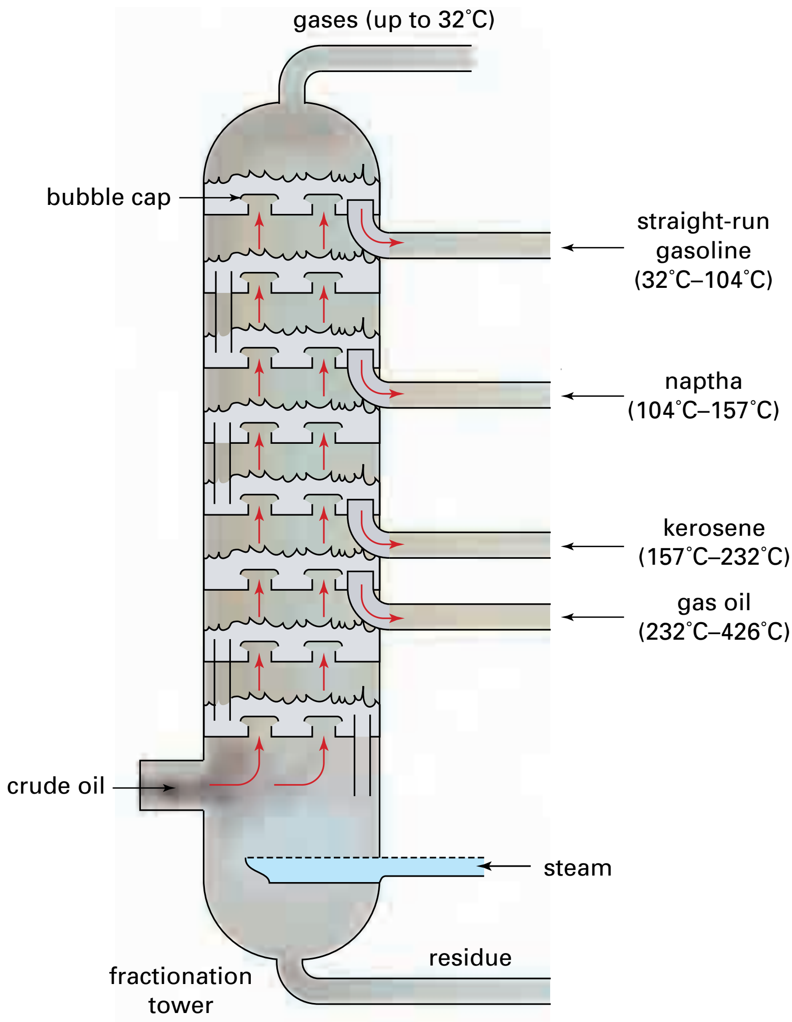


Figure 13.35 **This diagram shows how petroleum is separated into its hydrocarbon fractions. Each fraction has a different range of boiling points. The tower separates the fractions by a repeated process of heating, evaporating, cooling, and condensing.**

Perforated plates, which are fitted with bubble caps, are placed at various levels in the tower. As each fraction reaches a plate where the temperature is just below its boiling point, it condenses and liquefies. The liquid fractions are taken from the tower by pipes. Other fractions that are still vapours continue to pass up through the plates to higher levels.

Several plates are needed to collect each fraction. Heavier hydrocarbons (larger molecules) have higher boiling points. They condense first and are removed in the lower sections of the tower. The lighter hydrocarbons, with lower boiling points, reach the higher levels of the tower before they are separated.

Web LINK

www.school.mcgrawhill.ca/resources/
Canada's land mass has experienced dynamic changes over tens of millions of years. Climatic conditions, along with the deposition of countless remains of organisms, created the areas in which petroleum is found today. These areas are called *sedimentary basins*. Where are the sedimentary basins? Are they all active sites for oil and gas extraction? How much oil and gas do scientists estimate there is? How do Canada's reserves compare with those of other petroleum-producing nations? Go to the web site above to "tap" into Canada's and the world's petroleum resources. Go to **Science Resources**, then to **Chemistry 11** to find out where to go next. Decide on a suitable format in which to record your findings.

