Surfing

NSW CHEMISTRY 7&8

Module 7 Organic Chemistry

Module 8 Applying Chemical Ideas

Marilyn Schell • Margaret Hogan

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Science Press

First published 2018

Science Press
Bag 7023 Marrickville NSW 1475 Australia
Tel: (02) 9516 1122 Fax: (02) 9550 1915
sales@sciencepress.com.au
www.sciencepress.com.au

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Chemical Synthesis and Design

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What are the implications for society of chemical synthesis and design?

Introduction

This book covers the Chemistry content specified in the NSW Chemistry Stage 6 Syllabus. Sample data has been included for suggested experiments to give you practice to reinforce practical work in class.

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.

NSW CHEMISTRY 7&8

Module 7

Organic Chemistry

Content Focus

In this module you will:

- Focus on the principles and applications of chemical synthesis in organic chemistry, including pharmaceuticals, fuels and polymers.
- Investigate the naming, structure and classification of organic chemicals.
- Investigate the characteristic chemical properties and reactions of classes of organic compounds based on their functional groups.
- Consider the primary, secondary and tertiary structures of organic materials and how this affects properties such as strength, density and biodegradability of proteins, carbohydrates and synthetic polymers.

1 The Element Carbon

Carbon is a non-metal element. Its atomic number is 6 because it contains 6 positively charged protons in the nucleus of each atom. There are also 6 negatively charged electrons orbiting the nucleus, with two electrons in the first shell and four electrons in the outer shell. So the electron configuration of carbon is 2.4 and it has a valency of 4.

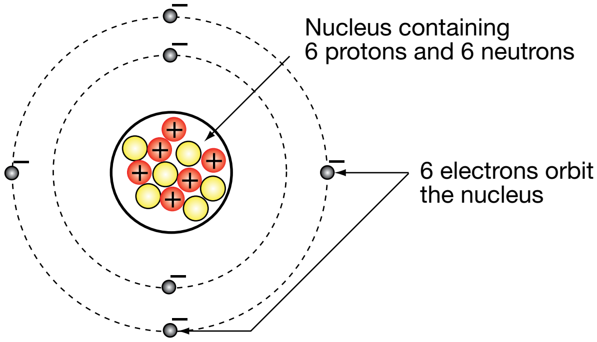


Figure 1.1 Atom of carbon-12.

Carbon is a special element because of the millions of compounds it can form and because carbon compounds are important constituents of living as well as non-living things.

The huge number of carbon compounds in existence is due largely to its ability to form strong bonds with other carbon atoms, making **chains and rings**, and also the stable bonds it can form with other elements.

Bonding of carbon atoms

Carbon atoms bond to each other by **sharing electrons**, forming strong covalent **carbon-carbon bonds**. You saw this last year when you studied carbon allotropes – diamond, graphite and fullerenes.

You will recall that carbon-carbon bonds can be single, double or triple bonds. Single bonds are the most common.

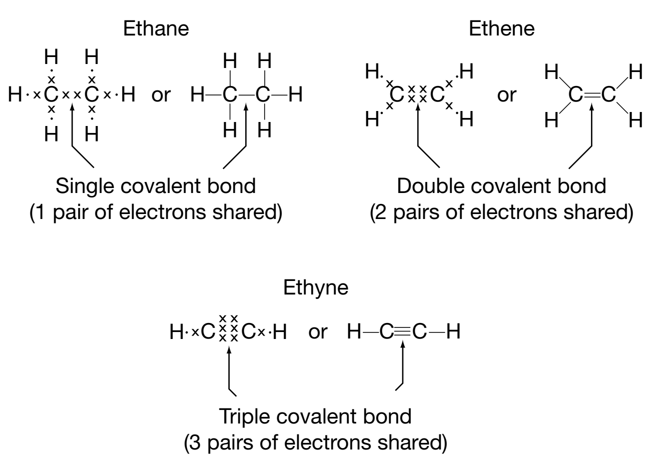


Figure 1.2 Single, double and triple C–C bonds.

Note: Although the electrons in all atoms are identical, they are sometimes illustrated as crosses and dots as in Figure 1.2 to show that the two electrons in a bond come from different atoms.

These are all strong covalent bonds and they increase in strength from single C–C bonds to double C=C bonds, with the shortest and strongest being triple C≡C bonds.

Table 1.1 Bond energies between carbon atoms.

Bond	Bond energy (kJ mol^{-1})
Single bond: C–C	348
Double bond: C=C	614
Triple bond: C≡C	839

Carbon also bonds with other elements. It forms strong **covalent bonds with hydrogen atoms**. These are considered to be non-polar bonds as the electronegativity difference between the atoms involved is very small.

Carbon also forms stable **polar bonds with oxygen, nitrogen, phosphorus and the halogens**.

You already know that the strength of these bonds varies with such factors as length of bonds (strength increases as length decreases) and differences in electronegativity (strength increases as electronegativity difference increases). For example, bond energy between carbon and the halogens decreases down the halogen group.

Table 1.2 Bond energies between carbon and some other atoms. (These vary slightly in different sources.)

Bond	Bond energy (kJ mol^{-1})
C–H	414
C–O	358
C–N	305
C–F	485
C–Cl	339
C–I	238

QUESTIONS

1. (a) Outline the position of carbon on the periodic table and state its electron configuration.
   (b) How many valence electrons are present in each atom of carbon?
2. List four factors that contribute to the huge number of carbon compounds that exist.
3. (a) Describe the type of bonding that occurs between carbon atoms.
   (b) Distinguish between single, double and triple carbon-carbon bonds.
4. (a) Name three other elements that bond to carbon atoms.
   (b) Identify two factors than can determine the strength of the bonds between atoms of carbon and other elements.

2 Organic Chemistry

Organic chemistry is the chemistry of carbon and its compounds. Carbon compounds are involved in our everyday life – the food we eat, fuels we burn, our own structure, and the polymers that we use to make everything from clothing to cars – all of these are carbon compounds.

Figure 2.1 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.

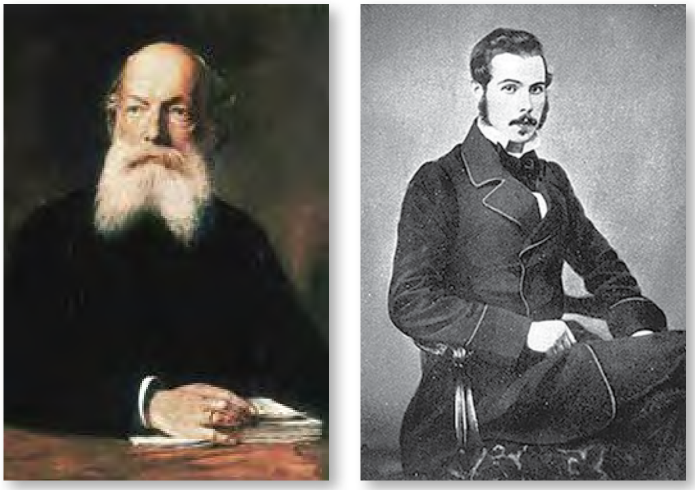


Figure 2.2 August Kekulé and Archibald Couper.

