1.9 Organic Molecules

Carbon atoms are special – there is a whole field of chemistry set aside for it – called Organic Chemistry. What makes carbon special is that a carbon atom can combine with other carbon atoms to form very complicated and large molecules of great variety. And, in fact, the chemistry of living things is based on organic chemistry.

Here you are going to discover some of the types of organic molecules that are found. And also see that the carbon atoms (C) like to also combine with certain other atoms – hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P) and sulfur (S) in particular. This increases the number of different organic molecules that we know of considerably.

1. Hydrocarbons.
Hydrocarbons are compounds made up of carbons and hydrogens only. There are three groups of hydrocarbons, depending on the type of bonds that are linking the C and H atoms together.

Alkanes
Alkanes are made up of C and H atoms bonded to one another by means of single C-C or C-H bonds only. Each C atom needs 4 atoms attached to it. So the simplest possible alkane is CH4 or methane. The next simplest is H3C-CH3 called ethane.
As simple as these bonds are, a great many different alkanes can be formed because the number and arrangement of the C atoms is almost endless.

Writing structural formulae.

Activity: Modelling See Gr 12 p196

A structural formula shows how the atoms within **organic** molecules are joined together by various (single, double or triple) **chemical** bonds.

(Sometimes the formula shows the 3-dimensional (3) arrangement of the atoms in space as well, but you need not worry about this now).

So, for the simplest alkane, methane, with 1 C atom and 4 H atoms (CH4), the structural formula is:

 H

 H-C-H

 H

For ethane, with 2 C atoms and 6 H atoms the structural formula is:

The condensed structural formula simply tells you how many atoms of each type are present, without showing the bonds between the atoms. These formulae are given in the Table below.

Now make sure that you can name and write the structural formulae for all the molecules up to a 8 C in length as given in the Table below:

|  |  |
| --- | --- |
| Condensed structural formula | Name |
| C1H4 | Methane |
| C2H6 | Ethane |
| C3H8 | Propane |
| C4H10 | Butane |
| C5H12 | Pentane |
| C6H14 | Hexane |
| C7H16 | Heptane |
| C8H18 | Octane |
| CnH2n+2 | General formula |

Interesting facts:

 Alkanes are used as fuels. Butane (C4H10) is used in cigarette lighters, propane (C3H8) is used for cooking and petrol is a mixture of alkanes from C5H12 to C10H22.

This growing family of alkanes is based on the addition of one more C atom to the chain each time. Such a family of closely related molecules is called an homologous series.

If you are smart you might even have noticed a pattern forming: the general formula for an alkane is CnH2n+2. That says for each C in the chain there are twice as many plus 2 H atoms.

The longer the C chain grows the greater the possibility of different configurations (arrangements) of the atoms involved. For example, C4H10 is the formula for butane, but it can also have a different structure as shown below:

Butane Isopropane

These are called **isomers**. They have different structures but the same numbers of different atoms combined.

 As the number of C atoms increases, the number of possible isomers increases. For example, butane (C4H10) has 2 isomers while decane (C10H22) has 75 isomers and C20H42 has 366,319 isomers!

* 1. Alkenes
	Alkenes are closely related to alkanes but there will be at least one C=C double bond in the molecule (This is a double bond between two C atoms). Such molecules containing double bonds are called *unsaturated hydrocarbons* meaning that they do not have the maximum possible number of H atoms present, as is true for alkanes.
	The simplest alkene is ethene:
	 (Insert structure plus structure of ethane for comparison)

	Notice that ethene is very similar to ethane except that there is a double bond between the 2 C atoms. This means that fewer H atoms are present as well because each C atom can only make 4 bonds.

	As the C chain length grows an alkene homologous series is developed.

	The general formula for an alkene is CnH2n.

|  |  |
| --- | --- |
| Condensed structural formula for alkenes | Name (C=C between first and second C atom) |
| C2H4 | Ethene |
| C3H6 | Prop-1-ene |
| C4H8 | But-1-ene |
| C5H10 | Pent-1-ene |
| C6H12 | Hex-1-ene |
| C7H14 | Hept-1-ene |
| C8H16 | Oct-1-ene |
| CnH2n | General formula |

Note: the 1 that has been inserted into the name tells us that the C=C is between the first and second C atom. As the chain gets longer the C=C can be found between other C atoms so the name would need to indicate that. For your purposes now, a double bond between the first 2 C atoms is all that matters.