Cracking and Reforming

Once the fractions are removed from the distillation tower, they may be chemically processed or purified further to make them marketable. (See Figure 13.36.) There has been a tremendous increase in the demand for a variety of petroleum products in the early twentieth century. This demand has forced the oil industry to develop new techniques to increase the yield from each barrel of oil. These techniques are called cracking and reforming.

Petroleum Fractionation Products

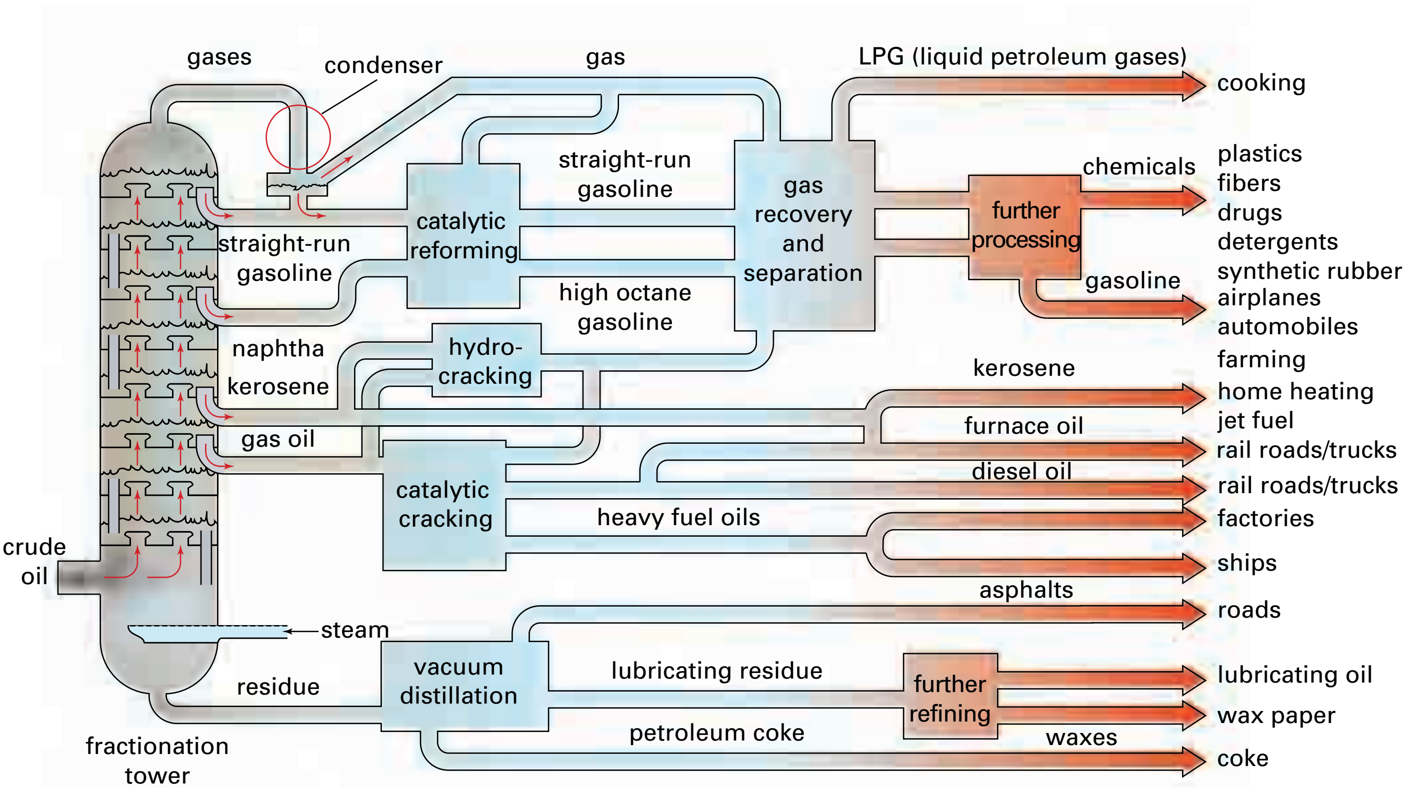


Figure 13.36 **Selected uses of petroleum fractions**

Cracking was first introduced in Sarnia, Ontario. This process uses heat to break larger hydrocarbon molecules into smaller gasoline molecules. Cracking is done in the absence of air and can produce different types of hydrocarbons. For example, the cracking of propane can produce methane and ethene, as well as propene and hydrogen. (See Figure 13.37.)

$$\underset{\text{propane}}{2\,CH_3CH_2CH_3} \xrightarrow{500^{\circ}C\text{–}700^{\circ}C} \underset{\text{methane}}{CH_4} + \underset{\text{ethene}}{CH_2{=}CH_2} + \underset{\text{propene}}{CH_3CH{=}CH_2} + \underset{\text{hydrogen}}{H_2}$$

Figure 13.37 **This chemical equation summarizes the cracking of propane.**

Electronic Learning Partner

The Chemistry 11 Electronic Learning Partner has an animation that illustrates how a fractionation tower works.

