Surfing

NATIONAL CHEMISTRY

Unit 4 Structure, Synthesis and Design

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Contents

Introduction

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

Words To Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Properties and Structure of Organic Materials

1 Organic Molecules

Organic chemistry is the chemistry of carbon and its compounds. Carbon is one of the most important elements on Earth as carbon compounds are an important constituent of living as well as non-living things.

Figure 1.1 Carbon fibre is used in car bodies.

Organic compounds make up over 80% of all known compounds and this does not include compounds such as carbon oxides and carbonates. Organic chemicals include the homologous series of alkanes and alkenes that you learned about in year 11 as well as many other groups of carbon compounds which are involved in everyday life such as alcohols, proteins, fats, carbohydrates, polymers and many more.

You will recall that alkanes and alkenes have functional groups (C–C for alkanes, C=C for alkenes). In this section you will be looking at more series of organic molecules that have other functional groups attached – the alcohols, carboxylic acids, esters, amines and amides. You will be seeing how the molecular structure of organic compounds and also the presence of functional groups are related to their properties. Later you will be looking at structures of proteins, carbohydrates and polymers.

The two scientists most influential in the initial development of carbon chemistry were a German chemist **August Kekulé** (1829-1896) and a Scottish chemist **Archibald Scott Couper** (1831-1892). Based on their observations of reactions, these two chemists independently developed a theory of how carbon formed bonds. They proposed that carbon was tetravalent (valency of 4) and described carbon atoms linking to each other, as well as to other atoms, and forming chains and rings.

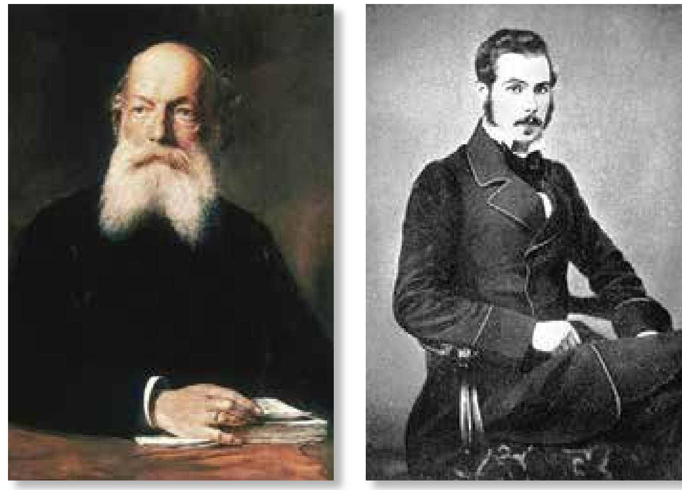


Figure 1.2 August Kekulé and Archibald Couper.

Their work represents the beginning of the concept of bonds between the elements in a compound, and they developed their ideas before anything was known about the attractions between atoms forming bonds.

Today the atomic model and models of bonding are used to explain the structure and properties of both elements and compounds. Models and theories of the structure of molecules have developed using evidence from a range of sources. And they can be used to explain and predict the properties of substances.

Data from analytical techniques such as mass spectrometry and crystallography have given us a deeper understanding of bonding and the chemical structure of carbon compounds and we classify organic molecules according to the functional groups that they contain. Conversely, if we know the formula of an organic compound then we can predict its chemical behaviour based on what we know about the behaviour of the functional groups it contains.

Functional groups

A **functional group** is a specific group of atoms, within a molecule, that is responsible for the chemical reactions of that molecule.

Functional groups are attached to the hydrocarbon 'backbone' of organic molecules. Figure 1.3 gives some examples of functional groups in organic compounds. You need to learn these.

The hydrocarbon backbone of organic compounds is represented by R in general formulas. An R can be added to the functional groups to indicate the position of any attached hydrocarbon chain. If there is more than one hydrocarbon chain, the chains are shown as R^1, R^2, R^3. Alternatively dashes may be used, e.g. R′, R″, R‴.

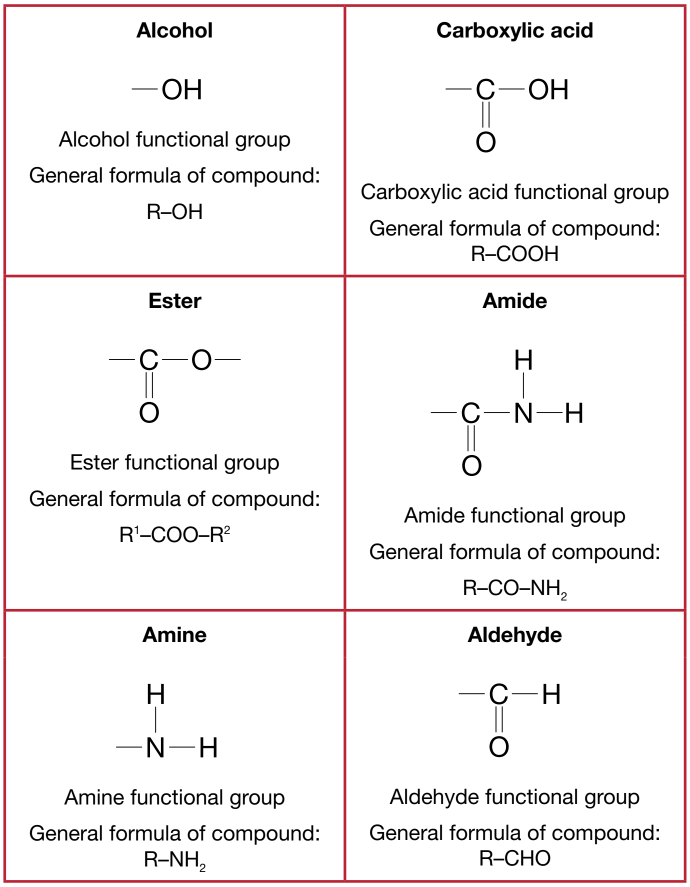


Figure 1.3 Functional groups.

