Organic chemistry is the study of carbon-containing compounds.

### 7.1 Bonding in Organic Compounds

Organic compounds are made up of only a few elements and the bonding is almost entirely covalent. The following table gives the “bonding requirements” of the elements commonly present in organic compounds.

<table>
<thead>
<tr>
<th>Element</th>
<th>Number of bonds</th>
<th>Bonding representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>4</td>
<td>—C— ( \text{or} ) ( - \text{C=} ) ( \text{or} ) ( - \text{C}≡ )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 single bonds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 single and 1 double bonds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 single and 1 triple bonds</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>H—</td>
</tr>
<tr>
<td>O</td>
<td>2</td>
<td>—O— ( \text{or} ) O=</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 single bonds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 double bond</td>
</tr>
<tr>
<td>N</td>
<td>3</td>
<td>—N—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 single bonds</td>
</tr>
<tr>
<td>F, Cl, Br, I</td>
<td>1</td>
<td>F— Cl— Br— I—</td>
</tr>
</tbody>
</table>

### 7.2 The Organization of Organic Compounds: Functional Groups

Millions of organic compounds have been discovered or made by chemists. This enormous number of compounds can be divided into relatively small number of classes according to the functional groups they contain.

A **functional group** is an atom, group of atoms, or bond that is present in each molecule of a class of compounds.

Table 7.1 summarizes some of the major classes of organic compounds.
Table 7.1 Some important classes of organic compounds.

<table>
<thead>
<tr>
<th>Class</th>
<th>Functional group</th>
<th>Example</th>
<th>Name ending</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkane</td>
<td>None</td>
<td>CH$_3$—CH$_3$</td>
<td>-ane</td>
</tr>
<tr>
<td>Alkene</td>
<td></td>
<td>CH$_2$—CH$_2$</td>
<td>-ene</td>
</tr>
<tr>
<td>Alkyne</td>
<td></td>
<td>CH≡CH</td>
<td>-yne</td>
</tr>
<tr>
<td>Aromatics</td>
<td></td>
<td>H–H</td>
<td>None</td>
</tr>
<tr>
<td>Alcohol</td>
<td>C–OH</td>
<td>CH$_3$–OH</td>
<td>-ol</td>
</tr>
<tr>
<td>Ether</td>
<td></td>
<td>CH$_3$–O–CH$_3$</td>
<td>None</td>
</tr>
<tr>
<td>Aldehyde</td>
<td>O–C=H</td>
<td>CH$_3$–C=H</td>
<td>-al</td>
</tr>
<tr>
<td>Ketone</td>
<td>C–O=C</td>
<td>CH$_3$–C=CH$_3$</td>
<td>-one</td>
</tr>
<tr>
<td>Carboxylic acid</td>
<td>C=O–OH</td>
<td>CH$_3$–C–OH</td>
<td>-ic acid</td>
</tr>
<tr>
<td>Ester</td>
<td></td>
<td>CH$_3$–C=O–CH$_3$</td>
<td>-ate</td>
</tr>
<tr>
<td>Amine</td>
<td>C–N</td>
<td>CH$_3$–NH$_2$</td>
<td>-amine</td>
</tr>
<tr>
<td>Amide</td>
<td></td>
<td>CH$_3$–C–NH$_2$</td>
<td>-amide</td>
</tr>
</tbody>
</table>
### 7.3 Hydrocarbons

The first four classes of organic compounds in Table 7.1 are known as hydrocarbons. A **hydrocarbon** is a compound composed of entirely carbon and hydrogen atoms. Hydrocarbons are classified as aromatic compounds (containing benzene rings) and aliphatics (all other hydrocarbons).

<table>
<thead>
<tr>
<th>Hydrocarbons</th>
<th>Alkanes</th>
<th>Alkenes</th>
<th>Alkynes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aliphatics</td>
<td>contain only <strong>single</strong> bonds</td>
<td>contain at least one <strong>double</strong> bond</td>
<td>contain at least one <strong>triple</strong> bond</td>
</tr>
<tr>
<td>Aromatics</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Alkanes: The Simplest Organic Compounds

Alkanes are called *saturated* hydrocarbons because only *single bonds* connect carbons to each other and to other hydrogen atoms. The molecular formula of all alkanes fit the general formula \( \text{C}_n\text{H}_{2n+2} \), where \( n \) equals the number of carbon atoms.

