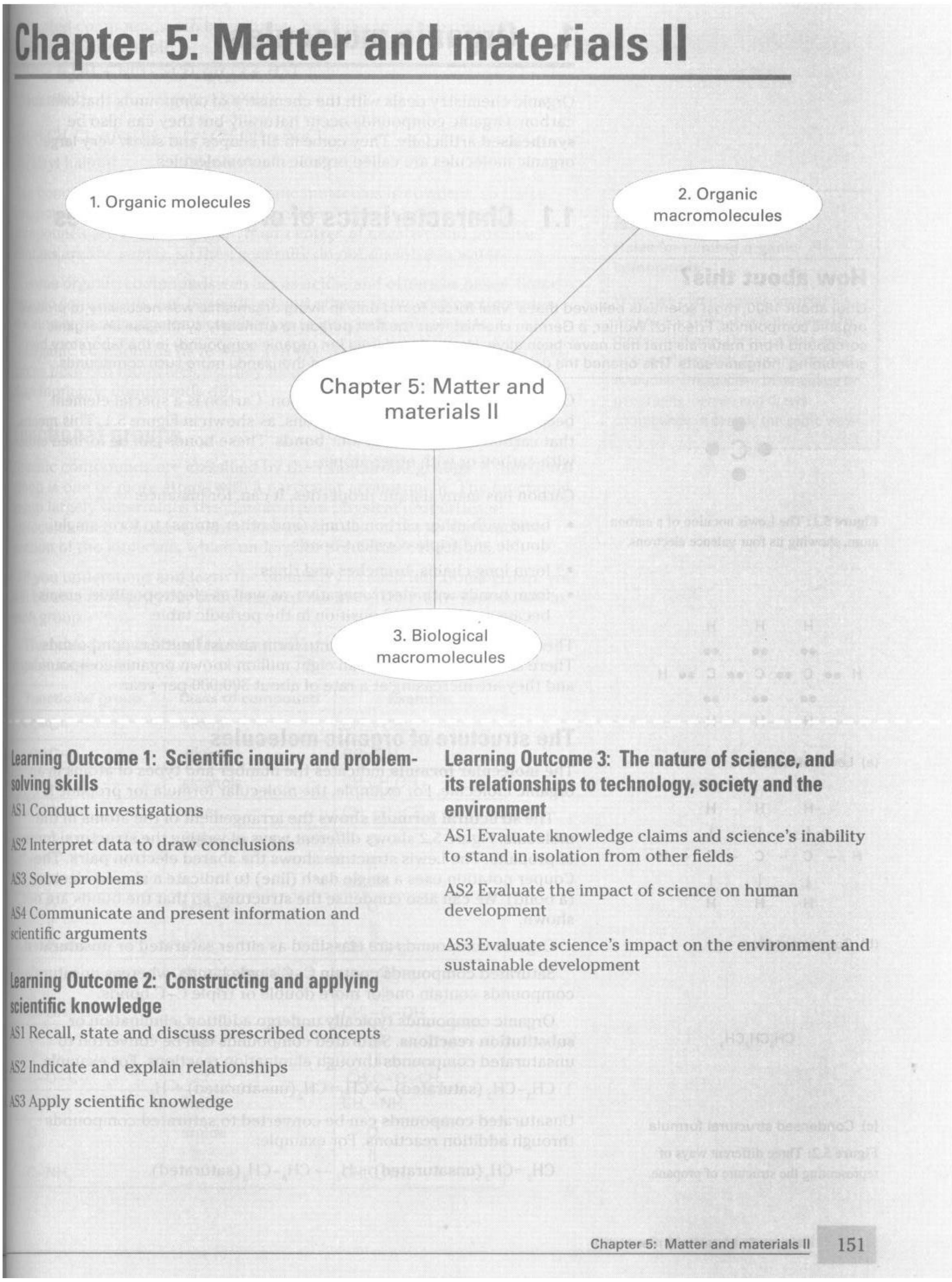


Chapter 5: Matter and materials II

1. Organic molecules

2. Organic macromolecules

Chapter 5: Matter and materials II

3. Biological macromolecules

Learning Outcome 1: Scientific inquiry and problem-solving skills

AS1 Conduct investigations

AS2 Interpret data to draw conclusions

AS3 Solve problems

AS4 Communicate and present information and scientific arguments

Learning Outcome 2: Constructing and applying scientific knowledge

AS1 Recall, state and discuss prescribed concepts

AS2 Indicate and explain relationships

AS3 Apply scientific knowledge

Learning Outcome 3: The nature of science, and its relationships to technology, society and the environment

AS1 Evaluate knowledge claims and science's inability to stand in isolation from other fields

AS2 Evaluate the impact of science on human development

AS3 Evaluate science's impact on the environment and sustainable development

Chapter 5: Matter and materials II 151

Figure 1 Focus on Physical Sciences

1. Organic molecules

Organic chemistry deals with the chemistry of compounds that contain carbon. Organic compounds occur naturally but they can also be **synthesised** artificially. They come in all shapes and sizes. Very large organic molecules are called organic macromolecules.

1.1 Characteristics of organic molecules

How about this?

Until about 1800, most scientists believed that a 'vital force', found only in living organisms, was necessary to produce organic compounds. Friedrich Wohler, a German chemist, was the first person to artificially synthesise an organic compound from materials that had never been alive. He produced urea (an organic compound) in the laboratory by combining inorganic salts. This opened the door for the artificial synthesis of thousands more such compounds.

Figure 5.1: The Lewis notation of a carbon atom, showing its four valence electrons.

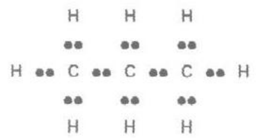
Organic compounds all contain carbon. Carbon is a special element because it has four valence electrons, as shown in Figure 5.1. This means that carbon is able to form four **bonds**. These bonds can be formed either with carbon or with other atoms.

Carbon has many unique properties. It can, for instance:

- bond with other carbon atoms (and other atoms) to form single, double and triple covalent bonds
- form long chains, branches and rings
- form bonds with electronegative, as well as electropositive, atoms because of its central position in the periodic table.

These properties enable carbon to form almost limitless compounds. There are currently more than eight million known organic compounds, and they are increasing at a rate of about 300,000 per year.

The structure of organic molecules



(a) Lewis structure

```
        H   H   H
        |   |   |
    H - C - C - C - H
        |   |   |
        H   H   H
```

(b) Couper notation

$CH_3CH_2CH_3$

(c) Condensed structural formula

Figure 5.2: Three different ways of representing the structure of propane.

The **molecular formula** indicates the number and types of atoms in an organic molecule. For example, the molecular formula for propane is C_3H_8.

The **structural formula** shows the arrangement of the atoms in the molecule. Figure 5.2 shows different ways of writing the structural formula of propane. The Lewis structure shows the shared electron pairs. The Couper notation uses a single dash (line) to indicate a shared electron pair (a bond). We can also condense the structure, so that the bonds are not shown.

Organic compounds are classified as either **saturated** or **unsaturated**.

Saturated compounds contain C–C single bonds, whereas unsaturated compounds contain one or more double or triple C–C bonds.

Organic compounds typically undergo addition, elimination or **substitution reactions**. Saturated compounds can be converted to unsaturated compounds through elimination reactions. For example:

$CH_3\text{–}CH_3$ (saturated) $\rightarrow CH_2\text{=}CH_2$ (unsaturated) + H_2

Unsaturated compounds can be converted to saturated compounds through addition reactions. For example:

$CH_2\text{=}CH_2$ (unsaturated) + $H_2 \rightarrow CH_3\text{–}CH_3$ (saturated).

Figure 2 Focus on Physical Sciences

Saturated compounds can interchange by undergoing substitution reactions. For example:

$CH_3CH_2OH + HCl \rightarrow CH_3CH_2Cl + H_2O$
(alcohol) (alkyl halide)

$CH_3CH_2Cl + NaOH \rightarrow CH_3CH_2OH + NaCl$
(alkyl halide) (alcohol)

The bonding between atoms in organic molecules is covalent, so these compounds tend to keep their original identity in solution. Organic compounds are also non-polar (their centres of negative and positive charges are the same), so they generally do not dissolve in water.

Some organic compounds can act as acids, and others as bases. Some organic compounds can be oxidised and others reduced. Reaction rates are slower in organic compounds than in inorganic compounds.

Organic compounds have weak Van der Waals (London and dispersion) forces between molecules, so they have lower melting and boiling points than inorganic compounds do.

Note

Rules for naming organic compounds

When we name organic compounds, we use the IUPAC rules, approved by the International Union of Pure and Applied Chemistry. This ensures that everyone, irrespective of language or geography, names and draws compounds in exactly the same way.

Functional groups

Organic compounds are classified by their **functional groups**. A functional group is one or more atoms with a particular arrangement. The functional group largely determines the chemical and physical properties of molecules that contain it. Functional groups also make up the reactive portion of the molecule, which undergoes predictable reactions.