Homologous series

A group of compounds with all members having the same functional group attached is called an **homologous series**. And we can write a general formula for each series.

In year 11 you studied two homologous series, alkanes and alkenes. This would be a good time to revise that work as other series build on these.

Table 1.1 Alkanes and alkenes.

Homologous series	Functional group	General formula
Alkane	Single C–C bond	C_nH_{2n+2}
Alkene	Double C=C bond	C_nH_{2n}

Alkanes are saturated compounds, as they contain only single C–C bonds whereas alkenes are unsaturated as they contain at least one double C=C bond.

Alkyl group

Another term you should recall is an **alkyl group**. This refers to a hydrocarbon chain with the general formula C_nH_{2n+1}. An example is a methyl group ($–CH_3$). This is a fragment of a methane molecule (CH_4). Alkyl groups do not exist on their own, they are branches of carbon molecules.

Table 1.2 Alkyl groups.

Alkane	Formula	Alkyl group	Formula
Methane	CH_4	Methyl group	$–CH_3$
Ethane	CH_3CH_3	Ethyl group	$–CH_2CH_3$
Propane	$CH_3CH_2CH_3$	Propyl group	$–CH_2CH_2CH_3$ or $–C_3H_7$

QUESTIONS

1. (a) Define organic chemistry.
   (b) Name five examples of organic compounds.
2. Identify two chemists influential in the initial development of carbon chemistry.
3. (a) Define a functional group.
   (b) Recall the functional group for an alkene, an alcohol and a carboxylic acid.
4. What does IUPAC stand for?
5. (a) What is meant by a general formula?
   (b) Distinguish between the general formula for an alkane and an alkene.
6. What is meant by an homologous series? Include an example in your answer.
7. (a) What is meant by an alkyl group?
   (b) Distinguish between butane and butyl.
8. Check your knowledge with this quick quiz.
   (a) Hydrocarbons with single C–C bonds are called (alkanes/alkenes).
   (b) The stem (prefix) of a carbon compound with four carbon atoms would be named ....
   (c) The carbon atom attached to a functional group is numbered so that it has the (lowest/highest) possible number.
   (d) State the general formula for an alkane.
   (e) The symbol R–OH is the general formula for an ....
   (f) Which part of the name of a compound tells you the functional group present?
   (g) What is the stem (prefix) of an alkane with two carbon atoms present?

2 Naming Organic Chemicals

All organic series are named according to IUPAC nomenclature. You have already seen this with the hydrocarbon series, alkanes and alkenes.

The **stem** (prefix) of the name tells us the length of the carbon chain, for example:

C_1 meth-	C_2 eth-	C_3 prop-
C_4 but-	C_5 pent-	C_6 hex-
C_7 hept-	C_8 oct-	

The suffix (ending) of the name indicates the functional group present and thus the family of organic compounds to which the compound belongs.

Table 2.1 Suffixes of organic compounds.

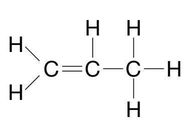
Suffix	Homologous series	Example
-ane	Alkane	Ethane C_2H_6
-ene	Alkene	Ethene C_2H_4

However, some compounds also have names that are not systematic but have been used for a long time, for example ethanol is often just called alcohol and ethene is historically called ethylene. When a non-systematic name is in common use, IUPAC refers to this as the 'preferred' name and it may be given preference over the systematic name.

Types of formulas

Carbon compounds can be shown as:

- a molecular formula, e.g. propene C_3H_6
- a condensed structural formula, e.g. CH_2CHCH_3
- or a structural formula, e.g. propene.



Numbering

The name of a compound must indicate the position of the functional group as this affects the properties of a compound. For example, but-1-ene and but-2-ene have the same molecular formula of C_4H_8. However, in but-1-ene the double bond is between the first and second carbon atoms and in but-2-ene the double bond is between the second and third carbon atoms. The carbon atoms are numbered so that the carbon with the functional group attached has the lowest possible number.

But-1-ene But-2-ene

Figure 2.1 But-1-ene and but-2-ene.

Notice that a carbon compound **can be numbered from either end**, e.g. hept-2-ene has the double bond on the second carbon from the end and it can be drawn from either direction – numbering from the left or from the right as shown in Figure 2.2.

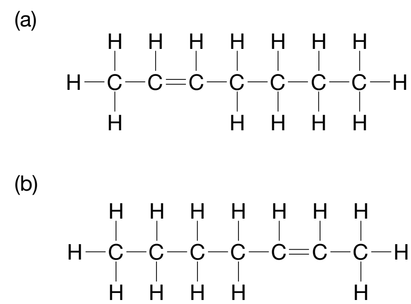


Figure 2.2 Two ways of illustrating hept-2-ene.

Structural formulas can be drawn in a way that gives some idea of the **structural orientation** of atoms within the molecule. For example, Figure 2.3 shows bends in the carbon chain of but-2-ene.

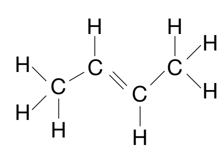


Figure 2.3 Structural formula of but-2-ene.

Structural formulas can also be reduced to just the bare **skeleton** as shown here by a structural formula and model of 2-methylbut-2-ene.