Reforming is another technique that uses heat, pressure, and catalysts to convert large hydrocarbons into other compounds. Reforming can produce larger hydrocarbons or a different type of hydrocarbon, called aromatic compounds. (See Figure 13.38.) Aromatic compounds contain special ring structures. You will learn about them in a later chemistry course.

Language LINK

What is a catalyst? Use reference books to find out.

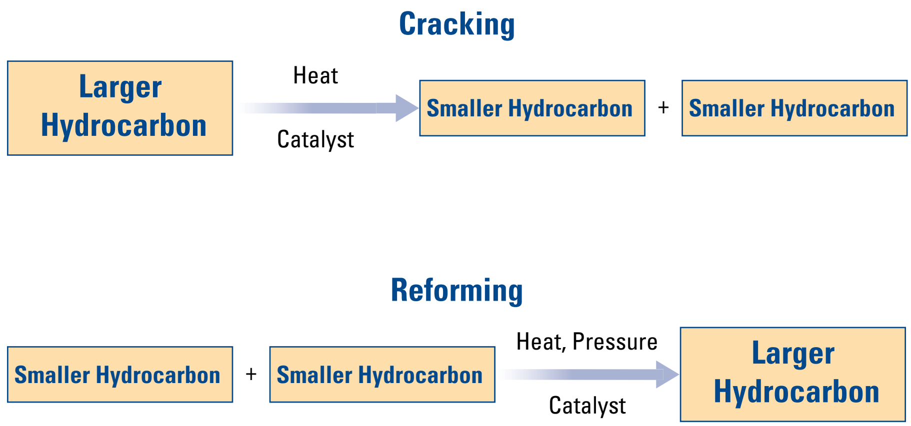


Figure 13.38 Comparing cracking and reforming

Some of the products of the refining process are transported to petrochemical plants. These plants convert complex hydrocarbons, such as naphtha, into simple chemical compounds, or a small number of compounds, for further processing by other industries. Canadian petrochemical plants produce chemicals such as methanol, ethylene, propylene, styrene, butadiene, butylene, toluene, and xylene. These chemicals are used as building blocks in the production of other finished products. Nearly every room in your school, your home, and your favourite shopping centre contains, or is made from, at least one petrochemical product. Yet, as you can see in Figure 13.39, petrochemicals represent only a small fraction of society's uses of petroleum.

In the next chapter, you will discover why hydrocarbons are so highly valued as fuels. As well, you will unravel the mystery of how so much energy can be locked up inside a hydrocarbon molecule.

