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.

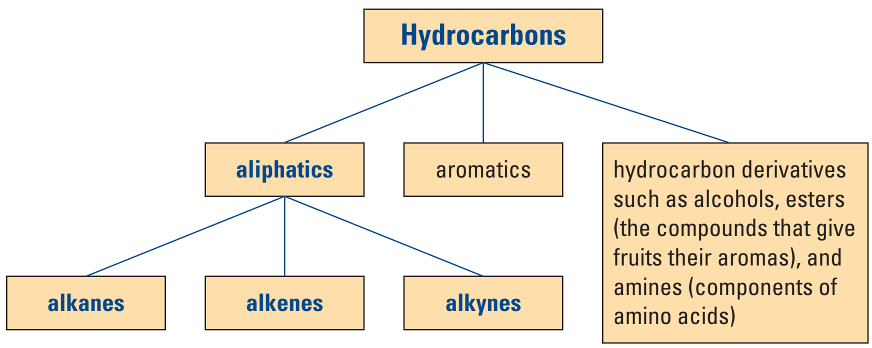


Figure 13.10 **This concept map illustrates a system for classifying organic compounds. In this chapter, you will explore only part of the family of organic compounds—the aliphatic hydrocarbons shown by the boldface type.**

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.

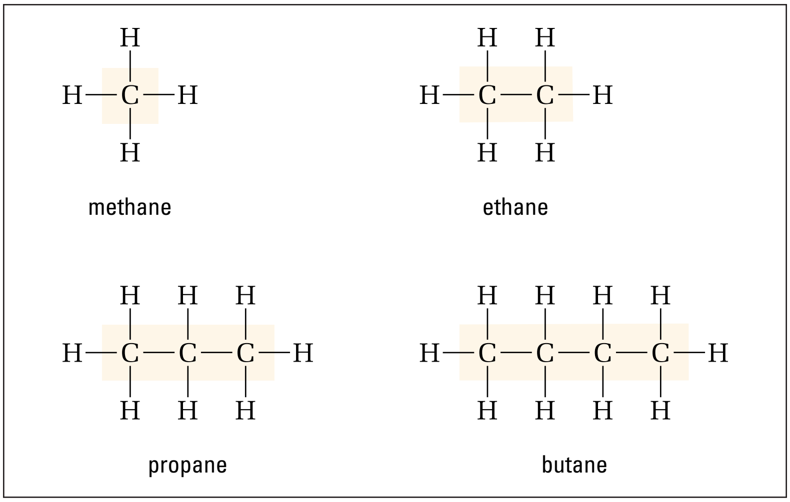


Figure 13.11 **Carefully examine these four molecules. They are the first four alkanes. In what ways are they similar? In what ways are they different?**

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

$CH_3—CH_3 + \text{-}\mathbf{CH_2}\text{-} \rightarrow CH_3—\mathbf{CH_2}—CH_3$

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.**

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.

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.

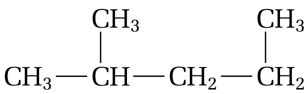


Figure 13.13 2-methylpentane

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.

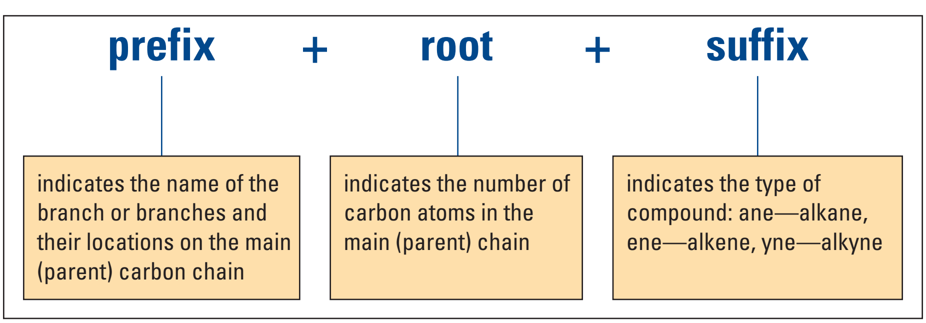


Figure 13.14 Parts of a hydrocarbon name

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?