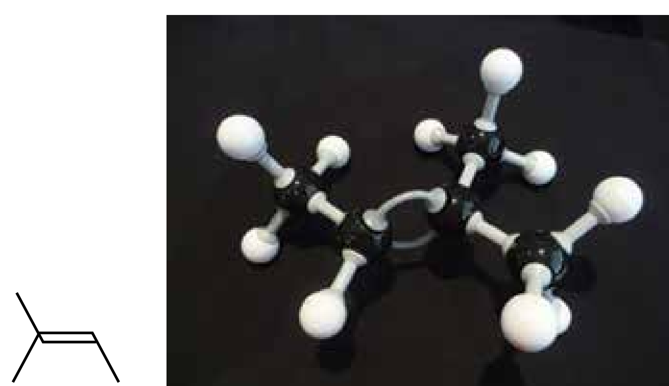
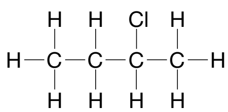


Figure 2.4 2-Methylbut-2-ene.

Other attachments to hydrocarbons

When **other atoms** are present in a molecule, for instance a halogen atom such as fluorine, chlorine, bromine or iodine, their position is also indicated by a number and a prefix, e.g. 2-chlorobutane and 3-bromoheptane. See Figure 2.5.

(a) 2-Chlorobutane



(b) 3-Bromohexane

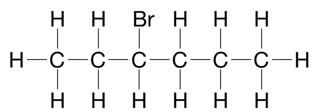


Figure 2.5 2-Chlorobutane and 3-bromoheptane.

The attachment of **other alkyl groups** such as methyl ($-CH_3$) is also indicated by numbering their positions. Name the longest chain and indicate any side chains as in Figure 2.6.

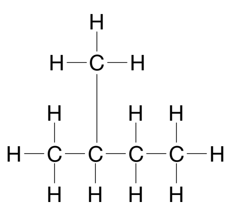


Figure 2.6 2-Methylbutane.

An example of a more complex molecule containing both a halogen atom and a methyl group attached to the chain is shown in Figure 2.7. You will notice that when you name a compound, commas are used between numbers and dashes are used between a number and a word.

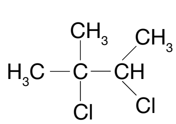
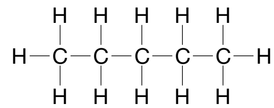
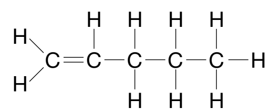
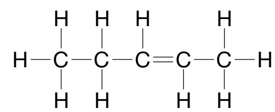
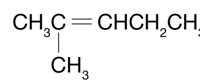
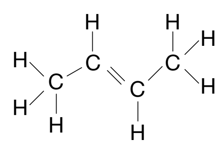
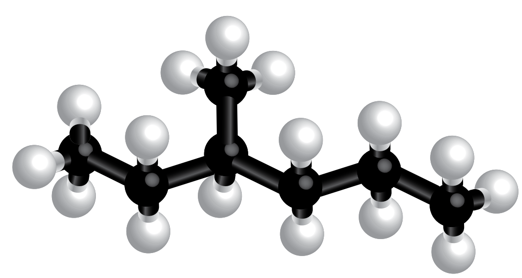


Figure 2.7 Structural formula of 2,3-dichloro-2-methylbutane.

QUESTIONS

1. Distinguish between the stem and suffix of an organic molecule.
2. State the IUPAC name for each of the following compounds.
   (a)
   
   (b)
   
   (c)
   
   (d)
   
   (e)
   
   (f) $H_3C-CH_2-CH_2-CH_2-C(CH_3)=CH-CH_3$
   (g)
   
3. Write structural formulas for the following compounds.
   (a) 3-Methylpentane.
   (b) Hept-2-ene.
   (c) 2-Chloro-2-methylpropane.
   (d) 2,3-Dimethylpentane.

3 Structural and Geometric Isomers

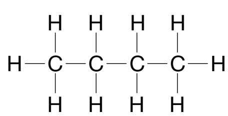
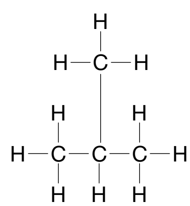
Some carbon compounds can exist as isomers.

Isomers are compounds with the same molecular formula but different arrangement of the atoms in space. Although isomers have the same molecular formulas they are different compounds with different properties.

Structural isomers

Butane and 2-methylpropane are examples of **structural isomers**. They both have the formula C_4H_{10}. However, their atoms are arranged in a different order so that their molecules have different structures, different names and different properties, as shown in Table 3.1.

Table 3.1 Structural isomers of C_4H_{10}.

Feature	Butane	2-Methylpropane
Structural formula		
Boiling point (°C)	–1	–11.7
Density (g mL^{-1})	2.48	2.51
Uses	A fuel	A refrigerant

Notice that the differences are not just due to rotation of atoms around carbon bonds, they are actually arranged differently.

Don't be tricked by molecules where atoms have simply rotated freely around –C–C– bonds. These are **not isomers**. For example, in Figure 3.1 you can see two pictures of dichloroethane. These are not isomers. They are the same compound as they have the same formula and properties. One carbon atom has just rotated about the single C–C bond.

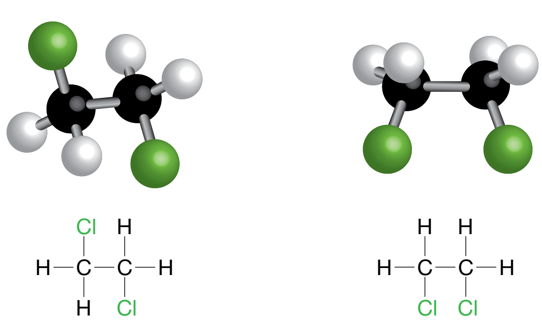


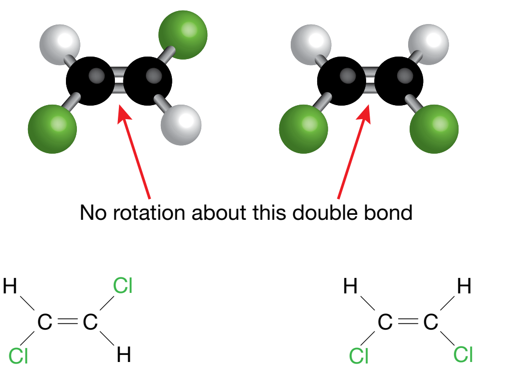
Figure 3.1 1,2-Dichloroethane showing rotation.

