8 Structure and nomenclature of organic compounds

8.1 Overview

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8.1.1 Introduction

Plastics, fuels, medicines, and simple and complex life forms are all part of the millions of natural or synthetic organic compounds that exist. To understand the basics of organic chemistry, we need to learn about carbon and why its unique chemical properties allow it to become a part of so many different organic compounds. We need to understand how these molecules are put together and how they exist physically and react chemically. Students of organic chemistry learn how to represent and name these molecules using a set of rules and symbols. It’s a bit like learning a new language: the further you go the more complex it becomes.

Organic compounds are marketed and sold to us every day, but they might not be instantly recognisable. For example, Prozac is the brand name given to a medication that treats a variety of conditions including depression and anxiety. Calling it ‘Prozac’ is a lot easier than using its systematic name: N-methyl-3-phenyl-3-[4-(trifluoromethyl)phenoxy]propan-1-amine!

However, Prozac and other commercial names are variations used to market the same chemical. To avoid confusion, a naming system maintained by the International Union of Pure and Applied Chemistry (IUPAC) is used to classify organic compounds. This ensures consistency in the way the scientific community names and classifies organic compounds.

In this topic you will examine carbon and its tendency to bond with itself and other elements in many stable forms that result in compounds with diverse chemical and physical properties. These compounds are named systematically and can be drawn as full structures, semi-structures and skeletal structures of familiar functional groups including alkanes, alkenes, alkynes, alcohols, carboxylic acids and esters. Amines and the application of rules for naming compounds that contain two functional groups on the same molecule are introduced.
8.1.2 What you will learn

**KEY KNOWLEDGE**
In this topic, you will investigate:

- the carbon atom with reference to valence number, bond strength, stability of carbon bonds with other elements and the formation of isomers (structural and stereoisomers) to explain carbon compound diversity, including identification of chiral centres in optical isomers of simple organic compounds and distinction between cis- and trans- isomers in simple geometric isomers
- structures including molecular, structural and semi-structural formulas of alkanes (including cyclohexane), alkenes, alkynes, benzene, haloalkanes, primary amines, primary amides, alcohols (primary, secondary, tertiary), aldehydes, ketones, carboxylic acids and non-branched esters
- IUPAC systematic naming of organic compounds up to C8 with no more than two functional groups for a molecule, limited to non-cyclic hydrocarbons, haloalkanes, primary amines, alcohols (primary, secondary, tertiary), carboxylic acids and non-branched esters.

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**PRACTICAL WORK AND INVESTIGATIONS**
Practical work is a central component of learning and assessment. Experiments and investigations, supported by a *Practical investigation logbook* and *Teacher-led videos*, are included in this topic to provide opportunities to undertake investigations and communicate findings.

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8.2 The carbon atom

**KEY CONCEPT**
- The carbon atom with reference to valence number, bond strength, stability of carbon bonds with other elements

8.2.1 Carbon: a remarkable element
The carbon atom is the one constant in the millions of organic compounds either found in natural substances or made (synthesised) in the laboratory. This incredible variety can even be seen in samples of pure carbon, which exist in different chemical and physical forms. The different physical forms in which an element can exist are called *allotropes*.

Carbon is found in so many compounds due to its arrangement of electrons. You may recall from Unit 1 that electron shells contain three-dimensional regions of space, called orbitals, where electrons at any given time may be found around the nucleus of an atom. The number of electrons, shells, and potentially occupied orbitals are collectively known as an element’s *electron configuration*.

Carbon is located at the top of group 14 of the periodic table of elements. This location is determined not only by the six protons in a carbon nucleus (atomic number) but also the electron configuration. A neutral carbon atom will have six electrons occupying its orbitals and these are situated in the first two electron shells of the atom.
Valence number 4

The *valence number* of an element refers to the number of electrons occupying the orbitals in the outermost electron shell. Only two of carbon’s six electrons occupy the first electron shell, therefore, the remaining four valence electrons are found in the second, outermost shell. These four electrons are available for bonding.

**ELECTRON CONFIGURATION OF CARBON**

The first two electron shells of carbon have a different number and type of orbitals. Each atomic orbital can hold a maximum number of two electrons. However, each orbital can contain one or two electrons, or none at all.

The first and second electron shells of a carbon atom have one s orbital each (called 1s and 2s respectively), and the valence shell has three p orbitals. An s orbital is a spherical shape around the nucleus; p orbitals are often described as having a dumbbell shape.

Figure 8.4 shows the orientation of the orbitals in three dimensions. If you are sitting at a table, reading this from your text book, the x- and y-planes cover the length and width of your page. The z-plane extends out of the page towards your eyes and behind the page towards your feet.

In its lowest energy state (ground state), the electron configuration of carbon is \(1s^22s^22p^2\). This can also be written as \(1s^22s^22p_x^22p_y^1\) to represent the different p orbitals potentially occupied.

The distance of the 2p orbitals from the nucleus is greater than the 2s orbital and this means electrons occupying p orbitals are higher in energy than those in s orbitals in the same shell. If energy is applied, the electrons move to higher energy orbitals. This is referred to as an *excited state*. For example, \(1s^22s^12p^3\) (\(1s^22s^22p_x^22p_y^12p_z^1\)) is an excited state of carbon.

When s and p orbitals overlap they produce a blend of the two types called sp hybrids. These hybrid regions of space allow electron pairs to be more stable than if they were in s or p orbitals exclusively.
8.2.2 Bonding

Bond energy

Energy transfer is involved when chemical bonds are formed and broken. Recall from Unit 3 the energy profiles showing activation energy required to break bonds and then an amount of energy lost when new bonds are formed. Carbon forms stable, lower energy compounds when its valence shell resembles that of Neon (2, 8, 8). How and with what this happens is varied and complex.

Bond energy can have a variety of units. One such unit is kilojoule(s) per one mole (kJ mol$^{-1}$), which tells us the amount of energy required to break the bonds of the reactants or the amount of energy released per mole when the covalent bond forms between two atoms. Bond energy differs by the element(s) sharing a covalent bond and is affected by the distance between the two atoms. If atoms are too close they repel, and if they are too far away they are unable to share the electrons. The distance between the nuclei of the atoms sharing the electrons is known as bond length.

<table>
<thead>
<tr>
<th>TABLE 8.1 Comparison of bond energies (kJ mol$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different elements</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>H–H 436</td>
</tr>
<tr>
<td>C–H 414</td>
</tr>
<tr>
<td>O–H 463</td>
</tr>
<tr>
<td>H–C 414</td>
</tr>
<tr>
<td>N–C 286</td>
</tr>
<tr>
<td>C–C 614</td>
</tr>
<tr>
<td>H–N 391</td>
</tr>
<tr>
<td>N–N 158</td>
</tr>
<tr>
<td>Cl–Cl 242</td>
</tr>
<tr>
<td>H–O 463</td>
</tr>
<tr>
<td>N–O 214</td>
</tr>
<tr>
<td>F–F 567</td>
</tr>
<tr>
<td>C–F 492</td>
</tr>
<tr>
<td>O–F 191</td>
</tr>
<tr>
<td>C–Cl 324</td>
</tr>
</tbody>
</table>

Bond angle and stability

The ability of carbon to form millions of compounds is also dependent upon the geometry (spatial arrangement) of atoms attached to it. The orbitals of molecules can combine (hybridise) to produce bond angles and covalent bonds with greater stability. For example, when carbon forms four, single covalent bonds, the bonds separate so that the angle between the bonds is 109.5°, forming a tetrahedral molecule shape.

Multiple carbon to carbon bonds

The majority of carbon atoms bond with this approximate angle of 109.5°. However, carbon has the ability to overlap orbitals in such a way that C=C double covalent bonds form. In this scenario, other atoms bonded to the two carbon atoms have bonds that are spaced at an approximate 120° angle, resulting in a planar geometry.

The bonds in a C=C double bond are shorter and stronger than C–C single bonds. It takes almost twice the amount of energy to break a C=C bond than it does a C–C bond. This is not surprising given there are four electrons providing stability in a C=C bond compared to just two in a C–C bond.

All the bonds in C$_2$H$_4$ occur in the same plane. This is why it is often referred to as a flat molecule.

The same can be said of carbon to carbon triple bonds because they have a linear geometry and 180° between bonds. C≡C triple bonds are stronger than C=C bonds. They are the shortest of C to C bonds, with a length of approximately 120 picometres ($1.2 \times 10^{-10}$ m).
SAMPLE PROBLEM 1

Calculate the energy, in kJ, required to break all covalent bonds in 1.6 g of CH₄ gas.

THINK
1. The standard unit for bond energy is kJ mol⁻¹ but the question has given a mass of CH₄ and not an amount in mol. Therefore, we need to convert mass into moles using \( n = \frac{m}{M} \).

2. There are four C–H bonds in CH₄. Use Table 8.1 to find the value stated for a C–H bond and multiply it by four.

3. To find the total bond energy to break all the bonds in 1.6 g methane, multiply bond energy per mol calculated in step 2 by the number of moles in 1.6 g of methane.

