Continued...

**(a)** Draw the structural formula for 4-propyldecane.

**(b)** Write two different balanced equations for the reaction described in this problem.

**(c)** Name the type of combustion. Explain.

## Substitution Reactions of Alkanes

Alkanes react with very few compounds other than oxygen. They are often considered to be almost inert. However, in the presence of ultraviolet light, they will react with halogens in substitution reactions. The reactions are hard to control and result in a mixture of products. For example, both of the following reactions occur in a mixture of butane and chlorine when they are exposed to ultraviolet light.

$$CH_3CH_2CH_2CH_3 + Cl_2 \xrightarrow{UV} CH_3CH_2CH_2CH_2Cl + HCl$$

$$CH_3CH_2CH_2CH_3 + Cl_2 \xrightarrow{UV} CH_3CH_2CHClCH_3 + HCl$$

Analysis of the products shows that 30% of the time, the chlorine atom bonds to a carbon on the end of the butane molecule and 70% of the time, it bonds to a carbon within the chain. You will also find small amounts of products in which chlorine atoms have substituted for more than one hydrogen atom. If enough chlorine is present in a mixture of chlorine and methane, all four possible products will be present as show below.

$$CH_4 + Cl_2 \xrightarrow{UV} CH_3Cl + HCl$$

$$+ \; Cl_2 \xrightarrow{UV} CH_2Cl_2 + HCl$$

$$+ \; Cl_2 \xrightarrow{UV} CHCl_3 + HCl$$

$$+ \; Cl_2 \xrightarrow{UV} CCl_4 + HCl$$

These reactions are not very useful because chemists usually want a specific product. If there are other reactions that will produce the product that they require, chemists will chose the more specific reaction.

So far in this section, you have learned how to name and draw alkanes, the most basic hydrocarbon family. You also examined some physical and chemical properties of alkanes. The next family of hydrocarbons that you will encouter is very similar to the alkane family. Much of what you have already learned can be applied to this next family as well.

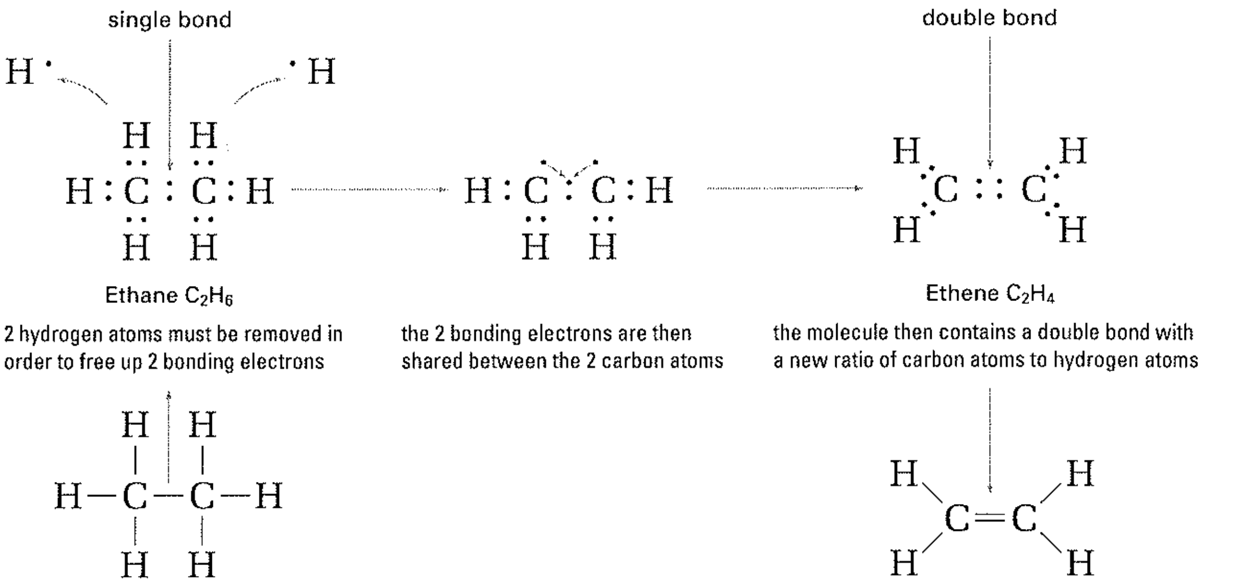
## Alkenes

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 9.18 to see how the presence of a double bond affects the number of hydrogen atoms in an alkene.

**Figure 9.18 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.

**Biology LINK**

According to many nutrition scientists, fats that contain double or triple bonds (unsaturated compounds) are healthier for us than fats 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 number of carbon atoms in the main chain is communicated in the root but the location of the double bond is included in the prefix. Follow the steps below to find out how to name alkenes.

