EDEXCEL INTERNATIONAL AS/A LEVEL

CHEMISTRY

Student Book 1

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TOPIC 4 INTRODUCTORY ORGANIC CHEMISTRY AND ALKANES

CHAPTER 4.A INTRODUCTION TO ORGANIC CHEMISTRY

Organic chemistry is one of the three traditional branches of chemistry (together with physical chemistry and inorganic chemistry). Students of biology will understand the importance of organic chemistry because most types of compounds in this topic are found in, or are formed in, plants and animals, including the human body.

Many aspects of our lives have been revolutionised by the production of new organic compounds, for example new polymers with special properties, more effective drugs to treat diseases, the ongoing search for new antibiotics and sustainable fuels to replace fossil fuels.

Fertilisers and pesticides have increased crop yields to feed the world's growing population. This is an example of how the application of the knowledge of chemistry can cause unforeseen problems. Some people prefer food grown naturally, without the use of man-made chemicals – ironically these foods are often described as 'organic'!

In this topic, you will learn about the basics of organic chemistry, such as:

- **homologous series** *(compounds that are very similar to each other)*
- **nomenclature** *(a systematic way of naming organic compounds)*
- **isomerism** *(two or more compounds that have the same molecular formula but are not the same)*

You will then look at simple hydrocarbons called alkanes, including how they are used as fuels.

MATHS SKILLS FOR THIS TOPIC

- Use ratios to construct and balance equations
- Represent chemical structures using angles and shapes in 2D and 3D structures

What prior knowledge do I need?

- The names of simple organic compounds
- Homologous series and general formula
- Calculation of empirical and molecular formulae
- Representing organic compounds by structural formulae

What will I study in this topic?

- Using different types of formulae to represent organic compounds
- Structural isomerism
- Problems caused by the combustion of fuels, and solutions to these problems
- Using reaction mechanisms to understand how organic reactions occur
- The formation of polymers and dealing with polymer waste

What will I study later?

- Optical isomerism (A level)
- Reactions of carbonyl and carboxyl compounds (A level)
- The type of bonding in benzene and other aromatic compounds (A level)
- Condensation polymers (A level)
- Nitrogen-containing compounds, including amino acids and proteins (A level)
- Planning reaction schemes to prepare organic compounds (A level)
- More practical techniques for preparing and purifying organic compounds (A level)

4.A 1 WHAT IS ORGANIC CHEMISTRY?

SPECIFICATION REFERENCE 4.9

LEARNING OBJECTIVES

- Understand that alkanes and cycloalkanes are saturated hydrocarbons.

fig A Friedrich Wöhler was a German chemistry professor and an early pioneer in the field of organic chemistry. He is well known for making urea (an organic compound) starting only from inorganic compounds.

EARLY DAYS

Since the 1800s, our knowledge and understanding of chemistry has grown rapidly. To help understanding of all this knowledge, chemists divided chemistry into three main categories: inorganic, organic and physical chemistry. Each category is equally important. There are millions of different compounds in existence, and the vast majority are organic compounds. So, what is organic chemistry?

Today, the word 'organic' has a very different meaning in everyday life, and it is often applied to farming and food. In 1800s, people believed that there was something special about some substances – that they were only made in plants or animals. One example is the compound called urea, which is present in human urine. People used to believe that it could only be produced in the human body. In 1828, the German chemist Friedrich Wöhler discovered that urea could be made by heating a compound (ammonium cyanate) that was not organic. This meant that the idea of organic compounds only coming from living things was incorrect.

HYDROCARBONS

The main feature of an organic compound is that it contains carbon. Almost all of these compounds also contain hydrogen. Some of the most important compounds contain elements such as nitrogen and oxygen. In this section, we look at some of the large numbers of compounds that contain only carbon and hydrogen. These are called **hydrocarbons**.

If an organic compound contains other elements as well as carbon and hydrogen, then it is not a hydrocarbon. For example, many foods contain a sugar called sucrose. Sucrose contains carbon and hydrogen, but also oxygen, so it is not a hydrocarbon. It is an example of a carbohydrate – the *-ate* ending shows that it contains oxygen.

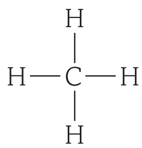
fig B Scientists still work to make new organic compounds.

SATURATED OR UNSATURATED?

Although there are many thousands of different hydrocarbons, most of them are classed as **saturated** or **unsaturated**. As with many chemical terms, these words have a very different meaning in everyday life. If you are caught in a heavy rain shower, you may say that your clothes are saturated, which means that they cannot absorb any more water.

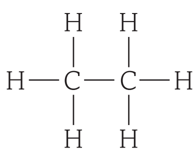
In organic chemistry, the terms 'saturated' or 'unsaturated' have nothing to do with water, although there is a connection. A hydrocarbon that is saturated contains as much hydrogen as possible, which depends on the number of carbon atoms in the molecule. If a hydrocarbon has fewer than the maximum possible number of hydrogen atoms, it is not saturated – we say it is unsaturated.