If you understand and learn the chemistry of each functional group, you will be able to apply your knowledge to the many different compounds in each group.

The table below shows the functional groups of the main classes of organic molecules.

Functional group	Class of compound	Example
$-C=C-$	alkene	$CH_2=CH_2$
$-C\equiv C-$	alkyne	$HC\equiv CH$
$-C-OH$	alcohols	CH_3CH_2OH
$-C-O-C-$	ether	CH_3-O-CH_3
$-\overset{O}{\overset{\|}{C}}-H$	aldehyde	$CH_3\overset{O}{\overset{\|}{C}}H$
$-C-\overset{O}{\overset{\|}{C}}-C-$	ketone	$CH_3\overset{O}{\overset{\|}{C}}CH_3$
$-\overset{O}{\overset{\|}{C}}-OH$	carboxylic acid	$CH_3-\overset{O}{\overset{\|}{C}}-OH$
$-\overset{O}{\overset{\|}{C}}-O-C-$	ester	$CH_3\overset{O}{\overset{\|}{C}}-O-CH_3$
$-C-NH_2$	amine	CH_3-NH_2
$-\overset{O}{\overset{\|}{C}}-NH_2$	amide	$CH_3\overset{O}{\overset{\|}{C}}\ NH_2$

Figure 3 Focus on Physical Sciences

Activity 5.1 Classifying organic compounds (individual)

LO2 AS1

Study the table of functional groups on the previous page.

1. Classify the following compounds on the basis of their functional groups:

(a) $CH_2{=}CHCH_3$ (b) $CH_3{-}O{-}CH_2CH_3$ (c) $CH_3CH_2NH_2$

(d) $CH_3CH_2CH_2OH$ (e) $CH_3CH_2\overset{\overset{\displaystyle O}{\|}}{C}CH_3$ (f) $CH_3CH_2CH_3$

(g) $CH_3CH_2\overset{\overset{\displaystyle O}{\|}}{C}OH$ (h) $CH_3CH_2\overset{\overset{\displaystyle O}{\|}}{C}{-}O{-}CH_3$ (i) $CH_3CH_2\overset{\overset{\displaystyle O}{\|}}{C}H$

2. Which of the compounds above is an example of a saturated hydrocarbon?
3. Which of the compounds above is an example of an unsaturated hydrocarbon?

1.2 Hydrocarbons

Hydrocarbons are compounds that consist only of carbon and hydrogen. **Aliphatic** hydrocarbons contain single, double or triple-bonded carbon atoms and occur as straight chains or rings (cyclic). **Aromatic** hydrocarbons contain a benzene ring (C_6H_6).

Alkanes and cycloalkanes are examples of saturated hydrocarbons. Alkenes and alkynes are examples of unsaturated hydrocarbons.

We can represent this relationship in the form of a mindmap (Figure 5.3).

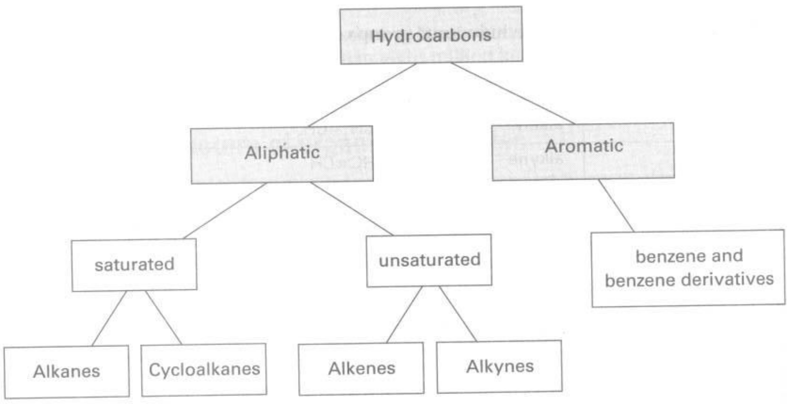


Figure 5.3: The major classes and subclasses of hydrocarbons.

Activity 5.2 Testing for saturation (pairs/groups)

LO1 AS1, 2

Read the information on hydrocarbons above.

Safety note

Use gloves – bromine water can stain your hands.

You will need: an alkane (e.g. hexane), an alkene (e.g. hexene), bromine water, three test-tubes.

1. Half-fill three test-tubes with bromine water. Add the alkane to test-tube A, and the alkene to test-tube B. Test-tube C serves as a control.
2. Shake the solutions in the test-tubes. Note any colour changes by comparing the solutions to the control.

Figure 4 Focus

You may notice that, when a saturated hydrocarbon (an alkane) is added to the bromine water, the solution stays brown. The bromine does not react with the alkane, and the bromine stays in solution:

$$CH_2 = CHCH_3 + Br_2 \rightarrow \underset{\text{Br}}{CH_2}\underset{\text{Br}}{CH}CH_3$$

When an unsaturated hydrocarbon (alkene or alkyne) is added to the bromine water, it turns colourless. This is because the bromine atoms (brown) are being taken up into the alkene to form a dibromoalkane, which is colourless: $CH_3CH_2CH_3 + Br_2 \rightarrow$ no reaction. Figure 5.4 illustrates the reactions.

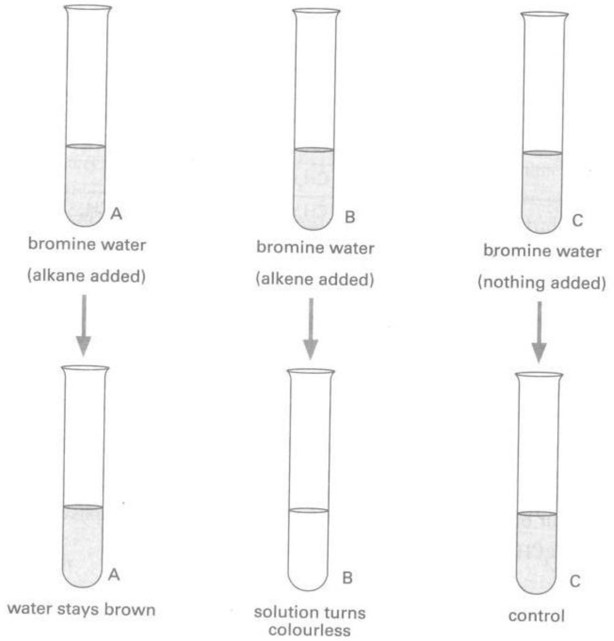


Figure 5.4: The reaction of an alkane and an alkene with bromine.

Activity 5.3 Determining whether an unknown hydrocarbon is saturated or unsaturated (pairs)

LO1 AS1, 3; LO2 AS2

Read the text above.

You are given a sample of an unknown hydrocarbon, X.

1. Design an investigation to determine whether X is a saturated or an unsaturated hydrocarbon.
2. After you have checked your experimental procedure with your teacher, you can carry out the investigation and record your findings.

Figure 5 Focus

1.3 Alkanes and their properties

Naming alkanes

> **Note**
> It is very important that you learn to name these basic compounds because we use this as a basis for naming other organic molecules.

Alkanes have a general formula of C_nH_{2n+2}, where *n* indicates the number of carbon atoms. The names of alkanes end in the suffix *-ane*. The prefix tells us how many carbon atoms are in the molecule. The table below shows the name, number of carbon atoms, parent name and formula of the first ten straight-chained (normal) alkanes:

Name	Number of carbon atoms	Prefix	Condensed formula
methane	1	meth-	CH_4
ethane	2	eth-	CH_3CH_3
propane	3	prop-	$CH_3CH_2CH_3$
butane	4	but-	$CH_3CH_2CH_2CH_3$
pentane	5	pent-	$CH_3CH_2CH_2CH_2CH_3$
hexane	6	hex-	$CH_3CH_2CH_2CH_2CH_2CH_3$
heptane	7	hept-	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
octane	8	oct-	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
nonane	9	non-	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
decane	10	dec-	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

Note that there is a pattern as we go down the column. Alkanes form a **homologous series**. If you look closely, you will see that each compound differs from the one before it and the one after it by a CH_2 group. Each compound in the group has the same general formula, and so they have similar properties and undergo the same kinds of reactions.

Molecules that have the same molecular formula but different structural formulae, are called **structural isomers**. Isomers differ in their physical and chemical properties. Isomers can occur only in hydrocarbons that consist of four or more carbon atoms. For example, C_4H_{10} can exist as

$$CH_3CH_2CH_2CH_3 \text{ (butane) or as } CH_3\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_3 \text{ (2-methylpropane).}$$

Worked example

Write down all possible isomers for pentane. The molecular formula for pentane is C_5H_{12}.

Solution

Possible arrangements for C_5H_{12} are:

$$\begin{array}{cccc}
\text{A} & \text{B} & \text{C} & \text{D} \\
CH_3CH_2CH_2CH_2CH_3 & CH_3CH_2\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_3 & CH_3\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_2CH_2 & CH_3\overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}CH_2
\end{array}$$

You can see that B and C are actually the same compound. Both have four carbon atoms, with a CH_3 (methyl) group on the second carbon. So pentane has three possible isomers: A, B or C, and D.