### Rules for Naming Alkenes

**Step 1** **Find the root:** Identify the longest continuous chain that contains the double bond. (This step represents the main difference from naming alkanes.)

**Step 2** **Find the suffix:** If the compound is an alkene, use the suffix *-ene*.

**Step 3** **Give position numbers:** Number the main chain from the end that is closest to the double bond. (The double bond should have the lowest possible position number, even if this means the branches have higher position numbers.) Identify the lowest position number that locates the double bond. If the double bond is between carbons 3 and 4, for example, the position number of the double bond is 3.

**Step 4** **Find the prefix:** Identify and locate the branches. As you did when naming alkanes, put the branches in alphabetical order. Use multiplying prefixes such as di- and tri- as required.

**Step 5** **Put the name together:** prefix + root + suffix

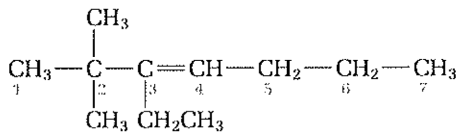
The following Sample Problem gives an example of naming an alkene. Complete the Practice Problems that follow to apply what you have just learned.

## Sample Problem

## Naming an Alkene

### Problem

Name the following alkene.



### Solution

**Step 1** Find the root: The longest chain in the molecule has seven carbon atoms. The root is -hept-.

**Step 2** Find the suffix: The suffix is -ene. The root and suffix together are -heptene.

**Step 3** Numbering the chain from the left, in this case, gives the smallest position number for the double bond.

**Step 4** Find the prefix: Two methyl groups are attached to carbon number 2. One ethyl group is attached to carbon number 3. There is a double bond at position 3. The prefix is 3-ethyl-2,2-dimethyl-3-.

**Step 5** The full name is 3-ethyl-2,2-dimethyl-3-heptene.

In the preceding Sample Problem, you learned how to name 3-ethyl-2,2-dimethyl-3-heptene. In this structure, the double bond and the branches are all at the same end of the main chain. What happens if the double bond is close to one end of the main chain, but the branches are close to the other end? For example, how would you name the compound in Figure 9.19?

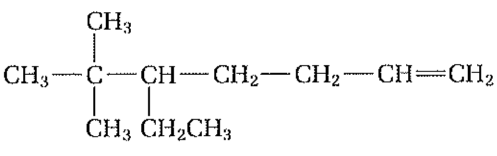


**Figure 9.19** **How does this structure differ from the one in the sample problem?**

The branches are close to the left end of the main chain. The double bond is close to the right end. Therefore, you need to follow the rule in Step 3: *The double bond should have the lowest possible position number.* Now you can name the compound as follows.

- Number the 7 carbon main chain from the right. Give the double bond position number 1. The root and suffix are heptene and the prefix includes a 1.
- There are two methyl groups at position 6 and an ethyl group at position 5. The prefix is 5-ethyl-6, 6-dimethyl-1-.
- The full name is 5-ethyl-6, 6-dimethyl-1-heptene. Although the compound you have just named has a different structural formula than the compound in the Sample Problem above, they both have the same molecular formula: $C_{11}H_{22}$. These compounds are both isomers of $C_{11}H_{22}$. 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. If you carefully analyze the structures in the sample problem and Figure 9.19, you will see that these isomers were made by rearranging the 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 9.20 illustrates this point. Be especially careful with the carbon atoms on each side of the double bond. The double bond is worth two bonds for each carbon. Now complete the Practice Problems to reinforce what you have learned about naming and drawing alkenes.

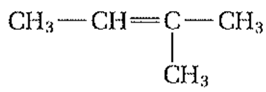
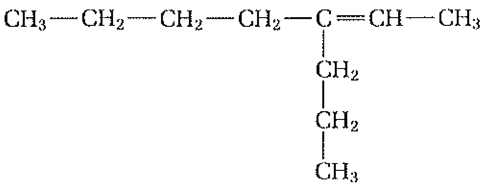


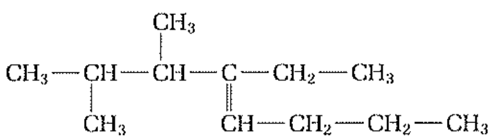
**Figure 9.20** Each carbon atom is bonded four times, once for each valence electron.