The formula of the simplest hydrocarbon, containing only one carbon atom, is:

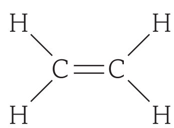


When a hydrocarbon contains two carbon atoms, there is a maximum of six hydrogen atoms.

There is a hydrocarbon that contains two carbon atoms and six hydrogen atoms, but also one that contains two carbon atoms and only four hydrogen atoms. The formulae of these hydrocarbons are:



saturated



unsaturated

You can see that in all three examples, each carbon atom has four bonds to other atoms. This is a general rule for organic compounds – in most cases, every carbon atom has four bonds.

The difference between a saturated hydrocarbon and an unsaturated hydrocarbon is to do with whether there is room, or not, for more hydrogen atoms.

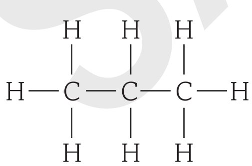
- If there is no room, then the hydrocarbon is saturated.
- If there is room, then the hydrocarbon is unsaturated.

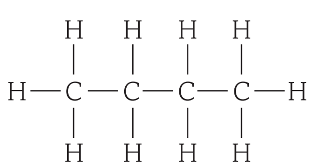
One easy way to decide whether a hydrocarbon is saturated or unsaturated is to look at structures like the ones above.

- If there are two bonds between the same carbon atoms (a double bond), the hydrocarbon is unsaturated.
- If there are only single bonds between the same carbon atoms, the hydrocarbon is saturated.

ALKANES AND CYCLOALKANES

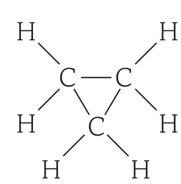
Look at the formulae below.

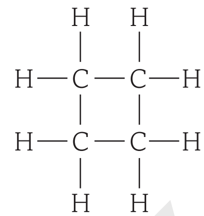




These are alkanes. Both structures have only single bonds. Therefore they are saturated.

Now look at these formulae below.





These are cycloalkanes. Both structures have only single bonds and so are saturated. They both have carbon atoms joined in a ring structure. The first has a triangular arrangement and the second has a square arrangement. These ring structures mean that they are cyclic compounds. We will look at alkanes and cycloalkanes in more detail in **Chapter 4.B**.

LEARNING TIP

The formulae of the hydrocarbons in this section show every bond and every atom. These formulae can also be written as molecular formulae – the first one can be written as CH_4. Try writing molecular formulae for the other hydrocarbons shown in this section.

CHECKPOINT

1 A saturated hydrocarbon contains five carbon atoms in its molecule. What are the two possible molecular formulae for this hydrocarbon?

2 Consider the compound with the formula $C_2H_4O_2$. Is it an organic compound? Explain your answer.

SUBJECT VOCABULARY

hydrocarbon a compound that contains only carbon and hydrogen atoms

multiple bond is two or more covalent bonds between two atoms

a saturated compound contains only single bonds.

an unsaturated compound contains one or more multiple bonds

4.A 2 DIFFERENT TYPES OF FORMULAE

SPECIFICATION REFERENCE
4.5ii

LEARNING OBJECTIVES

- Draw compounds using structural, displayed and skeletal formulae.

EXAM HINT

If an exam question asks for a particular type of formula in an answer, it is important that you use the types of formula requested. If the question asks for a displayed formula, you will not gain full marks if you provide a skeletal formula.

USING DIAGRAMS TO REFER TO ORGANIC COMPOUNDS

There are many millions of organic compounds. It can be challenging to be clear about which compounds we are referring to.

There are two main ways to refer to organic compounds. We can use:

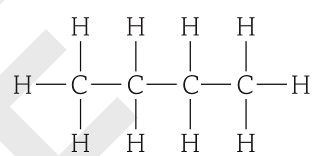
- formulae
- names.

In this section we will consider how to refer to organic compounds using formulae. The visual representation of some formula are like diagrams.

DISPLAYED FORMULAE

The formulae you saw in the **Chapter 4.A** are all **displayed formulae** – they show (display) every atom and every bond separately. In many situations, these are the best type of formulae to use, but sometimes it is better to simplify them.

Consider the hydrocarbon with this displayed formula (its name is butane):



STRUCTURAL FORMULAE

One way to simplify this displayed formula is to group all the atoms joined to a particular carbon atom together. We can choose to show the bonds between the carbons, or we can leave them out. These are both **structural formulae** of butane:

$$CH_3{-}CH_2{-}CH_2{-}CH_3 \quad \text{and} \quad CH_3CH_2CH_2CH_3$$

SKELETAL FORMULAE

Another way to represent a compound is by a **skeletal formula**. The word skeletal is connected with the word skeleton, which, as you know, shows only the bones in a human body.