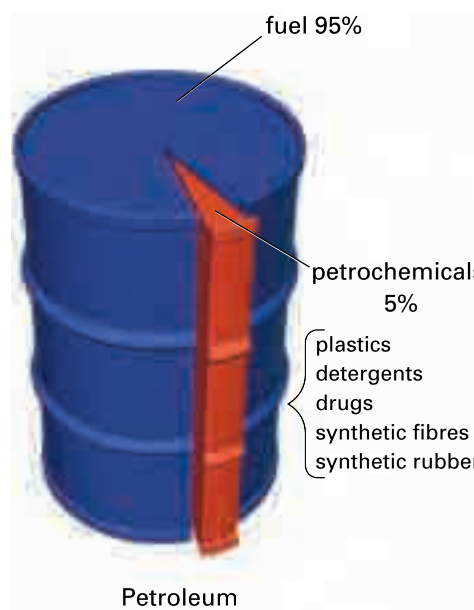


Figure 13.39 A tremendous number of petrochemical products enrich your life. Yet they still make up only about 5% of what is produced from a barrel of crude oil. A staggering 95% of all petroleum is used as fuel.

Section Wrap-up

In this section, you learned that petrochemicals, an essential part of our society and technology, are obtained from petroleum. You discovered how petroleum is separated into its components by fractional distillation, cracking, and reforming.

In this chapter, you learned a great deal about hydrocarbons. You learned how hydrocarbons are formed in section 13.1. In sections 13.2 and 13.3, you learned to draw, classify, and name different hydrocarbons. Finally, you learned about the practical side of hydrocarbons—how they are produced and used in everyday life.

Careers in Chemistry

Polymer Chemist

Bulletproof vests used to be heavy, bulky, and uncomfortable. Stephanie Kwolek changed that. Now police officers, police dogs, and soldiers, can wear light, strong bulletproof vests made of a synthetic fibre called Kevlar™. Kwolek (shown above) developed Kevlar™ while working for the DuPont chemical company. Kevlar™ first came into general use in 1971. It is five times stronger than steel, gram for gram, but almost as light as nylon. It is flame resistant, resists wear and tear, and does not conduct electricity. This versatile material is used not only in bulletproof vests, but also in other manufactured items, including hockey helmets, firefighters' suits, spacecraft shells, and surgeons' gloves.

Kwoluk's branch of organic chemistry—polymer chemistry—specializes in creating synthetic materials that are cheaper, faster, and stronger than natural materials. Polymer chemists often work by stringing together thousands of atoms to form long molecules called polymers. Then they manipulate these polymers in various ways. Polymer chemists have invented an amazing array of materials. These include polyvinyl chloride (used to make garden hose and duct tape), polyurethane (used to stuff teddy bears and make spandex bicycle pants), and acrylonitrile-butadiene-styrene, or ABS (used to make brakes and other auto body parts).

Make Career Connections

What kind of education do polymer chemists need for their jobs?

- Find out about polymer chemistry programs that are offered by a university near you.
- Research different companies that employ polymer chemists. If possible, interview a polymer chemist who is employed by one of these companies.

Section Review

Unit Project Prep

Before you choose a product to investigate for the end-of-unit Project, consider what you have learned about petrochemical products. What compound is used to produce most plastics, and thus almost all products' packaging?

1. **(a)** K/U What physical property allows various fractions of crude oil to be separated in a fractionation tower?

   (b) C What is this process of separation called? Briefly describe it. Include a diagram in your answer if you wish.

2. MC Our society's demand for petroleum products has increased dramatically over the last century. Describe two techniques that can be used to transform the petroleum fractions from a fractionation tower, in order to meet this demand.

3. MC List five types of petrochemicals that can be produced from refined hydrocarbons. Describe briefly how each type has affected your life.

4. MC Petrochemicals are not always helpful. Do research and prepare a presentation illustrating the effects of petrochemicals on the environment.