Figure 6 Focus

Activity 5.4 Writing structural isomers (pairs)

LO2 AS1

Read the information on naming alkanes on page 156.

1. Write down all the possible isomers for octane. The molecular formula for octane is C_8H_{18} You will notice that the greater the number of carbon atoms is, the greater the number of possible isomers there will be.
2. Identify the pairs of isomers from the compounds below:

(a)

$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$

(b)

$$\begin{array}{c} CH_3 \\ | \\ H_3CCCH_3 \\ | \\ CH_3 \end{array}$$

(c)

$$\begin{array}{c} CH_3CH_2 \\ | \\ H_3CCCH_3 \\ | \\ CH_3 \end{array}$$

(d)

$$\begin{array}{l} CH_3CH_2CH_2CH_2 \\ \qquad\qquad\quad | \\ \qquad\qquad CH_2CH_3 \end{array}$$

(e)

$$\begin{array}{l} CH_3CH_2CHCH_3 \\ \qquad\qquad\quad | \\ \qquad\qquad\;\; CH_3 \end{array}$$

Alkyl groups

An alkyl group (R–) is an alkane that has one less hydrogen. It is named after the parent alkane. For example, the methyl group ($-CH_3$) comes from methane (CH_4), the ethyl group (CH_3CH_2–) comes from ethane (CH_3CH_3), and so on.

An alkyl group is also called a side chain because it is attached to the side of the base molecule. The location of the side chain is indicated by the position number of the carbon atom to which it is attached. In the name of the compound, this number is separated from the alkyl group by a hyphen, as in, for example, 3-ethyloctane. We number the longest chain of carbon atoms from the side closest to where the side chain is attached, so that the side chain is indicated with the lower position number.

Note

In organic chemistry formulas, an R represents an element or an atom. Together with a bond sign, for example R– or –R, it indicates an alkyl group, that is, a side-chain.

Worked example

Name the following compound:

$$\begin{array}{l} CH_3CH_2CHCH_2CH_2CH_3 \\ \qquad\quad\;\; | \\ \qquad\quad CH_3 \end{array}$$

Solution

Number the longest chain of carbon atoms. If we number from left to right, the methyl group is attached to the carbon atom in position number 3. (If we had numbered it from right to left, it would have been on the carbon atom in position number 4.)

$$\begin{array}{l} \mathit{1\;\;\;2\;\;\;3\;\;4\;\;\;5\;\;\;6} \\ CH_3CH_2CHCH_2CH_2CH_3 \\ \qquad\quad\;\; | \\ \qquad\quad CH_3 \end{array}$$

The base name for this molecule is hexane because it has six carbon atoms.

A methyl group is attached to the carbon atom in position number 3, so the name of the molecule is 3-methylhexane.

Note

When you name organic compounds, you always need to separate numbers from letters with a hyphen.

Figure 7 Focus

How to draw the structural formula of a known compound.

Let's take 3-ethyloctane as an example.

- Determine the number of carbon atoms in the parent chain.
- Make sure that you show all four bonds for each carbon atom.
- In this case, we draw a parent chain with eight carbon atoms (octane) .

C–C–C–C–C–C–C–C

- Number the carbon atoms (from either side).

1 2 3 4 5 6 7 8
C–C–C–C–C–C–C–C

- Add the side chain (ethyl group) onto the appropriate carbon atom number 3).

1 2 3 4 5 6 7 8
C–C–C–C–C–C–C–C
|
CH_2CH_3 (ethyl group)

- Add hydrogen atoms.

$CH_3CH_2CHCH_2CH_2CH_2CH_2CH_3$
|
CH_2CH_3

To check that you are correct, use the IUPAC system to name the compound that you have drawn, and compare it with the name of the compound that you were given to draw.

Activity 5.5 Naming and drawing alkanes (individual)

LO1 AS3; LO2 AS1

Read the text about alkyl groups on page 157, and work through the example and the 'How to'-box about drawing structural formulae above.

1. Name the following compounds:
   (a) $CH_3CH_2CHCH_2CH_2CH_3$
   |
   CH_2CH_3
   (b) $CH_3CH_2CH_2CH_2CHCH_2CH_2CH_3$
   |
   CH_2CH_3
2. Draw structures for:
   (a) 2-methylpentane
   (b) 3-methylheptane.

Note

In Chapter 7, we deal with the boiling points of different hydrocarbons in a mixture, which makes it possible to separate them with fractional distillation (see page 236).

Uses of alkanes

Petroleum (crude oil) consists of a **heterogeneous mixture** of hydrocarbons (mostly alkanes) in solid, liquid and gaseous phases. Heating the more viscous (thicker) liquids breaks the bonds between the molecules, thereby decreasing the viscosity – that is, heating makes the liquids thinner.

Activity 5.6 Examining the relationship between the size of an alkane and its boiling point (individual)

LO1 AS2; LO2 AS2

Read the paragraph about the uses of alkanes above.

1. Look at Figure 5.5. What conclusion can you draw from this graph?
2. Use your knowledge from Grade 10 to provide an explanation for this phenomenon.
3. Use the graph to determine the approximate boiling point of:
   (a) butane
   (b) heptane.

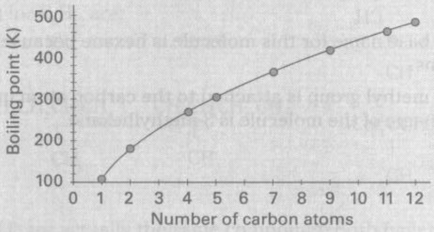


Figure 5.5: A graph showing the boiling points of different alkanes.

Figure 8 Focus

Properties of alkanes

Alkanes have very specific properties. These include:

- The first four alkanes are all gases at room temperature and pressure. Alkanes with between five and seventeen carbon atoms are oily liquids, whereas those that have more than seventeen carbon atoms are solids. (As the chain length increases, the state of alkanes at room temperature and pressure change from gas to liquid to solid.)
- The liquid alkanes are less dense, and insoluble in water. They are non-polar compounds, so they are soluble in non-polar solvents.
- The boiling point of alkanes increases as the chain length – and therefore molecular weight – increases. The longer an alkane is, the stronger the intermolecular forces (Van der Waals forces) are between them, and the greater the energy required to break these forces will be. Therefore the boiling point is higher.
- The more branched an alkane is, the lower the melting and boiling points will be. There are fewer intermolecular forces between the molecules, so less energy is required to break them apart. The melting or boiling point is thus lower than that of a straight-chained alkane with the same number of carbon atoms.
- The lower the boiling point of the alkane is, the higher the vapour pressure will be at a particular temperature. The vapour pressure is the pressure that the vapour exerts on the liquid. At a particular temperature, more liquid molecules will vaporise (and exert a higher vapour pressure) in a liquid with a lower boiling temperature, than in one with a higher boiling temperature (see Figure 5.5).

Alkanes generally have a low **reactivity** because single bonds are not broken easily. They can, however, undergo:

- *oxidation reactions* – these are also called **combustion reactions**. Oxidation reactions are important because they produce energy and are thus exothermic. When we light up our gas or primus stoves or make a fire, we are starting an oxidation reaction. Oxidation reactions also occur in our bodies during **respiration**. Alkanes burn in oxygen to form carbon dioxide, water and energy:

  $CH_4 + 2O_2 \xrightarrow{hf} CO_2 + 2H_2O$ + energy.
- *halogenation reactions* – alkanes undergo **substitution reactions**. Substitution of a hydrogen atom with a halogen atom – chlorine (Cl), bromine (Br) or iodine (I) – is called halogenation. A haloalkane, or alkyl halide, is formed. Ultraviolet light (*hf*) is required for halogenation of alkanes. An alkane can undergo more than one substitution to form various products:

$$CH_4 + Cl_2 \xrightarrow{hf} \underset{\text{(methylchloride)}}{CH_3Cl} \xrightarrow{Cl_2} \underset{\text{(methylene chloride)}}{CH_2Cl_2} \xrightarrow{Cl_2} \underset{\text{(chloroform)}}{CHCl_3} \xrightarrow{Cl_2} \underset{\text{(carbon tetrachloride)}}{CCl_4}$$

- *elimination reactions* – alkanes can lose hydrogen atoms to form alkenes. For example:

  $CH_3CH_3 \rightarrow CH_2{=}CH_2 + H_2$

  This reaction is used during the **cracking** of petroleum, when large alkanes are broken into smaller alkenes.

When alkanes can burn in oxygen and give off energy, they are called fuels. Fuels are used to drive vehicles and cook food. The natural gas found in the Earth's crust is mostly methane gas. Ethane is used to make ethene, an important compound used in the production of polyethene (plastic), soaps and nylon. Butane gas is used in cigarette lighters. The liquid petroleum gas (LPG) that we use in cylinders at home is a mixture of butane and propane. Hexane is the chief constituent of petrol.

