# Contents

## *Section 1 Physical Chemistry*



## *Section 2 Organic Chemistry*



## *Section 3 Inorganic Chemistry*

Optional task: Research the work of Mendeleev and others in developing the modern Periodic Table.

Total number of marks: 250

SECTION ONE - TOPIC 1

# 1 Worksheet 1

## Sub-atomic particles and the Periodic Table

The structure of the atom can be described in terms of certain key terms.

Use the terms in the middle column of the table below to write three short paragraphs on the structure of the atom and its importance.

| Paragraph | Terms to use | Marks awarded |
|---|---|---|
| 1 The three particles and their properties. | electron<br>neutron<br>proton<br>relative charge<br>relative atomic mass<br>sub-atomic particles<br>no charge | [6] |
| 2 The arrangement of the particles in the atom. | electrons<br>energy levels<br>protons<br>neutrons<br>nucleons<br>nucleus | [3] |
| 3 How the numbers of the different sub-atomic particles determine the properties of the atom and the position of the element in the Periodic Table. | atomic number<br>electrons<br>energy levels<br>group number<br>mass number<br>period number<br>protons<br>neutrons | [6] |

Total _____ Score: %
15

SECTION ONE - TOPIC 2

# 1 Worksheet 2

## Isotopes and relative atomic masses

**1** The table below shows the isotopes of two elements, magnesium and neon.
Copy and complete the table.

| **Element** | **Isotopes** | | |
|---|---|---|---|
| **Magnesium** | $^{24}_{12}Mg$ | $^{25}_{12}Mg$ | $^{26}_{12}Mg$ |
| Number of protons | | | |
| Number of electrons | | | |
| Number of neutrons | | | |
| **Neon** | $^{20}_{10}Ne$ | $^{21}_{10}Ne$ | $^{22}_{10}Ne$ |
| Number of protons | | | |
| Number of electrons | | | |
| Number of neutrons | | | |

[6]

**2** The relative atomic mass of an element is the weighted average atomic mass of the element relative to $\frac{1}{12}$ the mass of an atom of the $^{12}C$ isotope.

**a** What does *weighted* mean in the definition? [2]

**b** Why use $\frac{1}{12}$ the mass of an atom of the $^{12}C$ isotope? [2]

**3** The relative atomic mass of chlorine is 35.5. What does this tell you about the relative abundance of the two naturally occurring isotopes of chlorine, $^{35}_{17}Cl$ and $^{37}_{17}Cl$ ?
Explain your answer. [2]

**4** The naturally occurring isotopes of magnesium and neon are shown in the table below along with their relative abundance. Calculate the relative atomic mass for each element.

| **Element** | **Magnesium** | | |
|---|---|---|---|
| Atomic mass of isotope | 24 | 25 | 26 |
| Relative abundance % | 78.60 | 10.11 | 11.29 |
| | **Neon** | | |
| Atomic mass of isotope | 20 | 21 | 22 |
| Relative abundance % | 90.92 | 0.26 | 8.82 |

[6]

Total ——— Score: %
18

SECTION ONE - TOPIC 3

# 2 Worksheet 1

## Formulae and equations

**1** The formulae of some positive and negative ions are shown in the tables below.

| Name | Symbol | Charge |
|---|---|---|
| lithium | $Li^+$ | 1+ |
| sodium | $Na^+$ | 1+ |
| potassium | $K^+$ | 1+ |
| magnesium | $Mg^{2+}$ | 2+ |
| calcium | $Ca^{2+}$ | 2+ |
| barium | $Ba^{2+}$ | 2+ |
| aluminium | $Al^{3+}$ | 3+ |
| hydrogen | $H^+$ | 1+ |
| ammonium | $NH_4^+$ | 1+ |
| potassium | $K^+$ | 1+ |
| zinc | $Zn^{2+}$ | 2+ |
| iron(II) | $Fe^{2+}$ | 2+ |
| iron(III) | $Fe^{3+}$ | 3+ |

| Name | Symbol | Charge |
|---|---|---|
| fluoride | $F^-$ | 1– |
| chloride | $Cl^-$ | 1– |
| bromide | $Br^-$ | 1– |
| iodide | $I^-$ | 1– |
| oxide | $O^{2-}$ | 2– |
| sulfide | $S^{2-}$ | 2– |
| hydroxide | $OH^-$ | 1– |
| silicate | $SiO_3^{2-}$ | 2– |
| carbonate | $CO_3^{2-}$ | 2– |
| hydrogencarbonate | $HCO_3^-$ | 1– |
| sulfate(VI) | $SO_4^{2-}$ | 2– |
| nitrate(V) | $NO_3^-$ | 1– |
| phosphate(V) | $PO_4^{3-}$ | 3– |

What is the formula of each of the following compounds?

**a** sodium chloride
**b** lithium oxide
**c** zinc nitrate(V)
**d** ammonium carbonate
**e** potassium silicate
**f** potassium oxide
**g** aluminium oxide
**h** sodium phosphate(V)
**i** copper(II) fluoride
**j** copper(II) hydroxide
**k** iron(III) sulfate(VI)
**l** sodium bromide
**m** calcium carbonate
**n** ammonium phosphate
**o** calcium hydrogencarbonate [15]

2 Write balanced symbol equations for the following syntheses. The formulae of the covalent products (e.g. silicon dioxide) are given but you should be able to work out the formulae of the ionic products (e.g. sodium oxide).