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 2.3 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‴.

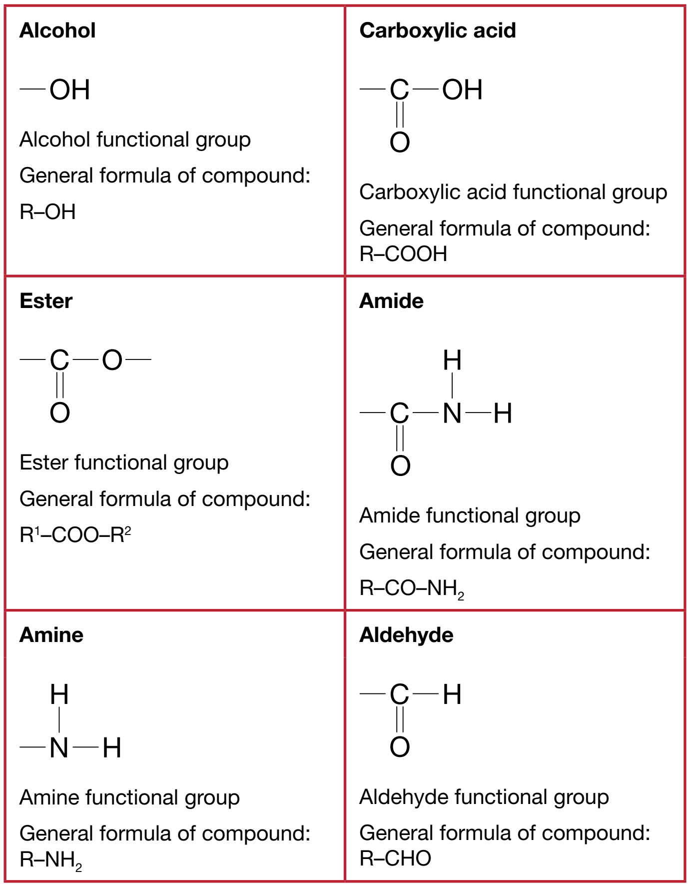


Figure 2.3 Functional groups.

Homologous series

Organic compounds containing only carbon and hydrogen atoms are called **hydrocarbons**. Each family of hydrocarbons is called an **homologous series**.

Homologous means that all members of a series have something in common – they share a **general formula** and a special feature or **functional group** (a grouping of atoms that is common to all members of that series).

There are three homologous series of hydrocarbons:

- Alkanes have only single –C–C– bonds.
- Alkenes contain at least one double –C=C– bond.
- Alkynes contain one or more triple –C≡C– bond.

Table 2.1 Three homologous series.

Homologous series	General formula	Functional group
Alkane	C_nH_{2n+2}	–C–C– Single bonded carbon atoms
Alkene	C_nH_{2n}	–C=C– Double bonded carbon atoms
Alkyne	C_nH_{2n-2}	–C≡C– Triple bonded carbon atoms

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 2.2 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 $-C_3H_7$

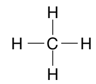
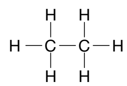
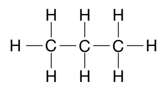
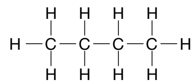
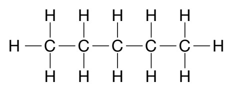
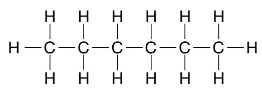
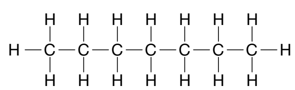
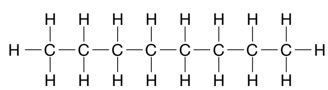
QUESTIONS

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?

3 Hydrocarbons – Alkanes

The following table shows the first eight alkanes.

Table 3.1 Alkanes.

Name of alkane	Molecular formula	Structural formula
Methane	CH_4	
Ethane	C_2H_6	
Propane	C_3H_8	
Butane	C_4H_{10}	
Pentane	C_5H_{12}	
Hexane	C_6H_{14}	
Heptane	C_7H_{16}	
Octane	C_8H_{18}	

- Molecules increase in size by a CH_2 grouping each step down a series. General formula C_nH_{2n+2}.
- Alkanes are saturated hydrocarbons – they contain only single carbon-carbon bonds.
- Alkanes are described as non-polar as there is no net charge on each molecule.
- Intramolecular bonds (within the molecule) are strong covalent bonds.
- Intermolecular bonds (between molecules) are weak dispersion forces. These are broken when the alkane changes state (melts or boils). C1 to C4 have the lowest boiling points. Larger molecules have higher boiling points because dispersion forces increase as the mass of the molecule increases.
- At 25°C and 100 kPa pressure, alkanes from C1 to C4 are gases, C5 to C20 are liquids and those with larger molecules are soft solids.

Naming alkanes

Carbon compounds are named systematically using IUPAC naming. IUPAC stands for the International Union of Pure and Applied Chemistry.

- The prefix or stem of the name indicates the number of carbon atoms that form the longest continuous chain. For example, meth– C_1, eth– C_2, prop– C_3, but– C_4, pent– C_5, hex– C_6, hept– C_7, oct– C_8.
- The **end of the name (suffix)** indicates the series to which the compound belongs. For example, ... ane indicates an alkane with single C–C bonds.

Cyclohexane

Some carbon compounds exist as ring structures. An example is cyclohexane, which is a cycloalkane with molecular formula C_6H_{12}.

Cyclohexane is a clear, colourless, flammable liquid which is used as a solvent and in the manufacture of nylon.

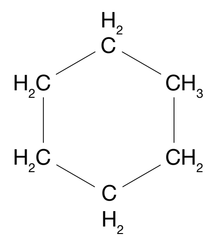
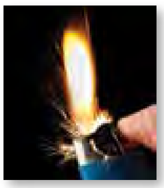


Figure 3.1 Cyclohexane.

Alkanes as fuels

The most common **fuels** are alkanes, derived from petroleum and summarised below.

Table 3.2 Alkanes as fuels.

Natural gas 	Mostly methane (75% to 90%), with small amounts of ethane (5% to 10%), propane (2% to 7%) and butane (3% to 6%). It can also contain nitrogen, water vapour, carbon dioxide and sometimes hydrogen sulfide.
LPG 	LPG is liquefied petroleum gas and it contains propane and/or butane. LPG is used as a fuel in heating appliances, cooking and in vehicles. It is also used as an aerosol propellant. LPG is heavier than air, so leaks will flow along the floor and settle in low spots.
Petrol, kerosene and diesel 	Used in industry and for transport. These are mixtures of carbon compounds, mostly alkanes. The composition varies, but petrol for cars is made mostly of alkanes from about C4 to C12, kerosene and aviation fuel from C9 to C18.
Liquefied butane 	Used for cigarette lighters and camp stoves and as a propellant and refrigerant. It is a gas at room temperature but is easily liquefied under pressure.

Safety issues associated with the storage of alkanes

The **weak intermolecular forces between molecules** of alkanes means that they have **low boiling points**. This makes them volatile.

