BTG Winter School ’10

Physical Sciences
Session 9 - Organic Chemistry

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Organic Molecules - Intro

Organic chemistry is the branch of chemistry that deals with organic molecules. An organic molecule is one which contains carbon, and these molecules can range in size from simple molecules to complex structures containing thousands of atoms!

Although the main element in organic compounds is carbon, other elements such as hydrogen (H), oxygen (O), nitrogen (N), sulfur (S) and phosphorus (P) are also common in these molecules.

Organic compounds make up a big part of our own bodies, they are in the food we eat and in the clothes we wear. Organic compounds are also used to make products such as medicines, plastics, washing powders, dyes, along with a list of other items.
Sources of Carbon

The main source of the carbon in organic compounds is carbon dioxide in the air.

Plants use sunlight to convert carbon dioxide into organic compounds through the process of photosynthesis.

Animals feed on plants or plant products so that they gain the organic compounds that they need to survive.

Another important source of carbon is fossil fuels such as coal, petroleum and natural gas. This is because fossil fuels are themselves formed from the decaying remains of dead organisms.
Uniqueness of carbon

Carbon has **four valence electrons** which means that each carbon atom **can form bonds with four other atoms**. Because of this, **long chain structures can form**.

These chains can either be **unbranched or branched**.

Because of the number of bonds that carbon can form with other atoms, **organic compounds can be very complex**.
Another important source of carbon is fossil fuels such as coal, petroleum and natural gas. This is because fossil fuels are themselves formed from the decaying remains of dead organisms (refer to chapter 21 for more information on fossil fuels).

9.3 Unique properties of carbon

Carbon has a number of unique properties which influence how it behave and how it bonds with other atoms:

- Carbon has four valence electrons which means that each carbon atom can form bonds with four other atoms. Because of this, long chain structures can form. These chains can either be unbranched (figure 9.1) or branched (figure 9.2). Because of the number of bonds that carbon can form with other atoms, organic compounds can be very complex.

- Because of its position on the Periodic Table, most of the bonds that carbon forms with other atoms are covalent. Think for example of a C-C bond. The difference in electronegativity between the two atoms is zero, so this is a pure covalent bond. In the case of a C-H bond, the difference in electronegativity between carbon (2.5) and hydrogen (2.1) is so small that C-H bonds are almost purely covalent. The result of this is that organic compounds are non-polar. This affects some of the properties of organic compounds.

9.4 Representing organic compounds

There are a number of ways to represent organic compounds. It is useful to know all of these so that you can recognise a molecule however it is shown. There are three main ways of representing a compound. We will use the example of 2-methylpropane to help explain the difference between each.

9.4.1 Molecular formula

The molecular formula of a compound shows how many atoms of each type are in a molecule. The number of each atom is written as a subscript after the atomic symbol. The molecular formula of 2-methylpropane is:

\[
\text{C}_8\text{H}_{18}
\]

an unbranched compound

\[
\text{C} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{C}
\]
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• Carbon has four valence electrons which means that each carbon atom can form bonds with four other atoms. Because of this, long chain structures can form. These chains can either be unbranched (figure 9.1) or branched (figure 9.2). Because of the number of bonds that carbon can form with other atoms, organic compounds can be very complex.

![Figure 9.1: An unbranched carbon chain](image1)

![Figure 9.2: A branched carbon chain](image2)

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\[ \text{C}_8\text{H}_{18} \]
Representing organic compounds
examples of different representations of the molecule:
2-methylpropane

Molecular formula
- shows how many atoms of each type are in a molecule

\[ \text{C}_4\text{H}_{10} \]
Representing organic compounds

examples of different representations of the molecule:

2-methylpropane

Structural formula

- shows every bond between every atom in the molecule
- each bond is represented by a line.

9.4.2 Structural formula

The structural formula of an organic compound shows every bond between every atom in the molecule. Each bond is represented by a line. The structural formula of 2-methylpropane is shown in figure 9.3.

9.4.3 Condensed structural formula

When a compound is represented using its condensed structural formula, each carbon atom and the hydrogen atoms that are bonded directly to it are listed as a molecular formula, followed by a similar molecular formula for the neighbouring carbon atom. Branched groups are shown in brackets after the carbon atom to which they are bonded. The condensed structural formula below shows that in 2-methylpropane, there is a branched chain attached to the second carbon atom of the main chain. You can check this by looking at the structural formula in figure ??.