**a** sodium + oxygen → sodium oxide [2]

**b** aluminium + oxygen → aluminium oxide [2]

**c** silicon + oxygen → silicon dioxide ($SiO_2$) [2]

**d** magnesium + chlorine → magnesium chloride [2]

**e** aluminium + chlorine → aluminium chloride ($Al_2Cl_6$) [2]

**f** silicon + chlorine → silicon tetrachloride ($SiCl_4$) [2]

**g** phosphorus ($P_4$) + chlorine → phosphorus pentachloride ($PCl_5$) [2]

**h** iron(II) bromide + sodium hydroxide → iron(II) hydroxide + sodium bromide [3]

**i** iron(III) sulfate(VI) + potassium hydroxide → iron(III) hydroxide + potassium sulfate(VI) [3]

3 Write an equation for each of the following decomposition reactions.

**a** calcium nitrate(V) decomposing to give calcium oxide, nitrogen dioxide and oxygen

**b** lithium nitrate(V) decomposing to give lithium oxide, nitrogen dioxide and oxygen

**c** magnesium carbonate decomposing to give magnesium oxide and carbon dioxide

**d** magnesium hydroxide decomposing to give magnesium oxide and water

**e** calcium hydrogencarbonate decomposing to give calcium carbonate, water and carbon dioxide [10]

Total ——— Score: %
45

SECTION ONE - TOPIC 4

# 2 Worksheet 2

## Moles

1 What is the mass in grams of one mole of the following?

- **a** zinc atoms
- **b** lead atoms
- **c** hydrogen atoms
- **d** hydrogen molecules
- **e** sulfur atoms
- **f** sulfur molecules ($S_8$)
- **g** copper(II) nitrate(V) formula units
- **h** water molecules
- **i** sodium chloride formula units

[9]

2 **a** How many moles of atoms are there in the following?
Give your answers to 3 significant figures.

- **i** 4.6 g of zinc
- **ii** 79 g of oxygen
- **iii** 0.156 g of calcium
- **iv** 109.6 g of sodium
- **v** 0.31 g of lead
- **vi** 5.3 g of hydrogen

**b** Which of these samples contains the greatest number of atoms?
**c** Which of these samples contains the smallest number of atoms? [8]

3 How many moles of molecules are there in the following?
Give your answers to 3 significant figures.

- **a** 9.0 g of water
- **b** 0.088 g of carbon dioxide
- **c** 56.3 g of carbon monoxide
- **d** 0.0465 g of ammonia

[4]

4 How many moles of formula units are there in the following?
Give your answers to 3 significant figures.

- **a** 1.00 g of calcium carbonate
- **b** 26.0 g of copper(II) nitrate(V)
- **c** 74.63 g of zinc chloride
- **d** 0.163 g of aluminium oxide

[4]

Total _____ Score: %
25

SECTION ONE - TOPIC 5

# 2 Worksheet 3

## Numbers of particles

Avogadro's number $N_A = 6.02 \times 10^{23}$.

Atomic masses: C = 12.0; H = 1.00; N = 14.0; O = 16.0.

**1 a** How many moles of atoms are there in 1.00 mol of the following molecules?

**i** $HNO_3$

**ii** $C_3H_8$

**iii** $HClO_4$

**iv** $C_8H_{18}$ [4]

**b** How many moles of $Ca^{2+}$ ions are there in 10.0 mol of $CaCl_2$? [1]

**c** How many moles of $Cl^-$ ions are there in 3.00 mol of $CaCl_2$? [1]

**d** How many moles of $OH^-$ ions are there in 0.0500 mol of $Al(OH)_3$? [1]

**2 a** How many grams of carbon are there in 0.500 mol of $C_3H_8$? [2]

**b** How many grams of carbon are there in 0.100 mol of $C_8H_{18}$? [2]

**c** How many grams of nitrogen are there in 2.00 mol of $HNO_3$? [2]

**d** How many grams of oxygen are there in 2.00 mol of $HNO_3$? [2]

**3 a** How many *molecules* are there in each of the following?

**i** 0.100 mol of $C_3H_8$ [1]

**ii** 5.00 mol of $HNO_3$ [1]

**iii** 0.0100 mol of $C_8H_{18}$ [1]

**b** How many *atoms* are there in each of the following?

**i** 0.100 mol of $C_3H_8$ [1]

**ii** 5.00 mol of $HNO_3$ [1]

**iii** 0.0100 mol of $C_8H_{18}$ [1]

**c** How many *ions* are there in each of the following?

**i** 10.0 mol of $CaCl_2$ [2]

**ii** 0.0500 mol of $Al(OH)_3$ [2]

Total ——— Score: %
25

SECTION ONE - TOPIC 6

# 2 Worksheet 4

## Empirical formulae

1 The following sets of data give the percentage composition by mass of three different oxides of sodium. Calculate the empirical formula of each oxide of sodium.
   **a** 74.2% sodium, 25.8% oxygen
   **b** 41.8% sodium, 58.2% oxygen
   **c** 59.0% sodium, 41.0% oxygen [6]

2 The following sets of data give the percentage composition by mass of four different oxides of nitrogen. Calculate the empirical formula of each oxide of nitrogen.
   **a** 36.8% nitrogen, 63.2% oxygen
   **b** 46.7% nitrogen, 53.3% oxygen
   **c** 25.9% nitrogen, 74.1% oxygen
   **d** 63.6% nitrogen, 36.4% oxygen [8]

## Calculating empirical formulae from composition data given in grams

Another way for the analytical data to be expressed is in grams. The technique used to calculate the empirical formula is identical.

