

## 21.3: Hydrocarbons: Compounds Containing Only Carbon and Hydrogen

Hydrocarbons—compounds that contain only carbon and hydrogen—are the simplest organic compounds. Because of carbon's versatility, many different kinds of hydrocarbons exist. We use hydrocarbons as fuels. Candle wax, oil, gasoline, LP (liquefied petroleum) gas, and natural gas are all composed of hydrocarbons. Hydrocarbons are also the starting materials in the synthesis of many different consumer products, including fabrics, soaps, dyes, cosmetics, drugs, plastic, and rubber.

As shown in [Figure 21.1](#), we classify hydrocarbons into four different types: [alkanes](#), [alkenes](#), [alkynes](#), and [aromatic hydrocarbons](#). Alkanes, alkenes, and alkynes—also called [aliphatic hydrocarbons](#)—are differentiated based on the kinds of bonds between carbon atoms. (We discuss aromatic hydrocarbons in detail in [Section 21.7](#).) As we can see in [Table 21.1](#), alkanes have only single bonds between carbon atoms, alkenes have a double bond, and alkynes have a triple bond.

Figure 21.1 Four Types of Hydrocarbons

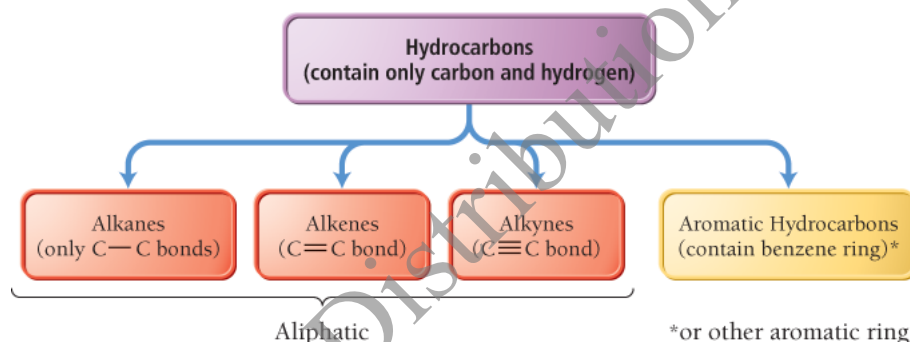


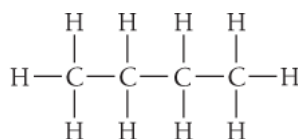
Table 21.1 Alkanes, Alkenes, Alkynes

Type of Hydrocarbon	Type of Bonds	Generic Formula*	Example
Alkane	All single	$C_nH_{2n+2}$	$\begin{array}{c} \text{H} & \text{H} \\   &   \\ \text{H}-\text{C}- & \text{C}-\text{H} \\   &   \\ \text{H} & \text{H} \end{array}$ ethane
Alkenes	One (or more) double	$C_nH_{2n}$	$\begin{array}{c} \text{H} & & \text{H} \\ & \diagdown & / \\ & \text{C}=\text{C} \\ & / & \diagdown \\ \text{H} & & \text{H} \end{array}$ ethene
Alkynes	One (or more) triple	$C_nH_{2n-2}$	$\text{H}-\text{C}\equiv\text{C}-\text{H}$ ethyne

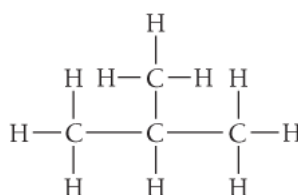
\*  $n$  is the number of carbon atoms. These formulas apply only to noncyclic structures containing no more than one multiple bond.

## Drawing Hydrocarbon Structures

Throughout this book, we have relied primarily on molecular formulas as the simplest way to represent compounds. In organic chemistry, however, molecular formulas are insufficient because, as we have already discussed, the same atoms can bond together in different ways to form different compounds. For example, consider an alkane with 4 carbon atoms and 10 hydrogen atoms. Two different structures, named butane and isobutane, are shown below.