Geometric isomers

Geometric isomers also have the same molecular formula, but they have a different geometric arrangement.

When you made models of compounds such as ethane and ethene, you probably noticed that there is free rotation about the –C–C– bond in ethane but the double –C=C– bond in ethene is rigid and cannot rotate.

This absence of rotation around a double –C=C– bond gives rise to geometric isomers such as those shown in Figure 3.2. The two forms of geometric isomers are named cis and trans forms.



Trans-1, 2-dichloroethene   Cis-1, 2-dichloroethene

Figure 3.2 Geometric isomers for dichloroethene $C_2H_2Cl_2$.

The trans isomer has the two chlorine atoms locked on opposite sides of the double bond.

The cis isomer has the two chlorine atoms locked on the same side of the double bond.

Geometric isomers can also occur in compounds with ring structures such as 2-methylcyclohexanol.

Cis-2-methylcylohexanol   Trans-2-methylcylohexanol

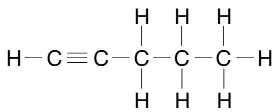
Figure 3.3 Cis- and trans-2-methylcyclohexanol.

Although geometric isomers can be considered just different forms of the same compound, they have different physical properties such as solubility, melting and boiling points. This is due to the difference in overall shape, electron density and polarity of the molecules. The difference is important in biochemistry such as in cis and trans fatty acids.

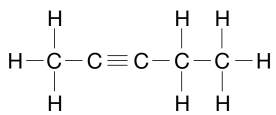
QUESTIONS

1. (a) What are isomers?
   (b) Pentane has three isomers. Draw and name them.
2. A bromine atom is substituted into a propane molecule. Show two possible isomers that could form.
3. Draw carbon skeletons to illustrate the structure of five isomers for hexane C_5H_{12}. Name these isomers.
4. (a) Draw three structural isomers for butene (C_4H_8).
   (b) Does the compound but-3-ene exist?
5. 1-Pentyne and 2-pentyne have the following structural formulas. Explain why these are considered to be structural isomers.

1-Pentyne

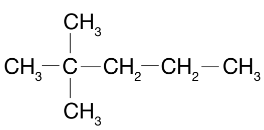


2-Pentyne

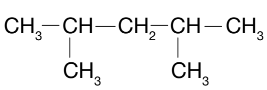


6. Explain why the following compounds are all structural isomers and name them.

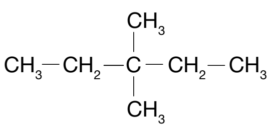
(a)



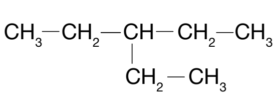
(b)



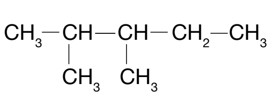
(c)



(d)

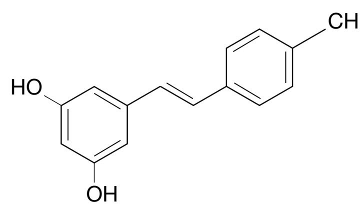


(e)

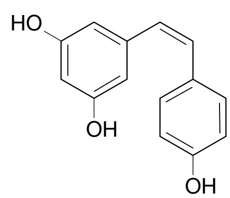


7. Try to make another structural isomer of C_7H_{16} not already shown in Question 6.
8. (a) 1,2-Dichloroethane and 1,1-dichloroethane are structural isomers. Explain.
   (b) Use information from a chemical data book to account for these two substances being considered as different chemicals despite the fact that they have the same molecular formula.
9. (a) Draw structural formulas to distinguish between cis- and trans-but-2-ene.
   (b) Are these structural or geometric isomers? Explain.
   (c) The diagrams show two isomers of a chemical, called resveratrol which is produced by plants to help protect them from any environmental stress. Decide if they are structural or geometric isomers and label them as cis- or trans-.

(i)



(ii)



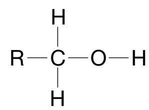
10. Trans fats have received a lot of adverse publicity recently as fats which are unhealthy and which should be restricted in the diet. Research the relationship between geometric isomers and the term trans fats.
11. Check your knowledge with this quick quiz.
    (a) Compounds with the same molecular formula but different arrangement of the atoms in space are called ....
    (b) Name two different types of isomers.
    (c) Which would form geometric isomers, an alkane or an alkene?
    (d) Which type of bond is not free to rotate, a single –C–C– bond or a double –C=C– bond?

4 Alcohols

An **alcohol** (also called alkanol) is an organic compound which contains a hydroxyl functional group (–OH) attached to a saturated carbon atom.

Homologous series	Functional group	General formula
Alcohol	Hydroxyl (–OH) group	R–OH or $C_nH_{2n+1}OH$

The general structure of an alcohol can be shown as:



Naming alcohols

Alcohols (like alkanes and alkenes) are named according to IUPAC nomenclature.

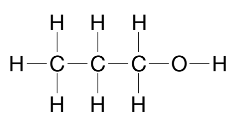
The stem (prefix) tells you the number of carbon atoms in the carbon chain.

