As noted before, alkenes are hydrocarbons with carbon-to-carbon double bonds (R₂C=CR₂) and alkynes are hydrocarbons with carbon-to-carbon triple bonds (R–C≡C–R). Collectively, they are called unsaturated hydrocarbons because they have fewer hydrogen atoms than does an alkane with the same number of carbon atoms, as is indicated in the following general formulas:

\[
\begin{align*}
\text{C}_n\text{H}_{2n} & \quad \text{An alkane} \\
\text{C}_n\text{H}_2 & \quad \text{An alkene} \\
\text{C}_n\text{H}_{2n-2} & \quad \text{An alkyne}
\end{align*}
\]

Alkenes

Some representative alkenes—their names, structures, and physical properties—are given in Table \(\PageIndex{1}\).

**Table \(\PageIndex{1}\): Physical Properties of Some Selected Alkenes**

<table>
<thead>
<tr>
<th>IUPAC Name</th>
<th>Molecular Formula</th>
<th>Condensed Structural Formula</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethene</td>
<td>C₂H₄</td>
<td>CH₂=CH₂</td>
<td>−169</td>
<td>−104</td>
</tr>
<tr>
<td>propene</td>
<td>C₃H₆</td>
<td>CH₂=CHCH₃</td>
<td>−185</td>
<td>−47</td>
</tr>
<tr>
<td>1-butene</td>
<td>C₄H₈</td>
<td>CH₂=CHCH₂CH₃</td>
<td>−185</td>
<td>−6</td>
</tr>
<tr>
<td>1-pentene</td>
<td>C₅H₁₀</td>
<td>CH₂=CH(CH₂)₂CH₃</td>
<td>−138</td>
<td>30</td>
</tr>
<tr>
<td>1-hexene</td>
<td>C₆H₁₂</td>
<td>CH₂=CH(CH₂)₃CH₃</td>
<td>−140</td>
<td>63</td>
</tr>
<tr>
<td>1-heptene</td>
<td>C₇H₁₄</td>
<td>CH₂=CH(CH₂)₄CH₃</td>
<td>−119</td>
<td>94</td>
</tr>
<tr>
<td>1-octene</td>
<td>C₈H₁₆</td>
<td>CH₂=CH(CH₂)₅CH₃</td>
<td>−102</td>
<td>121</td>
</tr>
</tbody>
</table>

We used only condensed structural formulas in Table \(\PageIndex{1}\). Thus, CH₂=CH₂ stands for

\[
\begin{align*}
\text{CH}_2\text{=CH}_2
\end{align*}
\]

The double bond is shared by the two carbon atoms and does not involve the hydrogen atoms, although the condensed formula does not make this point obvious. Note that the molecular formula for ethene is C₂H₄, whereas that for ethane is C₂H₆.

The first two alkenes in Table \(\PageIndex{1}\), ethene and propene, are most often called by their common names—ethylene and propylene, respectively (Figure \(\PageIndex{1}\)). Ethylene is a major commercial chemical. The US chemical industry produces about 25 billion kilograms of ethylene annually, more than any other synthetic organic
chemical. More than half of this ethylene goes into the manufacture of polyethylene, one of the most familiar plastics. Propylene is also an important industrial chemical. It is converted to plastics, isopropyl alcohol, and a variety of other products.

![Figure 1](PageIndex1) Ethene and Propene. The ball-and-spring models of ethene/ethylene (a) and propene/propylene (b) show their respective shapes, especially bond angles.

Note

Although there is only one alkene with the formula C\(_2\)H\(_4\) (ethene) and only one with the formula C\(_3\)H\(_6\) (propene), there are several alkenes with the formula C\(_4\)H\(_8\).

Here are some basic rules for naming alkenes from the International Union of Pure and Applied Chemistry (IUPAC):

1. The longest chain of carbon atoms containing the double bond is considered the parent chain. It is named using the same stem as the alkane having the same number of carbon atoms but ends in -ene to identify it as an alkene. Thus the compound CH\(_2\)=CHCH\(_3\) is propene.

2. If there are four or more carbon atoms in a chain, we must indicate the position of the double bond. The carbons atoms are numbered so that the first of the two that are doubly bonded is given the lower of the two possible numbers. The compound CH\(_3\)CH=CHCH\(_2\)CH\(_3\), for example, has the double bond between the second and third carbon atoms. Its name is 2-pentene (not 3-pentene).

3. Substituent groups are named as with alkanes, and their position is indicated by a number. Thus,

```
CH\(_3\)CH\(_2\)=CHCH\(_2\)CH\(_3\)
```

is 5-methyl-2-hexene. Note that the numbering of the parent chain is always done in such a way as to give the double bond the lowest number, even if that causes a substituent to have a higher number. The double bond always has priority in numbering.