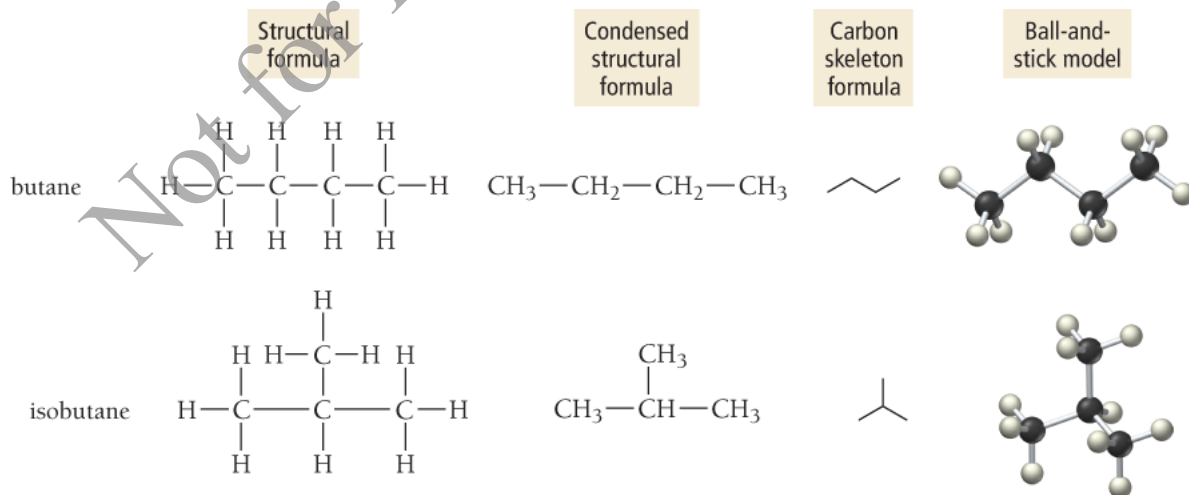
butane



isobutane

Butane and isobutane are **structural isomers**, molecules with the same molecular formula but different structures. More specifically, notice that the atoms are connected together in a different way in isobutane than in butane. Because of their different structures, they have different properties—indeed, they are different compounds. Isomerism is ubiquitous in organic chemistry. Butane has two structural isomers. Pentane ( $\text{C}_5\text{H}_{12}$ ) has three, hexane ( $\text{C}_6\text{H}_{14}$ ) has five, and decane ( $\text{C}_{10}\text{H}_{22}$ ) has 75!

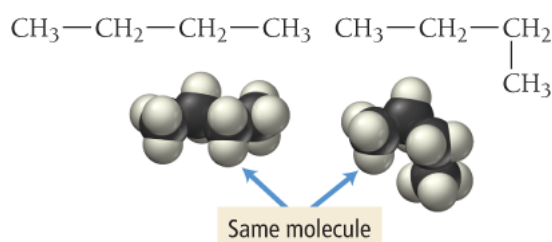
We represent the structure of a particular hydrocarbon with a **structural formula**, a formula that shows not only the numbers of each kind of atom, but also how the atoms are bonded together. Organic chemists use several different kinds of structural formulas. For example, we can represent butane and isobutane in each of the following ways:



The structural formula shows all of the carbon and hydrogen atoms in the molecule and how they are bonded together. The *condensed structural formula* groups the hydrogen atoms with the carbon atom to which they are bonded. Condensed structural formulas may show some of the bonds (as the previous examples do) or none at all. For example, the condensed structural formula for butane can also be written as  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ . The *carbon skeleton formula* (also called a line formula) shows the carbon–carbon bonds only as lines. Each end or bend of a line represents a carbon atom bonded to as many hydrogen atoms as necessary to form a total of four