Volatile substances turn to a gas easily and tend to have a high pressure of vapour above their liquid surface. Often their flash points are low, sometimes even lower than room temperature. A low flash point means they can be ignited by a flame at a low temperature. Because they are easily ignited, they often form explosive mixtures with air or oxygen.

These fuels must be **handled, transported and stored with care**, taking precautions such as the following.

- Store at low temperatures.
- Store in well-ventilated areas to prevent explosive fumes building up.
- Keep naked flames and sparks away.
- Have suitable fire extinguishers available.
- Use sturdy containers and check regularly for leaks in cylinders, pipes and valves.
- Keep containers of liquid fuels full to prevent the build-up of vapours.
- Do not inhale their vapours as some are toxic and/or carcinogenic.

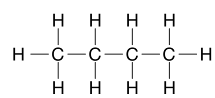
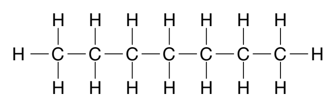
Table 3.3 summarises some precautions needed when dealing with specific alkanes.

Table 3.3 Precautions for using some alkanes.

Hydrocarbons	Precautions
Methane and ethane	Flammable gases. Store in high pressure cylinders in cool places. Check valves and cylinders often. Small quantities of smelly chemical added to detect leaks.
Propane and butane	Flammable gases stored as liquids, under low pressure, in steel cylinders. Store and use in ventilated areas. Inspect cylinders and valves regularly.
Kerosene, petrol and diesel	Volatile, flammable liquid fuels. Store in metal tins with lids, away from flames and sparks. Use outside, explosive fuel/air mixtures form easily.

Figure 3.1 Petrol pumps on fire.

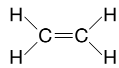
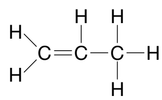
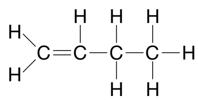
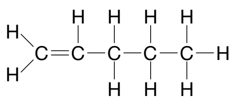
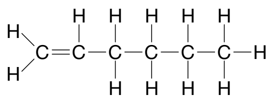
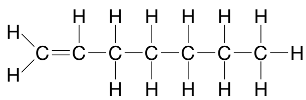
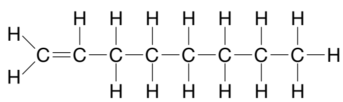
QUESTIONS

1. Draw structural and semi-structural formulas for:
   (a) Propane.
   (b) Octane.
   (c) Methane.
2. Write molecular formulas for:
   (a) Ethane.
   (b) Pentane.
   (c) Hexane.
3. Name the following compounds.
   (a) 
   (b) 
4. (a) State the general formula for an alkane.
   (b) Identify three alkanes that occur naturally as gases.
5. (a) Justify the application of the term 'homologous series' to alkanes.
   (b) Describe how you have modelled the structure of alkanes. Use a diagram to show one model of a named alkane.
   (c) Draw a diagram of two molecules of ethane and label them to show intramolecular covalent bonds and intermolecular dispersion forces.

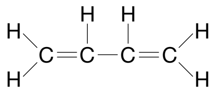
4 Hydrocarbons – Alkenes

Alkenes are an homologous series of hydrocarbons with the general formula C_nH_{2n}. Each alkene has a **carbon-carbon double bond**, so alkenes are described as **unsaturated**. The double bond makes alkenes **more reactive** than alkanes.

Table 4.1 The first seven alkenes.

Name	Molecular formula	Structural formula
Ethene	C_2H_4	
Propene	C_3H_6	
But-1-ene	C_4H_8	
Pen-1-tene	C_5H_{10}	
Hex-1-ene	C_6H_{12}	
Hept-1-ene	C_7H_{14}	
Oct-1-ene	C_8H_{16}	

- Notice that methene does not exist. You cannot have a double bond between two carbon atoms if the molecule only contains one carbon atom.
- If two double bonds are present in a hydocarbon, it is called a diene, for example buta-1,3-diene.



Uses of alkenes

Because alkenes are more reactive than alkanes they are widely used in industry. For example:

Ethene (ethylene) is widely used in the petrochemical industry, in the manufacture of such things as polymers, cosmetics, detergents, brake fluid and antifreeze.

Propene is used in the manufacture of polypropylene, glycerine and nitroglycerine.

Cycloalkenes

Alkenes can form cyclic compounds such as cyclohexene. Cyclohexene is a clear, colourless liquid which is insoluble in water and less dense than water.

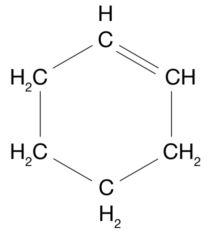
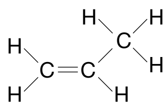
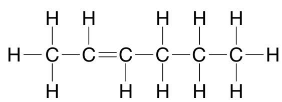
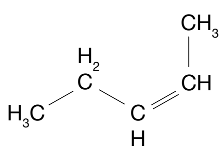


Figure 4.1 Cyclohexene (C_6H_{10}).

QUESTIONS

1. (a) State the general formula for an alkene.
   (b) Use this general formula to determine the molecular formula of:
      (i) An alkene with 11 carbon atoms per molecule.
      (ii) An alkene with 34 hydrogen atoms per molecule.
   (c) Identify the functional group for alkenes.
   (d) Are alkenes saturated or unsaturated compounds?
2. Name the following alkenes.
   (a)
   
   (b)
   
   (c) C_6H_{12}
   (d)
   
3. Write molecular, semi-structural (condensed) and structural formulas for the following compounds.
   (a) Prop-2-ene.
   (b) But-1-ene.
   (c) Hept-3-ene.
   (d) Hex-3-ene.

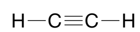
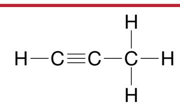
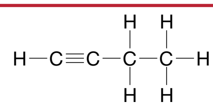
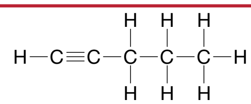
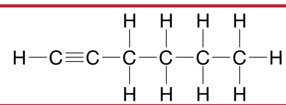
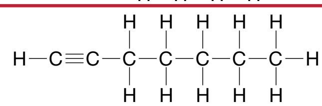
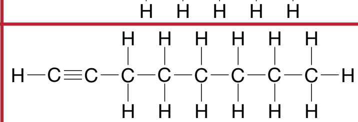
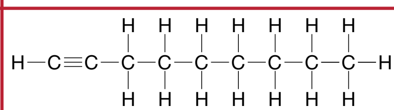
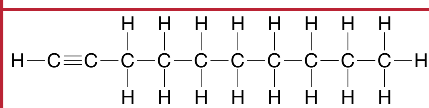
5 Hydrocarbons – Alkynes

Alkynes are a homologous series of hydrocarbons with the general formula C_nH_{2n-2}. Each alkyne has one or more **carbon-carbon triple bonds**.

Alkynes are described as **unsaturated** because of the presence of triple bonds and, like alkenes, they are **more reactive** than alkanes.

The following table shows the first nine alkynes. Notice methyne does not exist.

Table 5.1 Alkynes.