A skeletal formula is a zig-zag line that shows only the bonds between the carbon atoms. Every change in direction and every ending means that there is a carbon atom (with as many hydrogen atoms as needed). Atoms other than carbon and hydrogen need to be shown.

This is the skeletal formula of butane:

The start and end both represent CH_3, and the two junctions between lines each represent CH_2.

MOLECULAR FORMULAE

The displayed, structural and skeletal formulae above show the structures of the molecules unambiguously. In other words, each formula represents only one compound. With a displayed formula, this is very clear. With a structural formula, you have to imagine how the atoms are joined together in groups such as CH_2 and CH_3, but that is very straightforward. With a skeletal formula, once you know the rules, you can be sure how every atom is arranged in the molecule.

Now consider the formula C_3H_7Cl. This is clearly not a displayed formula or a skeletal formula, but it is also not a structural formula. This is because, with three carbon atoms, the chlorine atom could be attached to the middle carbon atom or to either of the end carbon atoms. The formula C_3H_7Cl actually represents two different compounds.

Formulae like this are called **molecular formulae** – they only show the numbers of each type of atom in the molecule, and not its structure. Of course, in very simple molecules such as CH_3Cl, the molecular formula can be used to work out the displayed, structural and skeletal formulae because there is only one way in which these five atoms can be joined together.

EMPIRICAL FORMULAE

Another type of formula is an **empirical formula**. This shows the compound like a molecular formula, but the numbers of each atom are in their simplest possible whole-number ratio. So, butane (molecular formula C_4H_{10}) has an empirical formula of C_2H_5.

In chemistry, the word empirical usually means 'as found from practical evidence'. You would normally work out this type of formula mathematically from the results of an experiment.

DIFFERENT TYPES OF FORMULA FOR CHLOROETHANE

So far, we have only considered the different types of formula using a hydrocarbon as the example.

Consider an example containing a third element – chloroethane. The table shows its different types of formula.

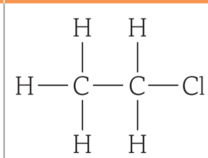
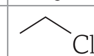
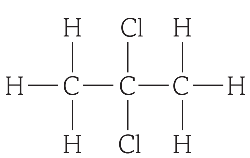
TYPE OF FORMULA	FORMULA
displayed formula	
structural formula	$CH_3{-}CH_2{-}Cl$ or CH_3CH_2Cl
skeletal formula	
molecular formula	C_2H_5Cl
empirical formula	C_2H_5Cl

table A Different types of formula for chloroethane.

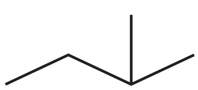
CHECKPOINT

1 The displayed formula of a compound is:



Use a table (like the one for chloroethane) to show its structural, skeletal, molecular and empirical formulae.

2 The skeletal formula of a compound is:



Use a table (like the one for chloroethane) to show its displayed, structural, molecular and empirical formulae.

SUBJECT VOCABULARY

displayed formula a formula which shows every atom and every bond
structural formula a formula which shows (unambiguously) how the atoms are joined together
skeletal formula a formula which shows all the bonds between carbon atoms
molecular formula a formula which shows the actual numbers of each atom in the molecule
empirical formula a formula which shows the numbers of each atom in the simplest whole-number ratio

LEARNING TIP

For some compounds, the numbers in the molecular formula cannot be simplified – this means that the molecular formula and the empirical formula are identical.

4.A

3 FUNCTIONAL GROUPS AND HOMOLOGOUS SERIES

SPECIFICATION REFERENCE 4.4

LEARNING OBJECTIVES

- Understand the concepts of 'homologous series' and 'functional group'.

FUNCTIONAL GROUP

A **functional group** in a molecule is an atom or group of atoms that gives the compound some distinctive and predictable properties. For example, the functional group of atoms shown as COOH gives molecules containing this group a sour, acidic taste.

There are many organic compounds containing this group. Here are some examples:

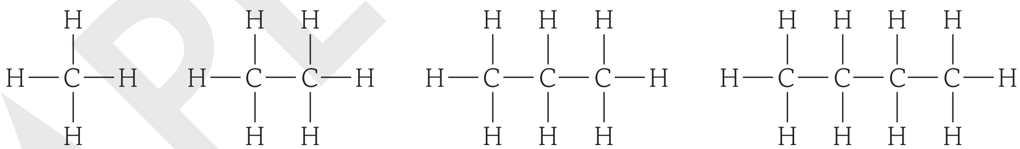
$HCOOH$ CH_3COOH CH_3CH_2COOH $CH_3CH_2CH_2COOH$

HOMOLOGOUS SERIES

If you look at the formulae above, you can see that each formula has one more carbon atom and two more hydrogen atoms than the previous one – they differ by CH_2. These compounds are the first four members of what is called a **homologous series**. This is a set of compounds with the same functional group, similar chemical properties and physical properties that show a gradation (a gradual change from one to the next).

