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.

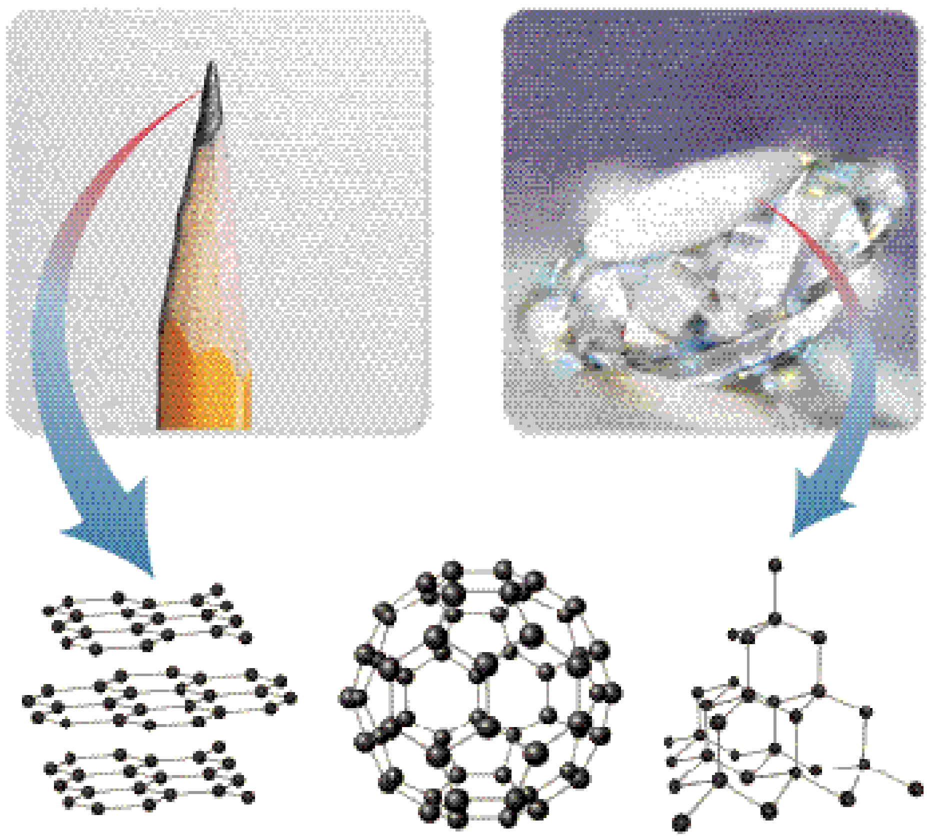


Figure 13.3 Each of these substances is pure carbon. What makes carbon a "chemical chameleon?"

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.

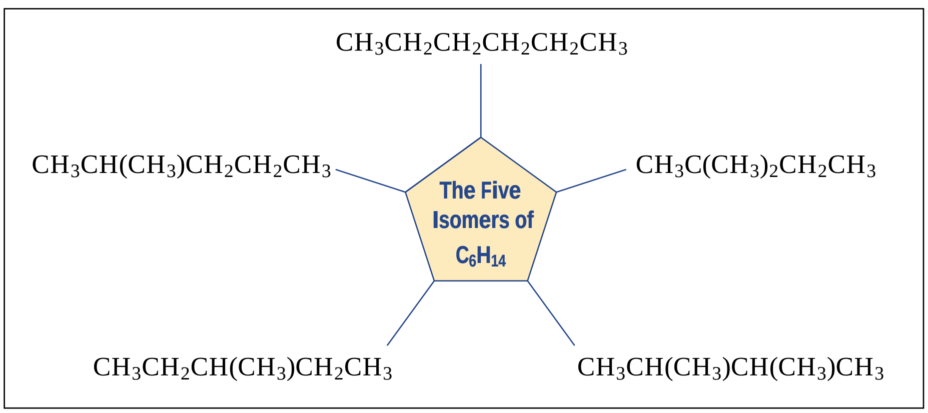


Figure 13.5 **Expanded molecular formulas for five structural arrangements of C_6H_{14}**

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

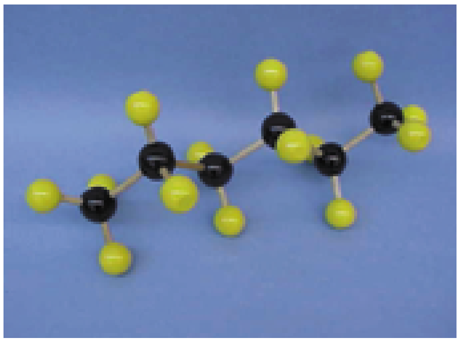
The number of isomers of an organic compound increases greatly as the number of carbon atoms increases. For example, C_5H_{12} has three isomers, C_6H_{14} has five isomers, and C_8H_{18} has 18 isomers. $C_{30}H_{62}$, a large hydrocarbon, has over four billion isomers!