***Worked example***

3.30 g of a compound consisting of carbon, hydrogen and oxygen only were analysed and found to contain 1.29 g of carbon and 0.29 g of hydrogen. Calculate its empirical formula.

**i** Find out how much oxygen the sample contained:

3.30 – 1.29 – 0.29 = 1.72 g of oxygen

**ii** Convert each mass into the number of moles of atoms, using $N = \frac{m}{M_r}$

- for carbon: $\frac{1.29}{12.0} = 0.11$ mol
- for hydrogen: $\frac{0.29}{1.0} = 0.29$ mol
- for oxygen: $\frac{1.72}{16.0} = 0.11$ mol

**iii** Divide by the smallest number:

- for carbon: $\frac{0.11}{0.11} = 1$
- for hydrogen: $\frac{0.29}{0.11} = 2.64$
- for oxygen: $\frac{0.11}{0.11} = 1$

**iv** Find the simplest whole-number ratio. This is 3 : 8 : 3, so the empirical formula is $C_3H_8O_3$.

3 Use the following sets of data to calculate the empirical formulae of the compounds involved.
   **a** Octane is a hydrocarbon. 5.00 g of octane contains 4.21 g of carbon.
   **b** 6.45 g of aluminium sulfide contains 2.32 g of aluminium.
   **c** Orthoclase, a mineral in feldspar, is a compound of potassium, aluminium, silicon and oxygen. 20.00 g of orthoclase contains 2.81 g of potassium, 1.94 g of aluminium and 6.04 g of silicon. [6]

4 Phosphorus and sulfur form several different compounds. The following sets of data give the mass of phosphorus contained in 1.000 g of each of these three compounds. Calculate the empirical formula of each compound.
   **a** 1.000 g of compound **A** contains 0.356 g of phosphorus.
   **b** 1.000 g of compound **B** contains 0.564 g of phosphorus.
   **c** 1.000 g of compound **C** contains 0.437 g of phosphorus. [6]

Total $\frac{\quad}{26}$ Score: %

SECTION ONE - TOPIC 7

# 2 Worksheet 7

## Moles in solution

**1** **a** Calculate the concentration of the following solutions.

**i** 0.840 moles of solute dissolved in 5.00 $dm^3$ of solution

**ii** 0.360 moles of solute dissolved in 300 $cm^3$ of solution

**iii** 0.0200 moles of solute dissolved in 25.0 $cm^3$ of solution

**iv** 24.0 moles of solute dissolved in 30.0 $dm^3$ of solution

**b** **i** Which of the solutions above is the most concentrated?

**ii** Which of the solutions above is the most dilute (least concentrated)?

**iii** Which of the solutions above have the same concentration? [7]

**2** Calculate the concentration of the following solutions.

**a** 0.760 g of potassium nitrate(V) ($KNO_3$) dissolved in 80.0 $cm^3$ of solution

**b** 12.0 g of $CuSO_4.5H_2O$ dissolved in 100 $cm^3$ of solution

**c** 54.0 g of glucose ($C_6H_{12}O_6$) dissolved in 300 $cm^3$ of solution

**d** 120 g of nitric(V) acid ($HNO_3$) dissolved in 200 $cm^3$ of solution [12]

**3** How many moles of solute do these samples contain?

**a** 60.0 $cm^3$ of a 2.00 mol $dm^{-3}$ solution

**b** 200 $cm^3$ of a 0.200 mol $dm^{-3}$ solution

**c** 0.500 $dm^3$ of a 1.00 mol $dm^{-3}$ solution

**d** 12.6 $cm^3$ of a 0.250 mol $dm^{-3}$ solution [4]

**4** What volume of a solution of concentration 0.0800 mol $dm^{-3}$ should be measured out to give the following amounts? Give your answers in both $cm^3$ and $dm^3$.

