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ORGANIC CHEMISTRY

Organic chemistry is the chemistry of carbon and its compounds. Carbon-containing minerals such as carbonates are not regarded as organic compounds. Carbon is the most plentiful element on earth. It occurs in all living things such as plants and animals.

1 Basic definitions

There are some basic terms that need to be defined so that we may discuss specific types of compounds meaningfully.

Hydrocarbons are compounds that contain only carbon and hydrogen atoms.

Examples of hydrocarbons are methane – CH_4 and butane – C_4H_{10} .

Carbon is tetravalent (has a valency of 4) and forms 4 bonds with other atoms. Carbon atoms can form multiple bonds (double or triple) with other atoms including carbon atoms. When a carbon atom bonds with four other atoms, the bonds formed can only be single bonds. Such compounds are said to be saturated.

A **saturated compound** is a compound in which all the bonds between carbon atoms are single bonds.

Compounds which contain multiple bonds between carbon atoms are said to be unsaturated.

An **unsaturated compound** is a compound in which there is at least one double or triple bond between carbon atoms.

The way in which organic compounds react depends on their functional group.

A **functional group** is an atom or group of atoms that forms the centre of chemical activity in a compound.

Various groups of compounds such as the alkanes and alkenes form a series called a homologous series.

A **homologous series** is a series of compounds which have the same general formula and functional group but which differ from each other by $-\text{CH}_2$.

The table below gives the functional groups that you need to be able to identify when they appear in compounds:

Homologous series	Functional group	
	Structure	Name/description
Alkanes	$\begin{array}{c} \\ -\text{C}- \\ \end{array}$	saturated hydrocarbon
Alkenes	$\begin{array}{c} \quad \\ -\text{C}=\text{C}- \end{array}$	carbon-carbon double bond
Haloalkanes	$-\text{X} \text{ where } \\ \text{X} = \text{F, Cl, Br} \\ \text{or I}$	halogen atom bonded to a carbon atom
Alcohols	$-\text{O}-\text{H}$	hydroxyl group
Carboxylic acids	$\begin{array}{c} \text{O} \\ \\ -\text{C}-\text{O}-\text{H} \end{array}$	carboxyl group
Esters	$\begin{array}{c} \text{O} \\ \\ -\text{C}-\text{O}- \end{array}$	ester group

2 IUPAC naming

The IUPAC system of naming organic compounds is a universal system of naming, to ensure that everybody names compounds in the same way. There are rules that need to be followed when naming organic compounds:

1. Find the longest continuous chain of carbon atoms containing the functional group and write down its name. This is the parent name of the chain.

Carbon chains of various lengths have the following names:

Number of carbon atoms	Name of prefix
1	meth-
2	eth-
3	prop-
4	but-
5	pent-
6	hex-
7	hept-
8	oct-

- Locate where the side chains are bonded to the parent chain by numbering the carbon atoms on the longest chain in such a way that they give the lowest possible combination of numbers.
- Name the side chains and write them down in **alphabetical order** in front of the name of the parent chain. The side chains are **alkyl chains** and must follow the naming accordingly.

alkane		alkyl	
CH ₄	methane	-CH ₃	methyl
C ₂ H ₆	ethane	-C ₂ H ₅	ethyl
C ₃ H ₈	propane	-C ₃ H ₇	propyl

- If more than one of the same side chains occurs in a molecule, the number of identical side chains is indicated by the prefix di-(2), tri-(3) or tetra- (4).
- In molecules that contain functional groups, the position of the functional group on the parent chain must be indicated. The functional group must have the lowest number, even if this results in higher number combinations of the side chains. This is not applicable to carboxylic acids, where the functional group is always on the end and to esters, which are named according to the carbon chains on either side of the functional group.

3 Formulae

There are 3 different types of formulae that used in organic chemistry:

- molecular formulae
- condensed structural formulae
- structural formulae

The table on the next page shows how these differ.

Molecular	Condensed structural	Structural
A molecular formula shows the number of atoms of each element present in the molecule, but tells us nothing about how they are bonded.	A condensed structural formula indicates how the carbon atoms are placed in relation to one another, but does not necessarily show any bonds.	All individual atoms are shown and all the bonds between them are indicated by lines (Couper notation).
C_3H_8O	$CH_3CH_2CH_2OH$	<pre> H H H H — C — C — C — O — H H H H </pre>

4 Isomers

When molecules contain more than 3 carbon atoms, there is more than one possible way of arranging the carbon atoms in relation to one another. Each possible arrangement is called an isomer of the compound or molecule.