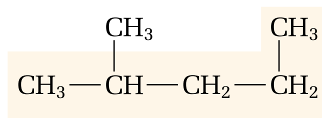
Language LINK

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

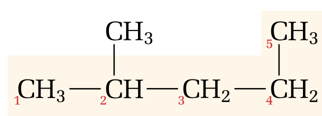
Find the longest continuous chain (the parent chain). It does not have to be straight. The number of carbons in the parent chain forms the root of the name.



- 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

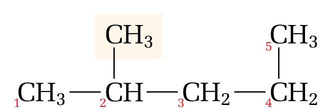
Identify any branches that are present. Then number the main chain from the end that gives the lowest number to the first location at which branching occurs.



- 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.

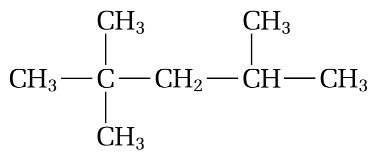


Figure 13.15 **This compound is 2,2,4-trimethylpentane, an isomer of C_8H_{18}. It is one of the main ingredients in gasoline.**

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-).

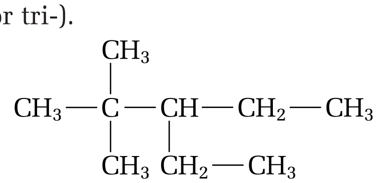


Figure 13.16 **3-ethyl-2,2-dimethylpentane**

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.

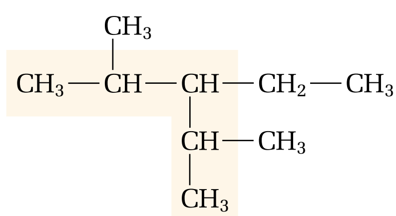


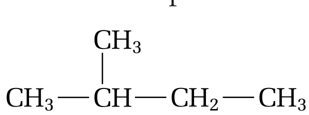
Figure 13.17 **3-ethyl-2,4-dimethylpentane**

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

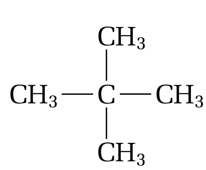
Practice Problems

5. Name each compound.

(a)



(b)



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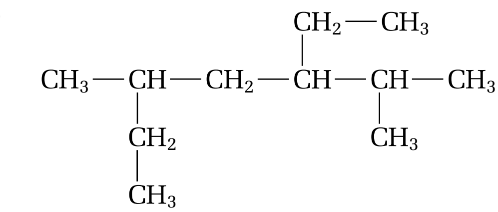
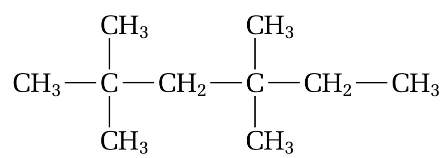
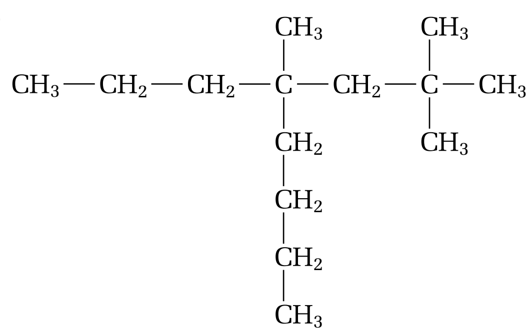
(c)



(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.

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.