Note

Cracking is covered in more detail in Chapter 7 (see page 237–238).

Note

The properties and uses of alkanes are discussed in more detail in Chapter 7 (see page 235).

Figure 9 Focus

1.4 Alkenes and alkynes

In Grade 11, we dealt with multiple bonds. Alkenes are hydrocarbons that contain one or more double bonds of carbon atoms, and alkynes have one or more triple bonds of carbon atoms.

Alkenes have the general formula C_nH_{2n}. An alkene with two double bonds is called a diene. Alkenes that have alternating double bonds, for example $CH_2{=}CH{-}CH{=}CH{-}CH{=}CH_2$ are called conjugated alkenes.

Naming and drawing alkenes and alkynes

To name alkenes, we number the longest continuous chain of carbon atoms (to determine the base name). The base name comes from the parent alkane but the *-ane* is replaced by *-ene*.

Then we number the carbon atoms, starting from the side closest to where the double bond is located. The location of the double bond is indicated by the position number of the lower numbered of the two carbon atoms that form the double bond.

Worked example

Name the following compound: $CH_3CH{=}CHCH_2CH_3$.

Solution

The base name (longest continuous chain of carbon atoms) consists of five carbon atoms, so the compound is pentene. In this case, we start numbering from the left

$CH_3CH{=}CH\,CH_2CH_3$
1 2 3 4 5

In this case, the double bond is between carbon atoms 2 and 3, so the lower numbered position number (2) forms part of the name of the molecule: 2-pentene or pent-2-ene.

Alkynes have the general formula C_nH_{2n-2}. Alkynes are named in exactly the same way as alkenes, except that the suffix is *-yne*. $CH_3C{\equiv}CCH_2CH_2CH_3$ is named 2-hexyne or hex-2-yne.
1 2 3 4 5 6

Activity 5.7 Naming alkenes and alkynes (individual)

LO2 AS1

Read the section above, on alkenes and alkynes, and then name the following compounds:

1. $CH_3CH_2CH{=}CHCH_3$
2. $CH_2{=}CHCH_3$
3. $CH_3CH_2CH_2C{\equiv}CCH_2CH_3$

Worked example

Draw the structural formula for 2-hexene.

Solution

We identify the compound as an alkene because of the suffix *-ene*.

We know that it has six carbon atoms (the prefix *hex-*). So we draw a base molecule consisting of six carbon atoms, and number the carbon atoms from one end of the molecule. We place the double bond between carbon atom numbers 2 and 3. Then we fill up the rest of the carbon atoms with hydrogen, bearing in mind that each carbon must form four bonds.

Figure 10 Focus

$C{-}C{-}C{-}C{-}C{-}C \rightarrow C{-}C{=}C{-}C{-}C{-}C \rightarrow CH_3CH{=}CHCH_2CH_2CH_3$

1 2 3 4 5 6   1 2 3 4 5 6

To draw alkynes, we follow the same procedure but we insert a triple bond, instead of a double bond.

Note
Remember to check the number of hydrogen atoms carefully.

Activity 5.8 Writing structural formulae for alkenes and alkynes (individual)

LO2 AS1

Read the section on the previous page, on the naming and drawing alkenes and alkynes, and then draw the structural formulae for the following compounds:

1. 3-octene 2. heptene 3. 2-pentyne 4. octyne.

Reactions in alkenes and alkynes

Alkenes and alkynes are more reactive than alkanes because double bonds are broken more easily than single bonds are.

Alkenes and alkynes can undergo addition reactions. The following are examples of typical reactions of unsaturated compounds:

- halogenation, for example $CH_2{=}CHCH_3 + Cl_2 \rightarrow \underset{Cl\ \ Cl}{\overset{|\ \ \ |}{CH_2CHCH_3}}$
- hydrogenation, for example $CH_2{=}CHCH_3 \xrightarrow{H_2/Pt} \underset{H\ \ H}{\overset{|\ \ \ |}{CH_2CHCH_3}}$ (or $CH_3CH_2CH_3$)

  This reaction is used to make margarine from unsaturated plant oils.
- hydration, for example $CH_2{=}CHCH_3 + H_2O \rightarrow \underset{H\ \ OH}{\overset{|\ \ \ |}{CH_2CHCH_3}}$
- **polymerisation reactions** – individual alkenes and alkyne molecules (**monomers**) can be added to one another to form long chains (**polymers**). This is called **addition polymerisation**. Example:

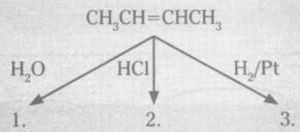
  $3(CH_2{=}CH_2) \rightarrow {-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}$

Note
Polymerisation reactions are covered in more detail in Chapter 7 (page 243).

Activity 5.9 Completing addition reactions (individual)

LO1 AS3; LO2 AS1

Read the section above, on reactions in alkenes and alkynes, and complete the following reaction sequences:



The uses of alkenes and alkynes

Alkenes are important because they form the basis of many polymerisation reactions. Alkenes are the monomers of many polymers, for example in the **polymerisation** of ethene ($H_2C{=}CH_2$) to form polyethene (–CH–CH–CH–CH–).

Alkenes form the base compounds in the synthesis of a variety of artificially produced substances because different atoms or groups can be added to them. Butadiene is used to make synthetic rubber and resins. Ethene is used to make ethylene glycol, which, in turn, is used to make cosmetics, make-up and face paint. Ethyne (acetylene) is used in oxyacetylene torches (like the one in Figure 5.6), which are used to cut and weld metals.

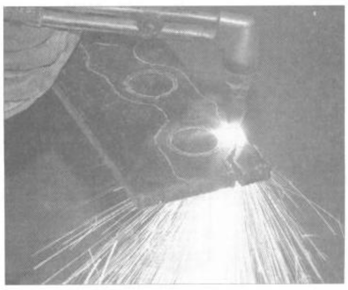


Figure 5.6: An oxyacetylene torch.

Figure 11 Focus

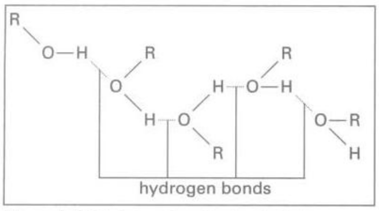


Figure 5.7: Hydrogen bonding in alcohols

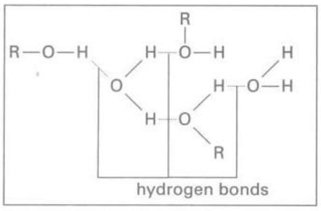


Figure 5.8: Alcohols form hydrogen bonds with water molecules.

1.5 Alcohols

Alcohols contain the functional group –OH (hydroxyl). The general formula of alcohols is ROH, where R is an alkyl group. Alcohols have relatively high boiling points, due to the extensive hydrogen bonding between alcohol molecules. Strong hydrogen bonds are formed between the hydrogen on one alcohol molecule and an electronegative oxygen on another (see Figure 5.7). Energy is required to break these bonds, so alcohols have high boiling points. As in alkanes, a longer carbon chain signifies higher melting and boiling points.

Alcohols are polar molecules because of the –OH group. They have dipole forces between molecules. They are soluble in water because they are able to fit in between the water molecules and form hydrogen bonds with them (see Figure 5.8). The larger the alcohol molecule is, however, the more difficult it is for it to fit in between the water molecules and the lower the solubility is likely to be.

Naming and drawing alcohols

Alcohols are named from the base alkane, with the *-e* being replaced by *-ol*. The position of the –OH group is specified according to the carbon to which it is attached.

1. $CH_3CH_2CH_2CH_2OH$ is called butanol or 1-butanol (from butane)
2. $$\begin{array}{l} \mathit{1}\ \ \mathit{2}\ \mathit{3}\ \ \mathit{4} \\ CH_3\underset{\displaystyle OH}{\underset{|}{CH}}CH_2CH_3 \end{array}$$ is called 2-butanol or butan-2-ol.

When we draw alcohols, we write down the number of carbon atoms (from the base name). We then number the carbon atoms. Then we add the –OH group to the appropriate C. Finally, we fill up the other carbon bonds with hydrogen.

Worked example

Draw 3-hexanol.

Solution

$$\begin{array}{ccc} \mathit{1\ 2\ 3\ 4\ 5\ 6} & \mathit{1\ 2\ 3\ 4\ 5\ 6} & \mathit{1\ \ 2\ \ 3\ 4\ \ 5\ \ 6} \\ C{-}C{-}C{-}C{-}C{-}C \rightarrow & C{-}C{-}\underset{\displaystyle OH}{\underset{|}{C}}{-}C{-}C{-}C \rightarrow & CH_3CH_2\underset{\displaystyle OH}{\underset{|}{CH}}CH_2CH_2CH_3 \end{array}$$

Uses of alcohol

Ethanol is used as fuel, and to make alcoholic drinks. Excessive consumption of ethanol can lead to liver and kidney failure. Methanol can cause blindness and death, if ingested. It is used as a solvent, and is found in methylated spirits, which is used as a fuel in primus stoves. Some examples of substances containing alcohol are shown in Figure 5.9.