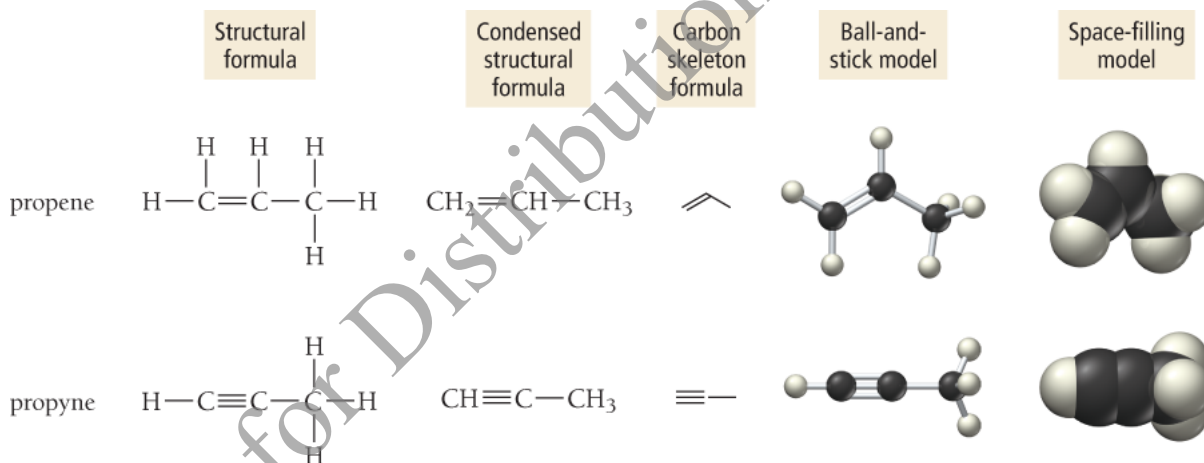
Note that structural formulas are generally not three-dimensional representations of the molecule, as space-filling or ball-and-stick models are. Instead, they are two-dimensional representations that show how atoms are bonded together. As such, the most important feature of a structural formula is the *connectivity* of the atoms, not the exact way the formula is drawn.

For example, consider the two condensed structural formulas for butane and the corresponding space-filling models below them:



Since rotation about single bonds is relatively unhindered at room temperature, the two structural formulas are identical, even though they are drawn differently.

We represent double and triple bonds in structural formulas with double or triple lines. For example, we draw the structural formulas for  $\text{C}_3\text{H}_6$  (propene) and  $\text{C}_3\text{H}_4$  (propyne) as follows:

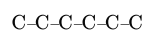


The kind of structural formula we use depends on how much information we want to portray. [Example 21.1](#) illustrates how to write structural formulas for a compound.

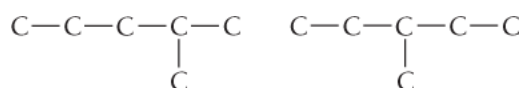
### Example 21.1 Writing Structural Formulas for Hydrocarbons

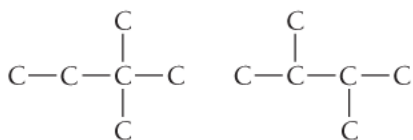
Write the structural formulas and carbon skeleton formulas for the five isomers of  $\text{C}_6\text{H}_{14}$  (hexane).

**SOLUTION** To begin, draw the carbon backbone of the straight-chain isomer.

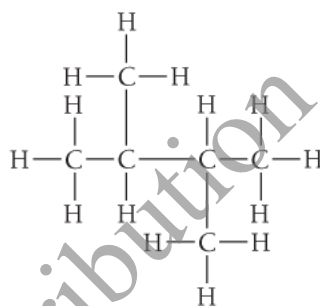
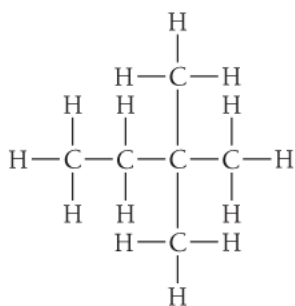
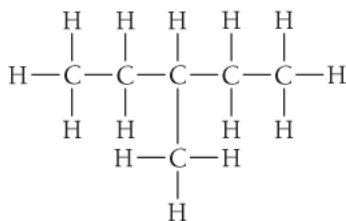
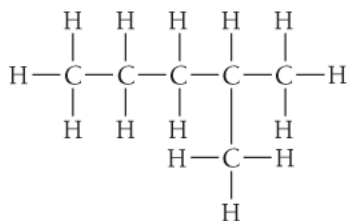
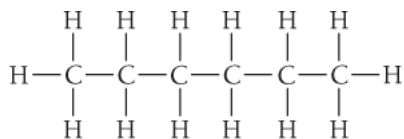


Determine the carbon backbone structure of the other isomers by arranging the carbon atoms in four other unique ways.