Name	Molecular formula	Structural formula
Ethyne	C_2H_2	
Propyne	C_3H_4	
Butyne	C_4H_6	
Pentyne	C_5H_8	
Hexyne	C_6H_{10}	
Heptyne	C_7H_{12}	
Octyne	C_8H_{14}	
Nonyne	C_9H_{16}	
Decyne	$C_{10}H_{18}$	

Alkynes are named in a similar way to alkenes. The ending –yne indicates the presence of a triple bond. A number before the name indicates the position of the triple bond. As for alkenes, you number from whichever end gives the smallest number (see Figure 5.1).

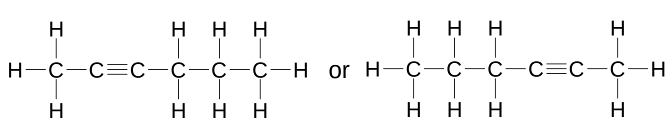


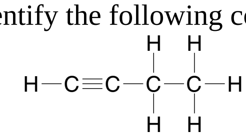
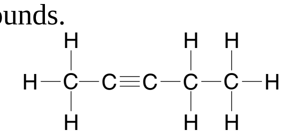
Figure 5.1 2-Hexyne (or hex-2-yne).

Ethyne (C_2H_2) is commonly called acetylene and is used as a fuel. Acetylene produces a high temperature flame and it is used in oxyacetylene torches to cut and weld metals. Ethyne changes from a solid to a gas at –84°C without becoming a liquid. That is, it sublimes.

QUESTIONS

1. Identify the following.
   (a) Molecular formula for ethyne.
   (b) Structural formula for ethyne.
   (c) Common name for ethyne.
2. Explain what is meant by:
   (a) Alkyne. (b) Triple bond. (c) Sublimes.
3. Complete the following table to compare ethane, ethene and ethyne.

Factor	Ethane	Ethene	Ethyne
Formula			
Boiling point (°C)	–89	–104	–84 (sublimes)
Homologous series			
Common feature			
Difference in reactivity			
Saturated/ unsaturated			
Uses			

4. Use the boiling points in the table in Question 3 to determine which of the three compounds, ethane, ethene or ethyne has the weakest dispersion forces. Justify your answer.
5. Justify the classification of alkanes, alkenes and alkynes as hydrocarbons.
6. Identify the following compounds.
   (a)  (b) 
   (c) $CHC(CH_2)_3CH_3$
7. For the compound 3-heptyne, write the:
   (a) Molecular formula. (b) Structural formula.
   (c) Condensed structural formula.
8. Check your knowledge with this quick quiz.
   (a) Hydrocarbons with a triple bond belong to which homologous series?
   (b) In a triple bond, ... electrons are shared.
   (c) Name the alkyne with three carbon atoms.
   (d) Write the molecular formula for the alkyne with five carbon atoms.
   (e) Identify the systematic name for acetylene.
   (f) State the functional group of the alkynes.
   (g) How many carbon atoms in heptyne?
   (h) Are alkynes saturated or unsaturated?

6 Naming Hydrocarbons

You already know that organic compounds are named systematically according to IUPAC nomenclature, with IUPAC standing for the International Union of Pure and Applied Chemistry.

Here we will recap what we already know about naming organic compounds.

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

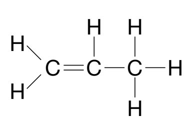
C_1 meth-	C_2 eth-	C_3 prop-	C_4 but-
C_5 pent-	C_6 hex-	C_7 hept-	C_8 oct-
C_9 non-	C_{10} dec-		

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

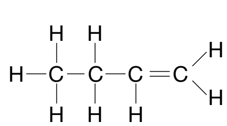
Table 6.1 Suffixes of some organic compounds.

Suffix	Homologous series	Example
-ane	Alkane	Ethane C_2H_6
-ene	Alkene	Ethene C_2H_4
-yne	Alkyne	Ethyne C_2H_2

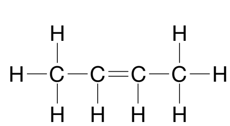
- **Types of formulas** include:
  - Molecular formula, e.g. propene C_3H_6.
  - Semi-structural formulas (also called condensed structural formulas), e.g. CH_2CHCH_3.
  - Structural formula, e.g. propene.



- **Carbon atoms are numbered** so that the carbon with the functional group attached has the lowest possible number.



But-1-ene or 1-Butene



But-2-ene or 2-Butene

Although these two compounds have the same molecular formula (C_4H_8), they are different compounds with different properties.

- Notice that the 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 6.1.

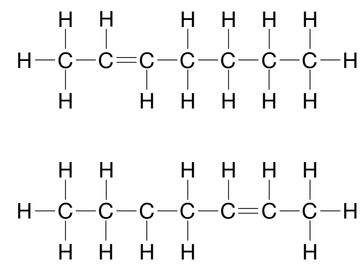
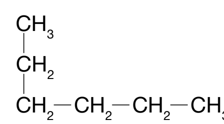


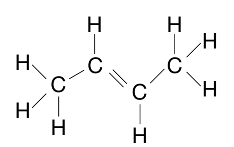
Figure 6.1 Two ways of drawing hept-2-ene.

- Watch out for **twisted or bent chains**. The following formula is hexane, not ethylbutane.



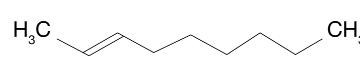
Hexane

- Formulas can be **drawn in different ways**. For example, this structural formula of but-2-ene gives a better idea of the structural orientation within the molecule.



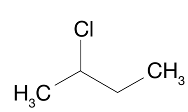
But-2-ene

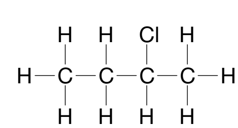
Also the carbon atoms in the main chain may be omitted as in this example of a structural formula for non-2-ene.



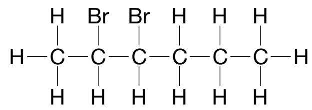
Of course, in an examination you would always give the full formula with all carbon and hydrogen atoms included.

- The position of atoms of **other elements** attached to a carbon chain, is also indicated by a number. Make sure you can see that each of the following formulas could be used to represent 2-chlorobutane.





- If there is more than one attachment, we number both in the same way. For example:



This compound would be called 2,3-dibromohexane.

Notice that you use commas between numbers and dashes between a number and a word.

Naming hydrocarbons with branched chains

Carbon compounds can have branched chains, and the position along the main chain of any attached groups is indicated by numbering.

To name a compound, first you find the longest chain. Then you identify any side chains by their length and their position along the chain.

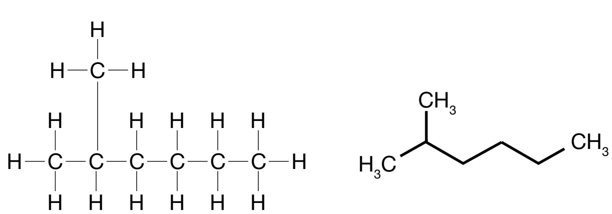
Table 6.2 Naming side chains.