Rules for Drawing Condensed Structural Diagrams

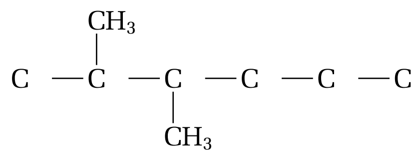
1. Identify the root and the suffix of the name. In 2,3-dimethylhexane, for example, the root and suffix are -hexane. The *-hex-* tells you that there are six carbons in the main chain. The *-ane* tells you that the compound is an alkane. Therefore this compound has single carbon-carbon bonds only.

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.

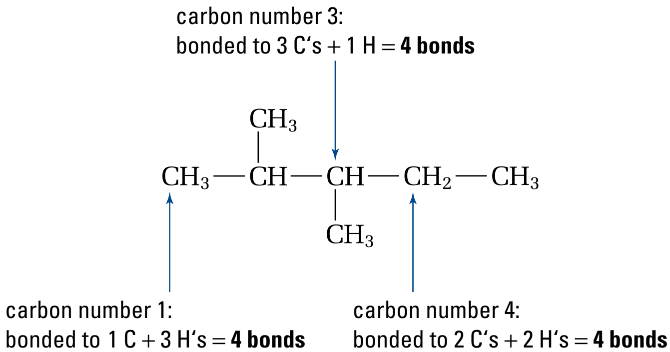
$$\mathrm{C\ -C\ -C\ -C\ -C\ -C}$$

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

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.



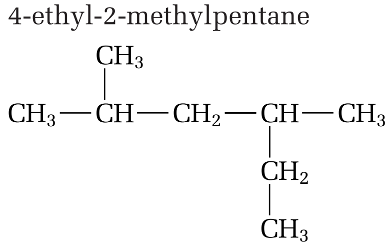
4. Finish drawing your diagram by adding the appropriate number of hydrogen atoms beside each carbon. Remember that each carbon has a valence of four. So if a carbon atom has one other carbon atom bonded to it, you need to add three hydrogen atoms. If a carbon atom has two other carbon atoms bonded to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



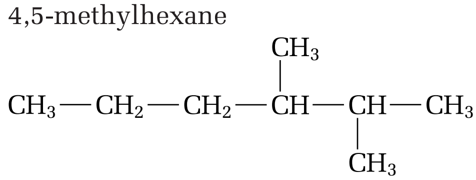
Practice Problems

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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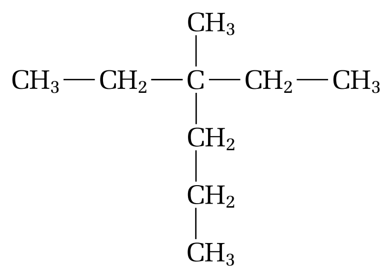
(c) 3-methyl-3-ethylpentane



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.

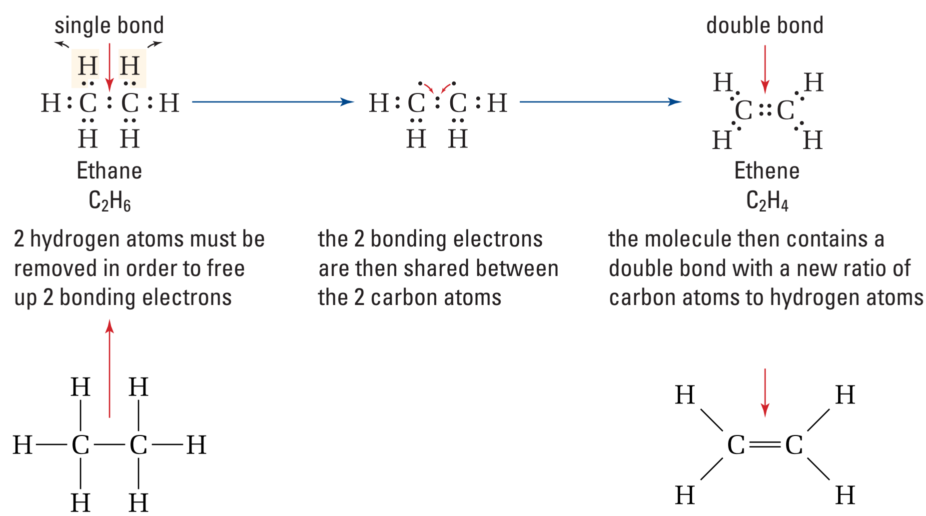


Figure 13.18 **This diagram shows how an ethane molecule can become an ethene molecule. The two hydrogen atoms that are removed from ethane often form hydrogen gas, $H_{2(g)}$.**

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.