There are several methods used to represent organic molecules. The **molecular formula** tells the kind and number of each type of atom in a molecule but does not show the bonding pattern. The **expanded structural formula** shows each atom and bond in a molecule. The **condensed structural formula** shows all the atoms in a molecule and place them in a sequential order that indicates which atoms are bonded to which. The **line formula**, a carbon atom is understood to be at every intersection of lines and hydrogen atoms are filled mentally.

Consider butane \( \text{(C}_4\text{H}_{10}) \) as an example.

- **molecular formula**: \( \text{C}_4\text{H}_{10} \)
- **expanded structural formula**: \[ \text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_3 \]
- **condensed structural formula**: \[ \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3 \]
- **line formula**: \[ \sim \]
Practice 7-1

Draw the expanded structural formula, condensed structural formula, and line formula for hexane (C\textsubscript{6}H\textsubscript{14}).

Answer

\[
\begin{array}{c}
\text{C}_6\text{H}_{14} \\
\text{molecular formula} \\
\text{expanded structural formula} \\
\text{condensed structural formula} \\
\text{line formula} \\
\end{array}
\]

Names and Structures of the first ten Continuous-Chain Alkanes

<table>
<thead>
<tr>
<th>*Name</th>
<th>molecular formula</th>
<th>condensed structural formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH\textsubscript{4}</td>
<td>CH\textsubscript{4}</td>
</tr>
<tr>
<td>Ethane</td>
<td>C\textsubscript{2}H\textsubscript{6}</td>
<td>CH\textsubscript{3}CH\textsubscript{3}</td>
</tr>
<tr>
<td>Propane</td>
<td>C\textsubscript{3}H\textsubscript{8}</td>
<td>CH\textsubscript{3}(CH\textsubscript{2})CH\textsubscript{3}</td>
</tr>
<tr>
<td>Butane</td>
<td>C\textsubscript{4}H\textsubscript{10}</td>
<td>CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{2}CH\textsubscript{3}</td>
</tr>
<tr>
<td>Pentane</td>
<td>C\textsubscript{5}H\textsubscript{12}</td>
<td>CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{3}CH\textsubscript{3}</td>
</tr>
<tr>
<td>Hexane</td>
<td>C\textsubscript{6}H\textsubscript{14}</td>
<td>CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{4}CH\textsubscript{3}</td>
</tr>
<tr>
<td>Heptane</td>
<td>C\textsubscript{7}H\textsubscript{16}</td>
<td>CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{5}CH\textsubscript{3}</td>
</tr>
<tr>
<td>Octane</td>
<td>C\textsubscript{8}H\textsubscript{18}</td>
<td>CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{6}CH\textsubscript{3}</td>
</tr>
<tr>
<td>Nonane</td>
<td>C\textsubscript{9}H\textsubscript{20}</td>
<td>CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{7}CH\textsubscript{3}</td>
</tr>
<tr>
<td>Decane</td>
<td>C\textsubscript{10}H\textsubscript{22}</td>
<td>CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{8}CH\textsubscript{3}</td>
</tr>
</tbody>
</table>

*The IUPAC system (International Union of Pure and Applied Chemistry) determines the protocol for naming organic compounds.
Isomers
Molecules that have the same molecular formula but different structural formulas are called structural isomers.
Structural isomers are possible in all alkanes containing four or more carbon atoms.

For example, we can write two different structural isomers for butane, C₄H₁₀, a straight chain and a branched chain isomer:

\[
\begin{align*}
\text{CH}_3 &- \text{CH}_2 - \text{CH}_2 - \text{CH}_3 \\
\text{CH}_3 &- \text{CH} - \text{CH}_3
\end{align*}
\]

Straight-chain       Branched-chain

Worked Example 7-1
Draw all structural isomers having the molecular formula C₅H₁₂.