**a** 0.000100 moles

**b** 0.000320 moles

**c** 0.0400 moles [6]

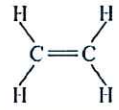
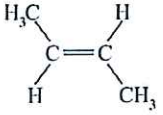
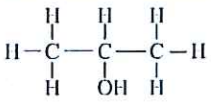
Total _____ Score: %
29

SECTION TWO – TOPIC 8

# 10 Worksheet 1

## Formulae in organic chemistry

Copy and complete the table using the information provided.

| Molecular formula | Empirical formula | Structural formula | Displayed formula | Skeletal formula |
|---|---|---|---|---|
| $C_2H_4$ | $CH_2$ | $H_2C{=}CH_2$ |  |  |
| $C_3H_8$ | 1 | 2 | 3 | 4 |
| 5 | 6 | $CH_3CH_2CHCH_2$ | 7 | 8 |
| | | $(CH_3)_2CCH_2$ | 9 | 10 |
| | | 11 | 12 |  |
| | | 13 |  | 14 |
| 15 | 16 | $CH_3OCH_2CH_3$ | 17 | 18 |
| | | $CH_3CH_2CH_2OH$ | 19 | 20 |
| | | 21 |  | 22 |

Total ——— Score: %
22

SECTION TWO – TOPIC 9

# 2.1 (2) Naming hydrocarbons

**By the end of this spread, you should be able to . . .**

* **Understand and be able to use the IUPAC rules of nomenclature for naming hydrocarbons.**

## Naming organic compounds

With over ten million organic compounds, it is important that each has its own unique name. Organic **nomenclature** (the system used for naming compounds) was developed by the International Union of Pure and Applied Chemistry and is known as the IUPAC system.

You must be able to:
- name compounds from given structures
- draw molecules from their names.

Organic molecules are typically made up of:
- a carbon chain;
- side chains or alkyl groups;
- one or more functional groups.

**Key definition**

Nomenclature is a system of naming compounds.

### Stem, prefix and suffix

The *stem* indicates the number of carbon atoms in the longest carbon chain present in the compound.

A *prefix* is added *before* the stem, as part of the name.

A *suffix* is added *after* the stem, as part of the name.

### Alkyl groups

As discussed in spread 2.1.1, methane ($CH_4$) and ethane ($C_2H_6$) are members of the homologous series, the *alkanes*.

If you remove a hydrogen atom from an alkane, you will get an **alkyl group**. Stems and alkyl groups for up to ten carbon atoms are shown in Table 1.

| Number of carbons | Stem | Alkyl group |
|---|---|---|
| 1 | meth- | methyl |
| 2 | eth- | ethyl |
| 3 | prop- | propyl |
| 4 | but- | butyl |
| 5 | pent- | pentyl |
| 6 | hex- | hexyl |
| 7 | hept- | heptyl |
| 8 | oct- | octyl |
| 9 | non- | nonyl |
| 10 | dec- | decyl |

**Table 1** Alkyl groups

**Key definition**

An alkyl group is an alkane with a hydrogen atom removed, e.g. $CH_3$, $C_2H_5$; any alkyl group is often shown as 'R'.

## Naming alkanes

When naming a molecule from its structure, you just need to follow some simple steps.

Alkanes are the simplest compounds to name. *All* alkanes end their names with the suffix –ane.

### Example 1

Identify the *longest unbranched* chain of carbon atoms in the structure. This is called the parent chain.

Name the *stem* of the parent chain using Table 1.
- There are four carbons in the longest unbranched chain, so the stem is *but-*.
- There are no side chains.
- The compound is an alkane, so the suffix is *-ane*.
- The name is *butane*.

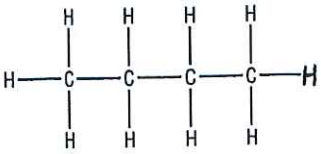


**Figure 1** Butane

**Examiner tip**

When naming compounds, you use the *smallest* numbers possible. So here the compound is 2-methylpentane, rather than 4-methylpentane.

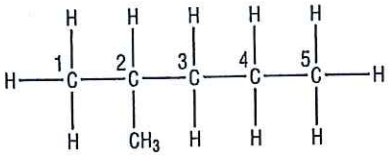


**Figure 2** 2-Methylpentane

### Example 2

Identify any alkyl groups as side chains. These are added to the stem as a *prefix*. Add a number before each alkyl group to show its position on the parent chain.
- There are five carbons in the longest chain, so the stem is *pent-*.
- There is one alkyl side chain, a *methyl-* group.
- The methyl group is on carbon *2-*.
- The compound is an alkane, so the suffix is *–ane*.
- The name is *2-methylpentane*.

**Example 3**

If there is more than one alkyl group on the main chain, the groups are named *alphabetically*.

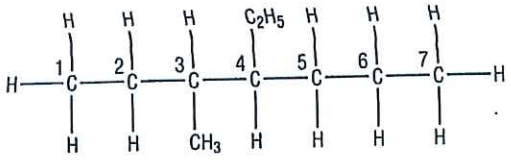


**Figure 3** 4-Ethyl-3-methylheptane

There are seven carbons in the longest chain, so the stem is *hept-*.
There are two alkyl side chains:
a *methyl-* group on carbon *3-*;
an *ethyl-* group on carbon *4-*.
The alkyl groups are listed alphabetically.
The compound is an alkane, so the suffix is *-ane*.
The name is *4-ethyl-3-methylheptane*.

**Examiner tip**

For the molecule in Figure 4, the two alkyl groups are the same and on the same carbon. The name is 2,2-dimethylbutane.

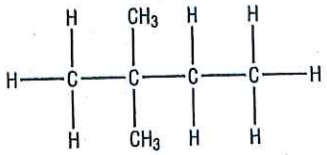


**Figure 4** 2,2-dimethylbutane

## Naming alkenes

An alkene is an unsaturated hydrocarbon with at least one carbon-to-carbon double bond, C=C.