Number of C atoms in chain	Formula	Name
1	CH_3	Methyl
2	CH_3CH_2	Ethyl
3	$CH_3CH_2CH_2$	Propyl
4	$CH_2CH_2\ CH_2CH_2$	Butyl
5	$CH_3CH_2CH_2\ CH_2CH_2$	Pentyl
6	$CH_3CH_2CH_2CH_2CH_2CH_2$	Hexyl
7	$CH_3CH_2CH_2CH_2CH_2CH_2\ CH_2$	Heptyl
8	$CH_3CH_2CH_2CH_2CH_2CH_2\ CH_2\ CH_2$	Octyl

Attachments to alkanes

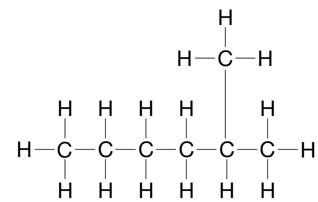
Here are some examples to give you an idea of how naming branch chains works using alkanes.

Example 1:



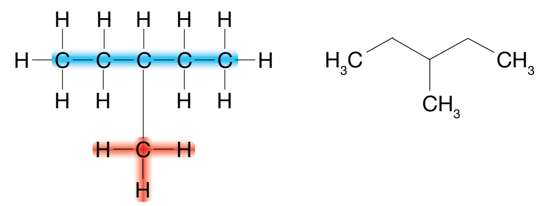
This structure is a 6 carbon chain, with all single C–C bonds, so it is hexane. And it has a CH_3 (methyl) group attached to the second carbon. So its name is **2-methylhexane**.

Notice that, as with other examples, this formula can also be written in reverse.



This is still 2-methylhexane – you number from whichever end will give you the smallest number for the attached group.

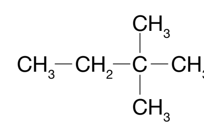
Example 2:



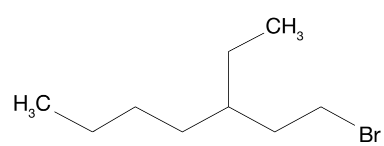
This is a 5 carbon alkane chain – pentane, with a methyl (CH_3) chain attached to the third carbon, **3-methylpentane**.

Example 3:

Compounds can have more than one side chain attached to the same main chain. Here is an example. It has two attached methyl groups, making it dimethyl, and they are both attached on carbon 2, so its name is **2,2-dimethylbutane**.



Example 4:

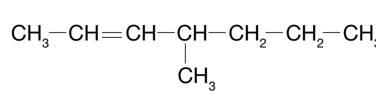


Numbering from the right again gives you the smallest numbers. The side attachments – bromo- and ethyl- (C_2H_5) are listed in alphabetical order. Bromine is on carbon 1 and the ethyl group is on carbon 3, so the name is **1-bromo-3-ethylheptane**.

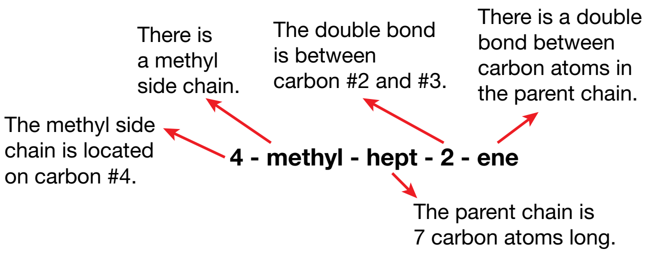
Attachments to alkenes and alkynes

So far we have only used alkanes for the main chain. It works the same way for alkenes and alkynes, but when numbering, you always begin with the carbon closest to the double or triple bond. Here are some examples using just the carbon skeleton.

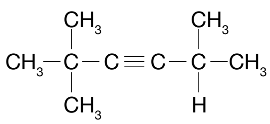
Example 1:



The main chain is 7 carbons with a double bond on the second C so it is hept-2-ene (or 2-heptene). The side chain is methyl (1 carbon) and it is attached to the fourth C in the main chain. So the name reflects all of this information.



Example 2:



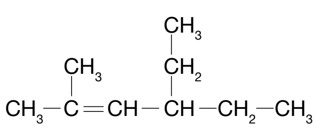
This compound has a 6 carbon chain with a triple bond on the third carbon – so it is hex-3-yne. There are 3 attached methyl groups. So we name it **2,2,5-trimethyl-hex-3-yne.**

Writing formulas

Now, let's try this in reverse – **start with a name** and try to draw a compound. Start with the carbon skeleton first.

Example:

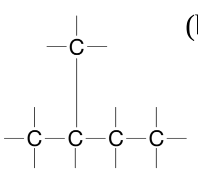
You are asked to write the structural formula for **2-methyl-4-ethyl-hex-2-ene**. Draw the carbon chain first, the hex-2-ene. Add the two side chains and then add all the hydrogen atoms.



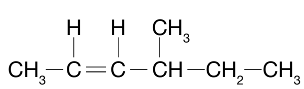
QUESTIONS

1. Name the following compounds based on their carbon backbones.

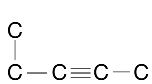
(a)



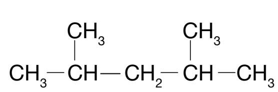
(b)



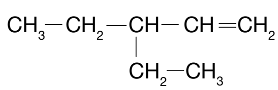
(c)



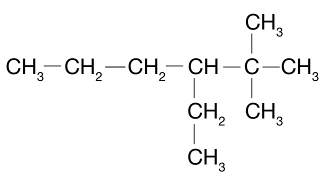
(d)



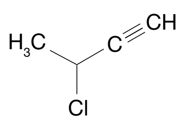
(e)



(f)

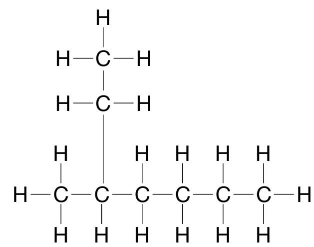


(g)

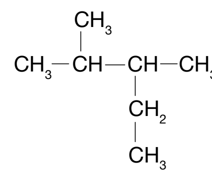


2. A student named each of the following structures incorrectly. State the correct name for each and explain why the student's answers were incorrect.

(a) This structure was named incorrectly as 2-ethylhexane.



(b) This structure was named incorrectly as 2-methyl-3-ethylbutane.



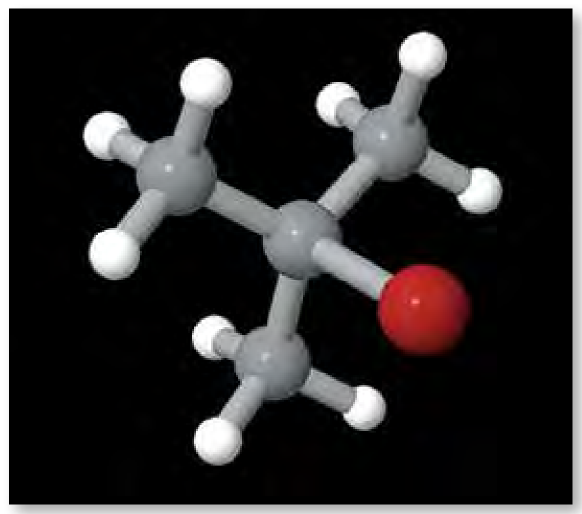
3. Write structural formulas for the following compounds.