Solution
continuous chain

Write five carbon atoms linked together to form a chain:

\[
\text{C} - \text{C} - \text{C} - \text{C} - \text{C} -
\]

Attach hydrogen atoms to the carbon atoms so each carbon atom forms four bonds.

\[
\begin{align*}
\text{H} &- \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\
\text{H} &- \text{H} - \text{H} - \text{H} - \text{H}
\end{align*}
\]

condensed form: CH₃—CH₂—CH₂—CH₂—CH₃

branched chains

Now try a four-carbon chain structure with a methyl group attached to one of the internal carbon atoms of the chain.

\[
\begin{align*}
\text{CH}_3 &- \text{CH} - \text{CH}_2 - \text{CH}_3 \\
\text{CH}_3 &- \text{CH}_2 - \text{CH} - \text{CH}_3
\end{align*}
\]

Next consider the possibilities of three-carbon structure to which two methyl groups may be attached.

\[
\begin{align*}
\text{CH}_3 &- \text{C} - \text{CH}_3 \\
\text{CH}_3 &- \text{C} - \text{CH}_3
\end{align*}
\]

\[
\begin{align*}
\text{CH}_3 &- \text{CH}_2 - \text{CH} - \text{CH}_3 \\
\text{CH}_3 &- \text{CH}_2 - \text{CH} - \text{CH}_3
\end{align*}
\]
Worked Example 7-2

Draw all structural isomers of C₆H₁₄.

Solution

continuous chain
CH₃−CH₂−CH₂−CH₂−CH₂−CH₃

branched chains

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3 \\
\text{CH}_3−\text{CH}−\text{CH}_2−\text{CH}_2−\text{CH}_3 & \quad \text{CH}_3−\text{CH}_2−\text{CH}−\text{CH}_2−\text{CH}_3 \\
\text{CH}_3−\text{CH}−\text{CH}−\text{CH}_3 & \quad \text{CH}_3−\text{CH}−\text{CH}_2−\text{CH}_3 \\
\text{CH}_3 & \quad \text{CH}_3
\end{align*}
\]

7.4 IUPAC Naming of Branched-Chain Alkanes

When naming branched-chain alkanes, we must name the branch(s) that are attached to the main-chain. If the branches (substituted groups) are smaller chain hydrocarbons they are called alkyl groups.

An alkyl group is a group derived by removing a single hydrogen atom from an alkane molecule, thus creating a point of attachment. The letter “R” is used as a general symbol for alkyl groups.

<table>
<thead>
<tr>
<th>Alkane</th>
<th>Alkyl</th>
<th>-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>methane ((\text{CH}_4))</td>
<td>methyl</td>
<td>−CH₃</td>
</tr>
<tr>
<td>ethane ((\text{CH}_3\text{CH}_3))</td>
<td>ethyl</td>
<td>−CH₂CH₃</td>
</tr>
<tr>
<td>propane ((\text{CH}_3\text{CH}_2\text{CH}_3))</td>
<td>{ propyl, isopropyl }</td>
<td>{ −CH₂CH₂CH₃, CH₃CHCH₃ }</td>
</tr>
</tbody>
</table>
IUPAC Rules for Naming Branched-Chain Alkanes

I) An Alkane With Only One Branch

1. Determine the name of the parent chain, the longest continuous carbon chain in the alkane.
2. The parent chain is numbered from the end nearest to the alkyl group. Give the alkyl group (the branch) a name and a number. Use a hyphen to connect the number to the name.
3. Write the name as single word.

**Worked Example 7-3**

Name the following alkane:

\[
\text{CH}_3 \\
\text{CH}_3\text{CH}_2\text{CH}\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3
\]

**Solution**

1. The longest continuous chain contains seven carbon atoms (heptane).
2. There is one methyl group on the chain on carbon 3: “3-methyl” (the numbering must be from the left to give the lowest number to the branch).
3. The correct name is 3-methylheptane.