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.

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.

Figure 13.19 **Plastics made from ethene**

PROBEWARE

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

SKILL FOCUS

Predicting

Performing and recording

Analyzing and interpreting

Conducting research

Investigation 13-B

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.

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

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

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

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?

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.

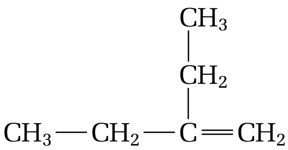


Figure 13.20

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.

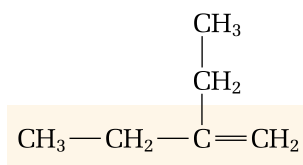
Naming Alkenes

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.

Naming 2-Ethyl-1-Butene

Step 1

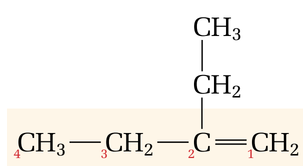
Find the longest continuous chain that contains the double bond. (This step represents the main difference from naming alkanes.)



- 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

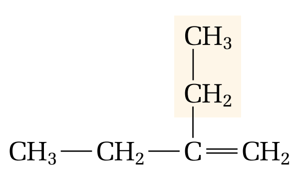
Number the main chain from the end that is closest to the double bond.



- 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.

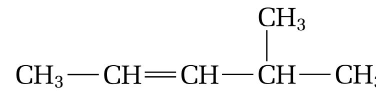


Figure 13.21

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.

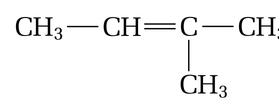


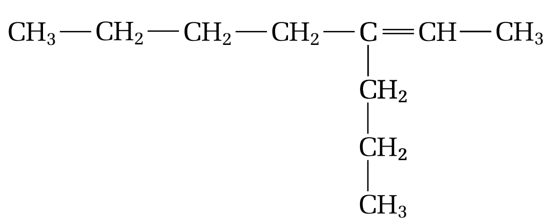
Figure 13.22 **Each carbon atom is bonded four times, once for each valence electron.**

Practice Problems

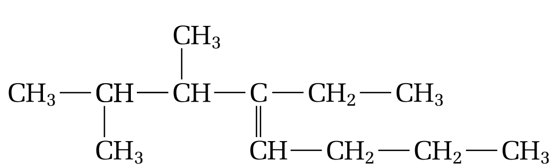
8. Name each hydrocarbon.

(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.

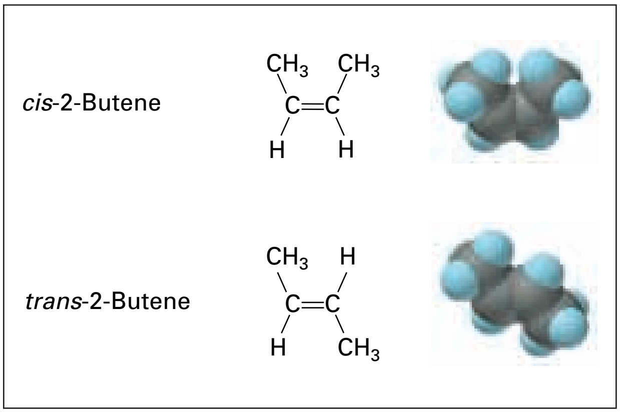


Figure 13.23 **These diagrams show the cis and trans isomers of 2-butene. Notice that the larger methyl groups are on the same side of the double bond (both above) in the cis isomer. They are on opposite sides (one above and one below) in the trans isomer.**

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.