**TIP:** Remember to give your answer to the correct number of significant figures.

WRITE
\[
\text{Energy in C–H bonds} = 4 \times 414 = 1656 \text{kJ mol}^{-1}
\]

\[
0.10 \text{ mol} \times 1656 \text{kJ mol}^{-1} = 166 \text{kJ}
\]

\[
1.7 \times 10^2 \text{kJ}
\]

PRACTICE PROBLEM 1

Calculate the energy required, in kJ, to break all covalent bonds in 64 g of CH₄ gas.

8.2 EXERCISES

To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au.

1. Which of the following molecules would have similar bond angles to CH₃Cl?
   A. C₂H₄
   B. C₂H₂
   C. CH₄
   D. CO₂

2. Why are C=C bonds stronger than C–C bonds?

3. If the bond energy of H–F is 565 kJ mol⁻¹, what is the overall bond energy of two moles of HF?

4. What is the difference in C–H bond angles between C₂H₂ and C₂H₄ molecules?

5. What amount of energy per mole would be released if all covalent bonds in CH₂F₂ were broken?
8.3 Structure and naming of organic compounds

KEY CONCEPT
- Structures including molecular, structural and semi-structural formulas of alkanes (including cyclohexane), alkenes, alkynes, benzene, haloalkanes, primary amines, primary amides, alcohols (primary, secondary, tertiary), aldehydes, ketones, carboxylic acids and non-branched esters
- IUPAC systematic naming of organic compounds up to C8 with no more than two functional groups for a molecule, limited to non-cyclic hydrocarbons, haloalkanes, primary amines, alcohols (primary, secondary, tertiary), carboxylic acids and non-branched esters.

8.3.1 Molecular modelling

We model the way atoms are bonded and arranged in a molecule in a number of ways. The simplest molecular models are electron dot (Lewis) diagrams and structural diagrams, which were covered in Unit 1. As molecules become larger and more complex, we look for easier ways to represent all of the bonded atoms.

Structural diagrams

Structural diagrams show all covalent bonds in the molecule. There are a number of different ways we draw structures. The simplest way is to show all atoms and all bonds in a molecule. These can then be modified to skeletal and semi-structural formulas.

Wedge–dash notation represents the spatial arrangement of atoms. Figure 8.9 shows the position of the hydrogen atoms in three-dimensional space relative to one another. The wedge shows the atom coming out of the page towards us, while dashes shows the atom going behind the page away from us. The unbroken lines represent bonds to atoms that are in the same plane as the page.

Wedge–dash diagrams can be simplified to structural formulas, as shown in figure 8.10. Structural formulas do not show the arrangement of atoms in three dimensions.

Semi-structural formula

Semi-structural formulas are used to simplify the structure presented while preserving the order of groups of atoms. This is done by not including the covalent bonds shown in structural diagrams. Semi-structures are useful when showing larger molecules that require a lot of bonds to be drawn in full structures.

The structure of C₇H₁₄ can be used to show the different ways of writing a semi-structure.

First, condense the structure by removing the bonds while maintaining the order of groups of atoms.
CH₃CH₂CHCHCH₃CH₂CH₃

If there is a sequence of the same group, such as CH and CH₂ as in the semi-structure shown above, we can condense it further using brackets. This allows further simplification and is useful for large molecules. Therefore, CH₃CH₂CHCHCH₂CH₂CH₃ becomes CH₃CH₂(CH)₂CH₂CH₃.

**Skeletal structural formulas**

Skeletal structural formulas are a further simplification of semi-structural formulas. Skeletal structures use lines and vertices to simplify a structural formula by omitting the carbon and the hydrogen atoms bonded to it. It is assumed that a carbon atom (and enough hydrogens to satisfy carbon’s valency) is present at each vertex (and also at the ends). Double bonds and other different types of atoms are specifically shown. Skeletal structures preserve the bond angles in a carbon chain and are the preferred method for representing complex organic molecules that are large and often contain ring or cyclic structures.

Returning to C₇H₁₄, the simplicity of skeleton structure compared to the full structure can be seen in figure 8.12. The C and associated H atoms have been omitted, but the C≡C bond has been preserved.

**SAMPLE PROBLEM 2**

For the structure shown, draw:

a. a semi-structural formula
b. a skeletal structural formula.

**WRITE**

a. For the semi-structural, remove all of the covalent bonds and write out the sequence of groups in the chain.

b. For the skeletal structural, remove all of the C and H atoms attached to the covalent bonds but retain the bonds.

**PRACTICE PROBLEM 2**

For the structure shown, draw:

a. a semi-structural formula
b. a skeletal structural formula.
8.3.2 Hydrocarbons

Hydrocarbons are the simplest organic compounds and are composed solely of carbon and hydrogen. They are obtained mainly from crude oil and are used as fuels or solvents, or in the production of plastics, dyes, pharmaceuticals, explosives and other industrial chemicals. The organic families studied in this topic contain various percentages of carbon and hydrogen atoms. They include the alkanes, alkenes and alkynes, which are classified as **aliphatic** compounds, and benzene, which is an **aromatic** compound.

A family of carbon compounds that are structurally related and where members of the family can be represented by a general formula is called a **homologous series**. Successive members of a homologous series have formulas that differ by CH\(_2\). Each is named for the number of carbon atoms in the longest chain.

**FIGURE 8.13** The structural arrangement of ethane (alkane), ethene (alkene), ethyne (alkyne) and the benzene ring (aromatic). Carbon can form ring structures as well as single or multiple bonds with itself.

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**Alkanes**

Alkanes with carbon atoms in long chains are known as straight-chain hydrocarbons. Alkanes have the structural formula C\(_n\)H\(_{2n+2}\), where \(n\) is an integer. They are classified as saturated hydrocarbons because only single covalent bonds exist between atoms and there are no available multiple carbon bonds to break and add atoms into the molecule. The first four alkanes are gases at room temperature, and they are summarised in table 8.2.

**FIGURE 8.14** Propane, the third member of the alkane homologous series, is used to fly hot air balloons.

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**TABLE 8.2** The first four members of the alkane homologous series

<table>
<thead>
<tr>
<th>Alkane</th>
<th>Semi-structural (condensed) formula</th>
<th>Source</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH(_4)</td>
<td>Natural gas or biogas</td>
<td>• Fuel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Synthesis of other chemicals</td>
</tr>
<tr>
<td>Ethane</td>
<td>CH(_2)CH(_3)</td>
<td>Natural gas</td>
<td>• Manufacture of ethene</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Refrigerant in cryogenic systems</td>
</tr>
<tr>
<td>Alkane</td>
<td>Semi-structural (condensed) formula</td>
<td>Source</td>
<td>Uses</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------</td>
<td>--------</td>
<td>------</td>
</tr>
</tbody>
</table>
| Propane | CH₃CH₂CH₃ | Natural gas processing or petroleum refining | • Fuel (e.g. in gas cylinders for heating)  
  • Propellant for aerosols |
| Butane  | CH₃CH₂CH₂CH₃ | Natural gas processing or petroleum refining | • Fuel (e.g. cigarette lighters and portable stoves)  
  • Synthesis of other chemicals  
  • Propellant for aerosols |

The next four members of the alkane homologous series are:

- pentane, C₅H₁₂
- hexane, C₆H₁₄
- heptane, C₇H₁₆
- octane, C₈H₁₈.

The name of each alkane has two parts. The prefix (the start) of each name tells us how many carbon atoms are in the straight chain. The suffix (the end) -ane of each name tells us that the hydrocarbon is an alkane. The prefixes are used to name the number of carbon atoms in a chain in the majority of the homologous series studied in this topic.

### Resources

**Video eLesson** Naming alkanes (eles-2484)

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**Alkenes**

Double bonds between carbon atoms are formed when two hydrogen atoms are removed from alkanes. These hydrocarbons are said to be unsaturated. Hydrocarbons with one or more carbon–carbon double bonds per molecule are members of the homologous series called alkenes. The general formula for alkenes is CₙH₂n. The first two members of the alkene series are ethene, C₂H₄, and propene, C₃H₆. Their structural formulas are shown in figure 8.15.

**FIGURE 8.15** Structural formulas of ethene and propene

**FIGURE 8.16** These tomatoes are the same age but the red one has been ripened using ethene gas.

Alkenes are unsaturated hydrocarbons with a double bond between two carbon atoms. They have the general formula CₙH₂n.

Ethene is also commonly known as ethylene. It is produced naturally by some plants and it aids in ripening fruit. It can also be produced artificially by heating petroleum in the absence of air in a process called cracking. Ethene is an important raw product for making many chemicals and plastics.
Table 8.3 shows the first seven members of the alkene series. Alkenes are named using the same general rules described for alkanes except that the suffix -ene is added instead of -ane, and the number of the carbon atoms after which the double bond is positioned is indicated. The longest unbranched chain must contain the double bond, so the molecule CH₂CH₂CH=CHCH₃ is named pent-2-ene. The ‘2’ indicates the position of the double bond between carbon atoms 2 and 3 (the lower number is used in the formula, and numbering starts from the carbon atom closest to the double bond) and ‘pent’ indicates that five carbon atoms are present in the unbranched chain. Some people prefer to name it 2-pentene. Either way, the number of carbon atoms in the chain and the position of the carbon bond are indicated. For consistency, we will use the first naming method.