### Practice Problems

**17.** Name each hydrocarbon.

**(a)** $CH_3-CH_2-CH=CH-CH_2-CH_3$

**(b)** 

**(c)** 

**18.** Draw a condensed structural diagram for each compound.

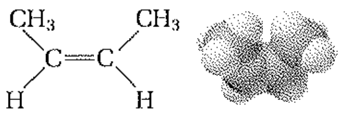
**(a)** 2-methyl-1-butene

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

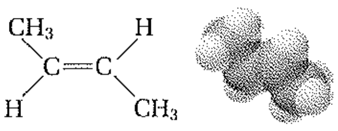
**19.** You have seen that alkenes, such as $C_{11}H_{22}$, can have isomers. Draw condensed structural formulas for the isomers of $C_4H_8$. Then name the isomers.

**PROBLEM TIP**

The easiest way to tell whether or not isomers are true isomers or different sketches of the same compound 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.



*cis*-2-Butene



*trans*-2-Butene

**Figure 9.21** 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. As a result, groups bonded to the carbon atoms that are joined by a double bond, remain on the same side of the double bond. Figure 9.21 shows the geometric isomers of 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 that are attached to the double bonded carbon atoms are on the same side of the double bond.
- In a *trans isomer*, the two larger groups that are attached to the double bonded carbon atoms are on opposite sides of the double bond.

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.

**Web LINK**

**www.mcgrawhill.ca/links/atlchemistry**

Click on the web site given above and go to the **Electronic Learning Partner** to find out more about cis-trans isomers.

### Practice Problems

**20.** Draw and name the cis-trans isomers for $C_5H_{10}$.

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

**22.** 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?

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

## Physical 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 properties that differ from those of saturated compounds. For example, the boiling points of alkenes are usually slightly lower 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 smaller 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 and other non-polar solvents. Alkenes, like all aliphatic compounds, are non-polar. They dissolve in non-polar solvents.

Earlier in this section, you learned that ethene is used to ripen fruit. How does this work? When a fruit ripens, enzymatic reactions in the fruit begin to produce ethene gas which acts as a plant hormone. 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 while they are transported. Once the fruits reach their final destination, ethene can be pumped into the fruit containers to hasten the ripening process.

**PROBEWARE**

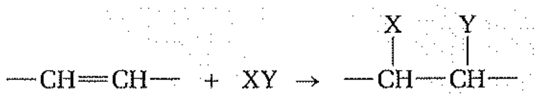
**www.mcgrawhill.ca/links/atlchemistry**

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

## Reactions of Alkenes

Like alkanes, alkenes react with oxygen in complete and incomplete combustion reactions. You can use the same steps you learned earlier for alkanes to write and balance equations for the combustion of alkenes.

As you will see, however, alkenes are much more reactive than alkanes. The reactivity of an alkene takes place around the double bond. Alkenes commonly undergo addition reactions. In an **addition reaction**, atoms are added to a multiple bond. One bond of the multiple bond breaks so that two new bonds can form. To recognize an addition reaction, remember that *two* compounds usually react to form *one* major product or two products that are isomers of each other. The product has more atoms bonded to carbon atoms than the organic reactant did. A general example of addition to an alkene is given below.




The letters XY represent a small molecule that adds to the double bond in the alkene. During the reaction, this small molecule is split up into two parts. Each part of the molecule bonds to one of the carbon atoms that originally formed a double bond. Some common atoms and groups of atoms that can be added to a double bond include:

- H and OH (the reacting molecule is $H_2O$)
- H and Cl (the reacting molecule is HCl. HBr and HI can react in the same way)
- Cl and Cl– (the reacting molecule is $Cl_2$. $Br_2$ and $I_2$ can react in the same way)
- H and H (the reacting molecule is $H_2$)

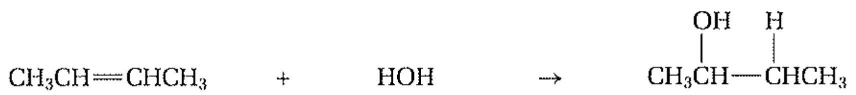
In the following investigation, you will compare the reactivity of alkanes and alkenes.

## Symmetrical and Asymmetrical Addition to Alkenes

The product of an addition reaction depends on the symmetry of the reactants. A *symmetrical alkene* has identical groups on either side of the double bond. Ethene, $CH_2{=}CH_2$, is an example of a symmetrical alkene. An alkene that has different groups on either side of the double bond is called an *asymmetrical alkene*. Propene, $CH_3CH{=}CH_2$, is an example of an asymmetrical alkene.

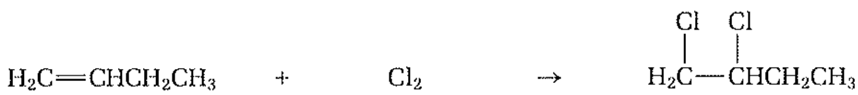
The molecules that are added to a multiple bond can also be classified as symmetrical or asymmetrical. For example, chlorine, $Cl_2$, breaks into two identical parts when it adds to a multiple bond. Therefore, it is a symmetrical reactant. Water, HOH, breaks into two different groups (H and OH) when it adds to a multiple bond, so it is an asymmetrical reactant.