Figure 5.9: Substances containing alcohol.

Figure 12 Focus

Case study: The effects of alcohol on unborn children

People have fermented fruit and grain to make alcoholic beverages for thousands of years. Alcoholic drinks are used in celebrations, and even in religious ceremonies. Sealed jugs of wine, thousands of years old, were even found in the Egyptian Pharaoh Tutankhamen's tomb!

Alcohol abuse, on the other hand, leads to pain and suffering. Alcohol is addictive, and many people become dependent on it. The over-consumption of alcohol can lead to a number of illnesses, and even innocent babies are affected.

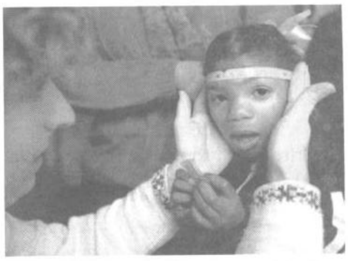


Figure 5.10: This child was born with FAS.

South Africa has a particularly high rate of Foetal Alcohol Syndrome (FAS). This is a condition that babies are born with when their mothers drink too much alcohol during their pregnancy. These children have growth problems, facial distortion and mental defects (see Figure 5.10). The rate of occurrence is the highest in the wine-growing region of the Western Cape (40–50 children per thousand), and in Gauteng the rate is still between 20 and 30 children per thousand.

Most of the mothers of FAS babies drink only socially – they do not consider themselves to be heavy drinkers. Medical research has shown that, when a mother drinks alcohol, it enters the bloodstream of her unborn child, and that the child's blood alcohol reaches the same level as that of the mother within fifteen minutes.

Because South Africa has many other health problems (HIV and TB in particular), FAS prevention does not get sufficient attention. However, the Health Ministry does recognise that alcohol abuse is harmful. It is compulsory for alcohol companies to add information to their advertising campaigns, advising consumers of the dangers of the irresponsible use of alcohol. The law also prohibits the sale of alcohol to anyone under the age of eighteen years.

Activity 5.10 Researching the effects of alcohol (individual)

LO3 AS2

Read the case study above, on the effects of alcohol on unborn children.

1. Conduct further research on some aspect of the effects of alcohol.
2. Formulate a research question.
3. Carry out your research and present your findings in the form of a report.

How about this?

It is against the law to drink more than a certain amount of alcohol if you are about to drive a vehicle. Alcohol impairs your judgment, slows down your response time, and impairs your vision. The legal limit of alcohol in the blood is 0,05 g alcohol per 100 mL of blood. Anyone caught driving above this limit may be jailed and may need to pay a heavy fine.

The traffic police use a 'breathalyser' test to see whether drivers have high levels of alcohol in their blood. The testing instrument contains an acidified dichromate solution (orange). The driver has to breathe out through the breathalyser. If there is a high level of alcohol in the breath, the alcohol is oxidised by the dichromate, and the dichromate changes to green.

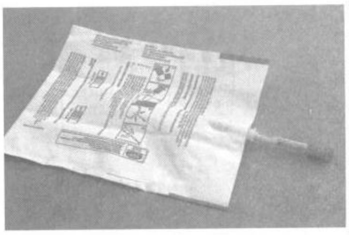


Figure 5.11: A breathalyser kit that you can use at home to check that your blood alcohol levels are within limits for driving.

If the breathalyser test is positive (that is, if it turns green) the driver is usually sent for a blood test, which can measure blood alcohol levels more accurately.

Breathalyser kits are also available for testing your blood alcohol levels at home (see Figure 5.11).

Figure 13 Focus

Activity 5.11 Naming and writing structural formulae for alcohols (individual)

LO2 AS1

Read the information on page 162 about naming and drawing alcohols.

1. Name the following compounds:
   (a) $CH_3CH_2CHCH_3$ with OH on the third carbon
   (b) $CH_3CH_2CH_2OH$
   (c) $CH_3CH_2CH_2CHCH_2CH_3$ with OH on the fourth carbon
2. Write down the structural formulae for:
   (a) heptanol
   (b) 2-pentanol.

1.6 Aldehydes and ketones

Aldehydes and ketones are called **carbonyl compounds** because they contain a carbonyl group

$$\begin{array}{c} -C- \\ \| \\ O \end{array}$$

In aldehydes, the carbonyl group is terminal (at the end of the compound), whereas in a ketone, the carbonyl group is non-terminal (in the middle).

Aldehydes have the functional group $\begin{array}{c} O \\ \| \\ -CH \end{array}$, whereas ketones are identified by $\begin{array}{c} -C-C-C. \\ \| \\ O \end{array}$

Reactions in aldehydes and ketones

Aldehydes and ketones have similar properties but ketones are less reactive than aldehydes are. Aldehydes can be oxidised to form carboxylic acids, whereas ketones do not undergo oxidation. This distinction between them is used to differentiate between reducing and non-reducing sugars.

Ketones and aldehydes display **tautomerism**. This means that atoms within a molecule can be rearranged to form new bonds, and therefore a different molecule. Molecules, that can occur in different arrangements, are called **tautomers**.

$$\begin{array}{c} OH \\ | \\ CH_2{=}CCH_3 \\ \text{(enol form)} \end{array} \text{ and } \begin{array}{c} O \\ \| \\ CH_3CCH_3 \\ \text{(keto form)} \end{array} \text{ are tautomers.}$$

Uses of aldehydes and ketones

Ketones and some aldehydes have pleasant odours. They are used in the perfume industry and as flavourings in the confectionary industry.

Examples of natural ketones are camphor (used for medicinal purposes) and testosterone (the male sex hormone). Acetone (propanone) is a solvent found in thinners and nail-polish removers (some examples are shown in Figure 5.12). A 37% solution of methanal, called formalin, is used to preserve biological specimens and to make plastics.

Figure 5.12: These substances all contain aldehydes or ketones.

Figure 14 Focus

1.7 Carboxylic acids

Organic acids are called carboxylic acids. They contain the carboxyl group $-\overset{\overset{\displaystyle O}{\|}}{C}OH$. The general formula is RCOOH. Carboxylic acids are weaker acids than the inorganic acids, and are found in nature and in household substances.

They have higher boiling points than similar-sized hydrocarbons or alcohols because of the strong hydrogen bonds that link the molecules. These bonds form between the acidic hydrogen atom of one acid molecule and the carbonyl oxygen atom of another. Two hydrogen bonds are therefore possible between two adjacent molecules.

Carboxylic acids are polar because of the carboxyl group in them. So they also have dipole forces between their molecules.

Naming and drawing carboxylic acids

We name carboxylic acids from their base alkane. The *-e* is replaced by *-oic acid*. CH_3COOH, for example, is called ethanoic acid (from ethane which consists of two carbon atoms). The common name for ethanoic acid is acetic acid.

Worked example 1

Name the following compound: $CH_3CH_2CH_2COOH$

Solution 1

The compound is an acid because it has a carboxyl group. It consists of four carbon atoms, so it is butanoic acid.

Worked example 2

Draw the structural formula of pentanoic acid.

Solution 2

We draw a chain of five carbon atoms (from the prefix *pentan-*). Then we attach a double-bonded oxygen atom and the –OH group to either the first or the last carbon atom. Finally, we fill in the hydrogen atom on the other carbon atoms, so that the carbon atoms each have four bonds.

$$\underset{1\ \ 2\ \ 3\ \ 4\ \ 5}{C-C-C-C-C} \rightarrow C-C-C-C-\overset{\overset{\displaystyle O}{\|}}{C}-OH \rightarrow CH_3CH_2CH_2CH_2\overset{\overset{\displaystyle O}{\|}}{C}OH$$

Activity 5.12 Naming and drawing carboxylic acids (individual)

LO2 AS1, 2

Read the section above, on the naming and drawing of carboxylic acids.

1. Name the following compounds:
   (a) $CH_3CH_2\underset{\underset{\displaystyle O}{\|}}{C}OH$ (b) $CH_2CH_2CH_2\ CH_2CH_2\underset{\underset{\displaystyle O}{\|}}{C}OH$
2. Write down the structural formula for heptanoic acid.
3. Draw a diagram to show the hydrogen bonding between carboxylic acids.
4. Are carboxylic acids soluble or insoluble in water? Explain your answer.

Figure 15 Focus

Uses of carboxylic acids

Methanoic acid, also called formic acid, is found in the sting of bees and ants. Carboxylic acids are found in the kitchen and can be used in cooking. Some common examples are citric acid (in citrus fruits), lactic acid (in sour milk), tartaric acid (used to make sour porridge) and acetic acid (in vinegar). Benzoic acid is used as a food preservative. Salicylic acid is used to make aspirin, an ester.