II) An Alkane With More Than One Branch

Where Branches Are Identical

1. Determine the name of the parent chain, the longest continuous carbon chain in the alkane.
2. The parent chain is numbered from the end nearer the first alkyl group. Give each alkyl group a name and a number. Use hyphens to separate the numbers from the different prefixes and commas to separate numbers. If two or more identical alkyls are present, use one of the prefixes di-, tri-, tetra-, and so forth, to the name of the alkyl.
3. Write the name as single word.
Worked Example 7-4

Name the following alkane:

\[
\begin{array}{c}
\text{CH}_3 \\
\text{CH}_3 \\
\text{CH}_3-\text{CH}-\text{CH}_2-\text{CH}-\text{CH}_2-\text{CH}_3 \\
\text{CH}_3 \quad \text{CH}_3
\end{array}
\]

Solution
1. The longest continuous chain contains seven carbon atoms (heptane).
2. There are four methyl groups on the chain: two methyl groups are on carbon 3, one CH\(_3\) on carbon 2, and one CH\(_3\) on carbon 5.
3. The correct name is **2,3,3,5-tetramethylheptane**.

III) An Alkane With More Than One Branch Where Branches Are Different

1. Determine the name of the parent chain, the longest continuous carbon chain in the alkane.
2. The parent chain is numbered from the end nearer the first alkyl group. Give each alkyl group a name and a number. Use hyphens to separate numbers from words; use commas to separate numbers. If different alkyl groups are present, write them in alphabetical order. If necessary, use one of the prefixes di-, tri-, tetra-, and so forth, but don’t use them for alphabetizing purposes.
3. Write the name as single word.

Worked Example 7-5

Name the following alkane:

\[
\begin{array}{c}
\text{CH}_2\text{CH}_3 \\
\text{CH}_3-\text{CH}-\text{CH}-\text{CH}_2-\text{CH}_2-\text{CH}_3 \\
\text{CH}_3 \quad \text{CH}_3
\end{array}
\]

Solution
1. The longest continuous chain contains seven carbon atoms (heptane).
2. There are three branches: two methyl groups on carbon 2 and 3; one ethyl group on carbon 4. Write the alkyl groups in alphabetical order (ethyl before methyl).
3. The correct name is **4-ethyl-2,3-dimethylheptane**.
**Practice 7-2**

Name each of the following compounds:

a) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3 \)

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

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

Answer

```
\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3

\text{CH}_3\text{CH}_2\text{CHCH}_2\text{CH}_3

\text{CH}_3\text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_3
```

**Practice 7-3**

Draw structure for each of the following compounds:

a) 3-ethyl-2-methylhexane

b) 2,2,5-trimethylheptane

c) 4,6-diethyl-6-methylnonane

d) 4-ethyl-4-isopropylloctane

Answer

```
\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3

\text{CH}_3\text{CH}_2\text{CHCH}_2\text{CH}_3

\text{CH}_3\text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_3
```

7.5 Cycloalkanes

A cycloalkane is an alkane in which carbon atoms are connected to one another in a cyclic (ring) arrangement. Cycloalkanes have two fewer hydrogen atoms than the corresponding alkanes.

Cycloalkanes are commonly represented using geometric formulas in which each corner of the figure represents a carbon atom and its attached hydrogen atoms.

Substituted cycloalkanes are named by identifying and numbering the position of groups on the ring, followed by the name of the parent cycloalkane. The ring numbering begins with the carbon attached the first carbon alphabetically and proceeds around the ring in the direction that will give the lowest numbers for the positions of the other attached groups.

1-ethyl-3-propylcyclohexane  1,2-dimethylcyclohexane  1-bromo-3-ethylcyclohexane

The position of single attached group does not need to be specified in the name because all positions in the ring are equivalent.
**Worked Example 7-6**

Draw the geometric formula for each of the following:

a) 1-ethyl-2-methylcyclobutane
b) 1-methyl-2-propylcyclopentane
c) 1,3,5-triethylcyclohexane

**Solution**

![Geometric formulas for alkanes](image)

---

**7.6 Reactions of Alkanes**

1. **Combustion** is a reaction between a substance and oxygen (usually from air) that proceeds with the evolution of heat and light.

   \[ \text{alkane} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{energy} \]

   \[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{energy} \]

**Worked Example 7-7**

Write a balanced equation for the combustion of pentane.