C_1 meth- C_2 eth- C_3 prop-

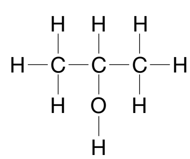
C_4 but- C_5 pent- C_6 hex-

C_7 hept- C_8 oct-

Numbering in the name tells you where the hydroxyl group is attached. For example:



Propan-1-ol



Propan-2-ol

Methanol is the simplest alcohol, and it is present in methylated spirits, which is not suitable for drinking as methanol causes blindness.

Perhaps the best known alcohol is **ethanol**, C_2H_5OH, which is used in alcoholic drinks, medications and in fuel for motor vehicles.

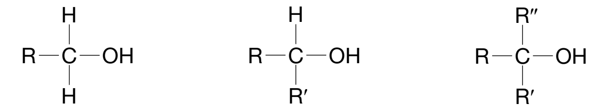
Alcohols with two hydroxyl groups are called **diols**, those with three hydroxyl groups are called **triols**.

Types of alcohols

Alcohols can be classified as **primary**, **secondary or tertiary alcohols** depending on the position of their hydroxyl (–OH) group.

Alkanols with their hydroxyl group at the end of the carbon chain are called **primary alcohols**. The carbon with the hydroxyl (–OH) group attached is terminal (at the end of the chain). We can write this as R–OH where R indicates an alkyl group or hydrocarbon chain. Some simple primary alcohols are shown in Table 4.1.

In **secondary** alcohols, the carbon with the OH group is bonded to two other carbon atoms. In **tertiary** alcohols, the carbon with the OH group is bonded to three carbon atoms.

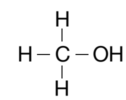
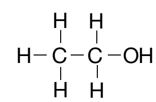
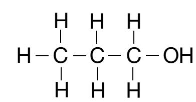
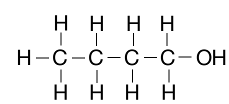
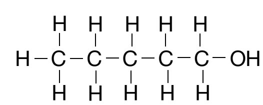
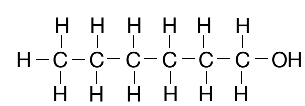
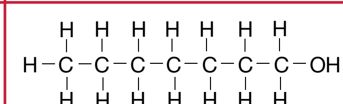
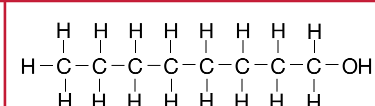


Primary alcohol Secondary alcohol Tertiary alcohol

Figure 4.1 Primary, secondary and tertiary alcohols.

In these formulas, **R**, **R′** and **R″** refer to alkyl groups (except in methanol where there is just a H atom).

Table 4.1 A series of alcohols.

Name	Molecular formula	Structural formula
Methanol	CH_3OH	
Ethanol	C_2H_5OH	
Propanol	C_3H_7OH	
Butanol	C_4H_9OH	
Pentanol	$C_5H_{11}OH$	
Hexanol	$C_6H_{13}OH$	
Heptanol	$C_7H_{15}OH$	
Octanol	$C_8H_{17}OH$	

Preparation of alcohols

Alcohols can be made using three different chemical reactions.

- One of the most commercially important alcohols is ethanol (ethyl alcohol). It can be made by the **fermentation of sugar using yeast** (a fungus) as a catalyst.

  $C_6H_{12}O_6(aq) \rightarrow 2CH_3CH_2OH(aq) + 2CO_2(g)$

- Alcohols can be made by the **hydrolysis of alkenes** using dilute phosphoric acid as a catalyst. Hydrolysis refers to the addition of water (as steam), so this is an addition reaction. For example, ethanol can be made by the hydrolysis of ethene.

  $CH_2CH_2 + H_2O(l) \rightarrow CH_3CH_2OH(l)$

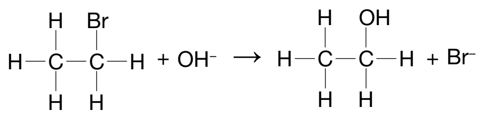
- Alcohols can also be made by **substituting an hydroxyl group** for a halogen in a haloalkane.

In this equation, X is a halogen atom, e.g. Cl or Br.

$CH_3CH_2X + OH^-(aq) \rightarrow CH_3CH_2OH + X^-$

Haloalkane + hydroxide ion → alcohol + halide ion

For example:



Properties of alcohols

Alcohols have **polar molecules** containing polar hydroxyl groups.

They tend to be **soluble in water** as they can form dipole-dipole and hydrogen bonds with water molecules. They also have **higher melting and boiling points** than alkanes of a similar size due to their stronger intermolecular forces, including dispersion forces, dipole-dipole forces and hydrogen bonds.

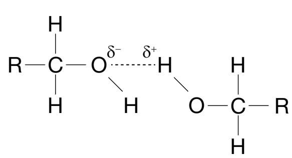


Figure 4.2 Hydrogen bond between two ethanol molecules.

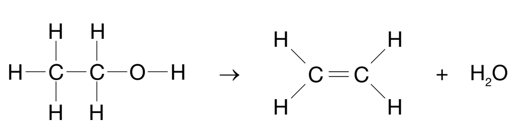
Reactions of alcohols

- Alcohols **react with active metals** to form hydrogen gas. This can be used as a **distinguishing test** for alkanols.

  $2Na + 2CH_3CH_2OH \rightarrow 2CH_3CH_2O^- Na^+ + H_2(g)$

  Sodium + ethanol → sodium ethoxide + hydrogen

- Alcohols can be **dehydrated** (have a molecule of water removed) to manufacture alkenes. To do this they are heated with concentrated phosphoric or sulfuric acid.



- Alcohols **burn in air or oxygen**, forming water and carbon dioxide.

  $C_2H_5OH(l) + 3O_2(g) \rightarrow 3H_2O(l) + 2CO_2(g)$

  If the air supply is restricted, carbon monoxide or carbon can form.