1.8 Esters

An ester has the functional group $-\overset{\overset{\displaystyle O}{\|}}{C}-O-C-$. The general formula is RCOOR′. Short-chained esters are volatile liquids, whereas those with longer chains are soft, oily solids or waxes.

Esters are formed when an alcohol reacts with a carboxylic acid. The process is called **esterification**. It is a **reversible reaction**. The forward reaction is favoured by using concentrated H_2SO_4 (sulfuric acid) as a catalyst.

Note
In a formula, in this case for esters, R and R′ represent two different alkyl groups.

$$\underset{\text{(alcohol)}}{R-COH} + \underset{\text{(carboxylic acid)}}{R'\overset{\overset{\displaystyle O}{\|}}{C}OH} \rightleftharpoons \underset{\text{(ester)}}{R-\overset{\overset{\displaystyle O}{\|}}{C}-O-C-R'} + H_2O$$

The name of the ester comes from the alcohol and the carboxylic acid that it is derived from. The alkyl group from the alcohol is named first, followed by the acid part of the name. The *-ic* from the acid is replaced by *-oate*.

Note
The –OH from the acid and the H from the alcohol forms water (H_2O).

For example, $CH_3CH_2CH_2CH_2\overset{\overset{\displaystyle O}{\|}}{C}-O-CH_3$ is methylpentanoate (from methanol and pentanoic acid).

Activity 5.13 Understanding esters (individual)

LO1 AS3; LO2 AS1, 2

Read the information on esters above.

Write down the names of the carboxylic acid and the alcohol that reacted to form the following esters:

1. ethyl ethanoate
2. methylhexanoate
3. $CH_3\overset{\overset{\displaystyle O}{\|}}{C}-O-CH_3$
4. $CH_3CH_2\overset{\overset{\displaystyle O}{\|}}{C}-O-CH_2CH_3$

Activity 5.14 Making esters (pairs)

LO1 AS1; LO2 AS1

Read the information on esters above.

You will need:
- organic acids – ethanoic (acetic) acid; salicylic acid, benzoic acid, butanoic acid
- alcohols – ethanol, methanol, propanol, pentanol
- concentrated sulfuric acid
- test-tubes, Petri dish or saucer, cold water
- a water bath.

Safety note
Concentrated acids are corrosive. If they spill onto your hands, wash your hands with cold water immediately.

Figure 16 Focus

1. Pour 2 cm^3 of the alcohol into a clean, dry test-tube. Add a few drops of concentrated H_2SO_4.
2. Add an equal amount of the organic acid and shake gently to mix. A solution of the solid acids can be used. Heat the test-tube in the water bath, pour the contents into a Petri dish with cold water, and smell it.
3. Repeat with different alcohols and acids. Record your results in the table:

Carboxylic Acid	Alcohol	Smell of ester	Name of ester formed
1. salicylic acid 2. 3.	methanol	Deep Heat (wintergreen)	methyl salicylate

Uses of esters

Esters occur naturally in flowers, plant oils, fats and waxes. Animal fats are esters of carboxylic acids with glycerol. They are called triglycerides.

Esters are characterised by their pleasant smells. They are used in the manufacture of flavourings, perfumes and medicines, and in the production of soaps and fabrics.

Note
Soap production processes are covered in more detail in Chapter 7 (see page 258).

1.9 Amines and amides

Many organic compounds contain nitrogen. Amino acids are important nitrogen-containing organic molecules, which form the building blocks of proteins.

How about this?
Many street children have taken to sniffing glue from a bag. This makes them 'high'. This practice is, however, very dangerous. The glue contains organic compounds, which may provide feelings of happiness, but can also cause hallucinations and permanently affect the brain.

Naming of amines and amides

Amines

Amines are derived from ammonia – one of the hydrogen atoms of the NH_3 is replaced by an alkyl group. Amines are classified as primary, secondary or tertiary. Here we deal only with primary amines.

$CH_3CH_2NH_2$	$CH_3-\underset{}{N}(CH_3)-H$	$CH_3-N(CH_3)-CH_3$
A primary amine	A secondary amine	A tertiary amine

Primary amines are named after the corresponding alkyl group to which the amino group is attached. The suffix *-amine* is added. Examples:

1. $\underbrace{CH_3CH_2}_{\text{ethyl group}}NH_2$ (or ethylamine) 2. $\underbrace{CH_3CH_2CH_2CH_2CH_2}_{\text{pentyl group}}NH_2$ (or pentylamine)

Amides

Amides also contain a carbonyl group, in addition to the amino group found in amines. The functional group in amides is the amide group:

$$-\overset{\overset{\displaystyle O}{\|}}{C}NH_2 \text{ (or } -CONH_2\text{)}$$

Amides are named after the corresponding alkane. The suffix *-amide* is added. Examples:

1. $CH_3\overset{\overset{O}{\|}}{C}NH_2$ is ethanamide (two carbon atoms)
2. $CH_3CH_2CH_2CONH_2$ is butanamide (four carbon atoms).

Figure 17 Focus

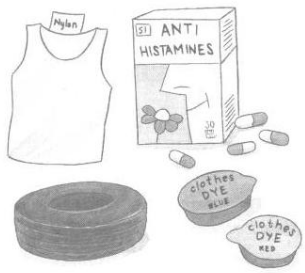


Figure 5.13: These substances all contain nitrogen compounds.

Properties and uses of amines and amides

Amines and amides are organic bases. They are able to accept protons (H^+) because of the lone pair of electrons on the nitrogen atom: $RNH_2 + H^+ \rightarrow RNH_3^+$. They react with acids to form salts (neutralisation reaction): $RNH_2 + HCl \rightarrow RNH_3Cl$.

Primary amines have boiling points that are higher than those of the corresponding hydrocarbon but lower than those of the corresponding alcohol. This is because, although they do form hydrogen bonds, these bonds are slightly weaker than those in alcohols. Amines that have a low molecular weight and are soluble in water.

Amines occur in nature as amino acids and vitamins. They are used in industry to make medicines, anaesthetics and synthetic fibres, like nylon and rubber (see Figure 5.13).

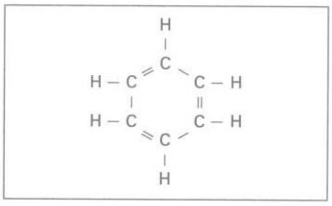


Figure 5.14: The structure of benzene.

1.10 Aromatic hydrocarbons

All aromatic compounds contain at least one benzene ring (C_6H_6).

Benzene occurs naturally in coal and oil deposits. It is commercially sold in the form of a colourless liquid. In the 1860s, Friedrich Kekulé von Stradonitz, a German scientist, showed that benzene is a cyclic molecule consisting of six carbon atoms. The ring contains double bonds between alternate carbon atoms, and each carbon atom also has one hydrogen atom attached to it (see Figure 5.14).

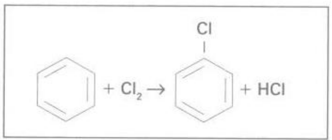


Figure 5.15: An example of a substitution reaction in benzene.

Benzene reactions

Although benzene has three double bonds, it does not undergo addition reactions as other alkenes do. However, benzene does undergo substitution reactions, in which the hydrogen atom on the benzene ring is replaced by other atoms or groups (see Figure 5.15). This ability has made benzene a **prime compound** for use as a base to synthesise other compounds (derivatives).

Activity 5.15 Investigating some common aromatic compounds (individual)

LO2 AS1, 3

Read the information on benzene in the paragraph above and on page 169.

Do research in books or on the Internet to find more information on aromatic compounds, and complete the table below:

Name of compound	Structure	Uses
1. toluene (methyl benzene)		
2. phenol		
3. benzoic acid		
4. benzaldehyde		
5. aniline		
6. nitrobenzene		
7. styrene		

Figure 18 Focus

Uses of aromatic hydrocarbons

Benzene is used to produce polystyrene, nylon, detergents and explosives (see Figures 5.16 and 5.17). It is non-polar and can act as a solvent for other non-polar substances. The use of benzene has been restricted since it was discovered to have cancer-inducing (**carcinogenic**) properties.

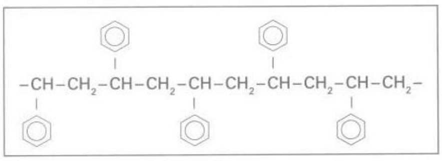


Figure 5.16: Polystyrene contains benzene rings.

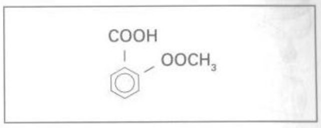


Figure 5.17: The structural formula of aspirin.

Case study: Health risks of benzene in coal and tobacco smoke

High incidences of skin cancer have been found among workers on coal plants, which can be attributed directly to the benzene that they are exposed to in their work.

Tobacco smoke is also known to contain harmful aromatic hydrocarbons. These substances accumulate in smokers' lungs over many years and can cause lung cancer. Tobacco companies have been forced to acknowledge the health risks (heart disease, pulmonary diseases and gangrene) related to smoking.