Exercise: Representing organic compounds

1. For each of the following organic compounds, give the condensed structural formula and the molecular formula.

(a)
Representing organic compounds

examples of different representations of the molecule:

2-methylpropane

Condensed structural formula

- each carbon atom and the hydrogen atoms that are bonded directly to it are listed as a molecular formula,

- Branched groups are shown in brackets after the carbon atom to which they are bonded.

\[ \text{CH}_3\text{CH(CH}_3\text{)}\text{CH}_3 \]
Definition: Functional group
In organic chemistry, a functional group is a specific group of atoms within molecules, that are responsible for the characteristic chemical reactions of those molecules.

The same functional group will undergo the same or similar chemical reaction(s) regardless of the size of the molecule it is a part of.
The Hydrocarbons

- Only contains carbon and hydrogen
- Aliphatic compounds

![Classification of Aliphatic Hydrocarbons](image)

**Acyclic compounds** (chain structures)
- Alkanes (single bonds)
- Alkenes (contain double bonds)
- Alkynes (contain triple bonds)

**Cyclic compounds** (ring structures e.g. benzene ring)

Interesting Fact

Fat that occurs naturally in living matter such as animals and plants is used as food for human consumption and contains varying proportions of saturated and unsaturated fat. Foods that contain a high proportion of saturated fat are butter, ghee, suet, tallow, lard, coconut oil, cottonseed oil, and palm kernel oil, dairy products (especially cream and cheese), meat, and some prepared foods. Diets high in saturated fat are correlated with an increased incidence of atherosclerosis and coronary heart disease according to a number of studies. Vegetable oils contain unsaturated fats and can be hardened to form margarine by adding hydrogen on to some of the carbon=carbon double bonds using a nickel catalyst. The process is called hydrogenation.
The Hydrocarbons

- Saturated & Unsaturated Compounds

![Figure 9.6: A saturated hydrocarbon](image)

![Figure 9.7: An unsaturated hydrocarbon](image)

Figure 9.6: A saturated hydrocarbon

Figure 9.7: An unsaturated hydrocarbon

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The Hydrocarbons: Alkanes

Alkanes & Naming Them
The alkanes are hydrocarbons that only contain single covalent bonds between their carbon atoms. This means that they are saturated compounds and are quite unreactive.

\[ C_nH_{2n+2} \]

(a) \[ \begin{array}{c} \text{H} \\ \mid \text{H} \\ \text{H} \end{array} \quad \text{C} \quad \text{H} \quad \text{H} \]

(b) \[ \text{CH}_4 \]

Interesting Fact
Some fungi use alkanes as a source of carbon and energy. One fungus, *Amorphotheca resinae*, prefers the alkanes used in aviation fuel, and this can cause problems for aircraft in tropical areas!
The Hydrocarbons: Alkanes

9.7 CHAPTER 9. ORGANIC MOLECULES - GRADE 12

We will now go on to look at each of the hydrocarbon groups in more detail. These groups are the alkanes, the alkenes and the alkynes.

9.7.1 The Alkanes

The alkanes are hydrocarbons that only contain single covalent bonds between their carbon atoms. This means that they are saturated compounds and are quite unreactive. The simplest alkane has only one carbon atom and is called methane. This molecule is shown in figure 9.8.

![Methane molecule](image)

The second alkane in the series has two carbon atoms and is called ethane. This is shown in figure 9.9.

![Ethane molecule](image)

The third alkane in the series has three carbon atoms and is called propane (Figure 9.10).

![Propane molecule](image)

When you look at the molecular formula for each of the alkanes, you should notice a pattern developing. For each carbon atom that is added to the molecule, two hydrogen atoms are added. In other words, each molecule differs from the one before it by CH$_2$. This is called a homologous series. The alkanes have the general formula C$_n$H$_{2n+2}$.

The alkanes are the most important source of fuel in the world and are used extensively in the chemical industry. Some are gases (e.g. methane and ethane), while others are liquid fuels (e.g. octane, an important component of petrol).

Interesting Fact

Some fungi use alkanes as a source of carbon and energy. One fungus, *Amorphotheca resinae*, prefers the alkanes used in aviation fuel, and this can cause problems for aircraft in tropical areas!
The Hydrocarbons: Alkanes

The alkanes are the **most important source of fuel in the world** and are used extensively in the chemical industry. Some are **gases** (e.g. methane and ethane), while others are **liquid fuels** (e.g. octane, an important component of petrol).
Naming the Hydrocarbons

**STEP 1:** Recognise the functional group in the compound. This will determine the suffix (the ’end’) of the name.

**STEP 2:** Find the longest continuous carbon chain (it won’t always be a straight chain) and count the number of carbon atoms in this chain. This number will determine the prefix (the ’beginning’) of the compound’s name.