  $C_2H_5OH(l) + 2O_2(g) \rightarrow 3H_2O(l) + 2CO(g)$

Later in this course, you will learn about other reactions of alcohols such as esterification.

QUESTIONS

1. Name the following primary alcohols.
   (a) C_4H_9OH (b) $C_7H_{15}OH$ (c) C_3H_7OH
2. Write molecular formulas for the following alcohols.
   (a) Methanol (b) Ethanol (c) Hexan-3-ol
3. Write structural formulas for each of the following compounds and state whether any alcohols are primary, secondary or tertiary alcohols.
   (a) Pent-2-ene (b) 3-Chlorohexane
   (c) Hexan-1-ol (d) Heptan-3-ol
   (e) Octan-4-ol (f) Pentan-3-ol
4. Does the compound butan-3-ol exist? Explain.
5. Distinguish between the following.
   (a) Hydroxide and hydroxyl.
   (b) Primary, secondary and tertiary alcohols.
6. Write an equation to show the substitution of a hydroxyl group into chloropropane.
7. Examine the table below and describe how the solubility of alcohols changes as the length of the carbon chain increases. Suggest a reason for this trend.

Compound	Formula	Solubility (g/100 g water)
Methanol	CH_3OH	Infinite
Ethanol	CH_3CH_2OH	Infinite
Propan-1-ol	$CH_3CH_2CH_2OH$	Infinite
Butan-1-ol	$CH_3CH_2CH_2CH_2OH$	8.0
Pentan-1-ol	$CH_3CH_2CH_2CH_2CH_2OH$	2.7
Hexan-1-ol	$CH_3CH_2CH_2CH_2CH_2CH_2OH$	0.6

8. Research the formulas and uses for the following more complex alcohols.
   (a) Ethane-1,2-diol (ethylene glycol)
   (b) 1,2,3-Propanetriol (glycerol).
   (c) Phenol.
9. Check your knowledge with this quick quiz.
   (a) Carbon compounds containing an OH group are called ....
   (b) The OH group in organic compounds is called an .... group.
   (c) Name the compound with formula $CH_3CHOHCH_2CH_3$.
   (d) Name the compound with formula $CH_2OHCH_2CH_3$.
   (e) The prefix of a primary alcohol with five carbon atoms would be ....
   (f) Name the compound with formula. $CH_3CH_2CH_2CHOHCH_3$.
   (g) State the general formula for an alcohol.

5 Ethanol

Ethanol (ethyl alcohol) is the most well known alcohol. Its molecular formula is C_2H_5OH. Ethanol consists of an **ethyl group** bonded to an **hydroxyl group** (–OH) which is the functional group for alcohols.

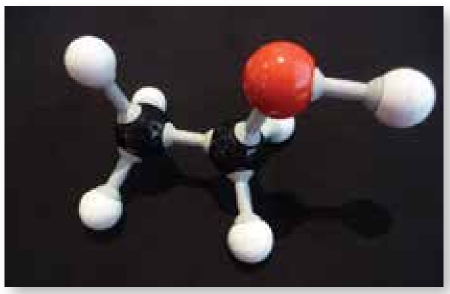


Figure 5.1 Model of ethanol.

Properties of ethanol

Ethanol molecules are **polar** due to the presence of the hydroxyl group. Oxygen is more electronegative than hydrogen or carbon, so a dipole forms.

Ethanol molecules are held together by **dispersion forces, dipole-dipole forces and hydrogen bonds**, so it has a higher melting and boiling point than alkanes with a similar mass.

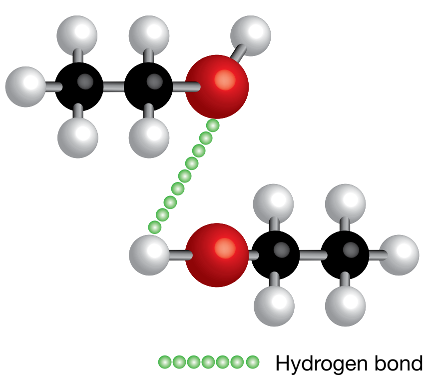


Figure 5.2 Hydrogen bonds between ethanol molecules.

Ethanol **mixes with both water and organic liquids**. Ethanol is polar so it bonds with other polar substances such as water (by dispersion forces, dipole-dipole forces and hydrogen bonds). Also its non-polar carbon chain allows it to bond with non-polar liquids such as hexane (by dispersion forces).

Uses of ethanol

The uses of ethanol include the following.

- In **alcoholic drinks** which can contain from 3% to 40% ethanol. Wine is made by fermenting grapes, beer by fermenting grains such as barley, and cider is made by fermenting apples. Fermented beverages are distilled to make spirits and liquors, e.g. whisky, vodka and gin.
- As a **solvent** in medicines such as cough mixtures and in many industrial processes such as the production of perfumes, varnish, adhesives and plastics.
- Ethanol can be **converted to ethene** by a **dehydration** reaction and ethene is the starting point for the manufacture of many polymers.

Dehydration involves heating the ethanol to a temperature between 180°C and 200°C and using concentrated sulfuric or phosphoric acid as a catalyst. An H and OH are removed from adjacent carbon atoms in the ethanol, producing water and ethene.

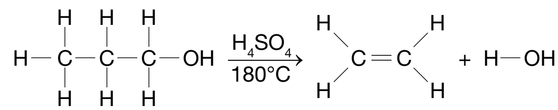


Figure 5.3 Dehydration of ethanol to form ethene.