Example (PageIndex1)

Name each compound.

1.
2.

SOLUTION

1. The longest chain containing the double bond has five carbon atoms, so the compound is a pentene (rule 1). To give the first carbon atom of the double bond the lowest number (rule 2), we number from the left, so the compound is a 2-pentene. There is a methyl group on the fourth carbon atom (rule 3), so the compound’s name is 4-methyl-2-pentene.

2. The longest chain containing the double bond has four carbon atoms, so the parent compound is a butene (rule 1). (The longest chain overall has five carbon atoms, but it does not contain the double bond, so the parent name is not pentene.) To give the first carbon atom of the double bond the lowest number (rule 2), we number from the left, so the compound is a 1-butene. There is an ethyl group on the second carbon atom (rule 3), so the compound’s name is 2-ethyl-1-butene.

Exercise \(\PageIndex{1}\)

Name each compound.

1. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}=\text{CHCH}_3\)

2. \(\text{Just as there are cycloalkanes, there are cycloalkenes. These compounds are named like alkenes, but with the prefix cyclo- attached to the beginning of the parent alkene name.}\)

Example \(\PageIndex{2}\)

Draw the structure for each compound.

1. 3-methyl-2-pentene
2. cyclohexene

SOLUTION

1. First write the parent chain of five carbon atoms: \(\text{C–C–C–C–C}\). Then add the double bond between the second and third carbon atoms:

   \[
   \begin{array}{c}
   1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \\
   \text{C–C = C–C–C–C}
   \end{array}
   \]

   Now place the methyl group on the third carbon atom and add enough hydrogen atoms to give each carbon atom a total of four bonds.

   \[
   \begin{array}{c}
   \text{CH}_3\text{CH=CHCH}_2\text{CH}_3
   \end{array}
   \]

2. First, consider what each of the three parts of the name means. Cyclo means a ring compound, hex means 6
carbon atoms, and -ene means a double bond.

Exercise \( \PageIndex{2} \)

Draw the structure for each compound.

a. 2-ethyl-1-hexene  
b. cyclopentene

Steroisomerism in Alkenes

There is free rotation about the carbon-to-carbon single bonds (C–C) in alkanes. In contrast, the structure of alkenes requires that the carbon atoms of a double bond and the two atoms bonded to each carbon atom all lie in a single plane, and that each doubly bonded carbon atom lies in the center of a triangle. This part of the molecule’s structure is rigid; rotation about doubly bonded carbon atoms is not possible without rupturing the bond. Look at the two chlorinated hydrocarbons in Figure \( \PageIndex{2} \).
Table \(\PageIndex{2}\): Rotation about Bonds. In 1,2-dichloroethane (a), free rotation about the C–C bond allows the two structures to be interconverted by a twist of one end relative to the other. In 1,2-dichloroethene (b), restricted rotation about the double bond means that the relative positions of substituent groups above or below the double bond are significant.

In 1,2-dichloroethane (part (a) of Figure \(\PageIndex{2}\)), there is free rotation about the C–C bond. The two models shown represent exactly the same molecule; they are not isomers. You can draw structural formulas that look different, but if you bear in mind the possibility of this free rotation about single bonds, you should recognize that these two structures represent the same molecule:

![Structural models for 1,2-dichloroethane](image)

In 1,2-dichloroethene (part (b) of Figure \(\PageIndex{2}\)), however, restricted rotation about the double bond means that the relative positions of substituent groups above or below the double bond become significant. This leads to a special kind of isomerism. The isomer in which the two chlorine (Cl) atoms lie on the same side of the molecule is called the cis isomer (Latin *cis*, meaning "on this side") and is named cis-1,2-dichloroethene. The isomer with the two Cl atoms
on opposite sides of the molecule is the trans isomer (Latin *trans*, meaning “across”) and is named *trans*-1,2-dichloroethene. These two compounds are cis-trans isomers (or geometric isomers), compounds that have different configurations (groups permanently in different places in space) because of the presence of a rigid structure in their molecule.

Consider the alkene with the condensed structural formula CH₃CH=CHCH₃. We could name it 2-butene, but there are actually two such compounds; the double bond results in cis-trans isomerism (Figure 7).

Table 7: Ball-and-Spring Models of (a) Cis-2-Butene and (b) Trans-2-Butene. Cis-trans isomers have different physical, chemical, and physiological properties.

Cis-2-butene has both methyl groups on the same side of the molecule. Trans-2-butene has the methyl groups on opposite sides of the molecule. Their structural formulas are as follows:

Note, however, that the presence of a double bond does not necessarily lead to cis-trans isomerism. We can draw two seemingly different propenes:

However, these two structures are not really different from each other. If you could pick up either molecule from the page and flip it over top to bottom, you would see that the two formulas are identical. Thus there are two requirements for cis-trans isomerism:

1. Rotation must be restricted in the molecule.
2. There must be two nonidentical groups on *each* doubly bonded carbon atom.