You name alkenes by following similar steps used to name the alkanes.

The main differences are:

- The suffix is *–ene*.
- The position of the double bond has to be stated. This applies to alkenes with *four* or *more* carbons in the longest chain. You only need to use the smaller number. If the double bond starts at carbon-1, it must go to carbon-2.

**Examiner tip**

When naming compounds, separate numbers by *commas*. Place *hyphens* between numbers and words.

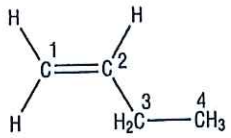


**Figure 5** But-1-ene

- There are four carbons in the longest chain, so the stem is *but-*.
- There is a double bond between carbons *-1-* and 2.
- The compound is an alkene, so the suffix is *-ene*.
- The name is *but-1-ene*.

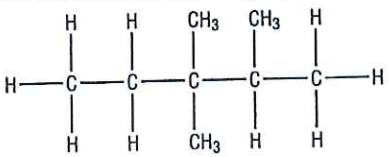
9 marks

## Questions

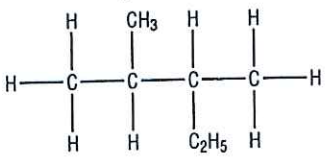
1 Draw out all the atoms and bonds to display the structures for the following molecules:
(a) pent-2-ene;
(b) 2,3-dimethylbutane;
(c) hexane;
(d) 2,3,4-trimethylhexane;
(e) 2-methylbut-2-ene.

2 Name each of the following hydrocarbons.

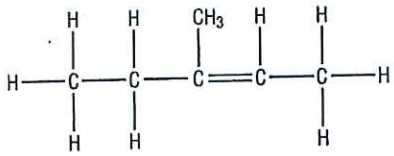
(a)



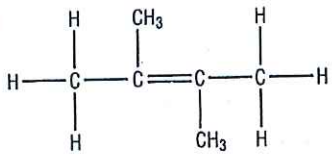
(b)



(c)



(d)



SECTION TWO – TOPIC 10

# 2.1 (4) Formulae of organic compounds

**By the end of this spread, you should be able to . . .**

- **Understand and use the following terms: empirical formula; molecular formula; general formula; displayed formula.**

## Empirical formula

An *empirical formula* is the simplest whole-number ratio of atoms of each element present in a compound. (See also spread 1.1.5.)

**Examples**

- Ethanoic acid ($CH_3COOH$) has two carbon, four hydrogen and two oxygen atoms. The empirical formula for ethanoic acid is $CH_2O$ as the simplest whole-number ratio.
- Benzene ($C_6H_6$) and ethyne ($C_2H_2$) have the same empirical formula, which is CH.

**Worked example**

A hydrocarbon was found to contain 85.63% carbon and 14.37% hydrogen. Calculate its empirical formula.

**Answer**

100.0 g of the compound contains 85.63 g of C and 14.37 g of H.

Find the molar ratio of atoms: C : H

$$\frac{85.63}{12.0} : \frac{14.37}{1.0}$$

$$7.14 : 14.37$$

Divide by smallest number (7.14): 1 : 2

Empirical formula = $CH_2$

**Remember**

$$\text{amount, } n = \frac{\text{mass, } m}{\text{molar mass, } M}$$

**Examiner tip**

Make sure that you divide by the smallest number of moles.

## Molecular formula

A *molecular formula* is the actual number of atoms of each element in a molecule. (See also spread 1.1.5.)

**Example**

The molecular formula of ethene is $C_2H_4$.

- In a molecule of ethene, there are two atoms of carbon and four atoms of hydrogen.

**Worked example**

A compound has an empirical formula of $CH_2O$ and a relative molecular mass of 60.0.

Find its molecular formula.

**Answer**

Find the relative empirical mass of the empirical formula.

$CH_2O = 12.0 + 1.0 + 1.0 + 16.0 = 30.0$

Then, divide the relative molecular mass by the relative empirical mass:

$$\frac{\text{relative molecular mass}}{\text{relative empirical mass}} = \frac{60.0}{30.0} = 2$$

The molecular formula is twice the empirical formula ($CH_2O$).

This gives the molecular formula as $C_2H_4O_2$.

**Examiner tip**

Even if the answer seems obvious to you, it is important to show all of your working. You will get marks for it, even if you make a mistake in your calculations.

## General formula

A **general formula** is the simplest algebraic formula for a member of a homologous series.

**Examples**

Alkanes: $C_nH_{2n+2}$.

| n | Molecular formula | Name |
|---|---|---|
| 1 | $CH_4$ | Methane |
| 2 | $C_2H_6$ | Ethane |
| 3 | $C_3H_8$ | Propane |
| 4 | $C_4H_{10}$ | Butane |

**Table 1** The alkanes

Alkenes: $C_nH_{2n}$.

| n | Molecular formula | Name |
|---|---|---|
| 1 | – | – |
| 2 | $C_2H_4$ | Ethene |
| 3 | $C_3H_6$ | Propene |
| 4 | $C_4H_8$ | Butene |

**Table 2** The alkenes

Alcohols: $C_nH_{2n+1}OH$.

| n | Molecular formula | Name |
|---|---|---|
| 1 | $CH_3OH$ | Methanol |
| 2 | $C_2H_5OH$ | Ethanol |
| 3 | $C_3H_7OH$ | Propanol |
| 4 | $C_4H_9OH$ | Butanol |

**Table 3** The alcohols

## Displayed formula

A **displayed formula** shows the relative positioning of all the atoms in a molecule, and the bonds between them.