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.

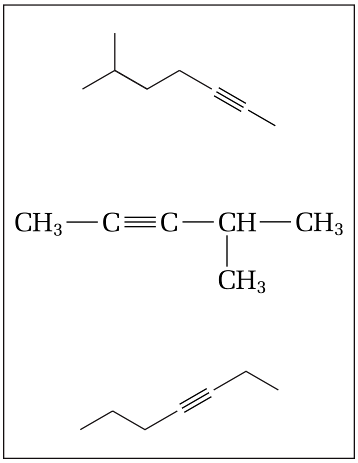
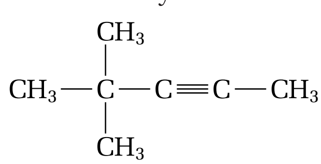


Figure 13.24 **Alkynes are linear around the triple bond, as these examples show.**

Practice Problems

15. Name each alkyne.

(a)



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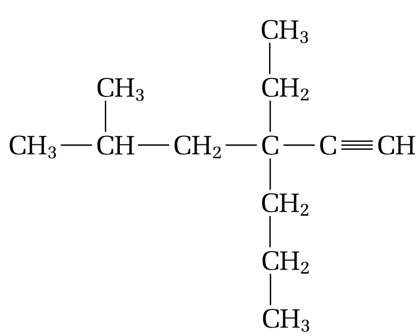


16. Draw a condensed structural diagram for each compound.

(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.