Alkynes

Alkynes contain a carbon–carbon triple bond and have the general formula CₙH₂n−2. Examples include ethyne, HC≡CH, and propyne, HC≡CCH₃. Ethyne is used to produce ethane and in oxyacetylene torches for welding to join metals. It can heat objects up to 3000 °C. Alkynes are named using the same general rules as for alkanes, but the -ane is dropped and replaced with -yne.

Cyclic hydrocarbons

Cyclic hydrocarbons are also known as ring structures because the carbon chain is a closed structure without open ends. The single-ringed cycloalkanes have the same molecular formula as alkenes due to all

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**TABLE 8.3** Members of the alkene homologous series

<table>
<thead>
<tr>
<th>Systematic name</th>
<th>Formula</th>
<th>Semi-structural formula with double bonds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethene</td>
<td>C₂H₄</td>
<td>H₂C=CH₂</td>
</tr>
<tr>
<td>Prop-1-ene</td>
<td>C₃H₆</td>
<td>H₂C=CHCH₃</td>
</tr>
<tr>
<td>But-1-ene</td>
<td>C₄H₈</td>
<td>H₂C=CHCH₂CH₃</td>
</tr>
<tr>
<td>Pent-1-ene</td>
<td>C₅H₁₀</td>
<td>H₂C=CH(CH₃)CH₃</td>
</tr>
<tr>
<td>Hex-1-ene</td>
<td>C₆H₁₂</td>
<td>H₂C=CH(CH₂)CH₃</td>
</tr>
<tr>
<td>Hept-1-ene</td>
<td>C₇H₁₄</td>
<td>H₂C=CH(CH₃)CH₃</td>
</tr>
<tr>
<td>Oct-1-ene</td>
<td>C₈H₁₆</td>
<td>H₂C=CH(CH₂)CH₃</td>
</tr>
</tbody>
</table>

**FIGURE 8.17** Prop-1-yne

\[
\text{H} \quad \text{C} \equiv \text{C} \equiv \text{C} \quad \text{H} \\
\quad \text{H} \quad \text{H}
\]
carbon atoms being covalently bonded to two others either side to form the closed ring. As well as having a different molecular formula to straight chain alkanes, the prefix ‘cyclo-’ is put at the start of the name to indicate the ring structure. The simplest cyclic hydrocarbon, cyclohexane, has the molecular formula C₆H₁₂ and is a colourless, flammable liquid that is used as a reactant in the production of nylon.

**FIGURE 8.18** Structural diagrams of cyclohexane

Another important group of cyclic hydrocarbons are the **arenes**. These compounds are derived from **benzene**. The benzene, C₆H₆, molecule consists of six carbon atoms arranged in a ring with one hydrogen atom bonded to each carbon. Originally, it was thought that there were alternating single and double carbon–carbon bonds in the ring. However, the lack of reactivity, high stability and same bond lengths between the carbon atoms did not support this theory. Currently, benzene is considered to be a molecule with six electrons from the three double bonds shared by all of the carbon atoms in the ring. The attraction of the electrons to all of the carbon atoms gives the molecule stability.

Benzene is a very important compound in organic chemistry. Even though benzene itself is carcinogenic, many of the chemicals produced from it are not. In fact, many foods and pharmaceuticals, such as paracetamol, contain benzene rings.

There are various ways of representing the benzene ring, as shown in figure 8.19.

**FIGURE 8.19** Representations of benzene

**Alkyl groups**

**Alkyl groups** are hydrocarbon branches coming off the longest carbon chain of an organic molecule. Alkyl branches use the same prefixes to represent the number of carbons in the branch as those used in straight chain molecules, but the suffix changes to ‘-yl’. To branch off the main chain, alkyl groups have one less hydrogen atom than the alkanes that share the same prefix in their name.

**TABLE 8.4** The first three alkane and alkyl groups

<table>
<thead>
<tr>
<th>Alkane</th>
<th>Semi-structural formula</th>
<th>Alkyl groups</th>
<th>Semi-structural formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>Methyl</td>
<td>-CH₃</td>
</tr>
<tr>
<td>Ethane</td>
<td>CH₃CH₃</td>
<td>Ethyl</td>
<td>-CH₃CH₃</td>
</tr>
<tr>
<td>Propane</td>
<td>CH₃CH₂CH₃</td>
<td>Propyl</td>
<td>-CH₂CH₃CH₃</td>
</tr>
</tbody>
</table>
Alkyl groups have to be named in both number and position on a carbon chain. As an example, let’s follow the IUPAC rules for naming the following branched alkane.

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

1. Count the longest carbon chain. This will determine the prefix used to name the main/parent chain.
2. Identify alkyl groups branching off the main chain.
3. Starting at the end, number the chain that gives the lowest number for an alkyl branch.

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

4. Write the number and the name of the alkyl group(s) attached in alphabetical order. 3-methyl
5. Write the name of the parent chain at the end. Six carbons separated by single bonds is a hex-ane:

3-methylhexane

When there are more than one of the same type of alkyl group branching off the parent chain, prefixes are used to indicate how many there are, and numbers are used to indicate which carbon atom they come off in the parent chain. For example, consider the following multi-branched alkane.

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

1. The longest chain is five carbons.
2. Three methyl (\text{CH}_3) groups are branching off the chain.
3. The chain is numbered from left to right because this gives two alkyl groups coming off C2 instead of C4 if named from the opposite end.

\[
\text{CH}_3 - \text{C} - \text{CH}_2 - \text{CH} - \text{CH}_3
\]
4. List the numbers of the C atoms the \( \text{CH}_3 \) groups are branching off separated by commas and then a hyphen before the prefix ‘tri-’ to indicate there are three methyl groups.

5. Add the parent chain name to the end: 2,2,4-trimethylpentane.

**TIP:** If there are molecules with two or more branches of the same type, the branch type is named and a prefix (di-, tri-, etc) is used to indicate the number of branches. Branches are listed in alphabetical order, ignoring the prefix (i.e. ethyl is written before methyl or dimethyl).

### SAMPLE PROBLEM 3

Write the systematic (IUPAC) name of the following hydrocarbon.

**THINK**

1. Examine the molecule to find the longest carbon chain.

2. Locate the alkyl groups.

3. Number the chain from an open end that gives one or more alkyl groups the lowest number.

4. Write the number(s) of the alkyl groups separated by commas and then hyphenated to the prefix to indicate the number of the same type of alkyl group.

5. List the different alkyl groups in alphabetical order, ignoring the prefix.

6. Add the name of the parent chain to the end of the name.

**WRITE**

- 2,6-dimethyl
- 4-ethyl

**PRACTICE PROBLEM 3**

Write the IUPAC name of the following hydrocarbon.
8.3.3 Functional groups

An atom or a group of atoms that determines the function (chemical nature) of a compound is called a **functional group**. As with the alkanes and alkenes, compounds containing the same functional group form a homologous series (a family with similar properties). A molecule with a functional group attached is usually less stable than the carbon backbone to which the functional group is attached and therefore more likely to participate in chemical reactions. Figure 8.21 shows three different functional groups attached to the basic carbon skeleton of methane.

8.3.4 Haloalkanes

Haloalkanes are a class of molecules that have one or more **halogens** attached to the carbon chain. They are used in a variety of applications including solvents, refrigeration and medicine.

Haloalkanes are often represented as \( R-X \). The \( R \) is used to represent the hydrocarbon chain of any length and the \( X \) is used to represent any of the halogens, such as fluorine (F), chlorine (Cl) and bromine (Br).

The naming system of haloalkanes follows the same rules as naming hydrocarbons. However, like all functional groups, halogen functional groups take priority over alkyl groups when numbering the longest carbon chain. We all use the same prefixes to name compounds with more than one of the same halogens.

Another difference in the naming is the replacement of the ‘-ine’ with ‘-o’. Fluorine becomes fluoro, chlorine becomes chloro and bromine becomes bromo when they are part of a haloalkane.

Consider the molecule:

```
H \ \ H \ \ Cl \ \ H
| \ | | |
Cl - C - C - C - H
| | | | |
H \ \ H \ \ H \ \ H
```

The molecule has a four-carbon chain with two chlorine atoms attached on C1 and C3. The systematic name of this compound is 1,3-dichlorobutane.

When there are different halogens on the carbon chain, they are numbered as usual but written alphabetically, like alkyl groups.

For example:

```
CH\sub{3} \ \ Br
Cl - CH\sub{2} - CH - CH - CH\sub{3}
3-bromo-1-chloro-2-methylbutane
```

Haloalkanes are hydrocarbons with one or more halogens attached to the carbon chain. They have the general formula \( R-X \), where \( R \) is a hydrocarbon chain of any length and \( X \) is a halogen.
8.3.5 Alcohols

Organic hydroxyl compounds containing the $-\text{OH}$ group belong to the homologous series called **alcohols**. A study of the properties of the $-\text{OH}$ group is important to chemists because of the industrial importance of compounds containing this functional group, and because of its wide occurrence in biological molecules. Ethanol is the most common alcohol and it has many uses. It is present in beer, wine and spirits, and is used in the preparation of ethanoic acid (acetic acid) and for sterilising wounds. Methylated spirits (containing 95% ethanol) is a very useful solvent and is used in the manufacture of varnishes, polishes, inks, glues and paints. Other alcohols that are volatile at low temperatures are also good solvents and are used in deodorants, colognes and aftershave lotions. Glycerol, $\text{C}_3\text{H}_5(\text{OH})_3$, is used for making fats and soaps. **Alkanols** are alcohols containing only carbon, hydrogen and oxygen.