**STEP 3:** Number the carbons in the longest carbon chain. (NB: Number closest to the functional group)

**STEP 4:** Look for any branched groups and name them.

**STEP 5:** Combine the elements of the name into a single word in the following order: branched groups; prefix; name ending according to the functional group and its position along the longest carbon chain.
The Hydrocarbons: Alkanes

There are four carbon atoms in the longest chain. The prefix of the compound will be 'but'.

Step 3: Number the carbons in the longest chain
In this case, it is easy. The carbons are numbered from left to right, from one to four.

Step 4: Look for any branched groups, name them and give their position on the carbon chain
There are no branched groups in this compound.

Step 5: Combine the elements of the name into a single word
The name of the compound is butane.

Worked Example 39: Naming the alkanes
Question:
Give the IUPAC name for the following compound:

Answer:
Step 1: Identify the functional group
The compound is an alkane and will have the suffix -ane.

Step 2: Find the longest carbon chain
There are three carbons in the longest chain. The prefix for this compound is -prop.

Step 3: Number the carbons in the carbon chain
If we start at the carbon on the left, we can number the atoms as shown below:

Step 4: Look for any branched groups, name them and give their position on the carbon chain
There is a branched group attached to the second carbon atom. This group has the formula CH₃ which is methane. However, because it is not part of the main chain, it is given the suffix -yl (i.e. methyl). The position of the methyl group comes just before its name (see next step).

Step 5: Combine the elements of the compound's name into a single word in the order of branched groups; prefix; name ending according to the functional group.
The compound's name is 2-methylpropane.

Worked Example 40: Naming the alkanes
Question:
Give the IUPAC name for the following compound:

Answer:
Step 1: Draw the compound from its condensed structural formula
The structural formula of the compound is:

Step 2: Identify the functional group
The compound is an alkane and will have the suffix -ane.

Step 3: Find the longest carbon chain
There are four carbons in the longest chain. The prefix for this compound is -but.

Step 4: Number the carbons in the carbon chain
If we start at the carbon on the left, we can number the atoms as shown above. A second way that the carbons could be numbered is:

Step 5: Look for any branched groups, name them and give their position on the carbon chain
There is a branched group attached to the second carbon atom. This group has the formula CH₃ which is methane. However, because it is not part of the main chain, it is given the suffix -yl (i.e. methyl). The position of the methyl group comes just before its name (see next step).

Step 6: Combine the elements of the compound's name into a single word in the order of branched groups; prefix; name ending according to the functional group.
The compound's name is 2-methylpropane.
Reactions of Alkanes

Substitution reactions
Involves the removal of a hydrogen atom which is replaced by an atom of another element, such as a halogen (F, Cl, Br or I).

The product is called a halo-alkane.

Heat or light is needed for this reaction to take place.

\[
\begin{align*}
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{C} \quad \text{C} \quad \text{H} \quad + \quad \text{HBr} & \rightarrow & \quad \text{H} & \quad \text{C} & \quad \text{C} & \quad \text{Br} \\
\text{H} & \quad \text{H} & \quad \text{H}
\end{align*}
\]
Reactions of Alkanes

Elimination reactions
Saturated compounds can also undergo elimination reactions to become unsaturated. In the example below, an atom of hydrogen and chlorine are eliminated from the original compound to form an unsaturated halo-alkene.

\[
\begin{align*}
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{C} \quad \text{C} \quad \text{H} \quad \rightarrow \quad \text{H} & \quad \text{C} \quad \equiv \quad \text{C} \quad \text{Cl} \quad + \quad \text{HCl} \\
\text{Cl} & \quad \text{Cl}
\end{align*}
\]
Reactions of Alkanes

Oxidation reactions
When alkanes are burnt in air, they react with the oxygen in air and heat is produced. This is called an oxidation or combustion reaction. Carbon dioxide and water are given off as products. Heat is also released during the reaction. The burning of alkanes provides most of the energy that is used by man.
Alkenes & Naming Them

In the alkenes, there is **at least one double bond between two carbon atoms**. This means that they are **unsaturated** and are **more reactive than the alkanes**.

\[ C_nH_{2n} \]
The Hydrocarbons: Alkenes

Worked Example 44: Naming the alkenes

Question:
Give the IUPAC name for the following compound:

Answer
Step 1: Identify the functional group
The compound is an alkene and will have the suffix -ene. There is a double bond between the first and second carbons and also between the third and fourth carbons. The organic compound is therefore a 'diene'.

Step 2: Find the longest carbon chain and number the carbon atoms
There are four carbon atoms in the longest chain and so the prefix for this compound will be 'but'. The carbon atoms are numbered 1 to 4 in the diagram above.