Government regulations force tobacco companies to print warnings on their products. The South African government tries to discourage smoking, by increasing taxes on cigarettes and by restricting the sale of cigarettes to those who are eighteen years and older. Smoking is prohibited in public places, like restaurants and shopping malls. In addition, tobacco companies are not allowed to sponsor sporting teams or events.

Activity 5.16 Summarising hydrocarbons (individual)

LO2 AS1, 2

Review the material in this unit. Then copy and complete this table to summarise what you have learnt about organic molecules.

Subclass	Examples	Important properties	Uses
alkanes			
alkenes and alkynes			
alcohols			
aldehydes and ketones			
carboxylic acids			
esters			
amines and amides			

Figure 19 Focus

Case study: Cloning and GM foods

Cloning has been very successful in stem cell research and has led to major breakthroughs in fighting cancer and other life-threatening diseases. Cloning can also potentially allow parents to choose characteristics for their children that are yet to be born. Many religious and moral leaders feel that cloning as such – or specific aspects of cloning – is unethical.

Genetically modified (GM) foods have resulted in a decrease in starvation in many Third World countries. However, the seeds from these crops cannot be replanted, so the poverty-stricken communities are completely dependent on the providers of the seeds, which are First World countries.

Research into GM peas in Australia has shown that they had massive allergenic effects on people, and these GM seeds were subsequently withdrawn. No widespread testing of allergenic proteins has happened in other countries, and food packaging is often not adequately labelled, so consumers cannot tell whether the food contains GM substances or not.

Cloning and GM foods both have advantages and disadvantages.

Activity 5.33 Researching and evaluating cloning and genetically modified foods (group)

LO2 AS1, 2, 3; LO3 AS1, 2, 3

Read the case study on cloning and GM foods above, and then carry out the instructions that follow.

1. Work in groups. Each group needs to select one of the topics: cloning or GM foods.
2. Discuss the issues, collect evidence and develop an argument for or against cloning or GM foods.
3. Each group will present their arguments and counterarguments orally to the class.
4. Listen to the various presentations and decide which argument you support for the issue that you did not choose. (In other words if you presented arguments on cloning, you will focus on GM foods. If you presented arguments on GM foods, you will focus on cloning.)
5. You will then write an essay explaining why you support or oppose either cloning or GM foods.

Summary Activity

Review this chapter before you do this activity.

1. Draw a detailed mind map to summarise the contents of this chapter. Include the categories 'organic molecules', 'industrial macromolecules' and 'biological macromolecules'.
2. Use your notes to make links between the categories.
3. Include the properties and uses of the examples provided in each category.
4. Try to use the correct terminology and to apply the vocabulary that you have developed in this chapter.

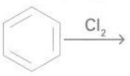
Summative assessment

Organic molecules

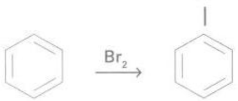
1. Name the following compounds:
   (a) $CH_3CH_2–O–CH_2CH_3$
   (b) $CH_3CH_2CH_2CHCH_3$ with OH on the fourth carbon
   (c) $CH_3CH_2CH_2NH_2$. (3)
2. Draw structures for:
   (a) 3-octyne
   (b) 2-hexanol
   (c) pentanoic acid. (3)
3. Given the following compounds,
   A. ethane B. ethene C. ethanol
   D. ethanoic acid E. ethanal
   choose:
   (a) the two compounds that are hydrocarbons (2)
   (b) the compound that gives compound D when oxidised (1)
   (c) the two compounds that can be used to make ethyl ethanoate (2)
   (d) the compound that can undergo polymerisation to form a plastic (1)
   (e) the compound that is found in vinegar (1)
   (f) the compound that would discolour bromine water. (1)
4. Explain why:
   (a) ethanol has a higher boiling point than ethane does (2)
   (b) hexane has a higher boiling point than ethane does (2)

Figure 20 Focus

(c) diethyl ether is not soluble in water (2)
(d) aldehydes can be oxidised, but ketones cannot (2)
(e) amines with a low molecular weight are soluble in water (2)
(f) decanol is less soluble in water than ethanol is. (2)

5. Complete the following reaction sequences:
(a) $CH_3CH{=}CH_2 + Br_2 \rightarrow$ (2)
(b) $CH_3CH_2CH_3 + Cl_2 \xrightarrow{hf}$ (2)
(c) $CH_3CH_2CH_2OH \xrightarrow{[O]}$ (2)
(d)

(2)
(e) $CH_3CH(OH)CH_3 \xrightarrow{[O]}$ (2)

6. Benzene is a poisonous organic compound that provides many useful substances.
(a) Explain the possible negative effects of benzene on the body. (2)
(b) Give examples of TWO useful substances that contain benzene. (2)

7. Classify the following reactions as substitution, addition, elimination or rearrangement reactions:
(a)

(b) $CH_3CH{=}CH_2 + H_2 \rightarrow CH_3CH_2CH_3$
(c) $n(CH_3CH{=}CH_2) \rightarrow (-CH_2CH_2CH_2CH_2CH_2CH_2-)_n$
(d) $CH_3C(OH){=}CH_2 \rightarrow CH_3C(=O)CH_3$
(e) $CH_3CH_2CH_2OH \xrightarrow{H^+} CH_3CH{=}CH_2 + H_2O$
[5 × 1 = 5]

8. Explain, using an example, what is meant by:
(a) unsaturated hydrocarbon
(b) structural isomers
(c) disaccharides
(d) tautomers
(e) esterification. [5 × 3 = 15]

9. 'In esterification, sulfuric acid acts as catalyst by serving as a dehydrating agent.' Explain what this statement means. (2)

10. You are given test-tubes containing colourless compounds, A and B. The molecular formulae of A and B are C_5H_{12} and C_5H_{10}. Bromine water is added to each of the test-tubes, and the solution is shaken. A becomes brown, whereas B stays colourless. (4)
(a) What is the molecular formula of A?
(b) What is the molecular formula of B? Explain your answer.

11. Given the following reactions,

$$\mathbf{A} \xrightarrow{H_2O} B \xrightarrow{[O]} CH_3CH(=O) \xrightarrow{[O]} C$$

$$\mathbf{B} + \mathbf{C} \xrightarrow{H_2SO_4} CH_3CH_2{-}O{-}C(=O)CH_3$$

name compounds **A**, **B** and **C**. [3 × 2 = 6]

12. The graph below (Figure 5.48) shows how the boiling points of organic compounds change as the chain length increases.
(a) Explain why the boiling points increase as the carbon chains get longer. (3)
(b) Explain the difference between the graphs for the three groups. (6)

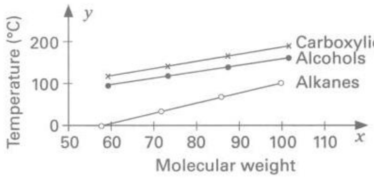
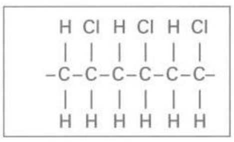


Figure 5.48: A graph showing boiling points of alkanes, alcohols and carboxylic acids.

13. Pentyl ethanoate is an ester, which is used to make banana essence.
(a) Draw the structure of this compound. (2)
(b) What substances would be used to make this ester? (2)
(c) What is the process of forming the ester called? (1)
(d) What catalyst is used in the reaction? (1)
(e) What other product is formed from this reaction? (1)

Organic macromolecules

1. Explain the difference between thermoset and thermoplastic polymers. (4)
2. Suppose that you are put in charge of a plastics recycling project at your school. Prepare a brochure that you will distribute to the school community, to encourage participation in the venture. (6)
3. The following is a portion of the polymer PVC (polyvinyl chloride)



(a) Write down the structure of the monomer of PVC. (2)
(b) Was the PVC formed by addition or condensation polymerisation? Explain. (3)

Figure 21 Focus

(c) Is PVC a homopolymer or a heteropolymer? Explain. (3)

4. Consider the polymerisation reaction that takes place in Figure 5.49:

$$nHOOC(CH_2)_3COOH + nHOCH_2CH_2OH$$
monomers
$$\downarrow -nX$$
$$-OOC(CH_2)_3COOCH_2CH_2-OOC(CH_2)_3COOCH_2CH_2-OOC(CH_2)_3COOCH_2CH_2-OOC(CH_2)_3COO-$$
polymer

Figure 5.49: A polymerisation reaction.