For naming purposes, alcohols have the general formula $R-O-H$. The first three members of the alcohol homologous are shown in figure 8.22. Again, the standard prefixes are used to name the number of carbon atoms in the chain. In the first two members (methanol and ethanol), the hydroxyl group is not numbered because its position is always C1. However, with the third member, the $-\text{OH}$ group could be on C1 or C2, and therefore needs to be stated in the name. The suffix ‘-ol’ is used instead of hydroxy in the name, which tells us that the $-\text{OH}$ is the functional group with priority. So the third member is named propan-1-ol rather than 1-hydroxypropane. When the hydroxyl group branches off C2 we simply change the ending of the name to -2-ol as shown in figure 8.23.

![FIGURE 8.22 Members of the alcohols: ethanol, ethanol and propan-1-ol](image)

![FIGURE 8.23 Butan-2-ol](image)

**TABLE 8.5** The first eight alkanols. The $-\text{OH}$ group is attached to the first carbon atom in each case.

<table>
<thead>
<tr>
<th>Systematic name</th>
<th>Semi-structural formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol</td>
<td>$\text{CH}_3\text{OH}$</td>
</tr>
<tr>
<td>Ethanol</td>
<td>$\text{CH}_3\text{CH}_2\text{OH}$</td>
</tr>
<tr>
<td>Propan-1-ol</td>
<td>$\text{CH}_3(\text{CH}_2)_2\text{OH}$</td>
</tr>
<tr>
<td>Butan-1-ol</td>
<td>$\text{CH}_3(\text{CH}_2)_3\text{OH}$</td>
</tr>
<tr>
<td>Pentan-1-ol</td>
<td>$\text{CH}_3(\text{CH}_2)_4\text{OH}$</td>
</tr>
<tr>
<td>Hexan-1-ol</td>
<td>$\text{CH}_3(\text{CH}_2)_5\text{OH}$</td>
</tr>
<tr>
<td>Heptan-1-ol</td>
<td>$\text{CH}_3(\text{CH}_2)_6\text{OH}$</td>
</tr>
<tr>
<td>Octan-1-ol</td>
<td>$\text{CH}_3(\text{CH}_2)_7\text{OH}$</td>
</tr>
</tbody>
</table>

Alcohols are classified as primary, secondary or tertiary, based on the number of carbon atoms connected to the carbon atom attached to the hydroxyl functional group.
Primary (1°): The C—OH is attached to one other carbon atom.
Secondary (2°): The C—OH is attached to two other carbon atoms.
Tertiary (3°): The C—OH is attached to three other carbon atoms.

Alcohols are hydrocarbons with the −OH functional group. They have the general formula R−OH. Primary (1°) alcohols have the C−H group attached to one other C atom. Secondary (2°) alcohols have the C−H group attached to two other C atoms. Tertiary (3°) alcohols have the C−H group attached to three other C atoms.

8.3.6 Aldehydes

The aldehyde functional group −CHO produces compounds that have characteristic odours. The familiar smells of vanilla and cinnamon are caused by aldehydes. Low-molecular-weight aldehydes, such as methanal (formaldehyde) and ethanal, have unpleasant odours; formaldehyde was previously used as a preservative but is now suspected to be carcinogenic. High-molecular-weight compounds have sweet, pleasant smells and are used in perfumes. Other uses of aldehydes include solvents and the manufacture of plastics, dyes and pharmaceuticals.

Aldehydes are generally written as R−CHO and are named by replacing the last −e on the name of the corresponding alkane with −al. For example, propane becomes propanal. Aldehydes have a C=O bond at the end of the carbon chain, at C1. Aldehydes are always named from C1, so they do not need a number in the name to reference where the functional group is.

Aldehydes are hydrocarbons with the −CHO functional group, with a C=O double bond at C1. They have the general formula R−CHO.

8.3.7 Ketones

Ketones contain the carbonyl (C=O) functional group and are used extensively to produce pharmaceuticals, perfumes, solvents and polymers. The ‘−e’ is replaced by ‘−one’ and the general formula of a ketone is R−CO−R′. Hence, the carbonyl functional group is never found at C1. They have important physiological
properties and are found in medicinal compounds and steroid hormones, including cortisone. The most familiar ketone is propanone (acetone), which has unlimited solubility in water and is a solvent for many organic compounds. It evaporates readily because of its low boiling point, which contributes to its usefulness.

Ketones are hydrocarbons with the carbonyl, C=O, functional group. They have the general formula R−CO−R’.

### 8.3.8 Carboxylic acids

The carboxyl functional group −COOH is part of the homologous series classed as carboxylic acids. They are generally written as R−COOH and the C in the carboxyl functional group is always assigned C1 for naming purposes. Because of this, the 1- is left off the start of the names. The ‘−e’ in the name is replaced by the suffix ‘-oic acid’.

Carboxylic acids are generally weak acids and occur widely in nature. Some common examples include citric acid, which is found in citrus fruits such as oranges and lemons, malic acid, found in apples, and ascorbic acid (vitamin C), found in a number of foods. Other carboxylic acids, such as stearic acid and oleic and palmitic acids, are used in the formation of animal and vegetable fats. Carboxylic acids are also used to make soaps and polyesters. The carboxylic acids with chains of four to eight carbons have a strong, unpleasant smell and are found in cheese, perspiration and rancid butter.

Carboxylic acids are hydrocarbons with the carboxyl, −COOH, functional group. They have the general formula R−COOH. The C in the carboxyl functional group is always assigned C1.

#### Table 8.6 Some carboxylic acids and their uses

<table>
<thead>
<tr>
<th>Systematic name</th>
<th>Semi-structural formula</th>
<th>Non-systematic name</th>
<th>Occurrence and uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanoic acid</td>
<td>HCOOH</td>
<td>Formic acid</td>
<td>Used by ants as a defence mechanism; also used in textile processing and as a grain preservative</td>
</tr>
<tr>
<td>Ethanoic acid</td>
<td>CH₃COOH</td>
<td>Acetic acid</td>
<td>Found in vinegar; used in making artificial textiles</td>
</tr>
<tr>
<td>Propanoic acid</td>
<td>CH₃CH₂COOH</td>
<td>Propionic acid</td>
<td>Calcium propionate used as an additive in bread manufacture</td>
</tr>
</tbody>
</table>

(Continued)
TABLE 8.6 Some carboxylic acids and their uses (Continued)

<table>
<thead>
<tr>
<th>Systematic name</th>
<th>Semi-structural formula</th>
<th>Non-systematic name</th>
<th>Occurrence and uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butanoic acid</td>
<td>CH₃CH₂CH₂COOH</td>
<td>Butyric acid</td>
<td>Present in human sweat; responsible for the smell of rancid butter</td>
</tr>
<tr>
<td>Benzoic acid</td>
<td>–COOH</td>
<td>Benzoic acid</td>
<td>Used as a preservative</td>
</tr>
</tbody>
</table>

FIGURE 8.28 Dogs can be trained to find fruit by sniffing out distinctive carboxylic acids, such as malic acid, which is found in apples. Sniffer dogs play an important part in quarantine procedures to prevent the illegal import and export of fruit.

8.3.9 Amines and amides

Primary amines (R−NH₂) and amides (R−CONH₂) contain the amino −NH₂ and amide −CON functional groups. However, primary amides can be thought of as −CONH₂. With amines, the ‘−e’ in the name is replaced by ‘-amine’ and this suffix follows a number for C3 and up. Primary amides are named the same way as carboxylic acids except they have the suffix ‘-amide’.

FIGURE 8.29 (a) Butan-1-amine and (b) butanamide
Amines are hydrocarbons with the amino, $-\text{NH}_2$, functional group. They have the general formula $R-\text{NH}_2$.

Amides are hydrocarbons with the amide, $-\text{CON}$ (or $-\text{CONH}_2$) functional group. They have the general formula $R-\text{CONH}_2$.

### TABLE 8.7 The first eight compounds of the amine homologous series

<table>
<thead>
<tr>
<th>Systematic name</th>
<th>Semi-structural formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanamine</td>
<td>CH$_3$NH$_2$</td>
</tr>
<tr>
<td>Ethanamine</td>
<td>CH$_3$CH$_2$NH$_2$</td>
</tr>
<tr>
<td>Propan-1-amine</td>
<td>CH$_3$(CH$_2$)$_2$NH$_2$</td>
</tr>
<tr>
<td>Butan-1-amine</td>
<td>CH$_3$(CH$_2$)$_3$NH$_2$</td>
</tr>
<tr>
<td>Pentan-1-amine</td>
<td>CH$_3$(CH$_2$)$_4$NH$_2$</td>
</tr>
<tr>
<td>Hexan-1-amine</td>
<td>CH$_3$(CH$_2$)$_5$NH$_2$</td>
</tr>
<tr>
<td>Heptan-1-amine</td>
<td>CH$_3$(CH$_2$)$_6$NH$_2$</td>
</tr>
<tr>
<td>Octan-1-amine</td>
<td>CH$_3$(CH$_2$)$_7$NH$_2$</td>
</tr>
</tbody>
</table>

### FIGURE 8.30 Wing suits are made from polymers containing amide links.

8.3.10 Esters

The ester functional group ($-\text{COO}$), also referred to as an ester link, forms via a condensation reaction between hydroxyl and carboxyl functional groups. Esters have the general formula $\text{RCOO}_\text{R'}$.