CHAPTER 13 Review

Reflecting on Chapter 13

Summarize this chapter in the format of your choice. Here are a few ideas to use as guidelines:

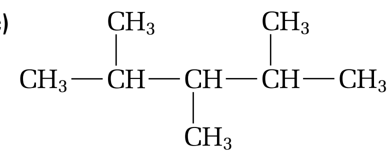
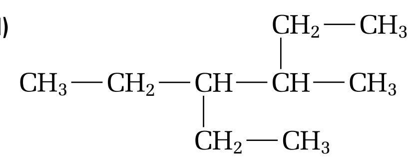
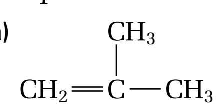
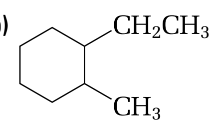
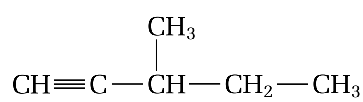
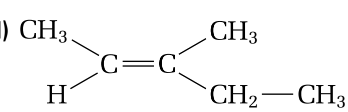
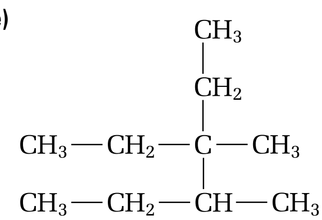
- Identify the origins and sources of hydrocarbons and other organic compounds.
- Describe the characteristics that enable carbon to form so many, varied compounds.
- Distinguish among complete, condensed, and line structural diagrams.
- Identify, draw, and name at least two examples of each kind of hydrocarbon you studied: alkanes, alkenes, alkynes, and cyclic hydrocarbons.
- Demonstrate, using suitable examples, true isomers of a hydrocarbon.
- Compare physical properties, such as boiling point, of aliphatic compounds.
- Describe the processes and techniques that the petrochemical industry depends on. Identify at least ten products of this industry.

Reviewing Key Terms

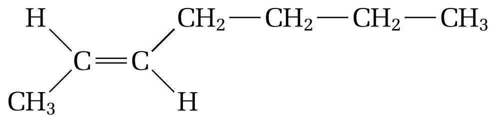
For each of the following terms, write a sentence that shows your understanding of its meaning.

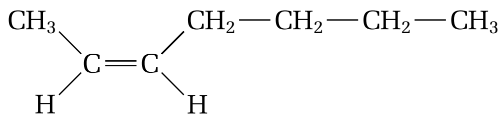
aliphatic hydrocarbons	alkanes
alkenes	alkynes
cis-trans isomer	cracking
cyclic hydrocarbons	expanded molecular formula
fractional distillation	geometric isomer
homologous series	isomers
hydrocarbons	organic compound
petrochemicals	petroleum
reforming	saturated hydrocarbons
structural diagram	structural model
unsaturated hydrocarbons	

Knowledge/Understanding

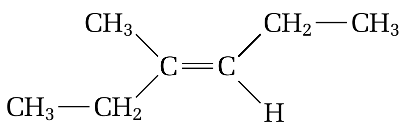
1. (a) What are the origins of most hydrocarbons and other organic compounds?
   (b) List three sources of hydrocarbons.
   (c) What is the main s'ource of hydrocarbons used for fuels?
2. List three factors that are required to change biological matter into petroleum.
3. What are the key properties of the carbon atom that allow it to form such diverse compounds?
4. Define the following terms: fractional distillation, petrochemical.
5. What are isomers? Give one example of a set of isomers for a molecular formula.
6. Describe how the boiling point changes as the chain length of an aliphatic compound increases. Explain why this happens.
7. Briefly compare alkanes, alkenes, and alkynes. (Give both similarities and differences.)
8. Describe the difference between structural isomers and cis-trans isomers.
9. Name each compound.
   (a) $CH_3—CH_2—CH_2—CH_3$
   (b) $CH_3—CH_3$
   (c) 
   (d) 
10. For each structural diagram, write the IUPAC name and identify the type of aliphatic compound.
   (a) 
   (b) 
   (c) 
   (d) 
   (e) 

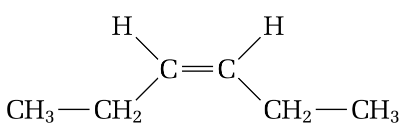
11. Name the following isomers of 2-heptene.