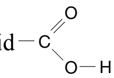
- Ethanol is used as a **fuel**. It is a renewable fuel, used to supplement fossil fuels. At this stage you might like to revise your earlier studies of ethanol as a fuel.
  $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$

QUESTIONS

1. (a) State the molecular formula of ethanol.
   (b) Identify the type(s) of intermolecular forces between ethanol molecules.
   (c) Which would you expect to have the higher boiling point, ethane or ethanol? Justify your answer.
2. Identify four uses of ethanol.
3. The electronegativity values for hydrogen, carbon and oxygen are 2.20, 2.25 and 3.44 respectively. Use the values to explain why:
   (a) Ethanol molecules are polar.
   (b) The O–H bond is not ionic.
4. Check your knowledge with this quick quiz.
   (a) Name the functional group for alcohols.
   (b) State the general formula for an alcohol.
   (c) Draw the structural formula for ethanol.
   (d) Ethanol has (polar/non-polar) bonds.
   (e) Ethanol has (polar/non-polar) molecules.
   (f) Identify three substances that use ethanol as a solvent in their production.
   (g) Identify the compound produced by the dehydration of ethanol.
   (h) Use an equation to show the combustion of ethanol in oxygen.

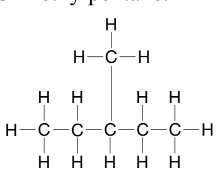
Answers

1 Organic Molecules

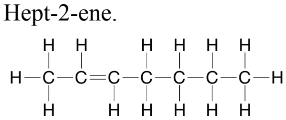
1. (a) Organic chemistry is the study of carbon and its compounds.
   (b) Various, e.g. sucrose, alkanol, starch, ethanol, glucose, any alkane, e.g. ethane, any alkene, e.g. ethene.
2. August Kekulé and Archibald Couper.
3. (a) A functional group is a specific group of atoms within a molecule that is responsible for the chemical reactions of that molecule.
   (b) Alkene a C=C bond. Alcohol –OH. Carboxylic acid 
4. IUPAC stands for International Union of Pure and Applied Chemistry.
5. (a) A general formula is one which applies to all the compounds in an homologous series.
   (b) Both are hydrocarbons. Alkanes have more hydrogen atoms per carbon atom than alkenes – alkanes are saturated and alkenes are unsaturated. Alkane – C_nH_{2n+2} and alkene C_nH_{2n}.
6. An homologous series is a group of compounds which all have the same functional group, e.g. alkanes, alkenes, alcohols.
7. (a) An alkyl group is part of an organic molecule that has the general formula C_nH_{2n+1}. For example, a methyl group CH_3, an ethyl group CH_3CH_2 or a butyl group C_4H_9.
   (b) Butane is the alkane C_4H_{10}. Butyl is the alkyl group of butane, with formula $-C_4H_9$.
8. (a) Alkanes. (b) But-
   (c) Lowest. (d) C_nH_{2n+2}
   (e) Alcohol. (f) Suffix.
   (g) Eth-

2 Naming Organic Chemicals

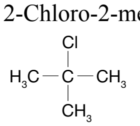
1. These terms refer to the beginning or prefix (stem) and ending (suffix) of the name of a carbon compound.
2. (a) Pentane.
   (b) 1-Pentene.
   (c) 2-Pentene.
   (d) 2-Methylpent-2-ene.
   (e) But-2-ene.
   (f) 3-Methylhept-2-ene.
   (g) 3-Methylhexane.
3. (a) 3-Methylpentane.



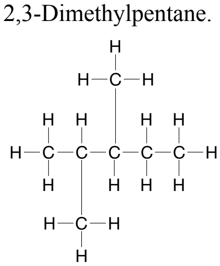
   (b) Hept-2-ene.



   (c) 2-Chloro-2-methylpropane.

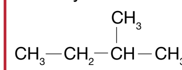
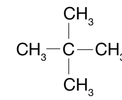


   (d) 2,3-Dimethylpentane.

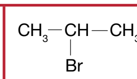


3 Structural and Geometric Isomers

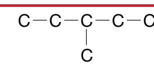
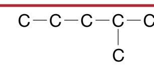
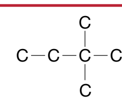
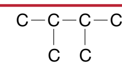
1. (a) Isomers are molecules with the same molecular formula but different arrangements of the atoms in space.
   (b)

Pentane	2-Methylbutane	2,2-Dimethylpropane
$CH_3-CH_2-CH_2-CH_2-CH_3$		

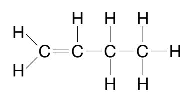
2.

$CH_3-CH_2-CH_2-Br$ 1-Bromopropane	 2-Bromopropane

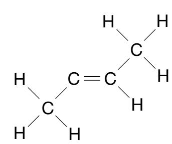
3.

C–C–C–C–C–C	Hexane
	3-Methylpentane
	2-Methylpentane
	2, 2-Dimethylbutane
	2, 3-Dimethylbutane

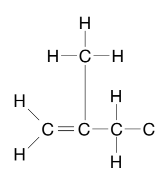
4. (a)



Butene or but-1-ene

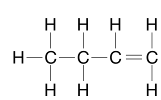
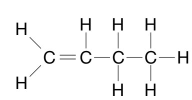


But-2-ene (this could also be drawn straight across the page.)

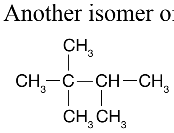


2-Methylprop-1-ene

   (b) No. But-3-ene would be but-1-ene drawn in reverse.

 is the same as 

5. 1-Pentyne and 2-pentyne each have the same molecular formula, C_5H_8. However, their molecules are arranged differently in that the triple bond is in a different position. This fits the definition of a structural isomer.
6. These structures are all structural isomers as, although they all have differences in structure, they all have the same molecular formula of C_7H_{16}.
   (a) 2,2-Dimethylpentane.
   (b) 2,4-Dimethylpentane.
   (c) 3,3-Dimethylpentane.
   (d) 3-Ethylpentane.
   (e) 2,3-Dimethylpentane.
7. Another isomer of C_7H_{16} is 2,2,3-trimethylbutane.