Activity: Write the structural formula for the alkenes up to C8

* 1. Alkynes
	Alkynes are closely related to alkanes and alkenes but there will be at least one C≡C triple bond in the molecule (This is a triple bond between two C atoms). Such molecules containing triple bonds are also called *unsaturated hydrocarbons* meaning that they do not have the maximum possible number of H atoms present, as is true for alkanes.
	The simplest alkyne is ethyne:
	 (Insert structure plus structure of ethane for comparison)

	Notice that ethyne is very similar to ethane except that there is a double bond between the 2 C atoms. This means only one H atoms is attached to each C atom involved in the triple bond because each C atom can only make 4 bonds.

	As the C chain length grows an alkyne homologous series is developed.

	The general formula for an alkyne is CnH2n-2.

|  |  |
| --- | --- |
| Condensed structural formula for alkenes | Name (C≡C between first and second C atom) |
| C2H2 | Ethyne |
| C3H4 | Prop-1-yne |
| C4H6 | But-1-yne |
| C5H8 | Pent-1-yne |
| C6H10 | Hex-1-yne |
| C7H12 | Hept-1-yne |
| C8H14 | Oct-1-yne |
| CnH2n-2 | General formula |

Note: the 1 that has been inserted into the name tells us that the C≡C is between the first and second C atom. As the chain gets longer the C≡C can be found between other C atoms so the name would need to indicate that. For your purposes now, a triple bond between the first 2 C atoms is all that matters.

Activity: Write the structural formula for the alkynes up to C8

Activity…: Name the following compounds:

1. CH2=CH-CH2-CH2-CH3
2. CH≡C-CH2-CH2-CH3
3. CH3-CH-CH2-CH=CH2
4. CH3- CH2- CH2-CH2-C≡CH

Answers:

1. 1-butene
2. 1-butyne
3. 1-butene
4. 1-pentyne

1. Functional groups

The organic molecules you have been looking at have been made up only of C and H atoms. However, even in these molecules you have seen how differences can occur when double or triple bonds are introduced in place of a single C-C bond. When this happens new reactions become possible for these molecules, so the double and triple bonds change the chemistry of the molecules. They are therefore called **functional groups**.

Definition: **Functional groups** are specific **groups** of atoms or bonds within molecules that are responsible for the characteristic **chemical** reactions of those molecules.

In this course you will be looking at a number of other functional groups as well.

* 1. Alkyl halides
	Alkyl halides are alkanes that contain one or more members of the halogen (Group 18 elements on the Periodic Table) family. The **halogens** found in **organic** molecules are chlorine, bromine, fluorine, and iodine.

	Alkyl halides form when a halogen gas (usually bromine or chlorine)reacts with an alkane and a H atom is replaced by a Cl or a B atom. The reaction usually requires heat for it to take place.

	Here is an example:

	CH3CH3 (g) + Cl2(g) → CH3CH2Cl(g) + HCl(g)
	Ethane gas + Chlorine gas → Chloroethane gas + hydrogen chloride gas

	Alkyl halides form part of a larger group of compounds called organohalogens. (Can you explain why they have that name?). Organohalogens are widely used in the laboratory, in garden and pet products (such as flea and tick killers), domestic insecticides and chloroform.

	Similar reactions can take place between halogens and alkenes or alkynes. In such reactions the H atoms that are replaced are those at the C=C or c≡C bonds.

	For example:

	CH2=CHCH2CH3 (g) + Br2(l) → CH2BrCHBrCH2CH3(l)
	But-1-ene gas + bromine liquid → 1,2-dibromobutane

	Activity: Draw structural formulae for but-1-ene and 1,2-dibromobutane.
	2. Alcohols
	An alcohol functional group is an –OH which can bond with a C atom in an organic molecule in place of an H atom. The two simplest alcohols are methanol and ethanol.