(a) Is this reaction addition or condensation polymerisation? Explain. (3)
(b) Is the polymer that is formed a homo- or a heteropolymer? Explain. (3)
(c) Name the compound X. (2)

5. List (a) the similarities and (b) the differences between nylon and polyester. (6)
6. Suppose that John and Peter are arguing about the advantages and disadvantages of plastics. Peter is calling for people to stop using plastic articles, whereas John feels that this is impossible. What do you feel? Explain your position on the matter, and why you feel that way. (8)
7. Humans have learnt over the years how to synthesise many products, which has had a great impact on human and social development. These production processes are, however, not always environmentally-friendly. Write an essay about the benefits and negative consequences of synthetically produced products on society and the environment. (10)
8. Suppose that your local newspaper is trying to get the public's input on whether plastics should be banned. Write a letter to the editor, explaining your stance. Remember that you need to support your argument with evidence. (8)
9. Every household in South Africa engages in the burning of fuel – whether it is for cooking food, for heat or when we drive our cars. Explain the risks involved in the burning of fuel. (4)
10. Suppose that your grandmother believes that using benzene is still the best way to clean your grandfather's clothes and suede shoes. What would you tell your grandmother to convince her about the risks of using benzene? (4)

Biological macromolecules

1. Do you think that (a) photosynthesis and (b) respiration is an endo- or an exothermic reaction? Explain your answer. (4)
2. Why are carbohydrates named with this term? (2)
3. Glucose can be broken down to form ethanol and carbon dioxide.
   (a) Write a balanced equation for the reaction. (2)
   (b) What is this process called? (1)
   (c) How much ethanol is obtained if we use 5 kg of glucose? (6)
   (d) How much glucose do we require to produce 2 kg of ethanol? (4)
4. Explain how the primary structure of a protein differs from its secondary structure. (2)
5. Show how a peptide bond is formed. (3)
6. What is the function of enzymes? (2)
7. Give an example of a process where carbohydrates are broken down by:
   (a) enzymes (1)
   (b) fermentation. (1)
8. Explain how you test whether a food sample contains reducing sugars. (4)
9. Explain how starch in plants can be used to produce alcohol. (3)
10. Starch and cellulose are polysaccharides. Both of them are homopolymers.
    (a) What is a polysaccharide? (2)
    (b) What is a homopolymer? (2)
    (c) List one similarity and one difference between starch and cellulose. (4)
11. Write down an equation to illustrate the hydrolysis of starch. (4)
12. Name the molecules labelled A, B and C in Figure 5.50. (3)

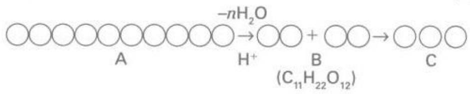


Figure 5.50: A condensation reaction.

13. Sucrose and lactose are disaccharides that are hydrolysed by strong acid to form monosaccharides (see Figure 5.51).

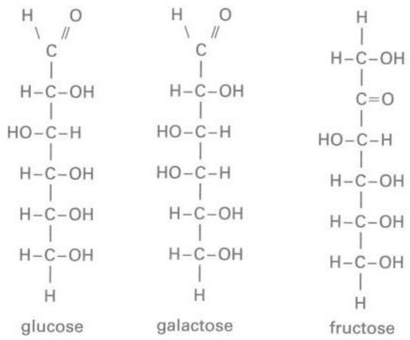


Figure 5.51: Monosaccharides – glucose, fructose and galactose.

(a) Explain what is meant by the terms (i) disaccharide and (ii) monosaccharide. (4)
(b) Which of the monosaccharides given above are formed from the acid hydrolysis of (i) sucrose and (ii) lactose? (2)
(c) In which foodstuffs would we find (i) lactose, (ii) fructose and (iii) sucrose? (3)
(d) What is the molecular formula for these monosaccharides? (2)
(e) How are these monosaccharide molecules (i) the same and (ii) different? (4)

Figure 22 Focus

(f) What is the relationship between these molecules called? (2)

14. List the differences and similarities between DNA and RNA. (6)

15. What is the function of nucleic acids in the body? (4)

16. A portion of a DNA strand is coded

AGCTAATGCCA

What would the coding be on:

(a) the complementary strand of DNA in the double helix, and (2)

(b) the corresponding strand of mRNA that will direct the formation of the protein. (2)

Summary of key concepts

Organic molecules

Organic compounds are divided into various groups based on the number, type and arrangement of atoms in their structures.

Each of these groups contains a functional group, which undergoes predictable reactions.

The structure of the molecule determines its name, the types of reaction that it undergoes and its properties.

Organic compounds that contain only carbon and hydrogen are called hydrocarbons.

Saturated compounds have only single C–C bonds, whereas unsaturated hydrocarbons have double or triple carbon bonds.

Saturated compounds can undergo substitution and elimination reactions, whereas unsaturated compounds undergo addition reactions.

The melting and boiling points of organic compounds generally increase with an increase in their carbon chain length, due to the increase in Van der Waals forces between their molecules.

Polar organic compounds are soluble in water. The longer the molecule is, the less its solubility will be.

Organic macromolecules

Polymers are long, chained molecules that are made up of simpler units called monomers, in a polymerisation process.

Organic macromolecules are polymers consisting mainly of carbon and hydrogen. They occur naturally but can also be synthesised. Carbohydrates, proteins and nucleic acids are examples of biological polymers, whereas plastic and nylon are examples of synthetic polymers.

Addition polymerisation takes place in unsaturated monomers. The double or triple bond is broken in the process. Condensation polymerisation involves the elimination of a small molecule, like H_2O or HCl.

Thermoplastic polymers can be heated and reshaped, whereas thermoset polymers cannot be reshaped after heating because of the cross-linking in its structure. Thermoplastics can be recycled.

The strength of the plastic depends on the length of their polymer molecules. Their properties and uses are determined by the composition and structure of the material.

Plastics are versatile and beneficial to humans but are non-biodegradable. However, some degradable plastics have been developed recently.

Recycling of plastics helps the environment because it takes the pressure off the limited fossil fuels that are used in the production of plastics.

Biological macromolecules

Carbohydrates are divided into monosaccharides, disaccharides (simple sugars) and polysaccharides (complex sugars). Glucose is an important monosaccharide. Sucrose (a disaccharide) is made up of two glucose molecules. Starch (a polysaccharide) is a polymer of glucose (the monomer). Starch can be acid-hydrolysed to form glucose.

Carbohydrates have important structural and energy storage functions in the body.

Proteins are polypeptide chains made up of sequences of amino acids that are linked by a peptide bond. This amino acid sequence forms the primary structure of the protein. Folding of the polypeptide chain results in the secondary structure of a protein. Hydrogen bonding is important in the secondary structure of a protein. The structure determines the properties and function of the protein. Proteins occur as enzymes and hormones, and in structural components of the body (hair). They serve mainly a regulatory function. Eggs, beans and meat contain protein.

DNA and RNA are nucleic acids, which are responsible for transferring hereditary information in the body. They are made up of sequences of nucleotides, which consist of a pentose sugar (ribose or deoxyribose), a phosphate group and a nitrogenous base. The synthesis of proteins are controlled by DNA.

Figure 23 Focus

Each person's DNA is unique. The sequence of nucleotides in DNA makes up the genetic code. It can be used to identify individuals. It can also be reproduced or modified. Forensic science and genetic engineering is based on DNA technology.

Summary of principle functional groups in organic compounds

Type of compound	General formula	Structural formula	Common examples
alkanes	C_nH_{2n+2}	CH_3CH_3 (ethane)	methane, butane
alkenes	C_nH_{2n}	$CH_2{=}CH_2$ (ethene)	propene, butene
alkynes	C_nH_{2n-2}	$CH{\equiv}CH$ (ethyne)	acetylene (ethyne)
alcohols	$C_nH_{2n+1}OH$ (R–OH)	CH_3CH_2OH (ethanol)	methanol, ethanol
aldehydes	$C_nH_{2n}O$ ($R{-}\overset{O}{\overset{\Vert}{C}}H$)	$CH_3\overset{O}{\overset{\Vert}{C}}H$ (ethanal)	ethanal (formaldehyde)
ketones	$C_nH_{2n}O$ ($R{-}\overset{O}{\overset{\Vert}{C}}{-}R'$)	$CH_3\overset{O}{\overset{\Vert}{C}}CH_3$ (propanone)	acetone, testosterone
carboxylic acids	$C_nH_{2n}O_2$ ($R\overset{O}{\overset{\Vert}{C}}OH$ or $R\overset{O}{\overset{\Vert}{C}}OOH$)	$CH_3{-}\overset{O}{\overset{\Vert}{C}}{-}OH$ (ethanoic acid)	benzoic acid, lactic acid
esters	$C_nH_{2n}O_2$ ($R\overset{O}{\overset{\Vert}{C}}{-}O{-}R'$)	$CH_3\overset{O}{\overset{\Vert}{C}}{-}O{-}CH_3$ (methyl ethanoate)	methyl salicylate (Deep Heat)
amines	$C_nH_{2n-1}NH_2$ ($R{-}NH_2$)	$CH_3CH_2{-}NH_2$ (ethylamine)	methylamine
amides	$\overset{O}{\overset{\Vert}{C}}{}_nH_{2n-1}ONH_2$ ($R{-}\overset{O}{\overset{\Vert}{C}}NH_2$)	$CH_3\overset{O}{\overset{\Vert}{C}}NH_2$ (ethanamide)	nylon