Step 3: Look for any branched groups, name them and give their position on the carbon chain
There is a methyl group on the first carbon and an ethyl group on the second carbon.

Step 4: Name the compound
The name of this compound is **1-methyl,2-ethyl-1,3 diene**.

Exercise: Naming the alkenes
Give the IUPAC name for each of the following alkenes:

1. C\_5\_H\_10
2. CH\_3\_CH\_CH\_CH\_3
The Hydrocarbons: Alkenes

**Exercise: Naming the alkenes**

Give the IUPAC name for each of the following alkenes:

1. C\textsubscript{5}H\textsubscript{10}
2. CH\textsubscript{3}CHCHCH\textsubscript{3}
3. 

\[
\begin{array}{c}
\text{H} & \text{H} & \text{H} \\
\text{H} & \text{C} & \text{C} & \text{C} & \text{C} & \text{C} & \text{H} \\
\text{H} & \text{H}
\end{array}
\]
The properties of the alkenes
The alkenes are more reactive because they are unsaturated. As with the alkanes, compounds that have four or less carbon atoms are gases at room temperature, while those with five or more carbon atoms are liquids.

Alkenes can undergo addition reactions because they are unsaturated. They readily react with hydrogen, water and the halogens. The double bond is broken and a single, saturated bond is formed. A new group is then added to one or both of the carbon atoms that previously made up the double bond.
Reactions of the Alkenes

Hydrogenation reactions

A catalyst such as platinum is normally needed for these reactions

\[ CH_2 = CH_2 + H_2 \rightarrow CH_3 - CH_3 \] (figure 9.16)
Reactions of the Alkenes

Halogenation reactions

\[ CH_2 = CH_2 + HBr \rightarrow CH_3 - CH_2 - Br \] (figure 9.17)

\[ \begin{array}{cccc}
\text{H} & \text{H} \\
\text{H} & \text{C} & \equiv & \text{C} & \equiv & \text{H} \\
\text{H} & \text{Br}
\end{array} \rightarrow \begin{array}{cccc}
\text{H} & \text{C} & \equiv & \text{C} & \equiv & \text{Br} \\
\text{H} & \text{H}
\end{array} \]
Reactions of the Alkenes

The formation of alcohols

\[ CH_2 = CH_2 + H_2O \rightarrow CH_3 - CH_2 - OH \]
Reactions of the Alkenes

The formation of alcohols

\[ CH_2 = CH_2 + H_2O \rightarrow CH_3 - CH_2 - OH \]
Reactions of the Alkenes

Exercise: The Alkenes

1. Give the IUPAC name for each of the following organic compounds:

   H
   
   H—C—C=CH—C—C—CH
   
   H   H   H   H
   
   (a)
   
   (b) CH₃CHCH₂
2. Refer to the data table below which shows the melting point and boiling point for a number of different organic compounds.

<table>
<thead>
<tr>
<th>Formula</th>
<th>Name</th>
<th>Melting point (°C)</th>
<th>Boiling point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₄H₁₀</td>
<td>Butane</td>
<td>-138</td>
<td>-0.5</td>
</tr>
<tr>
<td>C₅H₁₂</td>
<td>Pentane</td>
<td>-130</td>
<td>36</td>
</tr>
<tr>
<td>C₆H₁₄</td>
<td>Hexane</td>
<td>-95</td>
<td>69</td>
</tr>
<tr>
<td>C₄H₈</td>
<td>Butene</td>
<td>-185</td>
<td>-6</td>
</tr>
<tr>
<td>C₅H₁₀</td>
<td>Pentene</td>
<td>-138</td>
<td>30</td>
</tr>
<tr>
<td>C₆H₁₂</td>
<td>Hexene</td>
<td>-140</td>
<td>63</td>
</tr>
</tbody>
</table>

(a) At room temperature (approx. 25°C), which of the organic compounds in the table are:
   i. gases
   ii. liquids

(b) In the alkanes...
   i. Describe what happens to the melting point and boiling point as the number of carbon atoms in the compound increases.
   ii. Explain why this is the case.

(c) If you look at an alkane and an alkene that have the same number of carbon atoms...
   i. How do their melting points and boiling points compare?
   ii. Can you explain why their melting points and boiling points are different?
(d) Which of the compounds, hexane or hexene, is more reactive? Explain your answer.