**Examples**

Butane has the molecular formula $C_4H_{10}$. Its displayed formula is shown in Figure 1.

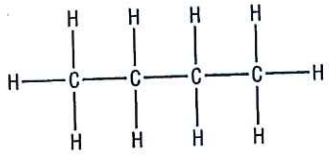


**Figure 1** Butane

Propan-2-ol has the molecular formula $C_3H_8O$. Its displayed formula is shown in Figure 2.

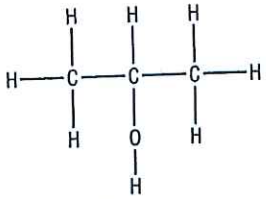


**Figure 2** Propan-2-ol

**Key definitions**

A **general formula** is the simplest algebraic formula of a member of a homologous series. For example, the general formula of the alkanes is $C_nH_{2n+2}$.

A **displayed formula** shows the relative positioning of all the atoms in a molecule and the bonds between them.

**Examiner tip**

When drawing the full displayed formula of a compound, you must remember to draw *all* atoms and *all* bonds, even those between the oxygen and hydrogen in an alcohol group.

15 marks

## Questions

1 A molecule contains 12.79% C, 2.15% H and 85.06% Br. The molecule has a relative molecular mass of 187.9.
   (a) Find the empirical and molecular formula.
   (b) Draw a possible displayed formula for the molecule.

2 What is the molecular formula for $n=5$ to $n=8$ for
   (a) the alkenes?
   (b) the alcohols?

3 Allicin is a powerful medicinal compound formed from garlic. Allicin has the following composition by mass: C, 40.66%; H, 6.26%; N, 7.90%; O, 27.08%; S, 18.10%. Allicin has a relative molecular mass of 177.1.
   (a) Determine the empirical formula of allicin.
   (b) Show that the molecular formula of allicin is the same as its empirical formula.

SECTION TWO – TOPIC 11

# 2.1 5 Structural and skeletal formula

**By the end of this spread, you should be able to . . .**

- **Understand and use the term structural formula.**
- **Understand and use the term skeletal formula.**

## Structural formula

**Key definition**

A structural formula shows the minimal detail for the arrangement of atoms in a molecule.

A **structural formula** shows the minimal detail for the arrangement of atoms in a molecule.

- This is a shorthand form of writing the displayed formula (see spread 2.1.4), with no bonds between atoms.

**Example 1**

The displayed and structural formulae for propane and 1-bromopropane are shown in Figure 1.

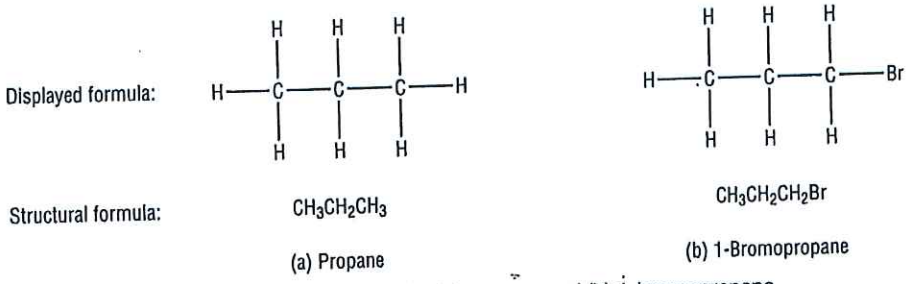



**Figure 1** Displayed and structural formulae for (a) propane and (b) 1-bromopropane

**Example 2**

The displayed and structural formulae for decanoic acid, $C_{10}H_{20}O_2$, are shown in Figure 2.

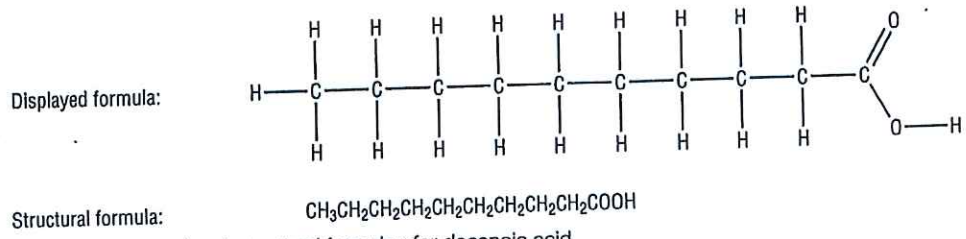



**Figure 2** Displayed and structural formulae for decanoic acid

The structural formula can be further simplified by collecting all the $CH_2$ groups together. The formula can then be represented using brackets.

- The structural formula for decanoic acid then becomes: $CH_3(CH_2)_8COOH$.

## Skeletal formula

**Key definition**

A skeletal formula is a simplified organic formula, with hydrogen atoms removed from alkyl chains, leaving just a carbon skeleton and associated functional groups.