**Solution**

\[ \text{C}_5\text{H}_{12} + 8\text{O}_2 \rightarrow 5\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy} \]
2. **Halogenation** is a reaction between a substance and a halogen (group VIIA) in which one or more halogens are incorporated into molecules of a substance.

alkane + halogen → halogenated alkane + hydrogen halide

$$\text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl} \quad \text{(Light or heat is needed for the reaction.)}$$

**Nomenclature of Halogenated Alkanes**
Halogen atoms are called fluoro- (F), chloro- (Cl), bromo- (Br), or iodo- (I).

**Practice 7-4**
Draw structural formula for each of the following:

a) 2,3-dichloropentane  
b) 2-bromo-3,4-difluorohexane  
c) 1,1-diiodocyclobutane  
d) 1,2-dibromo-3-methylcyclohexane

**Answer**

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>b)</td>
<td>c)</td>
<td>d)</td>
<td></td>
</tr>
</tbody>
</table>

7.7 **Alkenes and Alkynes**

Alkenes and alkynes are *unsaturated hydrocarbons* because their molecules do not contain the maximum possible number of hydrogen atoms. **Alkenes** are hydrocarbons that have at least one carbon-carbon double bond (\(\overset{\text{\_\_\_\_}}{\text{C=C\_\_\_\_}}\)).

**General formula for alkenes:** $\text{C}_n\text{H}_{2n}$

**Alkynes** are hydrocarbons that have at least one carbon-carbon triple bond (\(-\text{C=\_\_\_\_\_\_C-}\)).

**General formula for alkynes:** $\text{C}_n\text{H}_{2n-2}$
Alkenes and alkynes are named similar to the IUPAC rules used for naming alkanes.

**Guideline:**
- The parent name is the longest chain that has a carbon-carbon multiple bond.
- Number from the end closest to the multiple bond.
- Names of alkenes end with “ene” and alkynes end with “yne”.

\[
\text{CH}_3-\text{CH}≡\text{CH}-\text{CH}_2-\text{CH}_3 \quad \text{2-pentene}
\]

\[
\text{CH}_3-\text{C≡C}-\text{CH}_2-\text{CH}_2-\text{CH}_3 \quad \text{2-hexyne}
\]

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3 \\
\text{CH}_3-\text{CH}-\text{CH}≡\text{CH}-\text{CH}≡\text{C}-\text{CH}_3 & \quad \text{2,5-dimethyl-3-hexene}
\end{align*}
\]

\[
\begin{align*}
\text{CH}_2-\text{CH}_3 & \\
\text{CH}_3-\text{C≡C}-\text{CH}-\text{CH}_2-\text{CH}_2-\text{CH}_3 & \quad \text{4-ethyl-2-heptyne}
\end{align*}
\]

cyclopentene

3,6-dimethylcyclohexene
**Practice 7-5**

Give the IUPAC name for each of the following:

a) \(\text{CH}_2\equiv\text{CH}—\text{CH}_2—\text{CH}_3\)  

b) \(\text{CH}_3—\text{CH}_2—\text{CH}=\text{CH}_2\)  

c) \(\text{CH}_3\)

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

d) \(\text{CH}_3—\text{C}≡\text{C}—\text{CH}—\text{CH}—\text{CH}—\text{CH}_3\)

Answer

---

**Common Names (non-IUPAC Names)**

A small number of organic compounds have common names (non-IUPAC) that are used almost exclusively to identify them. These compounds are usually the smallest members of a particular class often containing only a few carbons. You need to be familiar to these names.

<table>
<thead>
<tr>
<th>IUPAC name</th>
<th>CH(_2) = CH(_2)</th>
<th>CH = CH</th>
<th>Common name</th>
</tr>
</thead>
</table>

- **Ethene**
- **Ethyne**

**7.9 Geometric Isomers**

Unlike alkanes, there is no free rotation around a carbon-carbon double bond in alkenes. If both carbons of the double bond have *two different groups* attached, *cis* and *trans* isomers exist.