ALKANES

The organic compounds that are mainly used as fuels are the alkanes (you will learn more about alkanes in **Chapter 4.B**). They are not considered to contain a functional group, but otherwise they form a homologous series. The displayed formulae of some of them are:



GENERAL FORMULAE

In **Section 4.A.2** we looked at five different types of formulae. Now we are going to look at another type of formula. For the compounds in a homologous series, we can use a general formula to represent all of them. This is done by using the letter n for the number of carbon atoms, excluding any in the functional group. For the compounds with formulae ending in COOH, the general formula is $C_nH_{2n+1}COOH$.

Table A shows some of the homologous series in this book.

NAME	GENERAL FORMULA	EXAMPLE
alkane	C_nH_{2n+2}	CH_4
alkene	C_nH_{2n}	C_2H_4
halogenoalkane	$C_nH_{2n+1}X$	CH_3CH_2Br
alcohol	$C_nH_{2n+1}OH$	CH_3CH_2OH

table A Examples of homologous series used in this book.

PROPERTIES OF A HOMOLOGOUS SERIES

ALKANES

We can use the alkanes to illustrate the similarity in chemical properties of a homologous series. For example, when alkanes are burned completely in air, they all form the same two products: carbon dioxide and water.

The commonest alkane is methane. The equation for its complete combustion is:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

ALCOHOLS

We can use the alcohols to illustrate the gradation in physical properties of a homologous series. For example, the boiling temperatures of the first four alcohols are shown in **Table B**.

FORMULA	BOILING TEMPERATURE / °C
CH_3OH	65
CH_3CH_2OH	79
$CH_3CH_2CH_2OH$	97
$CH_3CH_2CH_2CH_2OH$	117

table B You can see that as the number of carbon and hydrogen atoms increases, so does the boiling temperature.

EXAM HINT

An exam question may ask you to plot the boiling point of organic compounds (such as alcohols) with carbon number on the *x* axis. Be sure to use a suitable scale and suitable axes.

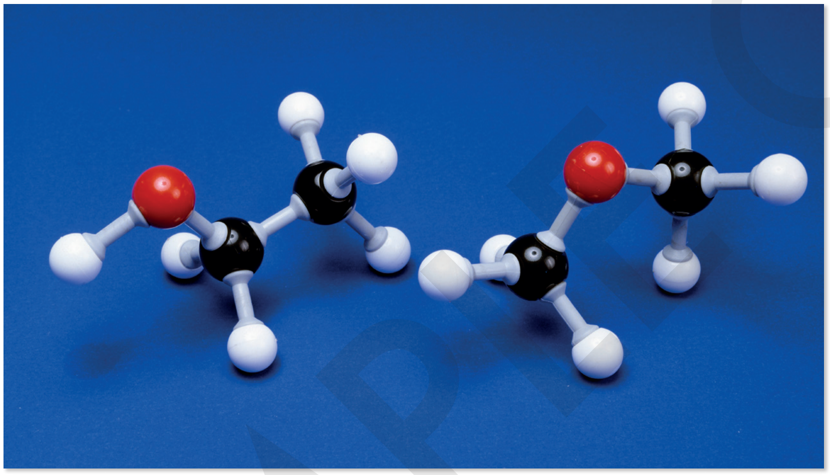


fig A Molecular models are very useful in organic chemistry. Both of these structures contain an oxygen atom (shown in red), but you can see that they belong to different homologous series.

LEARNING TIP

Remember that different elements are represented by different colours. The colours normally used in molecular models are black for carbon, white for hydrogen and red for oxygen.

CHECKPOINT

1 The equation for the complete combustion of propane is:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

What is the equation for the complete combustion of the alkane with five carbon atoms in its molecule?

2 The structural formula of a compound is CH_3CH_2CHO. What are the formulae of the two simpler compounds in the same homologous series?

SUBJECT VOCABULARY

functional group an atom or group of atoms in a molecule that is responsible for its chemical reactions

homologous series a family of compounds with the same functional group, which differ in formula by CH_2 from the next member

4.A 4 NOMENCLATURE

SPECIFICATION REFERENCE 4.5i

LEARNING OBJECTIVES

- Apply the rules of IUPAC nomenclature to name compounds relevant in the exam.

WHY DO WE NEED RULES TO NAME ORGANIC COMPOUNDS?

As the number of known organic compounds has increased, it has become harder to continue to find new names for them. In **Section 4.A.3**, we referred to the simplest organic compound (CH_4) as methane. In fact, this compound was originally known as marsh gas (because it was found in marshes when plants decayed). Many other organic compounds were named in similar ways.

International Union of Pure and Applied Chemistry is an organisation which has made rules about how to name organic compounds. The organisation's name is usually abbreviated to IUPAC ('eye-you-pack'). These rules create a system which is often known as 'nomenclature'. The detailed rules needed for naming very complicated compounds are complex, but the simpler rules for the compounds described in this book are much easier to understand and apply.