A **skeletal formula** is a simplified organic formula, with the hydrogen atoms removed from the alkyl chains. This leaves just a carbon skeleton with associated functional groups. The displayed and skeletal formulae for hexane are shown in Figure 3.

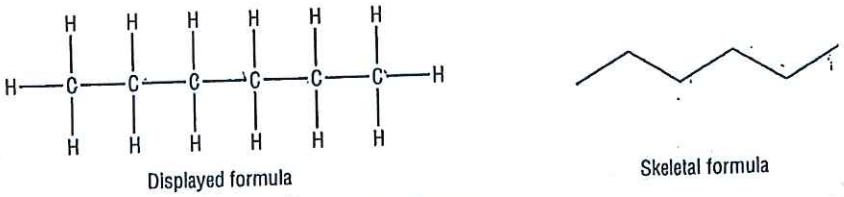



**Figure 3** Displayed and skeletal formulae of hexane

### Saturated hydrocarbons

The displayed, structural and skeletal formulae for pentane and 3-methylpentane are shown in Figure 4.

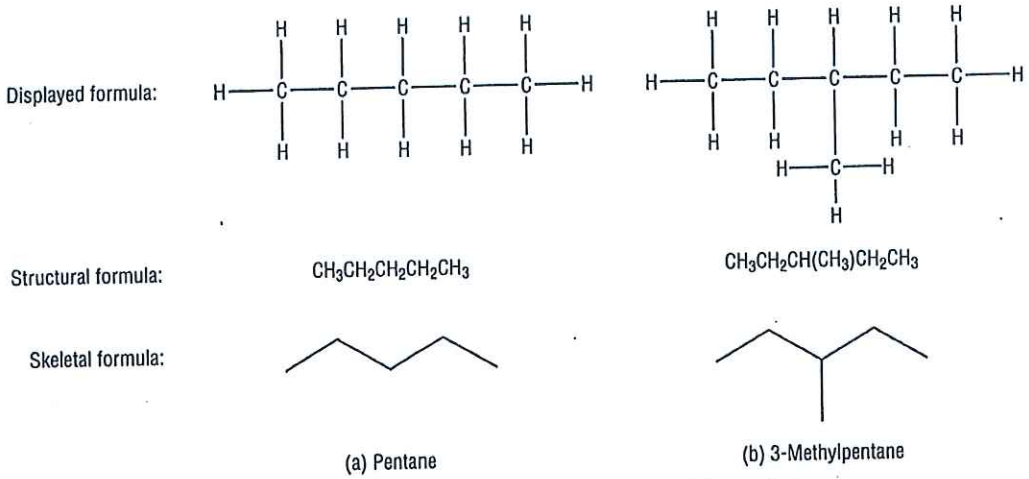



**Figure 4** Displayed, structural and skeletal formulae for (a) pentane and (b) 3-methylpentane

For a skeletal formula of a hydrocarbon:

- note that *no* carbon or hydrogen atoms are shown.
- there is a carbon atom at *each end* of the chain.
- there is a carbon atom at each point where two lines *meet*.

### Cyclic compounds

When you need to draw a cycloalkane or cycloalkene, you usually represent the compound as a *skeletal* formula rather than as a displayed one. The displayed and skeletal formulae for cyclopentane and cyclohexene are shown in Figure 5.

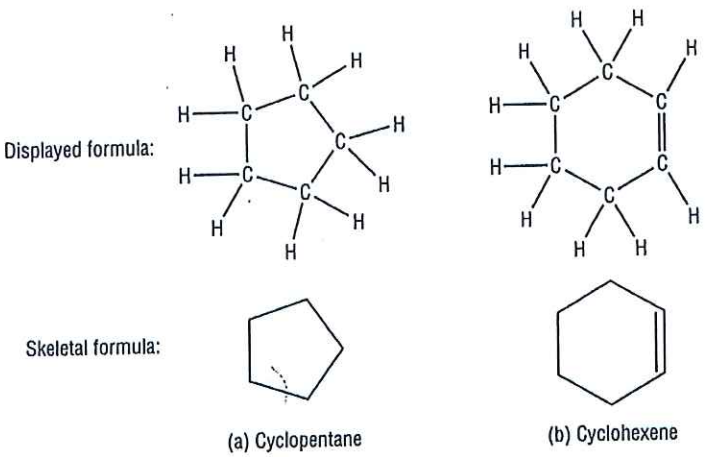



**Figure 5** Displayed and skeletal formulae for (a) cyclopentane and (b) cyclohexene

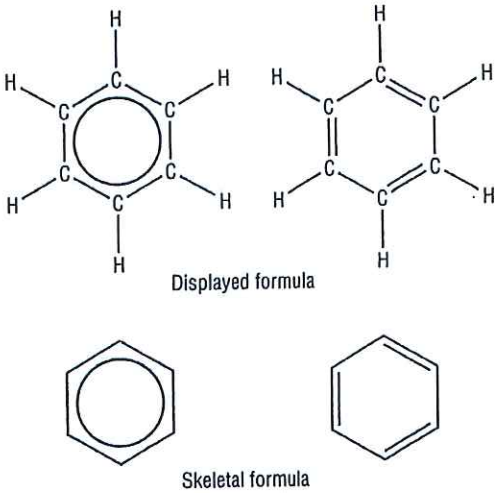



**Figure 6** Aromatic hydrocarbons. Benzene, $C_6H_6$, is an aromatic hydrocarbon. The structure of benzene is shown in different ways, and some of these are shown above. You will learn about aromatic compounds in detail during A2 Chemistry.