In Figures 9.22 and 9.23, at least one of the reactants is symmetrical. When one or more reactants in an addition reaction are symmetrical, only one product is possible. (You will learn how to name the products of these reactions in the next chapter.)



2-butene (symmetrical) | water (asymmetrical) | 2-butanol

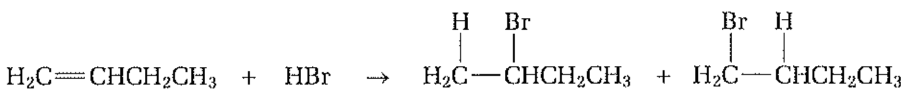
**Figure 9.22** The addition of water to 2-butene



1-butene (asymmetrical) | chlorine (symmetrical) | 1,2-dichlorobutane

**Figure 9.23** The addition of chlorine to 1-butene

When both reactants are asymmetrical, however, more than one product is possible. This is shown in Figure 9.24. The two possible products are isomers of each other.



1-butene (asymmetrical) | hydrobromic acid (asymmetrical) | 2-bromobutane | 1-bromobutane

**Figure 9.24** The addition of hydrobromic acid to 1-butene

Although both products are possible, 2-bromobutane is the observed product. This observation is explained by Markovnikov's rule. **Markovnikov's rule** states that *the halogen atom or OH group in an addition reaction is usually added to the more substituted carbon atom—the carbon atom that is bonded to the largest number of other carbon atoms.* Think of the phrase "the rich get richer." The carbon with the most hydrogen atoms receives even more hydrogen atoms in an addition reaction. According to Markovnikov's rule, the addition of two asymmetrical reactants forms primarily one product. Only a small amount of the other isomer is formed. The following Sample Problem shows how to use Markovnikov's rule to predict the products of addition reactions.

## Sample Problem

### Using Markovnikov's Rule

**Problem**

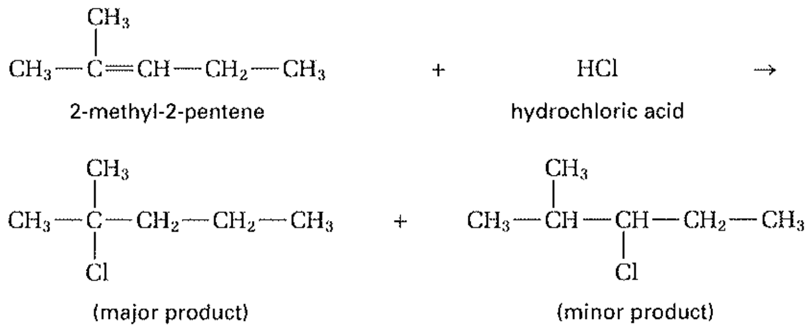
Draw the reactants and products of the following incomplete reaction.

2-methyl-2-pentene + hydrochloric acid →?

Use Markovnikov's rule to predict which of the two isomeric products will form in a greater amount.

**Solution**

According to Markovnikov's rule, *the hydrogen atom will go to the double-bonded carbon with the larger number of hydrogen atoms.* Thus, the chlorine atom will go to the other carbon, which has the larger number of C—C bonds. The product with the chlorine atom on the number 2 carbon (left) will form in the greater amount. Small amounts with the chlorine on the number 3 carbon (right) will also form. (You will learn to name these products in Chapter 10.)




## Practice Problems

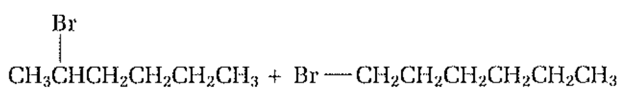
**24.** Draw the reactants and products of the following reaction.

3-ethyl-2-heptene + HOH →

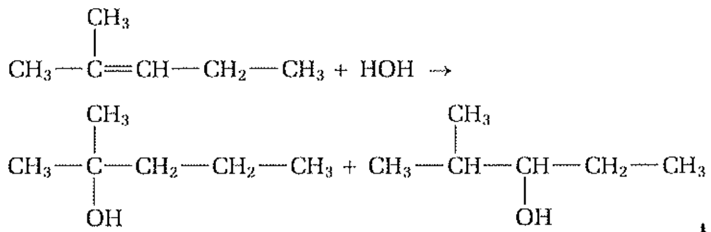
Use Markovnikov's rule to predict which of the two products will form in the greater amount.

**25.** Use Markovnikov's rule to predict which of the two products will form in the greater amount.

**(a)** $CH_2{=}CHCH_2CH_2CH_2CH_3$ + HBr →



**(b)**



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