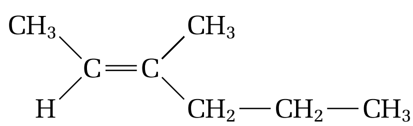


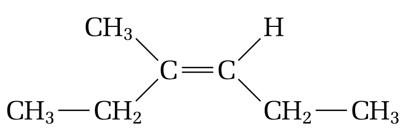


12. Match the following names and structural diagrams. Note that only four of the six names match.
   (a) cis-3-methyl-3-hexene
   (b) trans-3-hexene
   (c) trans-3-methyl-2-hexene
   (d) trans-3-methyl-3-hexene
   (e) cis-3-methyl-2-hexene
   (f) cis-3-hexene

(A) 

(B) 

(C) 

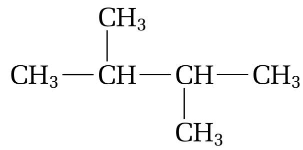
(D) 

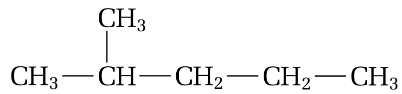
13. Is 1-methyl-2-cyclobutene the correct name for a compound? Draw the structural diagram for the compound, and rename it if necessary.

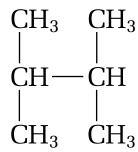
14. Explain why the rule "like dissolves like" is very useful when cleaning up an oil spill on a body of water.

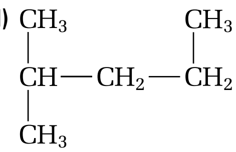
15. Why is it impossible for the correct name of a linear alkane to begin with 1-methyl?

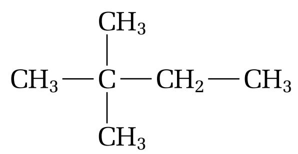
16. Which combinations of the following structural diagrams represent true isomers of C_6H_{14}? Which structural diagrams represent the same isomer?

(a) 

(b) 

(c) 

(d) 

(e) 

Inquiry

17. Someone has left two colourless liquids, each in an unlabelled beaker, on the lab bench. You know that one liquid is an alkane, and one is an alkene. Describe a simple test that you can use to determine which liquid is which.

18. Suppose that you were given a liquid in a beaker labelled "C_6H_{12}." Discuss how you would determine whether the substance was an alkane, a cycloalkane, an alkene, or an alkyne.

19. In Investigation 13-C, you constructed cyclobutane. In order to construct this isomer, you had to use springs for bonds.
   (a) Why did you have to use springs?
   (b) What do you think the bulging springs tell you about the stability of cyclobutane in real life?

Communication

20. Draw a complete structural diagram for each of these compounds.
   (a) 3-ethylhexane
   (b) 1-butene
   (c) 2,3-dimethylpentane

21. Draw a condensed structural diagram for each of these compounds.
   (a) methylpropane
   (b) 1-ethyl-3-propylcyclopentane
   (c) cis-3-methyl-3-heptene
   (d) 3-butyl-4-methyl-1-octyne
   (e) 4-ethyl-1-cyclooctene
22. **(a)** Draw three structural isomers of C_5H_{12}.
   (b) Draw four cis-trans isomers of C_8H_{16}.
23. In a fractionation tower, the gaseous fractions are removed from the top and the solid residues are removed from the bottom.
   (a) Explain why the fractions separate like this.
   (b) A sample of crude oil was tested and found to contain mostly smaller hydrocarbon molecules, less than 15 carbon atoms long. From what part of the tower would most of the fractions of this sample be removed? Why?
24. Use a diagram to describe the steps involved in refining petroleum to obtain gasoline.
25. Draw a concept map to illustrate how hydrocarbon molecules can start as crude oil and end up as synthetic rubber.
26. Imagine that you are the owner of an oil refinery. Your main supply of crude oil contains a high percent of longer-chain hydrocarbons (greater than 15 carbon atoms per molecule). A new customer is looking for a large supply of gasoline, which contains 7- and 8-carbon molecules. How will you meet your customer's needs?
27. Place the following alkanes in order from lowest to highest boiling point. Explain your reasoning.
   (a) $CH_3—CH_2—CH_2—CH_2—CH_3$
   (b) $CH_3—CH_2—CH_3$
   (c) $CH_3—CH(CH_3)—CH_3$
   (d) $CH_3—CH_2—CH_2—CH_3$
28. Draw the complete, condensed, and line structural diagrams for 2,3,4-trimethylpentane. Discuss the main advantage of each type of structural diagram.