Structural isomers are compounds having the same molecular formula but different structural formulae.

We will only consider the following types of structural isomers:

Chain isomers have the same molecular formulae but a different arrangement of carbon atoms, i.e. branching.

Positional isomers have the same molecular formula but the position of the functional group on the parent chain differs.

Functional isomers have the same molecular formula but have different functional groups.

5 The alkanes

The general formula of the alkanes is C_nH_{2n+2} .

The alkanes are saturated hydrocarbons, which means that they contain only single bonds between carbon atoms. Some of the physical properties of the alkanes are:

- they are not soluble in water
- short chain alkanes are gases at room temperature
- carbon chains of length 5 carbons up to 15 carbons are liquids
- long chain alkanes (above 15 carbons) are solids

An explanation for the fact that they are insoluble in water is simply that water is a polar substance and alkanes are non-polar substances.

The explanation for the respective phases of the various alkanes at room temperature is a little more complicated. It lies in the fact that the intermolecular forces between the molecules of alkanes increase in strength as the carbon chains increases in length. In the block below is a typical detailed explanation for this relationship.

Why do the melting points and boiling points of alkanes increase with increasing length of the carbon chain?

- The intermolecular forces between all alkane molecules are London forces.
- An increase in the number of carbon atoms in the carbon chain means the electron clouds around the molecules become larger (more electrons).
- The larger the electron cloud the more distortion occurs in it.
- This results in stronger and more frequent temporary dipoles between the molecules. The London forces thus become stronger.
- This means that more energy is required to separate the molecules and hence the higher m.p. and b.p.

There is a similar explanation for the fact that unbranched alkanes have higher melting and boiling points than their branched chain isomers.

Why do unbranched chains of isomers of alkanes have higher melting and boiling points than branched isomers?

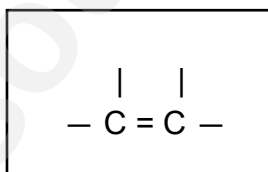
- The intermolecular forces between all alkane molecules are London forces.
- Unbranched (straight chain) isomers have a longer carbon chain and have a larger surface area along which the chains of unbranched isomers can make contact.
- Over and above greater distortion there are also more temporary dipole attractions and so stronger London forces.
- This means that more energy is required to separate the molecules and hence the higher m.p. and b.p.

7 The alkenes

The general formula for the alkenes is C_nH_{2n} .

The physical properties of the alkenes are like those of the alkanes. The explanations for the varying physical properties are also the same.

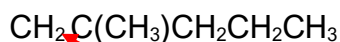
The functional group of the alkenes is:



When naming the alkenes, the position of the functional group i.e. the double bond must be indicated. Here are examples:



- firstly, note that the molecular formula is C_5H_{10} , so it is an alkene
- the double bond is between carbons 2 and 3
- there are 5 carbons, so the IUPAC name is pent-2-ene

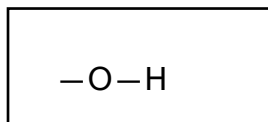


- the molecular formula is C_6H_{12} , so it is an alkene
- the double bond is between carbons 1 and 2

- there are 5 carbons in the main chain and one methyl side chain on carbon 2 (in brackets) so the name is 2-methylpent-1-ene

8 Alcohols (Alkanols)

The functional group of the alcohols is



This functional group is called the **hydroxyl group**.

Alcohols have higher melting points and boiling points than the alkanes or alkenes. This occurs because the predominant intermolecular forces in the shorter chain alcohols are hydrogen bonds which are stronger than London forces.

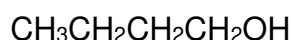
So, if we need to explain why propanol has a higher melting and boiling point than propane, the answer is as follows:

Why do alcohols have higher melting and boiling points than alkanes or alkenes with the same number of carbon atoms?

- The intermolecular forces between alkane and alkenes molecules are London forces.
- The predominant intermolecular forces between alcohol molecules are hydrogen bonds.
- Hydrogen bonds are stronger than London forces.
- This means that more energy is required to separate the molecules of alcohols and hence the higher m.p. and b.p.

When naming alcohols, the alkane name is used but the suffix changes to -ol. The position of the -OH group must also be indicated.