## Questions

1 Draw the skeletal formula for:
(a) hexane; (b) 4-methylnonane; (c) cyclobutane.

2 Show the structural formula for:
(a) octane; (b) 2,3-dimethylhexane.

3 Draw the skeletal formula for:
(a) methylcyclohexane; (b) cyclopentene; (c) methylbenzene.

SECTION TWO – TOPIC 12

# 2.1 (6) Skeletal formulae and functional groups

**By the end of this spread, you should be able to . . .**

- **Draw skeletal formulae for simple molecules containing functional groups.**
- **Draw and interpret the skeletal formula for complex molecules.**

## Unsaturated hydrocarbons

Pent-2-ene can be represented by the skeletal formula shown in Figure 1.

**Figure 1** Skeletal formula for pent-2-ene

- The double bond is shown between carbon-2 and carbon-3.
- When drawing skeletal formulae for alkenes, two parallel lines are used to repres the double bond.

## Compounds with functional groups

When functional groups are present, they must be included in the skeletal formula. Butan-2-ol has the structural formula: $CH_3CH(OH)CH_2CH_3$.

The skeletal formula for butan-2-ol is shown in Figure 2.

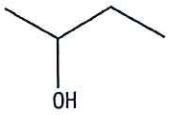



**Figure 2** Skeletal formula for butan-2-ol

- There are four carbon atoms in the main chain.
- There is an –OH group on carbon-2.
- The hydrogen on the –OH is shown, as it is part of the functional group.

Pentanoic acid has the structural formula: $CH_3CH_2CH_2CH_2COOH$ or $CH_3(CH_2)_3CO$
The skeletal formula for pentanoic acid is shown in Figure 3.

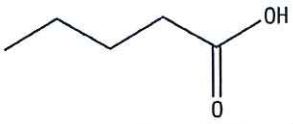



**Figure 3** Skeletal formula for pentanoic acid

- There are five carbon atoms in the main chain.
- Carbon-1 is part of a –COOH group.
- The hydrogen on the –OH is shown, as it is part of the functional group.

## More complex structures

During your AS and A2 course, you will come across some more complex structures for organic compounds. These are usually drawn in skeletal form. The skeletal formulae for paracetamol, retinol and salbutamol are shown below.

These compounds are all used as medicinal drugs.

- Paracetamol is used for pain relief.
- Retinol is used to treat acne.
- Salbutamol is used to treat asthma.

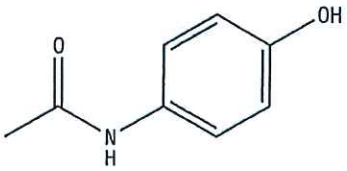



**Figure 4** Paracetamol

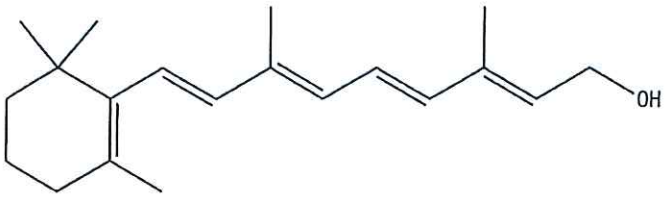



**Figure 5** Retinol, vitamin A

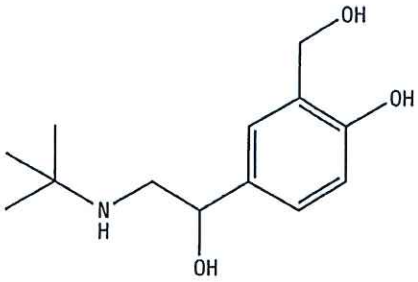



**Figure 6** Salbutamol

Notice that all these names end in -ol, used by chemists to indicate an –OH group.

## Questions

13 marks

1 Draw the skeletal formula for $CH_3CH_2CH_2CH_2CH_2CH_2OH$.

2 A molecule has the following skeletal formula.


**Figure 7**

   (a) Deduce the empirical, molecular and structural formulae.
   (b) Draw a displayed formula, showing *all* atoms and bonds.
   (c) Name the compound.

3 A compound has the following skeletal formula.

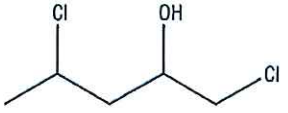



**Figure 8**

   (a) Name the compound.
   (b) Draw the displayed formula of the compound, showing all atoms and bonds.
   (c) What is the molecular formula and molecular mass of the compound?

4 Two compounds, A and B have the same molecular formula but different structural formulae. Compound A has the structural formula $CH_3(CH_2)_3OH$ and compound B has the structural formula $CH_3CH(OH)CH_2CH_3$.
   (a) Name compounds A and B.
   (b) Draw the skeletal formulae for compounds A and B.