The name of an unbranched ester is a product of the carboxylic acid and primary alcohol that produces it. The first part of the name comes from the hydrocarbon or alkyl part of the alcohol. For example, if methanol is used to make an ester the first part of the name will be methyl, and if ethanol is used, the first part of the name is ethyl.

The second part of the ester name comes from the carboxylic acid. The ‘-oic acid’ suffix is removed and replaced with ‘-oate’. If methanoic acid was used to make an ester, the second part of the name would be methanoate.

Figure 8.31 shows propanoic acid and ethanol being used to make ethylpropanoate.

This reaction can be summarised as:

$$\text{CH}_3\text{CH}_2\text{COOH} + \text{CH}_3\text{CH}_2\text{OH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COOCH}_2\text{CH}_3 + \text{H}_2\text{O}$$

Esters are used in a variety of applications. The small, volatile esters are used in artificial flavours and smells in food and fragrances. Larger esters occur naturally as fats and oils. They can also be used in the manufacture of materials as diverse as Perspex and artificial arteries used in open heart surgery.
Esters are hydrocarbons with the ester $-\text{COO}$, functional group. They have the general formula $\text{RCOOR}'$.
Esters form through condensation reactions between a primary alcohol and a carboxylic acid. The alcohol gives the first part of the name, the carboxylic acid gives the second half of the name, with the suffix ‘-oate’.

### 8.3.11 Functional group summary

#### TABLE 8.8 Functional group summary

<table>
<thead>
<tr>
<th>Group</th>
<th>Name</th>
<th>Homologous series</th>
<th>Method of naming</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-\text{O-}$</td>
<td>Hydroxyl</td>
<td>Alcohol</td>
<td>suffix -ol</td>
<td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ (propan-1-ol)</td>
</tr>
<tr>
<td>$-\text{C=}$</td>
<td>Aldehyde</td>
<td>Aldehyde</td>
<td>suffix -al</td>
<td>$\text{CH}_3\text{CHO}$ (ethanal)</td>
</tr>
<tr>
<td>$\text{t-}$</td>
<td>Carbonyl</td>
<td>Ketone</td>
<td>suffix -one</td>
<td>$\text{CH}_3\text{CH}_2\text{COCH}_3$ (3-pentanone)</td>
</tr>
<tr>
<td>$-\text{O=}$</td>
<td>Carboxyl</td>
<td>Carboxylic acid</td>
<td>suffix -oic acid</td>
<td>$\text{CH}_2\text{COOH}$ (acetic acid)</td>
</tr>
<tr>
<td>$-\text{O=}$</td>
<td>Ester</td>
<td>Ester</td>
<td>as alkyl alkanoate</td>
<td>$\text{CH}_3\text{CH}_2\text{COOCH}_3$ (methyl propanoate)</td>
</tr>
<tr>
<td>$\text{O}$</td>
<td>Ether</td>
<td>Ether</td>
<td>as alkoxyalkane, or name the two groups attached to the ether linkage</td>
<td>$\text{CH}_3\text{OCH}_3$ (methoxymethane or dimethyl ether)</td>
</tr>
<tr>
<td>$-\text{N=}$</td>
<td>Amine</td>
<td>Amine</td>
<td>suffix -amine</td>
<td>$\text{CH}_3\text{NH}_2$ (methanamine) $\text{CH}_3\text{CH}_2\text{NH}_2$ (ethanamine)</td>
</tr>
<tr>
<td>$\text{O}$</td>
<td>Primary amide</td>
<td>Primary amide</td>
<td>suffix -amide</td>
<td>$\text{CH}_3\text{CONH}_2$ (ethanamide) $\text{CH}_3\text{CH}_2\text{CONH}_2$ (propanamide)</td>
</tr>
<tr>
<td>$-\text{Cl}$</td>
<td>Chloro</td>
<td>Haloalkanes</td>
<td>prefix chloro-</td>
<td>$\text{CH}_3\text{Cl}$ (chloromethane) $\text{CH}_3\text{CH}_2\text{Br}$ (bromoethane) $\text{ICH}_2\text{CH}_3$, 1,2-diiodoethane</td>
</tr>
</tbody>
</table>
**SAMPLE PROBLEM 4**

For the following molecule:

a. Name the functional group and the homologous series

b. Write its systematic (IUPAC) name.

**THINK**

a. Find groups of atoms that are not alkyl groups. Remember, alkyl groups are hydrocarbon branches coming off the longest carbon chain of an organic molecule. The functional group is the hydroxyl group in the alcohol homologous series. The name will end in ‘-ol’.

b. 1. The longest chain is composed of 4 carbons, making the molecule butanol. Number the chain so that the functional group has the lowest number possible. The hydroxyl group is branching from C2.

   2. Identify any alkyl groups branching off the longest carbon chain. Methyl is branching from C3.

   3. Name the molecule. 3-methylbutan-2-ol

**PRACTICE PROBLEM 4**

For the following molecule:

a. Name the functional group and the homologous series

b. Write its systematic (IUPAC) name.
8.3 EXERCISES

To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au.

1. What is the molecular formula of the alkane containing 18 carbon atoms?
2. Show the molecular, empirical, semi-structural and skeletal formulas and structures of propane.
3. Study the following molecule.

(a) Write its systematic (IUPAC) name.
(b) Write its semi-structural formula.
(c) Write its molecular formula.
(d) Write its empirical formula.
5. Draw the structures of butanoic acid and octanoic acid.
6. What are the systematic names of the following molecules?
   (a) CH₃CH(NH₂)C(CH₃)₂CH₂CH₃
   (b) CH₂=CH-CH₂
   (c) CH₃-CH₂-CH₂
   (d) CH₂=CH₂
   (e) CH₂=C=CH-CH=CH₂
   (f) CH₃-C≡C-C≡C-CH₂-CH₂-CH₃
7. Which homologous series does this molecule belong to?

8. Draw the structure of the primary amide with the molecular formula C₃H₇NO.

9. Draw structural, semi-structural and skeletal diagrams for:
   (a) ethylpropanoate
   (b) propylethanoate.

10. Study the hydrocarbon below.

     (a) Name the alkyl groups present.
     (b) Write the systematic name.

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8.4 Functional groups and naming priority

KEY CONCEPT

• IUPAC systematic naming of organic compounds up to C₈ with no more than two functional groups for a molecule, limited to non-cyclic hydrocarbons, haloalkanes, primary amines, alcohols (primary, secondary, tertiary), carboxylic acids and non-branched esters.

8.4.1 Naming compounds with two functional groups

When molecules have two or more functional groups, the naming becomes more complex. A lot of the molecules with many functional groups are referred to by their commercial or simplified names. Pharmaceuticals are typically branded or referred to using non-preferred IUPAC names.
IUPAC naming of compounds with two functional groups

Compounds with two or more functional groups are classified by the principal group (the main functional group) defining the series to which they belong. Table 8.9 shows the priority scale for the groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Homologous series</th>
<th>Suffix</th>
<th>Highest priority name</th>
<th>Lowest priority name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carboxyl</td>
<td>Carboxylic acid</td>
<td>-oic acid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ester</td>
<td>Ester</td>
<td>-oate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aldehyde</td>
<td>Aldehyde</td>
<td>-al</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbonyl</td>
<td>Ketone</td>
<td>-one</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydroxyl</td>
<td>Alcohol</td>
<td>-ol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amine</td>
<td>Amine</td>
<td>-amine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkyne</td>
<td>Alkyne</td>
<td>-yne-ene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkane</td>
<td>Alkane</td>
<td>-ane</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The parent name of the compound is derived from the principal group according to the following rules:

- The numbering system used is that of the principal group.
- An alcohol is regarded as a hydroxyl side group, an amine is regarded as an amino side group and a ketone is regarded as a carbonyl side group.
- A compound containing both alcohol and aldehyde functional groups is named as an aldehyde with a hydroxyl side group.
- A compound containing an alcohol, a ketone and an acid is named as an acid with hydroxyl and carbonyl side groups.

Some examples are listed below.

**FIGURE 8.32** (a) 3-aminobutan-2-ol, (b) 3-hydroxypropanoic acid and (c) pent-2-en-1-ol
SAMPLE PROBLEM 5

Name the following organic compound.

THINK

1. Identify the functional groups on the molecule and assign priority.
   Aldehyde functional group takes priority over amino functional group. The name will end in ‘-al’.

2. The longest chain is composed of five carbons, making the molecule pentanal.
   Number the carbon chain with the lowest number for the priority functional group, aldehyde.
   Determine the branch position of the second functional group, amino.
   Amino is branching at C2.

3. Identify any alkyl groups branching off the longest carbon chain.
   Methyl is branching from C4.

4. Write the name with substituents in alphabetical order.
   2-amino-4-methylpentanal

WRITE

PRACTICE PROBLEM 5

Name the following organic compound.

8.4 EXERCISES

To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au.
1. Complete the following table.

<table>
<thead>
<tr>
<th>Functional group</th>
<th>Name</th>
<th>Priority</th>
<th>Homologous series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carboxyl</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ketones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₂</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Hydroxyl</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COO</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Write the semi-structural formula for 4-aminopentan-1-ol.