(a) 1-Chloro-prop-1-yne.

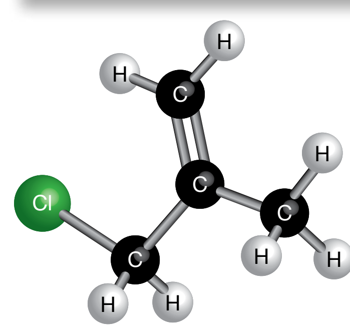
(b) 4-Ethyl-hex-2-ene.

4. Name the following models.

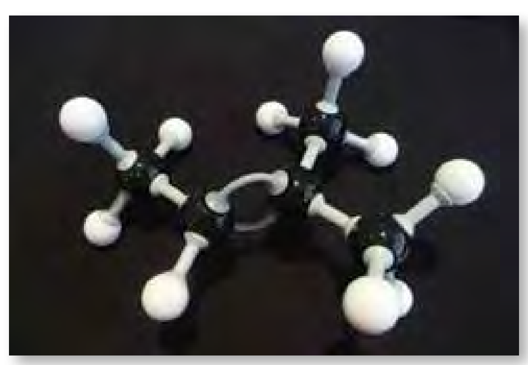
(a)



(b)



(c)



7 Alcohols

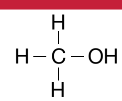
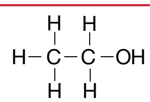
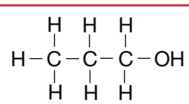
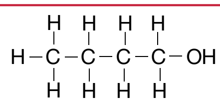
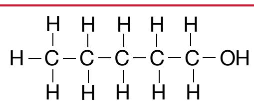
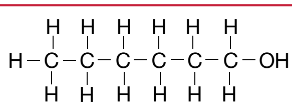
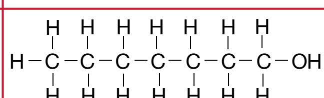
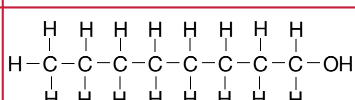
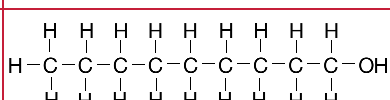
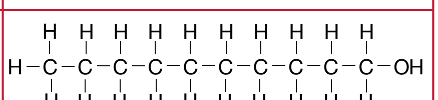
Another homologous series of organic compounds is the alcohols. They all contain the **hydroxyl functional group** (–OH) and their names all end with –anol as a suffix, for example, methanol, ethanol and propanol.

Alcohols made from an alkane and a hydroxyl group are called **alkanols** and have a general formula $C_nH_{2n+1}OH$.

Naming alcohols

The stem (prefix) tells you the length of the carbon chain in an alcohol.

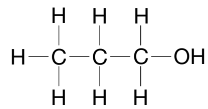
Table 7.1 A series of alcohols.

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	$C_8H_{17}OH$	
Nonanol	$C_9H_{19}OH$	
Decanol	$C_{10}H_{21}OH$	

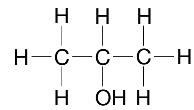
Methanol (CH_3OH) is the simplest alcohol; it is present in methylated spirits. This is not suitable for drinking, as methanol causes blindness.

Perhaps the best known alcohol is **ethanol** (C_2H_5OH) which is used in alcoholic drinks, in medicines, as a solvent and as a fuel.

In Table 7.1, the hydroxyl group is at one end of each molecule, but it can occur in other positions as indicated by numbering in the name of the alcohol.

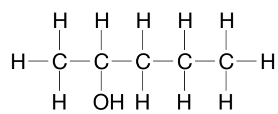
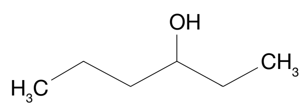
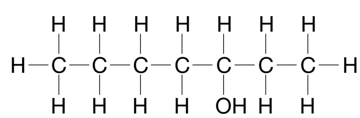
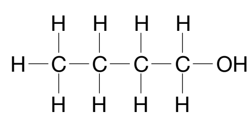
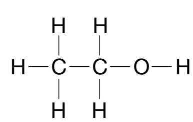
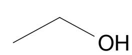
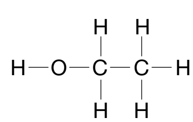
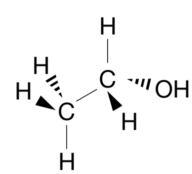


Propan-1-ol



Propan-2-ol

QUESTIONS

1. Name the following 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. Name the following alcohols.
   (a) 
   (b) 
   (c) 
   (d) 
4. Is there any difference between the four compounds as illustrated below?
   (a) 
   (b) 
   (c) 
   (d) 
4. Does the compound butan-3-ol exist? Explain.
5. Distinguish between the following.
   (a) Hydroxide and hydroxyl groups.
   (b) Primary, secondary and tertiary alcohols.

8 Carboxylic Acids

This is revision of work you covered in year 11. Carboxylic acids are organic acids which contain a **–COOH group**. The COOH group is the functional group of carboxylic acids and is called a **carboxyl group**.

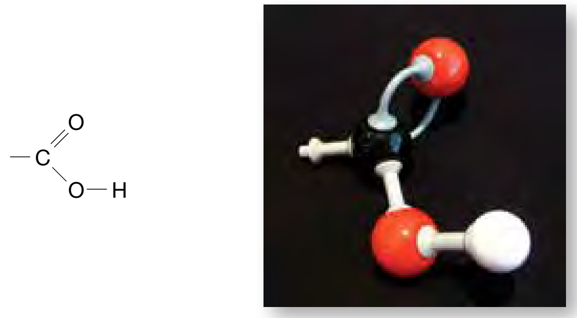
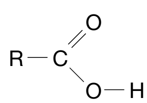


Figure 8.1 Carboxyl group formula.

In carboxylic acids, the carboxyl group is attached to a hydrogen atom or to a saturated carbon chain (an alkyl group) with the formula C_nH_{2n+1}. The general formula is RCOOH where R is a hydrogen atom or an alkyl group, C_nH_{2n+1}.

The general structure of **carboxylic acids** (also called alkanoic acids) is shown in the diagram.



The carboxyl group

The carboxyl group COOH is the functional group for carboxylic acids. In the carboxyl group, a carbon atom is bonded to two different oxygen atoms, one by a single C–O bond and the other by a double C=O bond.

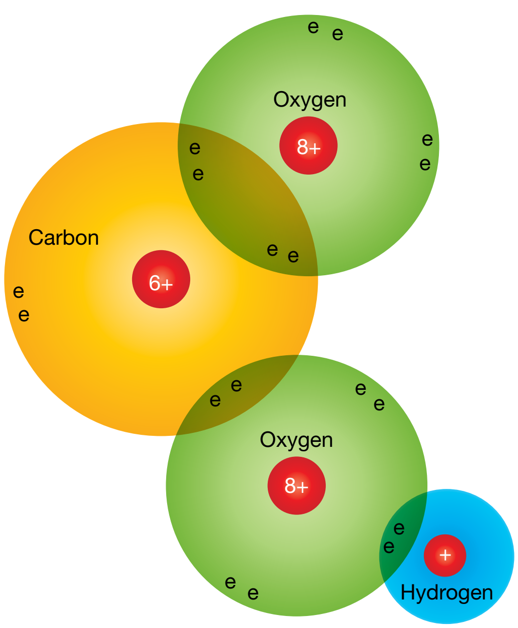


Figure 8.2 Structure of carboxyl group.