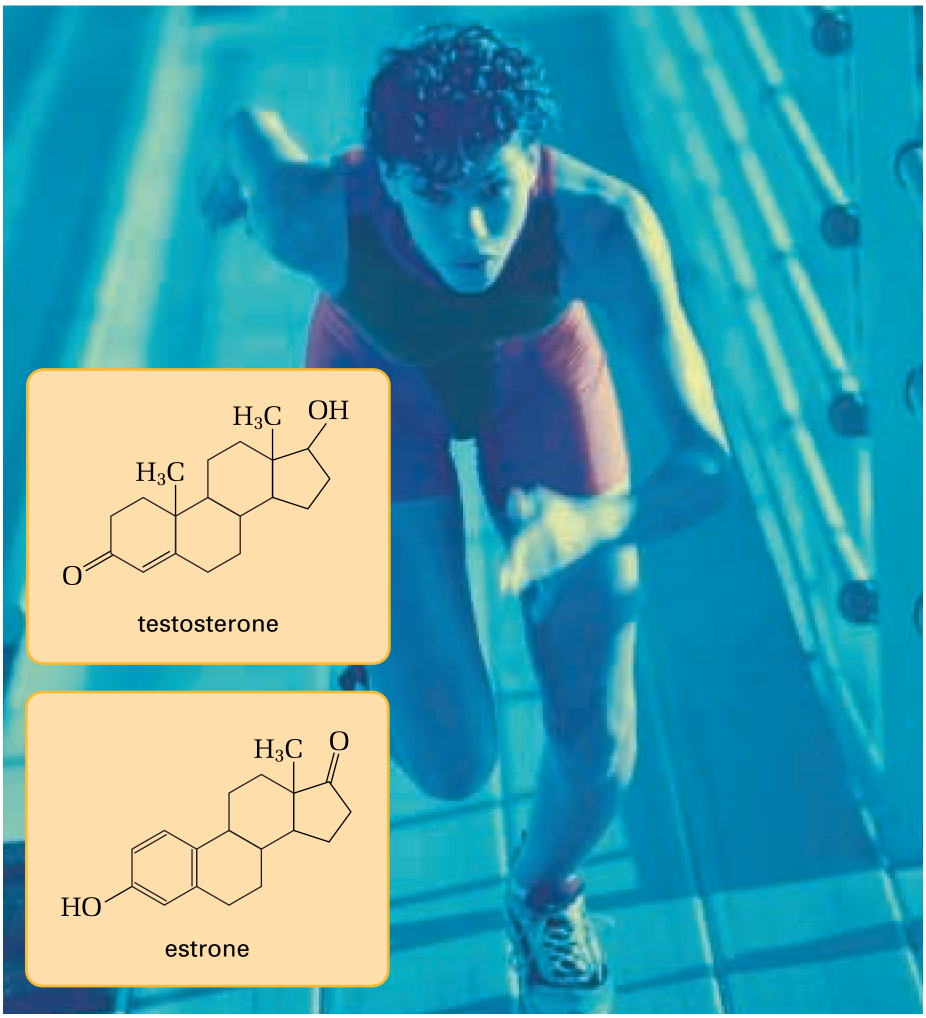


Figure 13.25 **Steroids are organic compounds. Our bodies make steroids naturally. Steroids may also be synthesized in chemical laboratories. What do the structures of these steroids have in common?**

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.

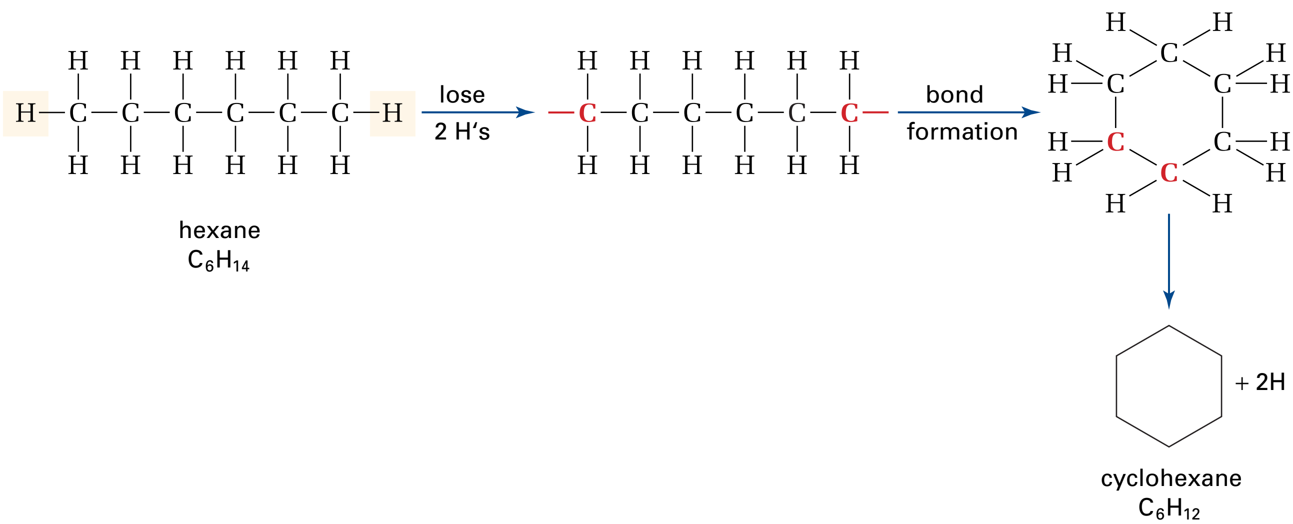


Figure 13.26 **How hexane, C_6H_{14}, can become cyclohexane, C_6H_{12}**

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

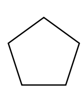


Figure 13.27

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.

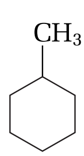


Figure 13.28

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.

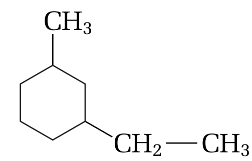


Figure 13.29

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.