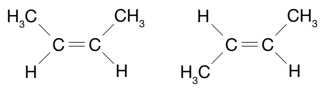
8. (a) They both have the same molecular formula, $C_2H_4Cl_2$, but their structural formulas differ and this fits the definition of a structural isomer.

(b)

Name	Density	Melting point (°C)	Boiling point (°C)
1,1-Dichloroethane	1.168	–97	57
1,2-Dichloroethane	1.246	–36	84

These two substances have different physical properties as seen in the table above. Therefore they are different compounds despite having the same molecular formulas.

9. (a)



Cis-2-butene   Trans-2-butene

(b) These are geometric isomers. They occur because the –C=C– bond is not able to rotate and so the CH_3 groups are held to the same side in cis-but-2-ene and to opposite sides of the molecule in trans-but-2-ene.

(c) Geometric isomers.

(i) Trans-resveratrol.

(ii) Cis-resveratrol.

10. A trans fat is a fat molecule which contains a double bond and the major groups surrounding that double bond are attached opposite one another. Trans fats are produced during food processing, they are not common in nature.

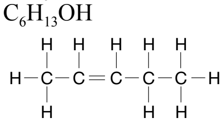
11. (a) Isomers.
(b) Structural and geometric isomers.
(c) Alkene.
(d) Double –C=C– bond.

4 Alcohols

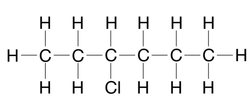
1. (a) Butan-1-ol
(b) Heptan-1-ol
(c) Propanol.

2. (a) CH_3OH
(b) C_2H_5OH
(c) $C_6H_{13}OH$

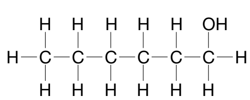
3. (a)



(b)

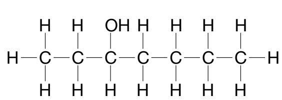


(c)



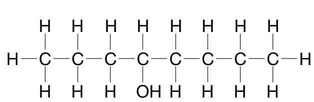
Primary alcohol

(d)



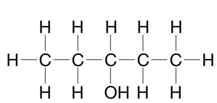
Secondary alcohol

(e)



Secondary alcohol

(f)

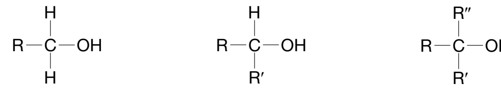


Secondary alcohol

4. No. It would be called butan-2-ol as you number from whichever end gives the smallest number to the carbon with the attached hydroxyl group.

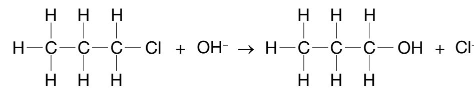
5. (a) Hydroxide is a negative ion (OH^-) present in some inorganic compounds, e.g. in sodium hydroxide NaOH. Hydroxyl is not an ion. It refers to the functional group (OH) for the series of organic compounds called alcohols.

(b) Primary alcohols have a terminal hydroxyl group. In secondary alcohols, the carbon with the OH group is also bonded to 2 other carbon atoms. In tertiary alcohols, the carbon with the OH group is bonded to 3 carbon atoms. For example:



Primary alcohol   Secondary alcohol   Tertiary alcohol

6.

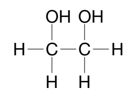


Chloropropane + hydroxide ion → propanol + chloride ion

7. Solubility in water decreases as length of carbon chain increases. Compounds with small molecules such as methanol and ethanol are completely soluble in water, butanol is less soluble – 7.3 g dissolves in 100 mL water. Larger molecules such as hexanol are almost insoluble – only 0.6 g dissolves in 100 mL water. This trend occurs because, as the carbon chain increases in length, it is the non-polar chain that is getting longer, and this does not form bonds with water molecules – which means it is less soluble.

8. (a) Ethane-1,2-diol (sometimes called ethyl glycol or ethylene glycol) is an odourless, toxic organic compound containing two hydroxyl groups (diol) attached to an ethyl group.

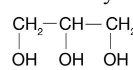
Formula:



It is infinitely soluble in water and has a very low freezing point (−34°C) so it is used as antifreeze in car radiators and brake fluid to lower the freezing point of water so the water does not freeze in very cold water. It is also used as a coolant, for heat transfer, and in the production of polymers, e.g. fabrics and PET bottles and fibreglass.

(b) 1,2,3-propane triol (also called glycerol or glycerine) is an alcohol with three hydroxyl groups.

Formula:



It absorbs water from the air so is used as a moisturising agent in cosmetics. It is also used as a solvent, as a sweetener and in the manufacture of many substances including dynamite, liquid soaps, candy, inks and lubricants. It is produced as a by-product of the soap making process.

(c) Phenol (also called carbolic acid) is a strongly smelling organic compound with molecular formula C_6H_5OH. It consists of a carbon ring with an OH (hydroxyl) group attached. Despite the presence of the OH group, it is not alkaline, instead it is mildly acidic. Its formula can be shown as either of the following.

9. (a) Alcohols.
(b) Hydroxyl.
(c) Butan-2-ol.
(d) Propan-1-ol.
(e) Pent-
(f) Pentan-2-ol.
(g) R-OH where R = C_nH_{2n+1} or $C_nH_{2n+1}OH$

5 Ethanol

1. (a) C_2H_5OH
(b) Dispersion forces, dipole-dipole forces, hydrogen bonds.
(c) Ethanol would have a higher boiling point than ethane because both have dispersion forces, but ethanol has a polar end and so it also forms dipole-dipole and hydrogen bonds.