- **Cis** isomer: two substituted groups are on the same side of double bond.
- **Trans** isomer: two substituted groups are on opposite sides of double bond.
Consider ethene:

\[
\begin{array}{c}
\text{H} \\
\text{C} \equiv \text{C} \\
\text{H} \\
\end{array}
\]

If one of the hydrogen atoms attached to each of the carbon atoms in ethene is replaced by a bromine atom, two distinct compounds are formed:

\[
\begin{array}{c}
\text{Br} \\
\text{C} \equiv \text{C} \\
\text{Br} \\
\text{H} \\
\end{array}
\quad \text{cis-1,2-dibromoethene}
\quad \text{(bromines on same side)}
\]

\[
\begin{array}{c}
\text{Br} \\
\text{C} \equiv \text{C} \\
\text{H} \\
\text{Br} \\
\end{array}
\quad \text{trans-1,2-dibromoethene}
\quad \text{(bromines on different sides)}
\]

This type of isomerism is called \textit{cis-trans isomerism}. The prefix \textit{cis} and \textit{trans} are derived from the Latin; \textit{cis-} “on this side” and \textit{trans-} “across.”

**Worked Example 7-8**

Give the name of the following alkenes, using \textit{cis} or \textit{trans}.

(a) \[
\begin{array}{c}
\text{CH}_3 \\
\text{C} \equiv \text{C} \\
\text{H} \\
\end{array}
\]

(b) \[
\begin{array}{c}
\text{CH}_3 \\
\text{C} \equiv \text{C} \\
\text{H} \\
\text{CH}_2\text{CH}_3
\end{array}
\]

**Solution**

a) The longest chain has 5 carbons with the double bond starts at carbon 2. The name is 2-pentene. The two identical groups (the hydrogen atoms) are on the same side of the double, so we use the prefix “\textit{cis}”. The full name is \textit{cis-2-pentene}.

b) The longest chain has 5 carbons with the double bond starts at carbon 2. The name is 2-pentene. The two identical groups (the hydrogen atoms) are on the opposite side of the double bond, so we use the prefix “\textit{trans}”. The full name is \textit{trans-2-pentene}. 

7-15
The most common reactions of alkenes are addition reactions. In an addition reaction, the double bond is broken and a single bond is formed at each carbon to new atoms or groups of atoms.

A generalized addition reaction is shown here:

\[
\text{C} = \text{C} + \text{A-B} \rightarrow \text{C-C}
\]

1) Addition of H₂: Hydrogenation

\[
\text{C} = \text{C} + \text{H-H} \xrightarrow{\text{catalyst}} \text{C-C}
\]

2) Addition of Cl₂ or Br₂: Halogenation

\[
\text{C} = \text{C} + \text{Cl-Cl} \rightarrow \text{C-Cl}
\]

3) Addition of H₂O: Hydration

\[
\text{C} = \text{C} + \text{H-OH} \xrightarrow{\text{acid [H⁺]}} \text{C-H}
\]
Worked Example 7-9

Give the organic product formed in each of the following reactions:

\[
\text{CH}_3\text{-CH}≡\text{CH} \cdot \text{CH}_3 + \text{H}_2 \xrightarrow{\text{catalyst}}
\]

\[
\text{CH}_3\text{-CH}≡\text{CH} \cdot \text{CH}_2 \cdot \text{CH}_3 + \text{Cl}_2
\]

\[
\text{H}_2\text{O} \xrightarrow{[\text{H}^+]} \text{[Water added to benzene.]}\]

Solution

\[
\text{CH}_3\text{-CH}≡\text{CH} \cdot \text{CH}_3 + \text{H}_2 \xrightarrow{\text{catalyst}} \text{CH}_3\text{-CH} \cdot \text{CH}_2 \cdot \text{CH}_3
\]

\[
\text{CH}_3\text{-CH}≡\text{CH} \cdot \text{CH}_2 \cdot \text{CH}_3 + \text{Cl}_2 \rightarrow \text{CH}_3\text{-CH} \cdot \text{CH} \cdot \text{Cl} \cdot \text{CH}_2 \cdot \text{CH}_3
\]

\[
\text{H}_2\text{O} \xrightarrow{[\text{H}^+]} \text{[Water added to benzene.]}\]

7.11 Aromatic Compounds

The simplest aromatic compound is called benzene, molecular formula \(\text{C}_6\text{H}_6\). A benzene molecule is a ring containing six carbon atoms with a single hydrogen atom attached to each carbon. Each carbon has one single bond and one double bond to neighboring carbon atoms.