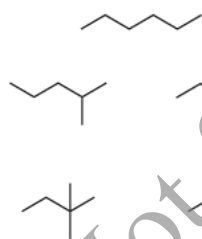




Fill in all the hydrogen atoms so that each carbon forms four bonds.



Write the carbon skeleton formulas by using lines to represent each carbon-carbon bond. Remember that each end or bend represents a carbon atom.



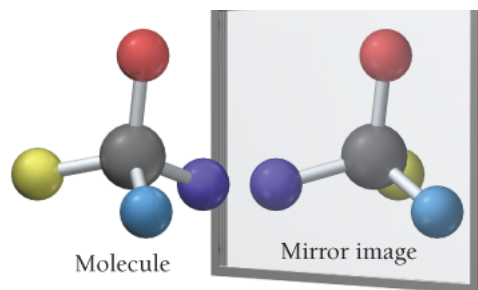
**FOR PRACTICE 21.1** Write the structural formulas and carbon skeleton formulas for the three isomers of  $\text{C}_5\text{H}_{12}$  (pentane).

### Conceptual Connection 21.1 Organic Structures

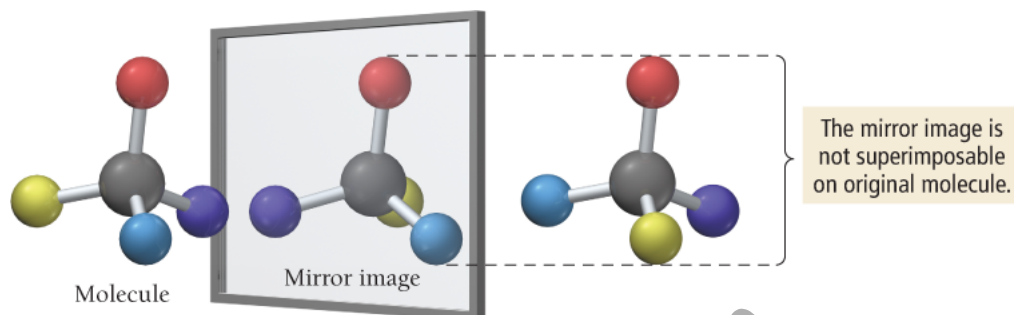
## Stereoisomerism and Optical Isomerism

**Stereoisomers** are molecules in which the atoms have the same connectivity but a different spatial arrangement. We categorize stereoisomers into two types: geometric (or cis-trans) isomers and optical isomers.

We discuss geometric isomers in Section 21.5. **Optical isomers** are two molecules that are nonsuperimposable mirror images of one another. Consider the molecule shown here with its mirror image:



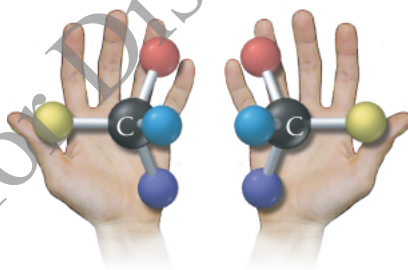
The molecule cannot be superimposed onto its mirror image. If we swing the mirror image around to try to superimpose the two, we find that there is no way to get all four substituent atoms to align together. (A substituent is an atom or group of atoms that is substituted for a hydrogen atom in an organic compound.)