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.

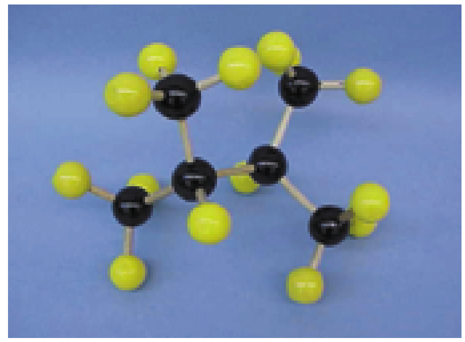
Using Structural Models to Represent Hydrocarbons

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.

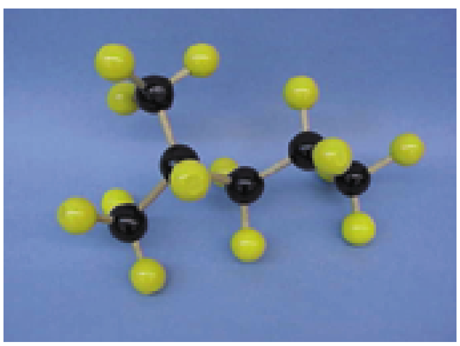
The Five Isomers of C_6H_{14}



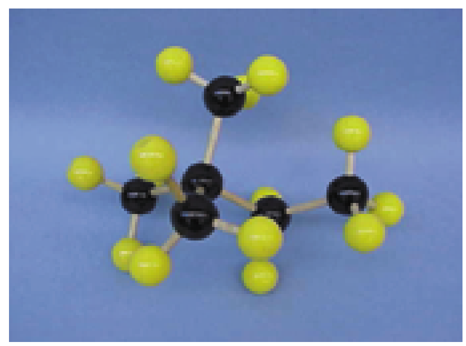
$CH_3CH_2CH_2CH_2CH_2CH_3$



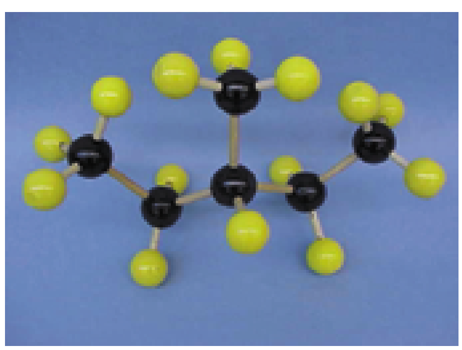
$CH_3CH(CH_3)CH(CH_3)CH_3$



$CH_3CH(CH_3)CH_2CH_2CH_3$



$CH_3C(CH_3)_2CH_2CH_3$



$CH_3CH_2CH(CH_3)CH_2CH_3$

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.

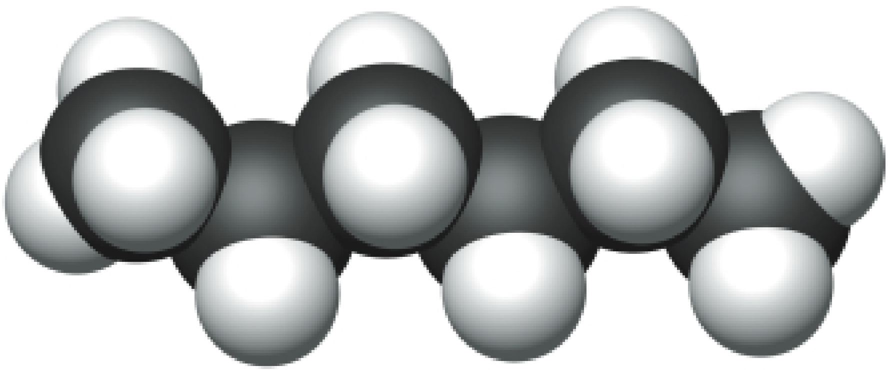
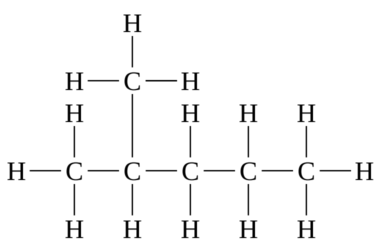