3. The following reaction takes place:

\[ CH_3CHCH_2 + H_2 \rightarrow CH_3CH_2CH_3 \]

(a) Give the name of the organic compound in the reactants.
(b) What is the name of the product?
(c) What type of reaction is this?
The Hydrocarbons: Alkynes

In the alkynes, there is at least one triple bond between two of the carbon atoms. They are unsaturated compounds and are therefore highly reactive. Many of the alkynes are used to synthesise other chemical products.

\[ C_nH_{2n-2} \]

\[ \text{H} \quad \text{C}≡\text{C} \quad \text{C} \quad \text{H} \]
Exercise: The alkynes

Give the IUPAC name for each of the following organic compounds.

1. \[ \text{H} - \text{CH}_3 \]
   \[ \text{H} \quad \text{C} \quad \text{C} \quad \text{C} \equiv \text{C} \quad \text{H} \]
   \[ \text{H} \quad \text{H} \]

2. \( \text{C}_2\text{H}_2 \)

3. \( \text{CH}_3\text{CH}_2\text{CCH} \)
The Alcohols

An alcohol is any organic compound where there is a hydroxyl functional group (-OH) bound to a carbon atom.

The simplest and most commonly used alcohols are methanol and ethanol.

The alcohols have a number of different uses:
• methylated spirits (surgical spirits) is a form of ethanol where methanol has been added
• ethanol is used in alcoholic drinks
• ethanol is used as an industrial solvent.

Alcohols with shorter carbon chains are usually more soluble than those with longer carbon chains. They tend to have higher boiling points than the hydrocarbons

\[ C_nH_{2n+1}OH \]
The Alcohols

Figure 9.20: (a) methanol and (b) ethanol

- methanol and ethanol can both be used as a fuel and they burn more cleanly than gasoline or diesel (refer to chapter 21 for more information on biofuels as an alternative energy resource.)
- ethanol is used as a solvent in medical drugs, perfumes and vegetable essences
- ethanol is an antiseptic
The Alcohols

Exercise: Naming the alcohols

1. Give the structural formula of each of the following organic compounds:
   (a) pentan-3-ol
   (b) butan-2,3-diol
   (c) 2-methyl-propanol

2. Give the IUPAC name for each of the following:
   (a) $\text{CH}_3\text{CH}_2\text{CH(OH)}\text{CH}_3$
   (b) $\text{OH}$
Carboxylic Acids

Carboxylic acids are organic acids that are characterised by having a carboxyl group, which has the formula -(C=O)-OH, or more commonly written as -COOH.

![Carboxylic Acid Diagram]

Interesting Fact

Methanoic acid (also known as formic acid) has the formula HCOOH and is found in insect stings. Ethanoic acid (CH₃COOH), or acetic acid, is the main component of vinegar. More complex organic acids also have a variety of different functions. Benzoic acid (C₆H₅COOH) for example, is used as a food preservative.
**Exercise: Carboxylic acids**

1. Refer to the table below which gives information about a number of carboxylic acids, and then answer the questions that follow.

<table>
<thead>
<tr>
<th>Formula</th>
<th>Common name</th>
<th>Source</th>
<th>IUPAC name</th>
<th>melting point (°C)</th>
<th>boiling point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{CH}_3\text{CO}_2\text{H} )</td>
<td>formic acid</td>
<td>ants</td>
<td>methanoic acid</td>
<td>8.4</td>
<td>101</td>
</tr>
<tr>
<td>( \text{CH}_3(\text{CH}_2)_2\text{CO}_2\text{H} )</td>
<td>butyric acid</td>
<td>vinegar</td>
<td>ethanoic acid</td>
<td>16.6</td>
<td>118</td>
</tr>
<tr>
<td>( \text{CH}_3(\text{CH}_2)_2\text{CO}_2\text{H} )</td>
<td>propionic acid</td>
<td>milk</td>
<td>propanoic acid</td>
<td>-20.8</td>
<td>141</td>
</tr>
<tr>
<td>( \text{CH}_3(\text{CH}_2)_4\text{CO}_2\text{H} )</td>
<td>caproic acid</td>
<td>butter</td>
<td>-5.5</td>
<td>164</td>
<td></td>
</tr>
<tr>
<td>( \text{CH}_3(\text{CH}_2)_4\text{CO}_2\text{H} )</td>
<td>valeric acid</td>
<td>valerian root</td>
<td>-34.5</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>( \text{CH}_3(\text{CH}_2)_6\text{CO}_2\text{H} )</td>
<td>caprylic acid</td>
<td>goats</td>
<td>-4</td>
<td>205</td>
<td></td>
</tr>
<tr>
<td>( \text{CH}_3(\text{CH}_2)_6\text{CO}_2\text{H} )</td>
<td>enanthic acid</td>
<td>vines</td>
<td>-7.5</td>
<td>223</td>
<td></td>
</tr>
</tbody>
</table>

(a) Fill in the missing spaces in the table by writing the formula, common name or IUPAC name.