Examples of carboxylic acids

Methanoic acid (HCOOH) is the simplest carboxylic acid. Pure methanoic acid has a pungent irritating odour and can blister the skin. Methanoic acid is also called formic acid as it was first isolated from ants (Latin: formica = ants). Ant stings can be neutralised with sodium hydrogen carbonate. Methanoic acid is **used** as a preservative and an antibacterial agent.

Ethanoic acid (CH_3COOH) is also called acetic acid and is the main component of vinegar. Vinegar is approximately 4% to 8% acetic acid. It is used to flavour and preserve food. Ethanoic acid is corrosive, and has a sour taste and a strong odour. It is **used** extensively in the production of glues and synthetic fibres.

Examples of carboxylic acids are shown in Table 8.1.

Table 8.1 Carboxylic acids.

Name	Structural formula	Molecular formula
Methanoic acid	H – C – C(=O)OH	HCOOH
Ethanoic acid	H H – C – C(=O)OH H	CH_3COOH
Propanoic acid	H H H – C – C – C(=O)OH H H	C_2H_5COOH
Butanoic acid	H H H H – C – C – C – C(=O)OH H H H	C_3H_7COOH
Pentanoic acid	H H H H H – C – C – C – C – C(=O)OH H H H H	C_4H_9COOH
Hexanoic acid	H H H H H H – C – C – C – C – C – C(=O)OH H H H H H	$C_5H_{11}COOH$
Heptanoic acid	H H H H H H H – C – C – C – C – C – C – C(=O)OH H H H H H H	$C_6H_{13}COOH$
Octanoic acid	H H H H H H H H – C – C – C – C – C – C – C – C(=O)OH H H H H H H H	$C_7H_{15}COOH$

As with other chemicals which are important in industry, some of the carboxylic acids are known by common names as well as their IUPAC names. Table 8.2 lists some examples.

Table 8.2 Names of carboxylic acids.

Formula	IUPAC name	Common name
HCOOH	Methanoic acid	Formic acid
CH_3COOH	Ethanoic acid	Acetic acid
C_2H_5COOH	Propanoic acid	Propionic acid
C_3H_7COOH	Butanoic acid	Butyric acid
$C_7H_{15}COOH$	Octanoic acid	Caprylic acid
$C_{11}H_{23}COOH$	Dodecanoic acid	Lauric acid
$C_{15}H_{31}COOH$	Hexadecanoic acid	Palmitic acid

Strength of carboxylic acids

The strength of an acid is determined by how easily it can release (donate) protons when it goes into solution. The easier the protons (H^+ ions) are released into solution, the stronger the acid.

The carboxyl group (–COOH) contains a double bonded oxygen atom (=O) and a single bonded hydroxyl group (–OH). The hydroxyl group can ionise and release hydrogen ions (H^+) in solution, forming a conjugate base ($-COO^-$). This ability to release hydrogen ions makes it an acid.

Carboxylic acids are described as **weak acids** because they do not ionise completely. Most of the acid (about 95%) is present as un-ionised molecules.

The ionisation of a weak acid can be shown as an equilibrium equation where the equilibrium lies far to the left.

$$AH + H_2O \rightleftharpoons A^- + H_3O^+$$

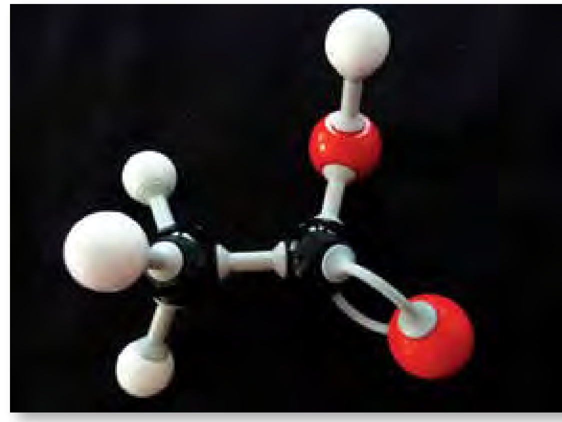
Or more simply as:

$$AH(aq) \rightleftharpoons A^-(aq) + H^+(aq)$$

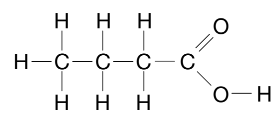
In these equations A stands for the anion (negative ion) in the acid.

QUESTIONS

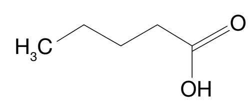
1. (a) Describe the meaning of a carboxylic acid.
   (b) Identify the general structure of a carboxylic acid.
2. Distinguish between a hydroxyl group and a carboxyl group.
3. Use diagrams to compare the size of molecules of ethanoic acid and methanoic acid.
4. Name the following carboxylic acids.
   (a) CH_3CH_2COOH
   (b) $CH_3CH_2CH_2CH_2CH_2CH_2CH_2COOH$
   (c)



   (d)



5. Sometimes formulas are drawn as follows. Each bend in the chain indicates the position of a carbon atom. Add the missing atoms to this chain and name the compound.



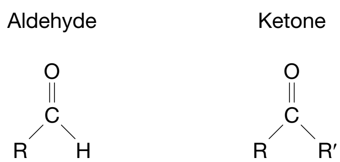
6. Research information on the following organic acids such as the number of carbon atoms in their hydrocarbon chains, and where they are found or used.
   (a) Lauric acid.
   (b) Stearic acid.
7. Justify the classification of organic acids as weak acids.
8. C_3H_7COOH is the molecular formula of two carboxylic acids.
   (a) What is the term used for compounds with the same molecular formula but different structural formulas?
   (b) Identify these two acids and draw their condensed structural formulas.
9. Check your knowledge with this quick quiz.
   (a) Identify the carboxylic acid made by ants and responsible for the sting of an ant bite.
   (b) Identify the carboxylic acid in vinegar.
   (c) What effect, if any, would you expect carboxylic acids to have on litmus paper?
   (d) Name the carboxylic acid used as a food preservative.

9 Aldehydes and Ketones

Aldehydes and ketones are considered together as they both contain the same functional group. This is called the **carbonyl functional group** and consists of an oxygen atom attached to a carbon atom by a double bond.

Figure 9.1 Carbonyl group.

Although aldehydes and ketones both have the carbonyl functional group, it is attached in a different position. In aldehydes, the carbonyl group is attached at the end of the carbon chain. In ketones the carbonyl group is attached along the chain, not at either end. This causes differences in some of the chemical reactions of aldehydes and ketones, especially oxidation reactions.



Where R and R′ are alkyl chains.

Figure 9.2 General formulas of aldehydes and ketones.