THE SIMPLE RULES OF NOMENCLATURE

Table A summarises the principles of naming organic compounds, including rules for **prefixes**, **suffixes** and **locants**.

THE PART OF THE NAME	HOW TO WRITE IT	EXAMPLE
Number of carbon atoms	This is shown by using a letter code (usually 3 or 4 letters).	meth = one carbon atom
Prefixes Suffixes	The presence of atoms other than carbon and hydrogen is shown by adding other letters before or after the code for the number of carbon atoms.	bromo = an atom of bromine ol = a hydroxyl group (OH)
Multiplying prefixes	The presence of two or more identical groups is shown by using the prefixes di-, tri-, etc.	di = two
Locants	Where atoms and groups can have different positions in a molecule, numbers and hyphens are used to show their positions. The numbers represent the carbon atoms in the longest chain that the atoms and groups are attached to.	2- = the atom or group is attached to the second carbon atom in the chain

table A The principles of naming organic compounds.

The letter codes for the number of carbon atoms (up to ten) are:

NUMBER	CODE	PREFIX
1	meth	methyl
2	eth	ethyl
3	prop	propyl
4	but	butyl
5	pent	pentyl

NUMBER	CODE	PREFIX
6	hex	hexyl
7	hept	heptyl
8	oct	octyl
9	non	nonyl
10	dec	decyl

APPLYING IUPAC RULES TO WRITE NAMES OF COMPOUNDS

ALKANES

We can see how these rules work for some of the alkanes. The names of all the alkanes end in *-ane*.

STRUCTURAL FORMULA	NAME
$CH_3—CH_2—CH_3$	propane
$CH_3—CH—CH_3$ | CH_3	methylpropane The locant 2- is not needed because if the methyl group below the horizontal chain were attached to one of the carbon atoms at either end of the chain, then there would be a sequence of four carbon atoms, and the compound would be named butane.
$CH_3—CH_2—CH—CH_2—CH_3$ | CH_3	3-methylpentane The longest carbon chain contains five carbon atoms, and there is a methyl group attached to the third one.
$CH_3—CH_2—CH_2—CH—CH_3$ | CH_3	2-methylpentane This is not 4-methylpentane because another rule is that the lowest locant numbers should be used.
CH_3 | $CH_3—CH—CH—CH_3$ | CH_3	2,3-dimethylbutane This example shows the use of a comma between the locants when the attached groups are the same.
$CH_2—CH_3$ | $CH_3—CH_2—CH—CH—CH_3$ | CH_3	3-ethyl-2-methylpentane This example illustrates the rule about prefixes being in alphabetical order. Ethyl comes before methyl because e comes before m in the alphabet. Notice also that it is not called 3-ethyl-4-methylpentane because these numbers (3 + 4) total more than the numbers 3 + 2 in the correct name.

table B Naming alkanes from structural formulae using the rules of IUPAC nomenclature.

ALCOHOLS

Next, look at the alcoholsin **Table C**. The rules for these are a bit different because the presence of the alcohol functional group is indicated by a suffix, not a prefix.

The names for all the alcohols end in -ol.

STRUCTURAL FORMULA	NAME
$CH_3—CH_2—OH$	ethanol
$CH_3—CH_2—CH_2—OH$	propan-1-ol This time, the locant appears near the end of the name, but, as before, it appears directly before the letters representing the group.
$CH_3—CH—CH—CH_3$ | | OH CH_3	3-methylbutan-2-ol This example illustrates the use of both a prefix and a suffix. This is not called 2-methylbutan-3-ol the lowest number locant should be used for the suffix functional group (-2-ol not -3-ol).
CH_3 | $CH_3—C—CH_2—CH_2—OH$ | CH_3	3,3-dimethylbutan-1-ol This example shows the use of prefixes, a suffix, locants and a comma! As with alkanes, the name uses locants that add up to the smallest possible number.

table C Naming alcohols from structural formulae using the rules of IUPAC nomenclature.

APPLYING THE RULES TO WRITE FORMULAE

Here are some examples of applying the rules to write a structural formula for a compound from its IUPAC name.

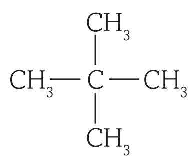
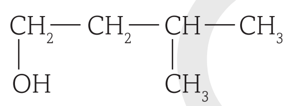
NAME	STRUCTURAL FORMULA
dimethylpropane	prop indicates a chain of three carbon atoms dimethyl indicates two methyl groups attached to the chain No locants are needed, so the two methyl groups must be attached to the carbon chain in a way that does not make the longest carbon chain any longer than three carbon atoms. So the structural formula is: 
3-methylbutan-1-ol	but indicates a chain of four carbon atoms methyl indicates a CH_3 group *1*- and *3*- indicate attachments to the first and third carbon atoms in the chain. So the structural formula is: 

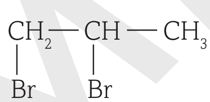
table D Writing structural formulae from IUPAC names.