Examples:



- it is a 4 carbon chain
- the functional group takes preference in the numbering
- the name of the compound is **butan-1-ol**

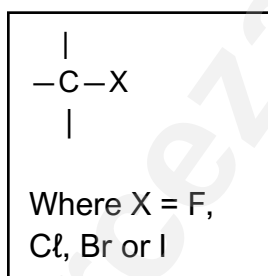


- this is also a 4 carbon chain
- the -OH group in this case is on carbon number 2 (note that there are as many hydrogen atoms in an alcohol as there are in an alkane)
- The name of the compound is **butan-2-ol**

9 Haloalkanes

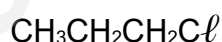
These compounds are halogen derivatives of the alkanes or alkenes. They can be formed by **substitution reactions of the alkanes** or by **addition reactions of the alkenes**.

The functional group is:



When naming the haloalkanes, the halogen's name comes first, ending in an -o and then the alkane name. The position of the halogen atom(s) must be indicated.

Examples:



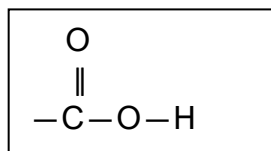
- there is a 3 carbon chain
- there is a chlorine atom on carbon number 1
- the name of the compound is **1-chloropropane**



- this is a 4 carbon chain
- there is a chlorine atom on carbons number 2 and 3
- the name of the compound is **2,3-dichlorobutane**

10 Carboxylic acids

The functional group of the carboxylic acids is the **carboxyl group**.

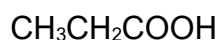


The carboxyl functional group is always at one end of the acid molecule.

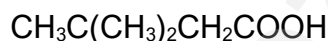
These acids are weak acids but display all the properties of inorganic acids.

When naming organic acids, the -e is dropped from the end of the alkane name and replaced with the suffix -oic and the word acid.

Examples:



- this is a 3 carbon chain
- the name of this compound is **propanoic acid**

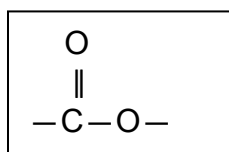


- the longest carbon chain is a 4 carbon chain
- there are 2 methyl side chains
- numbering starts at the carbon of the functional group
- the name of this compound is **3,3-dimethylbutanoic acid**

11 Esters

These are very sweet-smelling compounds, which are made from the reactions of carboxylic acids with alcohols. All fruit flavours are due to esters as well as perfumes and many other sweet-smelling compounds in foods.

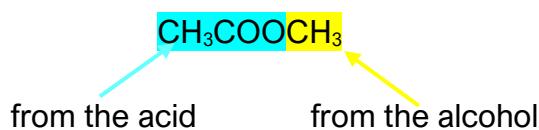
The functional group of the esters is known as the **ester group**.



This functional group is always in the body of a compound and never on the end of an ester.

When naming an ester, the two parts on either side of the functional group are named separately. In the name, the alkyl group (the part that came from the alcohol), is always named first. The acid name follows but the suffix is changed to -oate.

Examples:



- the name of this compound is **methylethanoate**

12 Organic chemical reactions

Many organic compounds are flammable liquids and should be heated with care preferably in a **water bath**. The fact that they are flammable also makes them suitable as fuels.

Combustion (oxidation) reactions

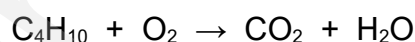
Combustion is the process whereby organic compounds react with oxygen and release lots of energy during the reaction. Fossil fuels are organic compounds that are of vital importance in today's world.

You need to be able to write balanced chemical equations for the combustion of alkanes, alkenes, and alcohols. The products of combustion in excess oxygen, i.e. complete combustion, are carbon dioxide and water.

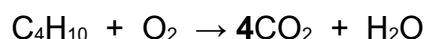
Balance equations in the following way:

Example 1

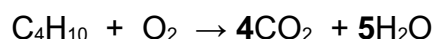
Write down a balanced molecular chemical equation for the complete combustion of butane.



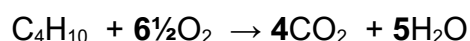
- balance the carbon atoms



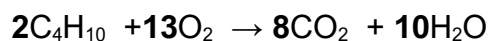
- now balance the hydrogen atoms



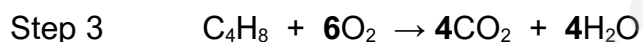
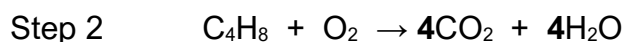
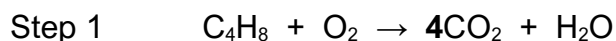
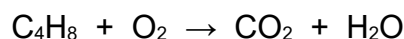
- lastly balance the oxygen atoms



- if there is an uneven number of oxygen atoms on the products side at this stage, balance the reactants oxygen using a multiple of $\frac{1}{2}$ and then multiply the whole equation by 2

**Example 2**

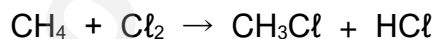
Write down a balanced molecular chemical equation for the complete combustion of butene.