3. (a) Name the following molecules.
   (b) Draw semi-structures for the molecules.
   (c) Draw skeletal structures for the molecules.

   i. 

   ii. CH₃—CH—CH—CH—CH₃
       Br  Cl  CH₃

   iii. H—O—C—C—O—C—O
        H  H  C—H  H

   iv. CH₃—CH—C—O
       Br  CH₂

   v. O
      H  H  H
      H  H  H
      O  N

4. A student named the molecule below 5-amino-2-chlorohexane. Is this name correct? Explain your answer.

   CH₃—CH—CH₂—CH₂—CH—CH₃
   Cl  NH₂

5. Draw the skeletal structure of but-3-en-1-ol.

6. Draw the structure and semi-structure of a four-carbon amide with 2,3-dihydroxy groups.

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8.5 Isomers

KEY CONCEPT

• The formation of isomers (structural and stereoisomers) to explain carbon compound diversity, including identification of chiral centres in optical isomers of simple organic compounds and distinction between cis- and trans- isomers in simple geometric isomers

8.5.1 Introduction to isomers

Another reason for the enormous number of organic compounds is the existence of isomers. These are two or more compounds with the same molecular formula but different arrangements of atoms. The effect on the properties of the substances depends on the type of isomerism present. If the atoms are arranged in different orders, they are structural isomers. If the atoms are connected in the same order but are oriented differently in space, they are stereoisomers. In many cases, three-dimensional space diagrams (using wedges and dashes) are used to show the different positions.

Resources

Video eLesson Isomers (eles-2478)

8.5.2 Structural (constitutional) isomers

Structural isomers are those where the connectivity (or arrangement) of atoms or groups of atoms are different. For the first three alkanes (methane, ethane and propane) there is only one way of arranging the atoms and that is the straight-chain arrangement. In butane, there are two ways of arranging the carbon and hydrogen atoms, therefore, there are two structures. One is the straight-chain structure and the other is the branched-chain structure.

Each of the two structures of butane satisfies the valence of carbon and hydrogen atoms, and each is a neutral and stable molecule (see figure 8.33). Their chemical and physical properties are similar but not identical. For instance, straight-chain butane has a boiling point of –1 °C, while the branched chain molecule, 2-methylpropane, has a boiling point of –12 °C. Butane and 2-methylpropane are called structural isomers because they have the same molecular formula but different arrangements of atoms.

Three types of structural isomers are chain, positional and functional isomers. An easy way of determining structural isomers is to go through the systematic naming process. A different name means a different structure.

Chain isomers

Chain isomers are structures that are different because of the size of the parent chain and the alkyl branches, if any, attached. Butane and 2-methylpropane (methylpropane) are examples of chain isomers.

The number of possible ways of combining the atoms to form chain isomers increases with the number of carbon atoms in the molecule. Pentane, C₅H₁₂, has three isomers, and heptane, C₇H₁₆, has nine, while decane, C₁₀H₂₂, has 75 isomers. For C₁₅H₃₂, there are 4347 possible
isomers and for C_{40}H_{82}, there are more than $6 \times 10^{13}$ possible isomers. Isomerism is responsible for the enormous number of organic compounds that are known.

**Positional isomers**

Isomers where the functional group is located on different carbon atoms in the structure are called **positional isomers**. Propan-1-ol and propan-2-ol are examples.

**SAMPLE PROBLEM 6**

**Draw and name all structural isomers of C_{4}H_{9}Cl.**

<table>
<thead>
<tr>
<th>THINK</th>
<th>WRITE</th>
</tr>
</thead>
</table>
| 1. This is a haloalkane, so the easiest place to start is to draw the straight-chain and put the chlorine atom on C1 and name it. | \[\begin{array}{c}
\text{Cl} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H}
\end{array}\] 1-chlorobutane |
| 2. Change the position of the Cl atom to make a different structure with a different name. **TIP:** There is no 3-chlorobutane or 4-chlorobutane because when they are flipped over they are actually just 1-chlorobutane and 2-chlorobutane. | \[\begin{array}{c}
\text{H} \\
\text{Cl} \\
\text{H} \\
\text{H} \\
\text{H}
\end{array}\] 2-chlorobutane |
| 3. Move the CH\textsubscript{3} group to make it a methyl group and have the Cl branch off the same carbon. Make sure it has a different name in case you have drawn the same structure but a different way. | \[\begin{array}{c}
\text{H} \\
\text{H} \\
\text{C} \\
\text{H} \\
\text{C}
\end{array}\] 2-chloro-2-methylpropane |
| 4. Make the last change possible by moving the chlorine back to C1 of the methylpropane. | \[\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \\
\text{H}
\end{array}\] 1-chloro-2-methylpropane |

**PRACTICE PROBLEM 6**

**Draw and name all structural isomers of C_{4}H_{9}OH with one hydroxyl functional group.**

**Functional isomers**

If isomers have **functional isomerism** they have the same molecular formula but different functional groups in their structures. Figure 8.34 is an example.
**8.5.3 Stereoisomers**

Stereoisomers have the same type and order of connected atoms but a different three dimensional orientation or arrangement in space.

**Enantiomers**

For a carbon atom to be able to form enantiomers, it must have four different atoms, or groups of atoms, bonded to it. Carbon atoms that meet this criteria are called chiral or have chiral centres.

Figure 8.35 shows a pair of enantiomers (I and II) with atoms bonded in a tetrahedral arrangement to the chiral carbon. They might look the same initially with the same atoms all connected to the same carbon atom, but W and Y have swapped places. They are reflections of each other. We can tell they are arranged differently in space because we cannot place or rotate them so that they sit exactly on top of one another. That is, the reflections cannot be superimposed. The only way we could make the two molecules exactly the same is if we pulled the ball and stick models apart and re-positioned the atoms.

Enantiomers are also called optical isomers. ‘Optical’ isomers cause (plane-polarised) light to be rotated in opposite directions once it has passed through a sample of each. When optically active substances are synthesised in the laboratory, they are often a 50:50 mixture of the two enantiomers. This is known as a racemic mixture or racemate.

A racemic mixture does not affect plane-polarised light and stereoisomers formed in biological systems consist of the one enantiomer. As a result of this, many of the natural and synthetic drugs used in medicine have different effects on the body. This is because the enantiomer in the body has a unique three-dimensional shape so the drug that interacts (bonds) with it must have a matching three-dimensional shape. With 50:50 mixes of enantiomers produced when making medicines, synthetic chemists are looking to develop pathways that only produce the medicinal enantiomer. Different effects on the body can mean the medicines don’t work as well, or at all. Worse, some medicines
can produce beneficial and harmful enantiomers. For example, between 1957 and 1962, the drug thalidomide was used to treat morning sickness in pregnant women. More than 10,000 babies were born with birth defects as a result of using this drug. Eventually, investigations found that thalidomide was a racemic mix of two enantiomers due to the presence of one chiral carbon atom. While one enantiomer did indeed cure morning sickness, the other enantiomer caused deformities in organs and limbs.

**USING POLARISED LIGHT TO DISTINGUISH OPTICAL ISOMERS**

Normally, a light wave is made up of a mixture of waves vibrating in every direction perpendicular to its direction of movement. Unpolarised light can be converted into a single polarised beam by passing it through a polarising filter. Sunglasses use a polarising filter to limit glare. Optically active molecules can rotate the plane of polarisation of plane-polarised light. An instrument called a polarimeter can be used to analyse this rotation. If it is rotated clockwise it is the (+) enantiomer; if it is rotated anticlockwise, it is the (–) enantiomer.

**Identifying chiral centres**

We often use our hands, feet or household objects to demonstrate the difference between symmetrical and asymmetrical (not symmetrical) objects. Symmetry is observed when a line cuts through an object and one half is the mirror image of the other half, and this can be extended to organic molecules. Organic molecules with a plane of symmetry are achiral (not chiral), whereas asymmetrical molecules will have chiral carbons and form enantiomers.
**Geometric (cis-trans) isomers**

Geometric isomers exist in compounds with C=C bonds. Unlike C−C single bonds, carbon to carbon double bonds do not rotate, so they can produce structures where the same type of atoms (substituents), or groups, are bonded to each carbon on either the same side of the double bond or on opposite sides of the double bond. As an example, let’s compare C_2H_4Cl_2 and C_2H_2Cl_2. The first compound has one C−C bond, which is able to rotate.

Although C_2H_4Cl_2 might look different initially, these molecules are the same due to the bond rotation. In other words, the C−C bond can be rotated to produce the same molecule.

**FIGURE 8.39** The single bond between carbons is able to rotate, meaning these molecules are not isomers.

The second compound, C_2H_2Cl_2, with its restricted C=C bond will produce different geometric isomers. When the substituents (Cl atoms) are on the same side the molecule has a **cis** geometry but the molecule with the substituents on opposite sides has **trans** geometry.

**FIGURE 8.40** The double bond between carbons is not able to rotate, meaning these molecules are isomers.

**SAMPLE PROBLEM 7**

Which of the following organic molecules would produce two enantiomers?