In these propene structures, the second requirement for cis-trans isomerism is not fulfilled. One of the doubly bonded carbon atoms does have two different groups attached, but the rules require that *both* carbon atoms have two different groups. In general, the following statements hold true in cis-trans isomerism:

- Alkenes with a C=CH₂ unit do not exist as cis-trans isomers.
- Alkenes with a C=CR₂ unit, where the two R groups are the same, do not exist as cis-trans isomers.
• Alkenes of the type R–CH=CH–R can exist as cis and trans isomers: cis if the two R groups are on the same side of the carbon-to-carbon double bond, and trans if the two R groups are on opposite sides of the carbon-to-carbon double bond.

Cis-trans isomerism also occurs in cyclic compounds. In ring structures, groups are unable to rotate about any of the ring carbon–carbon bonds. Therefore, groups can be either on the same side of the ring (cis) or on opposite sides of the ring (trans). For our purposes here, we represent all cycloalkanes as planar structures, and we indicate the positions of the groups, either above or below the plane of the ring.

Example \(\PageIndex{3}\)

Which compounds can exist as cis-trans (geometric) isomers? Draw them.

1. \(\text{CHCl} = \text{CHBr}\)
2. \(\text{CH}_2 = \text{CBrCH}_3\)
3. \((\text{CH}_3)_2 \text{C} = \text{CHCH}_2\text{CH}_3\)
4. \(\text{CH}_3\text{CH}=\text{CHCH}_2\text{CH}_3\)

**SOLUTION**

All four structures have a double bond and thus meet rule 1 for cis-trans isomerism.

1. This compound meets rule 2; it has two nonidentical groups on each carbon atom (H and Cl on one and H and Br on the other). It exists as both cis and trans isomers:

2. This compound has two hydrogen atoms on one of its doubly bonded carbon atoms; it fails rule 2 and does not exist as cis and trans isomers.
3. This compound has two methyl (CH\(_3\)) groups on one of its doubly bonded carbon atoms. It fails rule 2 and does not exist as cis and trans isomers.
4. This compound meets rule 2; it has two nonidentical groups on each carbon atom and exists as both cis and trans isomers:

Exercise \(\PageIndex{3}\)

Which compounds can exist as cis-trans isomers? Draw them.
a. \( \text{CH}_2=\text{CHCH}_2\text{CH}_2\text{CH}_3 \)

b. \( \text{CH}_3\text{CH}=\text{CHCH}_2\text{CH}_3 \)

c. \( \text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_2\text{CH}_3 \)

d. \( \begin{align*}
\text{CH}_2=\text{CH}_2\text{CH}_3 \\
\text{CH}_3
\end{align*} \)

e. \( \begin{align*}
\text{CH}_3\text{C}=\text{CHCH}_3 \\
\text{CH}_3
\end{align*} \)

---

**E,Z Convention**

E,Z Convention is a method used to specify relative configuration at carbon atoms in alkene groups. According to E,Z convention, if the pair of carbon atoms in an alkene group could exist in two relative configurations, one is designated using the label E and the other the label Z.

![E,Z Convention Diagram](image)

To determine whether an alkene group is E or Z, use the following two-step procedure.

**Step 1:** Assign priority numbers to the two ligands on each carbon atom in the alkene group. (See R,S convention for the procedure.)

**Step 2:**

<table>
<thead>
<tr>
<th>Like-numbered Ligands</th>
<th>Relative Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same side of double bond</td>
<td>Z</td>
</tr>
<tr>
<td>Opposite side of double bond</td>
<td>E</td>
</tr>
</tbody>
</table>
Alkynes

The simplest alkyne—a hydrocarbon with carbon-to-carbon triple bond—has the molecular formula $\text{C}_2\text{H}_2$ and is known by its common name—acetylene (Figure \(\PageIndex{1}\)). Its structure is $\text{H–C≡C–H}$. (Figure \(\PageIndex{4}\): Ball-and-Spring Model of Acetylene. Acetylene (ethyne) is the simplest member of the alkyne family.

Note

Acetylene is used in oxyacetylene torches for cutting and welding metals. The flame from such a torch can be very hot. Most acetylene, however, is converted to chemical intermediates that are used to make vinyl and acrylic plastics, fibers, resins, and a variety of other products.

Alkynes are similar to alkenes in both physical and chemical properties. For example, alkynes undergo many of the typical addition reactions of alkenes. The International Union of Pure and Applied Chemistry (IUPAC) names for alkynes parallel those of alkenes, except that the family ending is -yne rather than -ene. The IUPAC name for acetylene is ethyne. The names of other alkynes are illustrated in the following exercises.