**Substitution reactions**

These reactions are typical of saturated compounds.

1 **Halogenation (free-radical halogenation)**

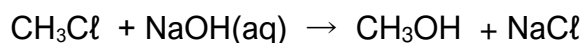
This converts **alkanes to haloalkanes**, e.g.



Condition: UV light or heat

2 **Hydrolysis**

This converts **haloalkanes to alcohols**, e.g.



Conditions: heat under reflux in a dilute alkali solution.

3 **Conversion of an alcohol to a haloalkane**



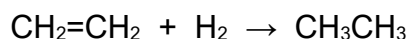
Condition: in acid medium

Addition reactions

These reactions are typical of UNsaturated compounds.

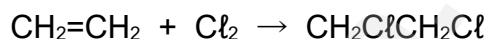
You must be familiar with the following **specific types** of reactions:

- 1 **Hydrogenation** – this is the addition of H_2 to an alkene, e.g.



Condition: Pt or Ni catalyst at high pressure

- 2 **Halogenation** – this is the addition of X_2 (where $X = Cl$ or Br), e.g.



- 3 **Hydrohalogenation** – this is the addition of HX to any alkene, e.g.



Condition: no water present

- 4 **Hydration** – addition of H_2O to any alkene, e.g.

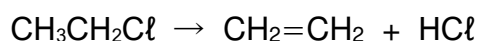


Conditions: use steam and a hot suitable catalyst such as H_3PO_4 (phosphoric acid)

Elimination reactions

You must be familiar with the following **specific types** of reactions:

- 1 **Dehydrohalogenation** – this is the elimination of HX from any haloalkane, e.g.



Conditions: hot concentrated solution of KOH or $NaOH$ (strong alkali) in ethanol, i.e. no water

- 2 **Dehydration** – this is the elimination of H₂O from any alcohol, e.g.



Conditions: acid catalysed dehydration. i.e. heating of the alcohol (in a water bath) with an excess of concentrated H₂SO₄ or H₃PO₄

- 3 **Cracking of hydrocarbons** – this is the breaking up of long chain hydrocarbon molecules into smaller molecules.

There are two ways in which cracking is carried out. The **conditions** are:

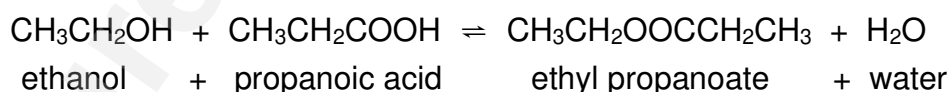
Thermal cracking is carried out at high temperatures and high pressures without a catalyst.

Catalytic cracking is carried out at lower temperatures and pressures in the presence of a catalyst.



The products are an alkane and an alkene. The number of carbon and hydrogen atoms on either side of the equation must balance.

Condensation (esterification) reactions – these are reactions between carboxylic acids and alcohols to form esters: e.g.



Conditions: H₂SO₄ as a catalyst (and dehydrating agent) and light heating.

13 Summary of reactions

Main reaction type	Occurs with	Reactants/products	Conditions
Combustion	Hydrocarbons/ alcohols	2 reactants; 2 products	
Substitution Specific types:	Saturated compounds to form saturated compounds	2 reactants; 2 products	
Halogenation	Alkanes to form haloalkanes		UV light or heating
Hydrolysis	Haloalkanes to form alcohols		Heat under reflux in dilute alkali medium
	Alcohols with a hydrogen halide to form haloalkanes		In acid medium
Addition Specific types:	Unsaturated compounds to form saturated compounds	2 reactants; 1 product	
Hydrogenation	H ₂ to an alkene		Under pressure, Ni or Pt catalyst
Halogenation	A halogen to an alkene		
Hydration	Water to an alkene		Steam and hot H ₃ PO ₄ as catalyst
Hydrohalogen- ation	Hydrogen halide to an alkene		No water present
Elimination reactions Specific types:	Saturated compounds to form unsaturated compounds	1 reactant: 2 products	
Dehydrohalog- enation	Haloalkanes to form alkenes		Hot concentrated KOH or NaOH in ethanol
Dehydration	Elimination of water from an alcohol		Heat in ethanol with excess conc. H ₂ SO ₄ or H ₃ PO ₄
Cracking	Splitting large hydrocarbons into smaller ones		Thermal or catalytic
Condensation	Acid + alcohol to form esters		Concentrated H ₂ SO ₄ as catalyst, slight warming