(b) Draw the structural formula for butyric acid.

(c) Give the molecular formula for caprylic acid.

(d) Draw a graph to show the relationship between molecular mass (on the x-axis) and boiling point (on the y-axis).
Esters

When an alcohol reacts with a carboxylic acid, an ester is formed. Most esters have a characteristic and pleasant smell. In the reaction, the hydrogen atom from the hydroxyl group, and an OH from the carboxylic acid, form a molecule of water. A new bond is formed between what remains of the alcohol and acid.

The name of the ester is a combination of the names of the alcohol and carboxylic acid.

The suffix for an ester is -oate.
Esters

When an alcohol reacts with a carboxylic acid, an ester is formed. Most esters have a characteristic and pleasant smell. In the reaction, the hydrogen atom from the hydroxyl group, and an OH from the carboxylic acid, form a molecule of water. A new bond is formed between what remains of the alcohol and acid. The name of the ester is a combination of the names of the alcohol and carboxylic acid. One example is shown in Figure 9.23.

**Figure 9.23: The formation of an ester from an alcohol and carboxylic acid**

9.10 The Amino Group

The amino group has the formula -NH₂ and consists of a nitrogen atom that is bonded to two hydrogen atoms, and to the carbon skeleton. Organic compounds that contain this functional group are called amines. One example is glycine. Glycine belongs to a group of organic compounds called amino acids, which are the building blocks of proteins.

**Figure 9.24: A molecule of glycine**

9.11 The Carbonyl Group

The carbonyl group (-CO) consists of a carbon atom that is joined to an oxygen by a double bond. If the functional group is on the end of the carbon chain, the organic compound is called a ketone. The simplest ketone is acetone, which contains three carbon atoms. A ketone has the ending 'one' in its IUPAC name.
The Carbonyl Group

The carbonyl group (-CO) consists of a carbon atom that is joined to an oxygen by a double bond.

If the functional group is on the end of the carbon chain, the organic compound is called an **aldehyde**. The names thus ends in “al”.

If the carbonyl group is placed in the middle the compound is a **ketone**. The simplest ketone is acetone, which contains three carbon atoms. A ketone has the ending ’one’ in its IUPAC name.
Exercise: Carboxylic acids, esters, amines and ketones

1. Look at the list of organic compounds in the table below:

<table>
<thead>
<tr>
<th>Organic compound</th>
<th>Type of compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃CH₂CH₂COOH</td>
<td></td>
</tr>
<tr>
<td>NH₂CH₂COOH</td>
<td></td>
</tr>
<tr>
<td>propyl ethanoate</td>
<td></td>
</tr>
<tr>
<td>CH₃CHO</td>
<td></td>
</tr>
</tbody>
</table>

(a) Complete the table by identifying each compound as either a carboxylic acid, ester, amine or ketone.
(b) Give the name of the compounds that have been written as condensed structural formulae.

2. A chemical reaction takes place and ethyl methanoate is formed.

(a) What type of organic compound is ethyl methanoate?
(b) Name the two reactants in this chemical reaction.
(c) Give the structural formula of ethyl methanoate.
Summary

- **Organic chemistry** is the branch of chemistry that deals with organic molecules. An **organic molecule** is one that contains carbon.

- All **living organisms** contain carbon. Plants use sunlight to convert carbon dioxide in the air into organic compounds through the process of **photosynthesis**. Animals and other organisms then feed on plants to obtain their own organic compounds. **Fossil fuels** are another important source of carbon.

- It is the **unique properties of the carbon atom** that give organic compounds certain properties.

- The carbon atom has **four valence electrons**, so it can bond with many other atoms, often resulting in long chain structures. It also forms mostly **covalent bonds** with the atoms that it bonds to, meaning that most organic molecules are **non-polar**.

- An organic compound can be represented in different ways, using its **molecular formula**, **structural formula** or **condensed structural formula**.

- If two compounds are **isomers**, it means that they have the same molecular formulae but different structural formulae.
## Summary

A **functional group** is a particular group of atoms within a molecule, which give it certain reaction characteristics. Organic compounds can be grouped according to their functional group.

The **hydrocarbons** are organic compounds that contain only carbon and hydrogen. They can be further divided into the alkanes, alkenes and alkynes, based on the type of bonds between the carbon atoms.

The **alkanes** have only **single bonds** between their carbon atoms and are unreactive.