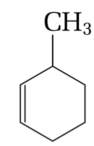
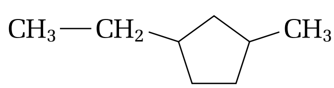


Figure 13.30

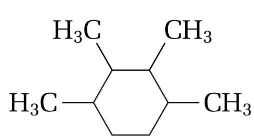
Practice Problems

17. Name each compound.

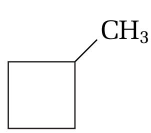
(a)



(b)



(c)



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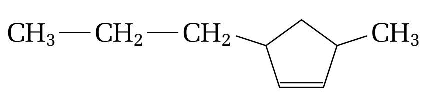

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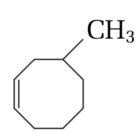

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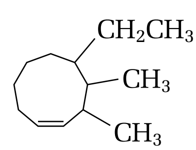

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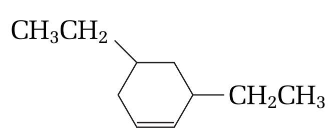

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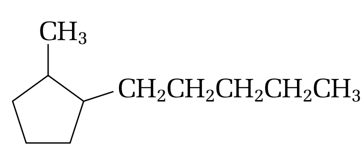


18. Draw a condensed structural diagram for each compound.

(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.)

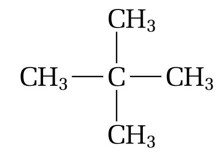


Figure 13.31 **Can you name this alkane?**

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.

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.)

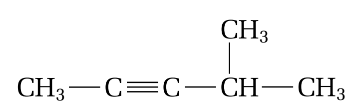


Figure 13.32 **Can you name this alkyne?**

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.

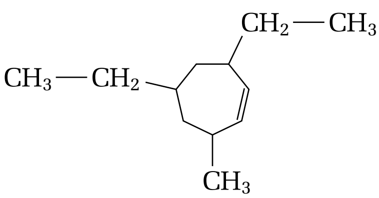


Figure 13.33 Can you name this cycloalkene?

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

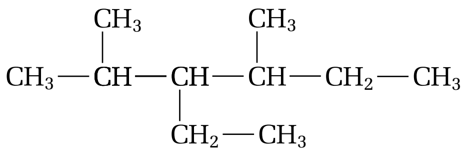
1 **(a)** K/U What are the names of the three types of aliphatic compounds that you studied in this section?

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

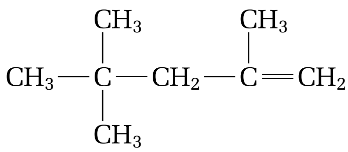
2 K/U List the roots used to name the first ten members of the alkane homologous series. Indicate the number of carbon atoms that each represents.

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

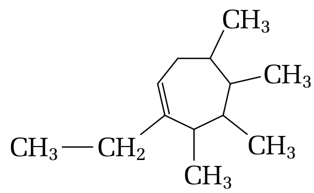
4 **(a)** K/U Name each compound.



(b)



(d)



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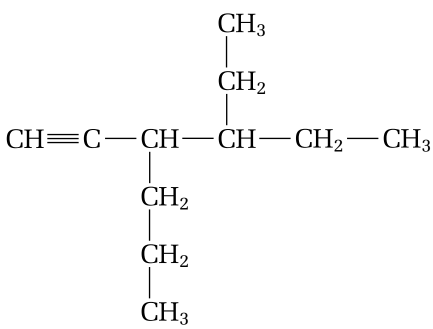


5 C Draw a condensed structural diagram for each compound.

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

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

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

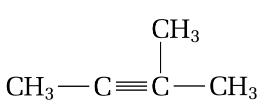
(d) trans-4-methyl-3-heptene

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

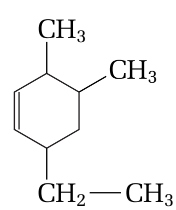
(a) C_3H_4 **(b)** C_5H_{12} **(c)** C_5H_{10}

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