- a. CH_4
- b. CH_2Cl_2
- c. CHBrF_2
- d. CHBrClF

**THINK**

1. A carbon atom must have four different atoms or groups of atoms to be classified as chiral and produce enantiomers.
   - a. CH_4 has four atoms of the same type attached to a carbon atom.
   - b. CH_2Cl_2 has two sets of two atoms of the same type attached to a carbon atom. This will produce molecules that are symmetrical. Therefore, it is achiral.
   - c. CHBrF_2 has one set of two atoms of the same type attached to a carbon atom. This will produce molecules that are symmetrical. Therefore, it is achiral.

**WRITE**

CH_4 does not have a chiral centre and will not produce enantiomers.

CH_2Cl_2 does not have a chiral centre and will not produce enantiomers.

CHBrF_2 does not have a chiral centre and will not produce enantiomers.
d. CHBrClF has four different atoms attached and therefore has a chiral centre. It will produce two enantiomers; that is, mirror images of each other that are not superimposable.

**PRACTICE PROBLEM 7**
Which of the following would produce two enantiomers?

a. CH₂ClF
b. CH₃CHBrF
c. (CH₃)₂CHF
d. CHBr₂F

8.5.4 Isomer summary
Table 8.10 summaries the different types of isomers.

<table>
<thead>
<tr>
<th>Isomer</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural isomers</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Chain isomers</strong></td>
<td>different branching in carbon chain</td>
</tr>
<tr>
<td>H-C-C-C-C-H</td>
<td>H-C-C-C-C-H</td>
</tr>
<tr>
<td>butane</td>
<td>methylpropane</td>
</tr>
<tr>
<td><strong>Positional isomers</strong></td>
<td>different positions of the functional group, which is usually indicated by a number in the name</td>
</tr>
<tr>
<td>H-C-C-C-H</td>
<td>H-OH</td>
</tr>
<tr>
<td>propan-1-ol</td>
<td>propan-2-ol</td>
</tr>
<tr>
<td><strong>Functional isomers</strong></td>
<td>same atoms but different functional groups</td>
</tr>
<tr>
<td>H-C-C-C-O</td>
<td>H-C-C-O</td>
</tr>
<tr>
<td>propanal</td>
<td>propanone (acetone)</td>
</tr>
<tr>
<td><strong>Stereoisomers</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Geometric (cis and trans) isomers</strong></td>
<td>different arrangements of atoms around a double bond or in a ring, which restricts rotation. If the groups on each carbon atom are on the same side of the molecule, that molecule is the cis isomer. If they are on opposite sites, it is the trans isomer.</td>
</tr>
<tr>
<td>CH₃</td>
<td>CH₃</td>
</tr>
<tr>
<td>C = C</td>
<td>C = C</td>
</tr>
<tr>
<td>cis-but-2-ene</td>
<td>trans-but-2-ene</td>
</tr>
<tr>
<td><strong>Enantiomers or optical isomers</strong></td>
<td>non-superimposable reflections containing an asymmetric carbon atom. These molecules are referred to as chiral.</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Br</td>
<td>Cl</td>
</tr>
<tr>
<td>C</td>
<td>Cl</td>
</tr>
<tr>
<td>F</td>
<td>Br</td>
</tr>
</tbody>
</table>
8.5 EXERCISES
To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au.

1. What is the difference between chiral and achiral carbon atoms?
2. Why are enantiomers called optical isomers?
3. What is the difference between a stereoisomer and a structural isomer?
4. Draw the enantiomers of CH$_3$CHBrF.
5. Draw all isomers of C$_4$H$_{10}$.
6. Describe the type of isomerism that exists in the following two molecules.

\[
\begin{align*}
\text{OH} & \quad \text{OH} \\
\text{Br} & \quad \text{Cl} \\
\text{H} & \quad \text{H} \\
\text{C} & \quad \text{C} \\
\text{Cl} & \quad \text{Br}
\end{align*}
\]

7. Draw the structure of a functional group isomer of ethanol, C$_2$H$_5$OH.
8. Name this geometric stereoisomer.

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

9. Draw skeletal structures and give systematic names for the cis and trans isomers of C$_2$H$_5$O.
10. Draw and give systematic names to all structural isomers with the molecular formula C$_4$H$_8$O that contain the carbonyl functional group.

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Fully worked solutions and sample responses are available in your digital formats.

8.6 Review
8.6.1 Summary
The carbon atom
- Organic chemistry is the study of the compounds of carbon. This does not include the inorganic compounds of cyanides, carbonates and oxides of carbon.
- Historically, organic compounds were associated with living things, but these days chemists can manufacture organic compounds for a variety of uses.
- Carbon can form many different compounds due to its ability to create four covalent bonds with itself or other elements.
- The electron configuration of carbon is 2,4. Therefore, it has a valence number of four.
In the methane molecule, a carbon atom can form covalent bonds with four other atoms. The resulting shape is tetrahedral, resulting in bond angles of 109.5°.

- Bond angle and bond length determine the strength of carbon covalent bonds. Bond strength is measured in kJ mol\(^{-1}\).
- C≡C are stronger than C=C, which are stronger than C−C bonds.

**Structure and naming of organic compounds**

- Molecular modelling is used to show the structure of molecules.
- Molecular representations include:
  - **Structures:**
    
    ![Methane Structure](image)

    Semi structures:
    \[CH_3C(CH_3)_2(CH_2)OH\]

    Skeletal structures:
    
    ![Skeletal Structure](image)

- A homologous series is a group of organic chemical compounds that have a similar structure and whose structures differ only by the number of CH\(_2\) units in the main carbon chain. They are compounds containing the same functional group and have similar properties.
- The alkanes, alkenes and alkynes are hydrocarbons and form homologous series with general formulas of C\(_n\)H\(_{2n+2}\), C\(_n\)H\(_{2n}\) and C\(_n\)H\(_{2n-2}\), respectively.
- Saturated hydrocarbons have only single C−C covalent bonds.
- Alkanes are saturated hydrocarbons. Alkenes and alkynes are unsaturated hydrocarbons with double and triple carbon bonds, respectively.
- Haloalkanes (R−X) are formed when halogens such as F, Cl, Br and I are substituted into hydrocarbon chains.

- Functional groups change the family of molecules or the type of homologous series. These include:
  - Alcohols (primary, secondary and tertiary) contain the hydroxyl (−OH) functional group. The suffix for alcohols on systematic names is ‘−ol’.
  - Aldehydes (R−CHO) and ketones (RCOR’) contain the carbonyl (C=O) functional group. The suffixes for naming are ‘−al’ and ‘−one’ respectively.
  - Carboxylic acids contain the carboxyl (−COOH) functional groups.
  - Primary amines (R−NH\(_2\)) contain the amino functional groups while primary amide links have the general formula R−CONH\(_2\).
  - Straight chain esters are made from carboxylic acids and primary alcohols. The ester (−COO) link gives esters the general formula RCOOR’ where R−CO comes from the carboxylic acid and R’−O comes from the alcohol. The first part of the ester name comes from the alkyl (R’) part of the alcohol (e.g. methyl, ethyl, propyl, etc). The second part of the ester name comes from the number of carbons in the RCOOH. The suffix ‘−oic acid’ becomes ‘−oate’ (e.g. methanoate, ethanoate, propanoate).

- Rules for naming organic compounds:
  - Identify and name the longest unbranched carbon chain containing the principal functional group. (It is helpful to highlight this chain.)
• Number the carbon atoms in the longest unbranched chain, starting with the carbon atom nearest the functional group or branch (if an alkane).
• Identify the branching group(s) of atoms and state the number of the carbon atom to which it is attached. Branches are named using –yl. For example, a branched group of −CH3 would be named methyl, CH3CH2− would be ethyl, and CH3CH2CH2− would be propyl. These go before the name of the longest chain.
• For molecules with two or more branches of the same type, the branch type is named and a prefix (di–, tri–, tetra–, etc) is used to indicate the number of branches.
• Branches are listed in alphabetical order, ignoring the prefix in the previous rule. Ethyl is written before methyl or dimethyl. Note that adjacent numbers in a name are separated by a comma and numbers are separated from words by a hyphen.
• If two or more side chains are in equivalent positions, assign the lowest number to the one that will come first in the name.

**Functional groups and naming priority**
• If more than one functional group is present, the order of decreasing priority in determining the suffix is carboxylic acid > ester > aldehyde > ketone > alcohol > amine > alkyne = alkene > alkane.

**Isomers**
• Isomers are compounds with the same molecular formula but different arrangements of atoms.
• In structural isomers, the atoms are arranged in different ways, which means that the chemical bonding is different. Structural isomers have different physical properties and, if different functional groups, chemical reactivities.
• Chain isomers have different branching in the carbon chain.
• Positional isomers show different positions of the particular functional group, which is usually indicated by a number in the name.
• Functional isomers have the same atoms but different functional groups.
• Stereoisomers have the same sequence of bonded of atoms, but the spatial arrangement of atoms differs.
• Geometric isomers can be either cis or trans. They are non-mirror-image molecules that have the same chemical bonding but different spatial arrangements of atoms. In restricted bonded compounds, cis isomers involve atoms or groups that are next to each other and trans isomers involved atoms or groups on opposite sides of the molecule.
• Enantiomers (optical isomers) are mirror-image molecules that cannot be superimposed on each other. These molecules are described as chiral. Enantiomers have identical physical properties and their chemical properties are also generally the same (except interactions with other molecules with optical properties). A chiral molecule rotates the plane of polarised light passing through the solution. Optical isomers can have radically different biological effects.