The **alkenes** have at least one **double bond** between two of their carbon atoms. They are more reactive than the alkanes.

The **alkynes** have at least one **triple bond** between two of their carbon atoms. They are the most reactive of the three groups.

A hydrocarbon is said to be **saturated** if it contains the maximum possible number of hydrogen atoms for that molecule. The alkanes are all saturated compounds.
A hydrocarbon is **unsaturated** if it does not contain the maximum number of hydrogen atoms for that molecule. The alkenes and alkynes are examples of unsaturated molecules. If a double or triple bond is broken, more hydrogen atoms can be added to the molecule.

There are three types of reactions that occur in the alkanes: **substitution**, **elimination** and **oxidation** reactions.

The alkenes undergo **addition** reactions because they are unsaturated.

Organic compounds are **named** according to their functional group and its position in the molecule, the number of carbon atoms in the molecule and the position of any double and triple bonds. The IUPAC rules for nomenclature are used in the naming of organic molecules.

Many of the **properties** of the hydrocarbons are determined by their **molecular structure**, the **bonds** between atoms and molecules, and their **surface area**.

The **melting point** and **boiling point** of the hydrocarbons increases as their number of carbon atoms increases.

The **molecular mass** of the hydrocarbons determines whether they will be in the gaseous, liquid or solid phase at certain temperatures.
An **alcohol** is an organic compound that contains a **hydroxyl group** (OH).

The alcohols have a number of different uses including their use as a solvent, for medicinal purposes and in alcoholic drinks.

The alcohols share a number of **properties** because of the hydroxyl group. The hydroxyl group affects the **solubility** of the alcohols. Those with shorter carbon chains are generally more soluble, and those with longer chains are less soluble. The strong hydrogen bond between the hydrogen and oxygen atoms in the hydroxyl group gives alcohols a higher melting point and boiling point than other organic compounds. The hydroxyl group also gives the alcohols both acidic and basic properties.

The **carboxylic acids** are organic acids that contain a **carboxyl group** with the formula COOH. In a carboxyl group, an oxygen atom is double-bonded to a carbon atom, which is also bonded to a hydroxyl group.

The carboxylic acids have weak **acidic properties** because the hydrogen atom is able to dissociate from the carboxyl group.

An **ester** is formed when an alcohol reacts with a carboxylic acid.
Summary

An **ester** is formed when an alcohol reacts with a carboxylic acid.

The **amines** are organic compounds that contain an **amino** functional group, which has the formula $\text{NH}_2$. Some amines belong to the **amino acid** group, which are the building blocks of proteins.

The **ketones** are a group of compounds that contain a **carbonyl group**, which consists of an oxygen atom that is double-bonded to a carbon atom. In a ketone, the carbonyl group is on the end of the carbon chain.
## Summary of some functional groups

<table>
<thead>
<tr>
<th>Name of group</th>
<th>Functional group</th>
<th>Example</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkane</td>
<td></td>
<td>Ethane</td>
<td><img src="image1" alt="Ethane Diagram" /></td>
</tr>
<tr>
<td>Alkene</td>
<td></td>
<td>Ethene</td>
<td><img src="image2" alt="Ethene Diagram" /></td>
</tr>
<tr>
<td>Alkyne</td>
<td></td>
<td>Ethyne (acetylene)</td>
<td><img src="image3" alt="Ethyne Diagram" /></td>
</tr>
</tbody>
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<tbody>
<tr>
<td>Halo-alkane</td>
<td></td>
<td>Chloroethane</td>
<td><img src="haloalkane.png" alt="" /></td>
</tr>
<tr>
<td>Alcohol/ alkanol</td>
<td></td>
<td>Ethanol</td>
<td><img src="alcohol.png" alt="" /></td>
</tr>
<tr>
<td>Carboxylic acid</td>
<td></td>
<td>Ethanoic acid</td>
<td><img src="carboxylic.png" alt="" /></td>
</tr>
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Hydrocarbons that contain double or triple bonds are called **unsaturated hydrocarbons** because they don’t contain as many hydrogen atoms as possible. Figure 9.7 shows some molecules of unsaturated hydrocarbons.
### Summary of some functional groups

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<tr>
<td>Amine</td>
<td>R–N</td>
<td>Glycine</td>
<td><img src="image" alt="Glycine Diagram" /></td>
</tr>
</tbody>
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Hydrocarbons that contain double or triple bonds are called **unsaturated hydrocarbons** because they don’t contain as many hydrogen atoms as possible. Figure 9.7 shows an example of ethene which is an unsaturated hydrocarbon. If you compare the number of carbon and hydrogen atoms: 156
Revision Exercise

Exercise: Summary exercise

1. Give **one word** for each of the following descriptions:

   (a) The group of hydrocarbons to which 2-methyl-propene belongs.
   (b) The name of the functional group that gives alcohols their properties.
   (c) The group of organic compounds that have acidic properties.
   (d) The name of the organic compound that is found in vinegar.
   (e) The name of the organic compound that is found in alcoholic beverages.
2. In each of the following questions, choose the one correct answer from the list provided.