Making Connections

29. List two ways in which ethene is important in everyday life.
30. Research the similarities and differences in drilling for oil offshore versus onshore. Write a report of your findings.
31. The National Energy Board has estimated that Canada's original petroleum resources included 4.3×10^{11} m^3 (430 billion cubic metres) of oil and bitumen (a tar-like substance) and 1.7×10^{14} m^3 (170 trillion cubic metres) of natural gas. Canada's petroleum-producing companies have used only a small fraction of these resources. Why, then, do you think many people are so concerned about exhausting them?

Answers to Practice Problems and Short Answers to Section Review Questions:

Practice Problems: **1.** C_7H_{16} **2.** C_9H_{20} **3.** 10 **4.** 25 **5.(a)** 2-methylbutane **(b)** 2,2-dimethylpropane **(c)** 3-ethyl-2,5-dimethylheptane **(d)** 2,2,4,4-tetramethylhexane **(e)** 2,2,4-trimethyl-4-propyloctane **7.(a)** 2,4-dimethylhexane **(b)** 2,3-dimethylhexane **(c)** 3-ethyl-3-methylhexane **8.(a)** 3-hexene **(b)** 3-propyl-2-heptene **(c)** 4-ethyl-2,3-dimethyl-4-octene **10.** 2-butene, 1-butene, 2-methyl-1-propene **11.** cis-2-pentene, trans-2-pentene **14.** cis-2-hexene, trans-2-hexene; cis-3-hexene, trans-3-hexene; 3-methyl-cis-2-pentene, 3-methyl-trans-2-pentene; 4-methyl-cis-2-pentene, 4-methyl-trans-2-pentene **15.(a)** 4,4-dimethyl-2-pentyne **(b)** 3-ethyl-5-methyl-3 -propyl-1-hexyne **17.(a)** 1-ethyl-3-methylcyclopentane **(b)** 1,2,3,4-tetramethylcyclohexane **(c)** methylcyclobutane **(d)** 3-methyl-5-propyl-1-cyclopentene **(e)** 4-methyl-1-cyclooctene **(f)** 5-ethyl-3,4-dimethyl-1-cyclononene **(g)** 3,5-diethyl-1-cyclohexene **(h)** 1-methyl-2-pentylcyclopentane
Section Review 13.1: **5.(a)** organic **(b)** organic **(c)** inorganic **(d)** inorganic **(e)** organic **(f)** inorganic **(g)** organic **(h)** inorganic **13.3:** **1.(a)** alkane, alkene, alkyne **2.** meth (1), eth (2), prop (3), but (4), pent (5), hex (6), hept (7), oct (8), non (9), dec (10) **4.(a)** 3-ethyl-2,4-dimethylhexane **(b)** 2,4,4-trimethyl-1-pentene **(c)** 4-ethyl-3-propyl-1-hexyne **(d)** 2-ethyl-3,4,5,6-tetramethyl-1-cycloheptene **6.(a)** propyne, cyclopropene **(b)** pentane, 2-methylbutane, 2,2-dimethylpropane **(c)** 1-pentene, cis-2-pentene, trans-2-pentene, 2-methyl-2-butene, 2-methyl-1-butene, cyclopentane **13.4:** **1.(a)** boiling point **(b)** fractional distillation