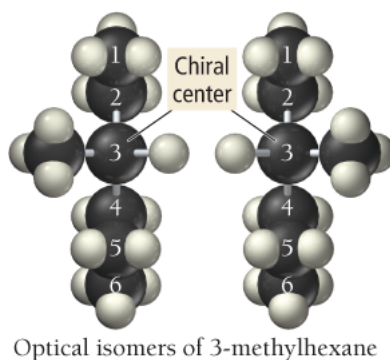
Optical isomers are similar to your right and left hands (Figure 21.2). The two are mirror images of one another, but you cannot superimpose one on the other. For this reason, a right-handed glove does not fit on your left hand and vice versa.

**Figure 21.2 Mirror Images**

The left and right hands are nonsuperimposable mirror images, just as are optical isomers.



Any carbon atom with four different substituents in a tetrahedral arrangement exhibits optical isomerism. Consider 3-methylhexane:



These two 3-methylhexane molecules are nonsuperimposable mirror images and are optical isomers of one

another. Optical isomers are also called **enantiomers**. Any molecule, such as 3-methylhexane, that exhibits optical isomerism is said to be **chiral**, from the Greek word *cheir*, which means "hand."

Optical isomerism is important, not only to organic chemistry, but also to biology and biochemistry. Most biological molecules are chiral and usually only one or the other enantiomer is active in biological systems. For example, glucose, the primary fuel of cells, is chiral. Only one of the enantiomers of glucose has that familiar sweet taste, and only that enantiomer can fuel our cellular functioning; the other enantiomer is not even metabolized by the body.

Some of the physical and chemical properties of enantiomers are indistinguishable from one another. For example, both of the optical isomers of 3-methylhexane have identical freezing points, melting points, and densities. However, the properties of enantiomers differ from one another in two important ways: (1) in the direction in which they rotate polarized light (which is one way to tell them apart) and (2) in their chemical behavior in a chiral environment.

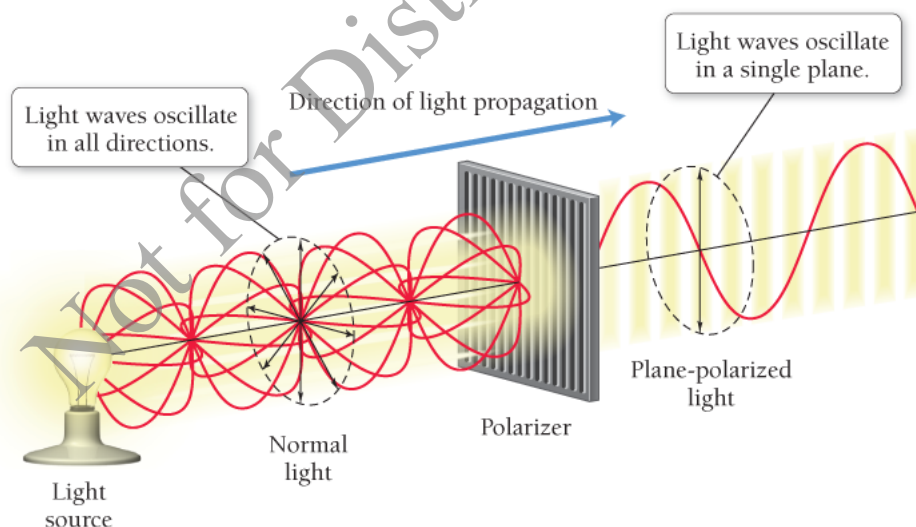
## Rotation of Polarized Light

*Plane-polarized light* is light that is made up of electric field waves that oscillate in only one plane as shown in Figure 21.3. When a beam of plane-polarized light is directed through a sample containing only one of two optical isomers, the plane of polarization of the light rotates, as shown in Figure 21.4. One of the two optical isomers rotates the polarization of the light clockwise and is called the **dextrorotatory** isomer (or the *d* isomer). The other isomer rotates the polarization of the light counterclockwise and is called the **levorotatory** isomer (or the *l* isomer). An equimolar mixture of both optical isomers does not rotate the polarization of light at all and is called a **racemic mixture**.