	CH3OH (Methanol) CH3CH2OH (Ethanol)

	You probably know both these liquids: methanol is found in methylated spirits and ethanol is in alcoholic beverages!

	Methanol is sometimes called wood alcohol. It is used as a starting material in the industrial manufacture of many substances such as formaldehyde and acetic acid (vinegar). It is very toxic to human beings – small amounts can cause blindness and larger amounts cause death.

	Ethanol is naturally produced by fermenting grains and sugars and forms the basis of the whole alcoholic beverage industry. Beer contains around 2-4% ethanol while wine contains 8-10% and spirits go much higher.

	Ethanol is also being explored as a renewable and environmentally friendly source of fuel. It is sometimes added to petrol, and it has been used as fuel in some space rockets.
	More complicated alcohols are also widely used. For example, ethylene glycol is used in antifreeze (to prevent freezing) and glycerol is used as a moisturizing agent. Phenol is used in the preparation of nylon, epoxy adhesives and other synthetic resins.

	Naming alcohols
	When the alcohol group (-OH) is at the end of a C chain the chain is named as usual but the ending is changed to –ol. So ethane becomes ethanol, butane becomes butanol etc. If the –OH group is on a different C atom from the end one, the name must include the number of the C in the chain on which the –OH group is found.

	For example:

	butan-2-ol is CH3CHOHCH2CH3

	Activity: Exploring alcohols in household products

Read the labels of household products, at home or at the grocery store and look for alcohols in the ingredients. How would you identify an alcohol from its name?

Draw up a table and add the following information: the product name, the alcohol present, the amount (concentration) of alcohol present. Maybe you could find out what the role of the alcohol is in the product? And maybe the structure of the product?

* 1. Aldehydes
	An aldehyde functional group looks like this:

	 -C-HO

	Aldehyde groups are always located *at the end of a carbon chain*.
	So the simplest adehydes are methanal and ethanal:

	Naming aldehydes
	When the alcohol group (-CHO) is at the end of a C chain the chain is named as usual but the ending is changed to –al. So ethane becomes ethanal, butane becomes butanal etc.
	2. Ketones
	A ketone functional group that is closely related to an aldehyde. However, a ketone is *always located on a C other than one at the end of a carbon chain* and it looks like this:

	 -C=O

	Ketones are found in carbon chains that are at least 3 C atoms long, so the simplest ketone is acetone:

	 CH3-CO-CH3

	Acetone is a colourless liquid with a mild smell. It is used as a solvent in cleaning fluids, paints, rubber cement and as nail polish remover.

	Actone is also a product produced by our bodies under certain circumstances. For example, diabetics, people who are fasting and people eating high protein and high fat diets. If the blood levels of acetone increase enough you can even smell the acetone on the breath of the person. This condition is called ketosis. Ketoacidosis, on the other hand, is a dangerous medical condition. It happens when the blood becomes acidic ([pH](http://en.wikipedia.org/wiki/PH) level drops). This can cause coma and eventually death if not treated. Diabetic ketoacidosis occurs in some patients with Type 1 diabetes and alcohol ketoacidosis occurs in alcoholics.

	Naming ketones
	3. Carboxylic acids
	A carboxylic acid is an organic compound with a –COOH functional group attached to one of the C atoms in the chain. A simple carboxylic acid is ethanoic acid. It has 2 C atoms (like ethane from which it is derived) but one of the C atoms has looks like this: –COOH, instead of like this: -CH3

	So the formula for ethanoic acid can be written in the following different ways:

	 CH3 CO2H, CH3COOH or CH3-C-O-H

	Ethanoic acid is actually the proper name for a substance that you probably know well by a different name: vinegar. It is also sometimes called acetic acid.

	It is used as a preservative (pickling agent). Some carboxylic acids are used in asthma medication.

	Many carboxylic acids are found in the plant and animal kingdom. Another one you might know is butanoic acid which causes the unpleasant flavor in rancid butter.
	4. Esters
	Esters are formed from a combination of a carboxylic acid and an alcohol.