Benzene: \[
\begin{align*}
\text{HC} & \text{-CH} \\
\text{HC} & \text{-CH} \\
\text{H} & \text{-CH} \\
\end{align*}
\]

or \[
\text{C}_\text{6}
\]

For convenience, we write the structure of benzene in the following abbreviated form:

\[
\text{C}_\text{6}
\]

The circle in the center of the ring represents the six shared electrons (three double bonds.)

7-17
The word *aromatic* originally referred to the unpleasant odor characteristic to many of these substances, but this meaning is not in use anymore.

**Naming Benzene Derivatives**

When one or more hydrogen atoms of the benzene ring are replaced with other groups, the compound is named as a derivative of benzene.

Examples:

![Chemical structures](image)

- ethylbenzene
- bromobenzene
- chlorobenzene
- nitrobenzene

The IUPAC system retains the common names for the following:

![Chemical structures](image)

- toluene
- phenol
- aniline
- benzoic acid

**Worked Example 7-10**

Draw the structural formula for each of the following:

a) 1,3-dichlorobenzene  
b) 2,4,6-trinitrotoluene (TNT)  
c) 2-bromo-3,4-dichlorophenol

**Solution**

![Chemical structures](image)

a)  
b)  
c)
Homework Problems

7.1 Write condensed structures for each of the following compounds:
   a. 2,2,4-trimethylpentane
   b. 5-isopropyl-2-methyloctane
   c. 1,1,3,3-tetrabromopropane
   d. 1,1-dichlorocyclopentane
   e. 1,4-diethylcyclohexane
   f. 1-bromo-2-methylcyclobutane

7.2 What are the IUPAC names of the following compounds?

a) \( \text{CH}_2\text{CH}_3 \quad \text{CH}_3 \)
   \( \text{CH}_3 \quad \text{CH}_2\text{CH}_2\text{CH} \)
   \( \text{CH}_3 \quad \text{CH}_2\text{CH}_3 \quad \text{CH}_3 \)

b) \( \text{CH}_2\text{CH}_3 \)
   \( \text{CH}_2\text{CH}_3 \)
   \( \text{CH}_2\text{CH}_3 \)
   \( \text{CH}_2\text{CH}_3 \)

7.3 Write the structural formulas and names for FOUR isomers of cycloalkane, \( \text{C}_5\text{H}_{10} \).

7.4 Propose structures for molecules that fit the following descriptions:
   a. an alkene with three carbons
   b. an alcohol with two carbons
   c. an ether with three carbons
   d. an amine with four carbons
   e. a three-carbon ester
   f. a ketone with four carbons
   g. a four-carbon carboxylic acid
   h. a cycloalkene with six carbons
7.5 Write equations for the reaction of cyclopentene with each of the following:
   a. H₂ and Pd catalyst
   b. Br₂
   c. H₂O and H₂SO₄ catalyst

7.6 Write a structural formula for each of the following:
   a. cis-3-heptene
   b. trans-3-heptene
   c. 1,1-dibromo-2,2-dichloroethene
   d. 1,2-dibromo-1,2-dichloroethene
   e. 4-methyl-2-hexyne
   f. 3-ethyl-1-heptyne
   g. 1,2-dimethylcyclopentene
   h. trans-2,5-dimethyl-3-hexene
   i. diisopropylacetylene

7.7 Name the following compounds:

   a) \[
   \begin{array}{c}
   \text{CH}_3 \\
   \text{I} \\
   \end{array}
   \]

   b) \[
   \begin{array}{c}
   \text{COOH} \\
   \end{array}
   \]

   c) \[
   \begin{array}{c}
   \text{Br} \\
   \text{OH} \\
   \text{Br} \\
   \text{Br} \\
   \end{array}
   \]

   d) \[
   \begin{array}{c}
   \text{NH}_2 \\
   \text{C}_2\text{H}_5 \\
   \text{C}_2\text{H}_5 \\
   \end{array}
   \]

   e) \[
   \begin{array}{c}
   \text{F} \\
   \text{F} \\
   \text{F} \\
   \text{F} \\
   \end{array}
   \]

   f) \[
   \begin{array}{c}
   \text{CH}_2\text{CH}_2\text{CH}_3 \\
   \text{CH}_3 \text{CH} \text{CH}_3 \\
   \end{array}
   \]