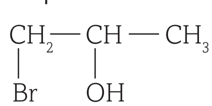
LEARNING TIP

When you practise writing names from structural formulae, always check that the code you have used for the longest carbon chain is for the longest chain. This may not be the one shown horizontally. When you practise writing structural formulae from names, always check that each carbon has only four bonds. Showing three or five bonds is a common error.

CHECKPOINT

1 Write IUPAC names for the compounds with these structural formulae.





2 Write structural formulae for the compounds with these IUPAC names.

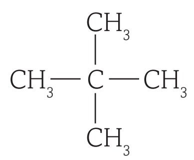
2,2-dimethylpentane 2,3-dimethylbutan-2-ol

SUBJECT VOCABULARY

locant a number used to indicate which carbon atom in the chain an atom or group is attached to
prefix a set of letters written at the beginning of a name
suffix a set of letters written at the end of a name

4.A EXAM PRACTICE

1 An organic compound is shown by this formula:



What type of formula is this?

A displayed formula
B general formula
C molecular formula
D structural formula

[1]

[Total: 1]

2 Which statement is correct for the members of a homologous series?

A They have similar boiling points.
B Their molecular formulae differ by CH_3.
C They contain the same functional group.
D Their chemical properties are different.

[1]

[Total: 1]

3 What is the IUPAC name for this compound?

A 3,4-dichlorobutene
B 1,2-dichlorobutane
C 3,4-dichlorobutane
D 1,2-dichlorobutene

[1]

[Total: 1]

4 Which fuel is carbon-neutral?

A ethanol
B natural gas
C petrol
D wood

[1]

[Total: 1]

5 Which equation represents a substitution reaction?

A $C_2H_4 + H_2O \rightarrow C_2H_5OH$
B $C_2H_4 + Br_2 \rightarrow C_2H_4Br_2$
C $C_2H_6 + F_2 \rightarrow C_2H_5F + HF$
D $C_2H_6 \rightarrow C_2H_4 + H_2$

[1]

[Total: 1]

6 Which equation represents a substitution reaction?

A ·CH2Cl + Cl· → CH2Cl2
B H· + Cl· → HCl
C $\cdot CH_3 + Cl_2 \rightarrow CH_3Cl + Cl\cdot$
D $CH_3Cl + Cl_2 \rightarrow CH_2Cl_2 + HCl$

[1]

[Total: 1]

7 The table lists the boiling temperatures of some alkanes.

Alkane	Molecular formula	Boiling temperature/K
butane	C_4H_{10}	273
pentane	C_5H_{12}	309
hexane	C_6H_{14}	342
heptane	C_7H_{16}	372
octane		399
nonane	C_9H_{20}	
decane	$C_{10}H_{22}$	447

(a) Give the molecular formula of octane. [1]

(b) (i) Explain the trend in boiling temperature of the alkanes. [2]

(ii) Predict a value for the boiling temperature of nonane. [1]

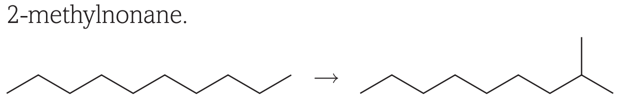
(c) Long chain alkanes, such as decane, can be cracked into shorter chain alkanes and alkenes.

(i) Write an equation for the cracking of decane into octane and ethene. [1]

(ii) The ethene produced can be converted into ethanol by direct hydration with steam.
Write an equation for this reaction and state the conditions that are used in industry. [4]

(d) Reforming is a process used in the production of petrol. Unbranched-chain alkanes can be reformed to produce either branched-chain alkanes or cycloalkanes.

The equation shows the reforming of decane into 2-methylnonane.



(i) Using skeletal formulae, write an equation for the reforming of decane into 2,3-dimethyloctane. [1]

(ii) Using skeletal formulae, write an equation for the reforming of heptane into methylcyclohexane. [2]

(iii) State why reforming is used in the production of petrol. [1]

[Total: 13]

8 Compound **Y** is a hydrocarbon containing 85.7% of carbon by mass.

(a) (i) Calculate the empirical formula of **Y.** [2]

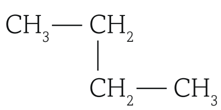
(ii) The molar mass of **Y** is 56 g mol^{-1}. Show that the molecular formula of **Y** is C_4H_8. [1]

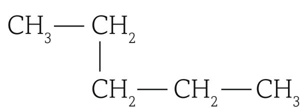
(b) There are six isomers for compound **Y**: four unsaturated molecules and two saturated molecules.

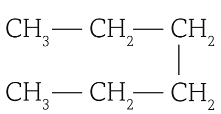
Draw a displayed formula for each of the five isomers and name each compound. [6]

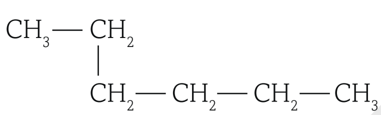
[Total: 9]

9 The structural formulae of four hydrocarbons, A, B, C and D, are shown.

A 

B 

C 

D 

(a) Identify the homologous series to which all these hydrocarbons belong.