	Look at the following example:

	 Acetic acid + methanol → Methyl acetate

	You can see that the –OH group of the carboxylic acid is replaced by the –O-CH3 of the methanol with the release of water, H2O.

	This kind of reaction is called *esterification*.

	Naming esters

	Activity…: Draw the structures of the following compounds and draw a circle around the functional groups and name the functional groups.

	 a. butanoic acid
	 b. 1-hexyne
	 c.

Many of the fragrances of perfumes and flowers and flavours of fruits are caused by esters. For example, pears are flavoured by propyl acetate, oranges by octyl acetate, pineapple by ethyl butyrate and bananas by pentyl acetate. These compounds can be made synthetically and they are then used in the soft-drink and confectionary industry. Those from flowers are used in the perfume industry.
Esters are also used in the manufacture of soaps and detergents, as organic solvents and in the manufacture of plastics.

Basic rules for naming simple organic molecules

**Rules for naming alkanes, branched alkanes and cyclic alkanes**

1. Find the longest continuous chain of carbon atoms that includes the carbon carrying the functional group. The number of carbon atoms in this chain determines the major part of the name (parent). For straight alkanes this is the final name. It will always have the suffix –ane e.g. pentane for CH3-CH2-CH2-CH2-CH3
2. For branched alkanes
	1. Find the number of C atoms in the longest unbranched chain. This gives the parent name.
	2. Number the C atoms in the this part of the molecule from the end that gives the C carrying the branched alkyl group the lowest possible number. This gives the prefix to use in the name.
	3. Name the alkyl group attached to the C in the main chain.
	4. Assemble the name of the branched alkane as follows:
		1. Write down the prefix found in 2. above, followed by a hyphen, e.g. 3-
		2. Add the name of the alkyl group e.g. 3-methyl
		3. Attach the parent portion of the name, with the suffix –ane e.g. 3-methylhexane for CH3-CH2-CH-CH2-CH2-CH3 CH3
3. To name cyclic alkanes, count the number of carbon atoms in the ring and name as for the straight chain alkane (See 1. above). Now attach the prefix cyclo e.g. cyclohexane for (Insert diagram please)

2.3 **Naming of alkenes and alkynes**

As with the naming of alkanes there is a systematic way in which the alkenes and alkynes are named. The double (or triple) bond can be located between any two carbon atoms in the carbon chain. Included in the name, therefore, one must indicate the position of the multiple bond.

Consider the following alkane: CH3-CH2-CH2-CH2-CH3

Since it contains 5 carbon atoms it is called pentane

A related alkene would have the following formula: CH2=CH-CH2-CH2-CH3

This molecule still contains 5 carbon atoms but it also contains a double bond, located between the first and second carbon atoms of the chain. It is therefore called

1-pentene. The number (1 in this case) indicates the position of the double bond.

If the double bond is located between the second and third carbons of a 5-carbon chain the molecule would be called 2-pentene.

**Ask yourselves:**
Name the following compounds:

1. CH2=CH-CH2-CH2-CH3
2. CH3-CH=CH-CH2-CH3
3. CH3-CH2-CH=CH-CH3
4. CH3-CH2-CH2-CH=CH2

**Suggested answers:**

* 1. CH2=CH-CH2-CH2-CH3 1-pentene
	2. CH3-CH=CH-CH2-CH3 2-pentene
	3. CH3-CH2-CH=CH-CH3 2-pentene
	4. CH3-CH2-CH2-CH=CH2 1-pentene

Note: Ensure that the learners understand that example d. is a mirror image of example a. and therefore is the same molecule, carrying the same name. Similarly for examples b. and c.

Now consider the following formula: CH≡CH-CH2-CH2-CH3

This molecule also contains 5 carbon atoms but now it contains a triple bond, located between the first and second carbon atoms of the chain. It is therefore called

1-pentyne.