Figure 13.7 **A space-filling model for hexane, one of the isomers of C_6H_{14}**

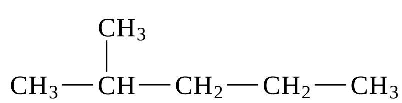
Using Structural Diagrams to Represent Hydrocarbons

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.

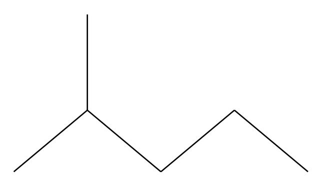
In the next investigation, you will have an opportunity to make your own models of the isomers of several organic compounds.



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**

Investigation 13-A

SKILL FOCUS

Predicting

Analyzing and interpreting

Communicating results

Modelling concepts

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

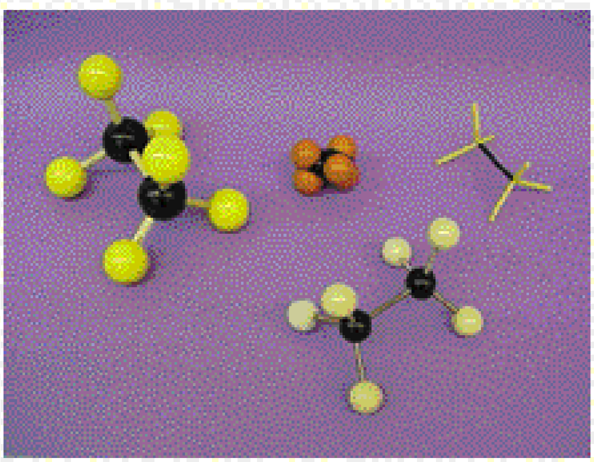
How do models help you visualize the isomers of organic compounds?

Predictions

Predict the complete, condensed, and line structural diagrams for the three isomers of . Then predict the complete and condensed structural diagrams for the four isomers of .

Materials

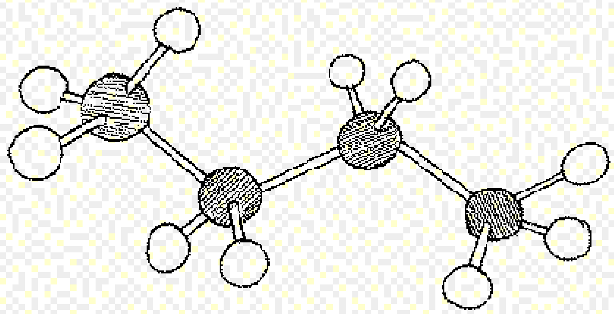
paper and pencil
molecular modelling kit



These representations of the hydrocarbon ethane, , 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 . 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 .

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

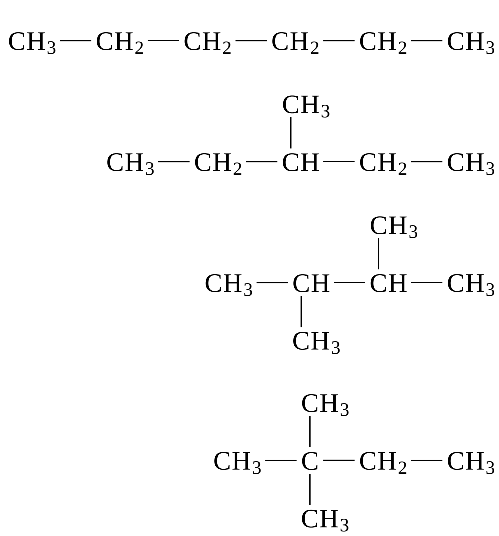
3. How accurately do you think your models represent the real-life structural arrangements of and ?

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 . 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.



hexane

3-methylpentane

2,3-dimethylbutane

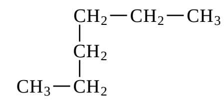
2,2-dimethylbutane

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.