Give a reason for your answer. [2]

(b) Explain which structural formulae represent only one compound. [2]

(c) Give the structural formulae for the two isomers of B.

Give the IUPAC name for each isomer. [4]

[Total: 8]

10 Halogenoalkanes undergo both substitution reactions with aqueous KOH and elimination reactions with ethanolic KOH.

(a) Draw the mechanism for the substitution reaction between 1-chlorobutane and aqueous potassium hydroxide. [3]

(b) Explain why substitution reactions are faster with 1-bromobutane than with 1-chlorobutane. [3]

(c) Which pair of chlorobutanes would both give a hydrocarbon of formula C_4H_6 when separately treated with hot ethanolic KOH? [1]

A $CH_3CH_2CH_2CH_2Cl$ and $CH_3CH_2CH_2CHCl_2$

B $CH_3CHClCHClCH_3$ and $ClCH_2CH_2CH_2CH_2Cl$

C $CH_3CH_2CH_2CH_2Cl$ and $ClCH_2CH_2CH_2CH_2Cl$

D $CH_3CH_2CH_2CH_2Cl$ and $CH_3CH_2CHClCH_3$

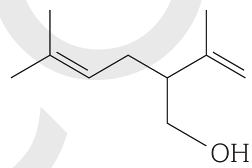
(d) Which chlorobutane is classified as a tertiary halogenoalkane? [1]

A $H_3CH_2CH_2CH_2Cl$ **B** $CH_3CH_2CHClCH_3$

C $(CH_3)_3CCl$ **D** $(CH_3)_2CHCH_2Cl$

[Total: 8]

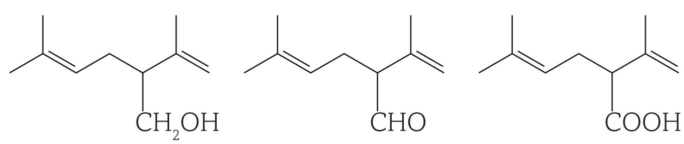
11 Lavandulol is a compound that is found in lavender oil. The skeletal formula of lavandulol is



(a) (i) Give the molecular formula of lavandulol. [1]

(ii) Give the names of the two functional groups that are present in lavandulol. [2]

(b) Lavandulol can be oxidised by acidified potassium dichromate(VI) solution to produce either compound **X** or compound **Y**.



lavandulol compound **X** compound **Y**

(i) State the conditions required to produce compound **X**. [2]

(ii) State the conditions required to produce compound **Y**. [2]

(iii) Describe a chemical test that could be performed to show that the compound formed was **X** and not **Y**. [2]

[Total: 9]

THINKING BIGGER

TOWARDS A GREENER ENVIRONMENT

SKILLS PROBLEM SOLVING, ANALYSIS, INTERPRETATION

The extract below considers examples of the roles of catalysts in the modern petroleum industry.

A JOURNAL ARTICLE

CATALYSTS FOR A GREEN INDUSTRY

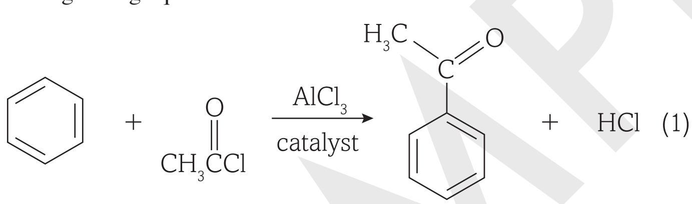
Important catalytic reactions

Today, the industrial world relies upon an enormous number of chemical reactions and an even greater number of catalysts. A selection of important reactions reveals the scope of modern catalysis and demonstrates how crucial it will be for chemists to achieve their environmental objectives.

A sacrifice: worst case catalyst

A sacrificial, or stoichiometric, catalyst is used once and discarded. The amount of waste produced is not insignificant since these catalysts are used in stoichiometric amounts. For example, the catalyst may typically be in a 1 : 1 mole ratio with the main reactant.

In the manufacture of anthraquinone for the dyestuffs industry, for example, aluminium chloride is the sacrificial catalyst in the initial step, the acylation of benzene, see **fig A**. This is a type of Friedel–Crafts reaction in which the spent catalyst is discarded along with waste from the process. Fresh catalyst is required for the next batch of reactants. The problem is that the aluminium chloride complexes strongly with the products, i.e. Cl–, forming $[AlCl_4]^-$ and cannot be economically recycled, resulting in large quantities of corrosive waste.



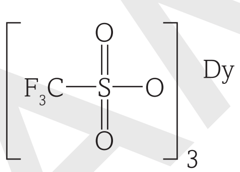


fig A Dysprosium trifluoromethane sulfonate.