(a) When 1-propanol is oxidised by acidified potassium permanganate, the possible product formed is...
   - i. propane
   - ii. propanoic acid
   - iii. methyl propanol
   - iv. propyl methanoate
   (IEB 2004)

(b) What is the IUPAC name for the compound represented by the following structural formula?

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

3. Write balanced equations for the following reactions:

(a) Ethene reacts with bromine

(b) Ethyne gas burns in an excess of oxygen

(c) Ethanoic acid ionises in water

4. The table below gives the boiling point of ten organic compounds.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Formula</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1   methane</td>
<td>CH₄</td>
<td>-164</td>
</tr>
<tr>
<td>2   ethane</td>
<td>C₂H₆</td>
<td>-88</td>
</tr>
<tr>
<td>3   propane</td>
<td>C₃H₈</td>
<td>-42</td>
</tr>
<tr>
<td>4   butane</td>
<td>C₄H₁₀</td>
<td>0</td>
</tr>
<tr>
<td>5   pentane</td>
<td>C₅H₁₂</td>
<td>36</td>
</tr>
<tr>
<td>6   methanol</td>
<td>CH₃OH</td>
<td>65</td>
</tr>
<tr>
<td>7   ethanol</td>
<td>C₂H₅OH</td>
<td>78</td>
</tr>
<tr>
<td>8   propan-1-ol</td>
<td>C₃H₇OH</td>
<td>98</td>
</tr>
<tr>
<td>9   propan-1,2-diol</td>
<td>CH₂OHCHOHCH₂OH</td>
<td>189</td>
</tr>
<tr>
<td>10  propan-1,2,3-triol</td>
<td>CH₂OHCHOHCH₂OH</td>
<td>290</td>
</tr>
</tbody>
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The following questions refer to the compounds shown in the above table.

(a) To which homologous series do the following compounds belong?
   - i. Compounds 1, 2 and 3
   - ii. Compounds 6, 7 and 8

(b) Which of the above compounds are gases at room temperature?

(c) What causes the trend of increasing boiling points of compounds 1 to 5?

(d) Despite the fact that the length of the carbon chain in compounds 8, 9 and 10 is the same, the boiling point of propan-1,2,3-triol is much higher than the boiling point of propan-1-ol. What is responsible for this large difference in boiling point?

(e) Give the IUPAC name and the structural formula of an isomer of butane.
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(e) Give the IUPAC name and the structural formula of an isomer of butane.

(f) Which one of the above substances is used as a reactant in the preparation of the ester ethylmethanoate?

(g) Using structural formulae, write an equation for the reaction which produces ethylmethanoate.
4. Refer to the numbered structural formulae below and answer the questions that follow.

(a) Which one of the above compounds is produced from the fermentation of starches and sugars in plant matter?
(b) To which one of the following homologous series does compound 1 belong?
(c) The correct IUPAC name for compound 3 is...
(d) What is the correct IUPAC name for compound 4?
5. Answer the following questions:

(a) What is a homologous series?

(b) A mixture of ethanoic acid and methanol is warmed in the presence of concentrated sulphuric acid.
   i. Using structural formulae, give an equation for the reaction which takes place.
   ii. What is the IUPAC name of the organic compound formed in this reaction?

Consider the following unsaturated hydrocarbon:

\[
\begin{array}{c}
\text{H} \\
\text{H} \quad \text{H} \quad \text{H}
\end{array}
\]

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

\[
\begin{array}{c}
\text{H} \\
\text{H} \quad \text{H}
\end{array}
\]

i. Give the IUPAC name for this compound.

ii. Give the balanced equation for the combustion of this compound in excess oxygen.
Consider the organic compounds labelled A to E.
A. CH₃CH₂CH₂CH₂CH₂CH₃
B. C₆H₆
C. CH₃-Cl
D. Methylamine
E. Methylamine

Question 7

(a) Write a balanced chemical equation for the preparation of compound C using an alkane as one of the reactants.

(c) Write down the IUPAC name for compound E.

(e) Write down the structural formula of an isomer of compound A that has only FOUR carbon atoms in the longest chain.

(g) Write down the structural formula for compound B.