**8.6.2 Key terms**

- **Alcohols** organic hydroxyl compounds containing the −OH group
- **Aliphatic** describes organic compounds in which carbon atoms form open chains
- **Alkanols** alcohols containing only carbon, hydrogen and oxygen
- **Alkenes** the family of hydrocarbons that contain one carbon–carbon double bond
- **Alkyl groups** hydrocarbon branches joined to the parent hydrocarbon chain (e.g. CH3 (methyl) CH2CH3 (ethyl))
- **Alkynes** the family of hydrocarbons with one carbon–carbon triple bond
**allotropes** different physical forms in which an element can exist
**arenes** aromatic, benzene-based hydrocarbons
**aromatic** describes a compound that contains at least one benzene ring and is characterised by the presence of alternating double bonds within the ring
**benzene** an aromatic hydrocarbon with the formula C₆H₆
**bond length** the distance between two nuclei involved in covalent bonding
**chain isomers** a type of structural isomer that involves more branching
**chiral** describes compounds containing an asymmetric carbon atom or chiral centre. The molecule cannot be superimposed upon its mirror image.
**chiral centres** asymmetric carbon atoms
**cis–trans isomers** types of stereoisomers that are formed when the same two different groups are bonded to each of the carbon atoms in a carbon–carbon double bond. A cis isomer has identical groups on the same side of the double bond; a trans isomer has the groups on opposite sides.
**covalent bonds** bonds involving the sharing of electron pairs between atoms
**electron configuration** the number of electrons and shells they occupy (e.g. 2,4 or 1s²2s²2p²)
**enantiomers** chiral molecules that are non-superimposable mirror images of one another
**excited state** when electrons moved to higher energy orbitals when energy is applied
**functional group** elements in Group 17 (7) of the periodic table: F, Cl, Br, I and At.
**functional isomerism** isomers containing different functional groups
**halogens** elements in Group 17 of the periodic table: F, Cl, Br, I and At.
**homologous series** a series of organic compounds that have the same structure but in which the formula of each molecule differs from the next by a CH₂ group
**optical isomers** see enantiomers
**positional isomers** isomers where the position of the functional group differentiates the compounds
**racemate** a 50:50 mixture of two enantiomers; often occurs when optically active substances are synthesised in the laboratory
**racemic mixture** see racemate
**stereoisomers** two or more compounds differing only in the spatial arrangements of their atoms
**structural isomers** molecules that have the same molecular formula but different structural formulas
**unsaturated** describes hydrocarbons containing at least one double carbon–carbon bond
**valence number** the number of electrons occupying the orbitals in the outermost electron shell

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**8.6.3 Practical work and experiments**

**Experiment 8.3**
Constructing models of structural isomers
**Aim:** To construct models of structural isomers
**Digital document:** doc-31268
**Teacher-led video:** tlvd-0754

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**Resources**

- **Digital document** Key terms glossary - Topic 8 (doc-31412)
- **Digital documents** Practical investigation logbook (doc-31413)
  - Experiment 8.1 Constructing models of hydrocarbons (doc-31266)
  - Experiment 8.2 Constructing models of organic compounds (doc-31267)
  - Experiment 8.4 Investigating optical isomers (doc-31269)
8.6 Exercises

To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au.

8.6 Exercise 1: Multiple choice questions

1. Which of the following does not apply to alkanes?
   A. They have the general formula C\(_n\)H\(_{2n}\).
   B. They contain C and H.
   C. Each has at least one C–C bond.
   D. They are saturated hydrocarbons.

2. The functional groups and suffixes for naming alcohols and carboxylic acids respectively are:
   A. –OH, –COOH, -oate, -ol
   B. –COOH, –OH, -ol, -oic
   C. –OH, –COOH, -ol, -oic
   D. –OH, –COOH, -ol, -oate.

3. Cycloalkanes have the same molecular formula as:
   A. alkanes
   B. alkenes
   C. alkynes
   D. benzene.

4. In the IUPAC nomenclature system, the name of which of the following would end in –al?
   A. An alcohol
   B. An aldehyde
   C. An alkane
   D. A ketone.

5. This compound is:

   A. an ester
   B. an aldehyde
   C. a ketone
   D. a carboxylic acid.

6. The structural arrangement of 2,2-dimethylbutan-1-ol is:

   A. 
   B. 
   C. 
   D. 

7. The IUPAC name for the compound (CH\(_3\))\(_2\)CHCH\(_2\)CH(NH\(_2\))CH\(_3\) is:
   A. 2-methylpentanamine
   B. 4-methylpentan-2-amine
   C. 2-methyl-4-pentanamine
   D. 4-methyl-2-pentanamine.
8. Identify the chiral carbon atom in the following molecule.

A. a  
B. b  
C. c  
D. d  

9. What is the IUPAC name of the following molecule?

A. 1-amino-2-methylbutan-4-ol  
B. 2-aminobutan-4-ol  
C. 4-amino-3-methylbutan-1-ol  
D. 3-aminobutan-1-ol.  

10. The following two molecules are best described as:

A. optical isomers  
B. structural isomers  
C. cis–trans isomers  
D. stereoisomers.  

8.6 Exercise 2: Short answer questions

1. Draw three-dimensional space (wedge-dash) diagrams for the following molecules.
   a. CH₄  
   b. C₂H₄  
   c. C₂H₂  
   d. C₂H₅ClF  

2. Explain why carbon to carbon triple bonds are higher in energy than carbon to carbon double bonds.  

3. Calculate the energy required to break all covalent bonds in 20.0 g of CCl₄. The C–Cl bond energy is 324 kJ mol⁻¹.  

4. Define the following terms.
   a. Hydrocarbon  
   b. Homologous series  
   c. Saturated hydrocarbon  
   d. Unsaturated hydrocarbon  
   e. Structural isomer  

5. Define the terms ‘alkane’ and ‘alkene’ and describe their similarities and differences.  

6. Name the following organic compounds.
   a. CH₃CH₂CH=CHCH₃  
   b. CH₂=CHCI  
   c. CF₂Cl₂  
   d. CH₃CH₂OH  
   e. \[ \text{CH₃} \quad \text{CH₃} \quad \text{C} \quad \text{CH₃} \quad \text{CH₃} \]
7. Draw the structural formulas for the following compounds.
   a. 2-methylpentan-3-ol
   b. butan-2-ol
   c. 2,2-dimethylbutan-1-ol
   d. 2,3-dimethylpentan-2-ol
   e. pentanoic acid
   f. 2-methylpropanoic acid
   g. butanoic acid
   h. pentanal
   i. 2-chloropropan-1-amine
   j. butyl methanoate
   k. butanone
   l. 2-pentyne

8. Give the systematic name of the following compounds.
   a. 
   b. 
   c. 
   d. 

9. Draw and label the cis and trans isomers with the molecular formula C$_2$H$_2$F$_2$.

10. Describe the type of isomerism present in each of the following pairs of compounds.
   a. 
   b. 
   c. 

8.6 Exercise 3: Exam practice questions

Question 1
An organic molecule with the molecular formula C₄H₁₀O is shown.

Which of the following statements about the molecule is true?

A. It is a primary alcohol and its systematic name is butan-2-ol.
B. It is a primary alcohol and its systematic name is butan-3-ol.
C. It is a secondary alcohol and its systematic name is butan-2-ol.
D. It is a secondary alcohol and its name is butan-3-ol.

Question 2
Which of the following contains a chiral carbon?

A. prop-1-ene CH₂CHCH₃
B. 1,2-dichloropropane CH₂ClCHClCH₃
C. 2-chloropropane CH₃CHClCH₃
D. 2-bromobutane CH₃CHBrCH₂CH₃

Question 3
The semi-structure of the following compound is:

A. CH₃(CH₂)₂CH₂Cl
B. CH₃CH₂CH₂Cl
C. (CH₃)₂CHCl
D. CH₃CHCH₂Cl

Question 4
Which of the following structures is a primary amide?

A. 
B. 
C. 
D. 

298 Jacaranda Chemistry 2 VCE Units 3 & 4 Second Edition
Question 5  

(10 marks)

The diverse nature of organic compounds can be attributed to carbon and its unique chemical properties. In fact, there are millions of organic compounds found in nature and synthesised in the laboratory. To be able to identify these molecules IUPAC has developed naming conventions and models.

a. Consider the alcohol 2-methylpropan-2-ol.
   i. Draw the structural formula of the alcohol.  
      1 mark
   ii. What is the name of the functional group?  
       1 mark
   iii. Is this a primary, secondary or tertiary alcohol? Justify your answer.  
       1 mark

b. Write the semi-structural formula of methyl butanoate.  
   1 mark

c. Stereoisomers such as cis-but-2-ene and trans-but-2-ene are also known as geometric isomers.
   i. Draw the structures of cis and trans but-2-ene.  
      2 marks
   ii. Write a balanced chemical equation for the combustion of but-2-ene gas.  
       2 marks
   iii. Calculate the volume of CO\textsubscript{2} gas collected from the complete combustion of 1.50 kg of but-2-ene at SLC.  
       2 marks