**Ask yourselves:**

Name the following compounds:

1. CH≡C-CH2-CH2-CH3
2. CH3-C≡C-CH2-CH3
3. CH3-CH2-C≡C-CH3
4. CH3-CH2-CH2-C≡CH

**Suggested answers:**

1. CH≡C-CH2-CH2-CH3 1-pentyne
2. CH3-C≡C-CH2-CH3 2-pentyne
3. CH3-CH2-C≡C-CH3 2-pentyne
4. CH3-CH2-CH2-C≡CH 1-pentyne

Note: Again, ensure that the learners understand that example d. is a mirror image of example a. and therefore is the same molecule, carrying the same name. Similarly for examples b. and c.

**IUPAC Rules for Naming Organic Compounds

Alkenes and alkynes**

1. Find the longest continuous chain of carbon atoms that contains a multiple bond. The number of carbon atoms in this chain determines the major part of the name (also called the parent). For example, for a 4-C chain the name would be butene (for an alkene – C=C) and butyne (for an alkyne - C≡C)
2. Number the C atoms in the chain starting at the end closest to the multiple bond. Take the number of the first C in the bond, and attach it as a prefix to the name decided on in the previous step to indicate the position of the multiple bond e.g. 2-pentyne for CH3-C≡C-CH2-CH3

 **Rules for naming alkanes carrying other functional groups**

**Alkyl halides**

1. Find the longest continuous chain of carbon atoms to determine the parent name of the compound e.g. 5 C chain would be pentan…. Now find the C atoms carrying halogen atoms. Number the parent chain C from the end that reaches the first halogen atom soonest. For example in a 5C chain halogens can be on C-1, C-2 or C-3 (C-4 would be C-2 if counted from the other end).
Consider the following formula: CH3CHClCHClCH2CH3. The name of this compound would then be 2,3-dichloropentane
And for CH3CH2CHClCHClCH3 the name would also be 2,3-dichloropentane (and NOT 3,4-dichloropentane)

**Alcohols**

1. Find the longest continuous chain of carbon atoms that includes the carbon carrying the alcohol group. The number of carbon atoms in this chain determines the parent name. Now add to the parent name -anol e.g. ethanol for CH3CH2OH. This would be the full name if the alcohol group it attached to a terminal (at one end) C atom.
2. If the alcohol group is attached to a non-terminal C atom, number the C atoms in the chain from the end that gives the C carrying the alcohol group the lowest possible number. This gives the prefix to use in the name e.g. 2-butanol says that the –OH group is on the second C atom of a 4-C chain - OH
 CH3-CH-CH2-CH3

**Aldehydes**

1. Find the longest continuous chain of carbon atoms that includes the carbon carrying the aldehyde group. The number of carbon atoms in this chain determines the parent name. Now add to the parent name the suffix -al e.g. ethanal for CH3CHO
(Note: Make sure that the carbon chain is numbered in such a way that the aldehyde group is always attached to carbon number 1).

**Ketones**

1. Many ketones are still given their common names, such as acetone. However the preferred rules for naming are as follows:
	1. Find the number of carbon atoms in the longest carbon chain that includes the carbonyl group. This gives the parent name. Now add the suffix –anone to the parent e.g. butanone for CH3-CO-CH2-CH3
	2. Number the carbons such that the C atom of the carbonyl group is its lowest possible value, and use this as a prefix to indicate the position of the carbonyl (ketone) group e.g. 3-pentanone for CH3-CH2-CO-CH2-CH3

**Carboxylic acids**

1. Find the longest continuous chain of carbon atoms that includes the carbon carrying the carboxylic acid group. The number of carbon atoms in this chain determines the parent name. Now add to the parent name -anoic acid e.g. ethanoic acid for CH3-CH2-COOH.
(Note: Make sure that the carbon chain is numbered in such a way that the carboxyl group is always attached to carbon number 1).

**Esters**

1. To name esters one names the part of the molecule derived from the acid using the parent name and attaching the suffix –anoate e.g. ethanoate from ethanoic acid.
2. The part of the molecule derived from the alcohol is given the name of the parent with the suffix –yl attached e.g. methyl. O
3. Join the two parts of the name as shown in the following example: methyl ethanoate for CH3-O-C-CH3

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