New catalysts, with better environmental credentials, are now being tried out. Compounds, such as the highly acidic dysprosium(III) triflate (trifluoromethane sulfonate, see **fig A**) offer the possibility of breaking away from the sacrificial catalyst by enabling the catalyst to be recycled.

Low sulfur fuels: desulfurisation catalysis

Petroleum-derived fuels contain a small amount of sulfur. Unless removed this sulfur persists throughout the refining processes and ends up in the petrol or diesel. Pressure to decrease atmospheric sulfur has driven the development of catalytic desulfurisation. One of the problems was that much of the sulfur present was in compounds such as the thiophenes, which are stable and resistant to breakdown.

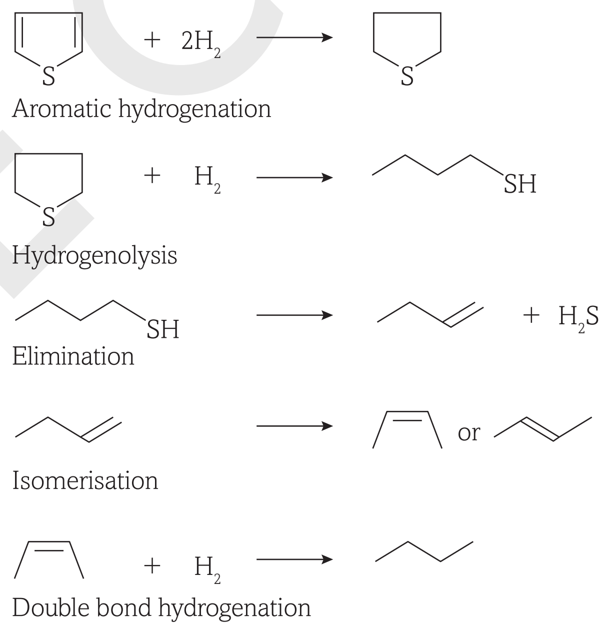


fig B Desulfurisation of thiophenic compounds from petroleum

The catalyst molybdenum disulfide coated on an alumina support provided one solution. Cobalt is added as a promoter, suggesting that the active site is a molybdenum-cobalt sulfide arrangement. In the catalytic reaction (see **fig B**), which is essentially a hydrogenation sequence, the adsorbed thiophene molecule is hydrogenated and its aromatic stability destroyed. This enables the C–S bond to break and release the sulfur as hydrogen sulfide. This is an interesting example of a catalyst performing different types of reactions: hydrogenation, elimination and isomerisation.

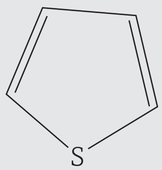
Based on an article in *Education in Chemistry* magazine, published by the Royal Society of Chemistry

SCIENCE COMMUNICATIONS

1 A lot of scientific literacy is required to read this extract. Imagine that you need to convince the general public that we must try to remove the sulfur from fuels although it is expensive. Design a pamphlet to present a strong argument.

CHEMISTRY IN DETAIL

2 a Work out the molecular formula of thiophene (shown below).



b Calculate the percentage by mass of sulfur in the molecule.

c Write a balanced equation for the complete combustion of thiophene. (You can assume the oxidised product of sulfur is SO_2 only.)

3 a During the elimination (**fig B**) part of the reaction sequence, butan-1-thiol is converted into two products. Name them.

b The isomerisation process gives rise to two stereo isomers. Explain what is meant by a geometric isomer and name both.

c Why can the double bond hydrogenation reaction be considered to have 100% atom economy?

SKILLS CONTINUOUS LEARNING, INTELLECTUAL INTEREST AND CURIOSITY

COMMUNICATION TIPS

Think about how illustrations can elicit very emotive responses. How might you use illustrations in your pamphlet?

THINKING BIGGER TIPS

In Chemistry, you will often need to make assumptions to help simplify calculations. In general these assumptions make little difference to the results and have a very small impact on the real world answers.

ACTIVITY

You may wonder why sulfur appears in fossil fuels at all! The chemistry of sulfur gives it some special properties. Apart from carbon, hydrogen. oxygen and nitrogen, it is the only other element present in amino acids, which are the building blocks of all proteins. Prepare a 5-minute presentation to the class about the importance of sulfur in proteins: Your presentation should include:

- which amino acids contain sulfur
- what properties of sulfur make it so important in protein structure
- what the consequences of a diet low in sulfur can be

SKILLS INITIATIVE, SELF DIRECTION

DID YOU KNOW?

Hydrogen sulfide (H_2S) is highly toxic. Luckily, most humans can detect it at concentrations of less than 0.5 parts per billion (or ppb; that's 1 molecule in 2×10^9 air molecules). H_2S smells like rotten eggs so we get plenty of warning before the potentially fatal concentration level of 800 000 ppb, which can be fatal, is reached.