Aldehydes

Aldehydes (also called **alkanals**) are organic compounds with the general formula RCHO and a **carbonyl group attached to a terminal (end) carbon atom of the chain**.

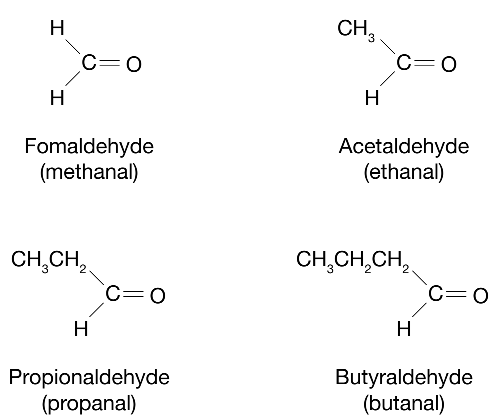


Figure 9.3 Examples of aldehydes.

For IUPAC naming:

1. Choose the longest unbranched chain containing the carbonyl group.
2. Number from the C with the attached =O.
3. Replace the 'e' at the end of the alkane with –'al'. For example: Methanal is an aldehyde which contains one C and ethanal contains two C's .

Ketones

Ketones (also called **alkanones**) are organic compounds with general formula RCOR′ where R and R′ are alkyl chains. In ketones the carbonyl group is on a carbon atom which is not in a terminal position (not at either end). The simplest ketone, called acetone or propanone has three carbon atoms.

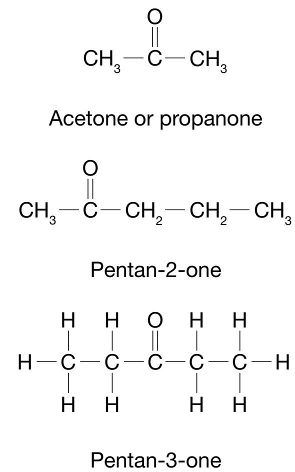


Figure 9.4 Examples of ketones (alkanones).

For IUPAC naming:

1. Choose the longest unbranched chain containing the carbonyl group.
2. Number so that the C with the attached =O has the smallest possible number.
3. Replace the 'e' at the end of the alkane name with 'one'. For example:
   Acetone has 3 carbon atoms and is called propanone.
   Pentanone (with 5 C atoms in the chain) can be pentan-2-one or pentan-3-one depending on the position of the carbonyl group.

QUESTIONS

1. Identify the functional group in aldehydes and ketones.
2. Distinguish between aldehydes and ketones.
3. Name the following substances.
   (a) $CH_3CH_2CH_2COCH_3$
   (b) $CH_3CH_2CH_2CH_2CH_2COCH_3$
   (c) $CH_3CH_2CH_2CHO$
4. Write structural formulas for:
   (a) Butanal.
   (b) Butanone.
   (c) The simplest aldehyde.
   (d) The simplest ketone.

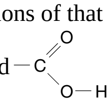
Answers

Module 7 Organic Chemistry

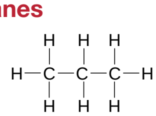
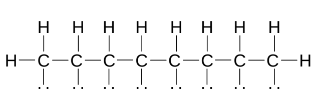
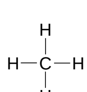
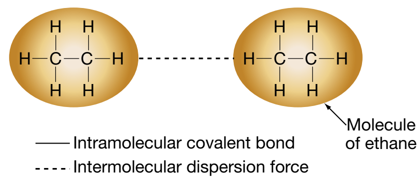
1 The Element Carbon

1. (a) Atomic number 6, group 4, period 2, electron configuration 2.4.
   (b) 4
2. Carbon has four valence electrons; it can bond with other carbon atoms to form rings and chains of carbon atoms; it can form single, double and triple bonds; it can form stable bonds with many other elements.
3. (a) Carbon-carbon bonds are strong, stable covalent bonds. They can be single, double or triple bonds, of which triple bonds are the shortest and strongest.
   (b) A single carbon-carbon bond involves the sharing of 2 valence shell electrons.
   A double bond involves the sharing of 4 (2 pairs) valence shell electrons.
   A triple bond involves 2 carbon atoms sharing 6 (3 pairs) valence shell electrons.
4. (a) Various, e.g. oxygen, nitrogen, sulfur, chlorine, iodine, fluorine, bromine.
   (b) The length of the bond and the difference in electronegativity of the bonding elements.

2 Organic Chemistry

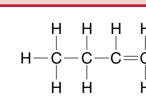
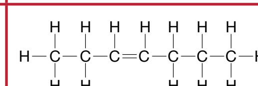
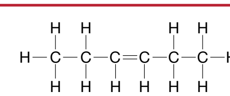
1. (a) Organic chemistry is the study of carbon and its compounds.
   (b) Various, e.g. sucrose, starch, ethanol, glucose, any alkane, e.g. ethane, any alkene, e.g. ethene.
2. August Kekulé and Archibald Couper.
3. (a) A functional group is a specific group of atoms within a molecule that is responsible 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-

3 Hydrocarbons – Alkanes

1. (a) $CH_3CH_2CH_3$ 
   (b) $CH_3(CH_2)_6CH_3$ 
   (c) CH_4 
2. (a) C_2H_6
   (b) C_5H_{12}
   (c) C_6H_{14}
3. (a) Butane
   (b) Heptane
4. (a) C_nH_{2n+2}
   (b) Methane, ethane, propane.
5. (a) Homologous series is a group of carbon compounds which have a general formula and functional group. Alkanes are a series of hydrocarbons with a general formula C_nH_{2n+2} and all alkanes have single C–C bonds as the functional group.
   (b) Various. You may have used model kits or materials such as plasticene or foam balls. Use a diagram to show the 3-D structure of one of the alkanes you modelled.
   (c) 

4 Hydrocarbons – Alkenes

1. (a) C_2H_{2n}
   (b) (i) $C_{11}H_{22}$
   (ii) $C_{34}H_{68}$
   (c) One or more double C=C bonds present in the molecule.
   (d) Alkenes are unsaturated as they contain one or more double C=C bonds; they do not have the maximum number of hydrogen atoms in their molecules.
2. (a) Propene.
   (b) Hex-2-ene.
   (c) Hexene. *Note:* The molecular formula does not indicate the position of the double bond.
   (d) Pent-2-ene.
3. (a) Prop-2-ene does not exist – it would be the same as prop-1-ene, just numbered from the opposite end.

	Molecular formula	Semi-structural formula	Structural formula
(b) But-1-ene	C_4H_8	$CH_3–CH_2–CH=CH_2$	
(c) Hept-3-ene	C_7H_{14}	$CH_3(CH_2)_5CH_3$	
(d) Hex-3-ene	C_6H_{12}	$CH_3CH_2CH=CHCH_2CH_3$	

5 Hydrocarbons – Alkynes

1. (a) C_2H_2
   (b) H−C≡C−H
   (c) Acetylene.
2. (a) Homologous series of hydrocarbons with a triple C≡C bond.
   (b) A bond formed by sharing three pairs of electrons between two atoms.
   (c) Changes from a solid to a gas without becoming a liquid.