*Dextrorotatory* means turning clockwise or to the right. *Levorotatory* means turning counterclockwise or to the left.

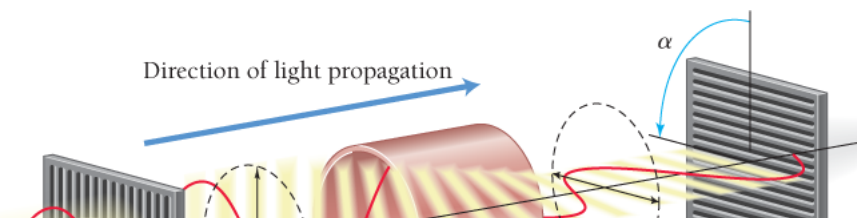
**Figure 21.3 Plane-Polarized Light**

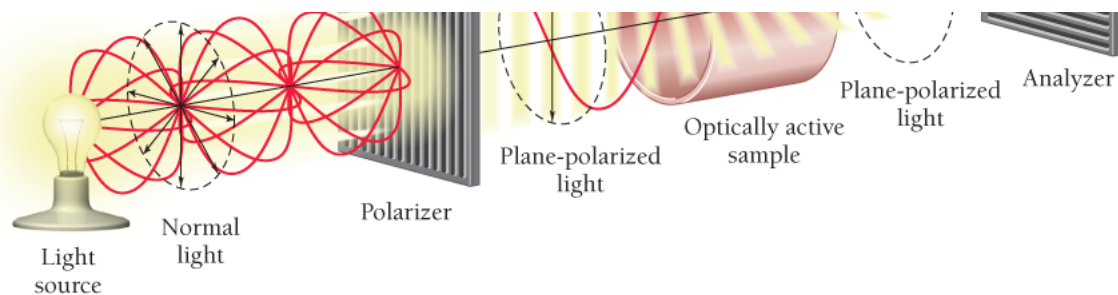
The electric field of plane-polarized light oscillates in one plane.



**Figure 21.4 Rotation of Plane-Polarized Light**

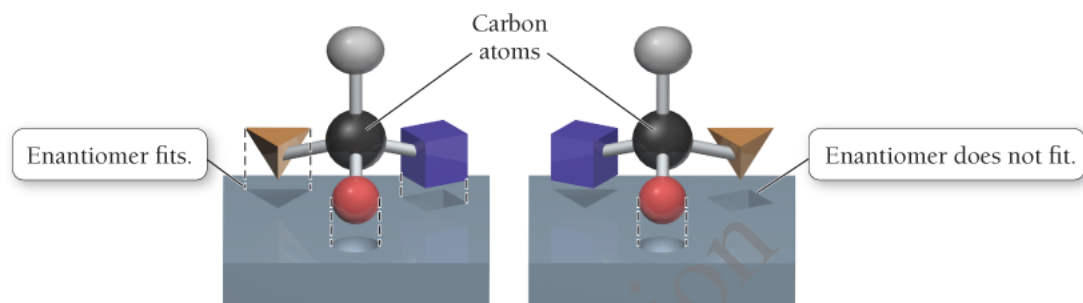
Plane-polarized light rotates as it passes through a sample containing only one of two optical isomers.





## Chemical Behavior in a Chiral Environment

Optical isomers also exhibit different chemical behavior when they are in a chiral environment (a chiral environment is one that is not superimposable on its mirror image). Enzymes are large biological molecules that catalyze reactions in living organisms and provide chiral environments. Consider the following simplified picture of two enantiomers in a chiral environment:



As the figure illustrates, one of the enantiomers fits the template, but the other does not, no matter how it is rotated. In this way, an enzyme is able to catalyze the reaction of one enantiomer because that particular enantiomer fits the "template." As we have already seen, most biological molecules are chiral, and usually only one or the other enantiomer is active in biological systems. Even subtle differences in structure, such as the difference between one enantiomer and the other, affect properties.

### Conceptual Connection 21.2 Optical Isomers

Interactive

*Not for Distribution*



*Not for Distribution*