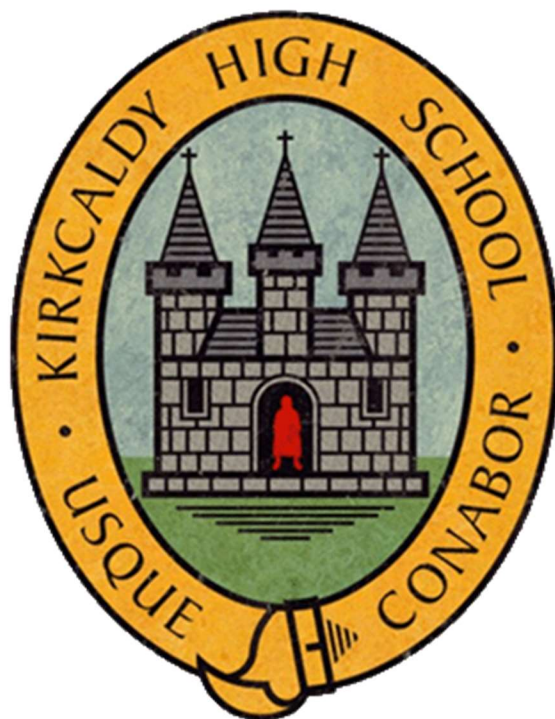


Kirkcaldy High School



Chemistry

Higher

Unit 2 - Nature's Chemistry

NOTES

Course Overview

Contents

The Higher Course is split into three units. *Italic* shows the contents of this notes booklet.

Unit 1 - Chemical Changes in Structure

- (a) Periodicity
- (b) Structure and Bonding
- (c) Oxidising and Reducing Agents

Unit 2 - *Nature's Chemistry*

- (a) *Systematic Carbon Chemistry* page 3
- (b) *Alcohols* page 7
- (c) *Carboxylic Acids* page 10
- (d) *Esters, Fats, and Oils* page 12
- (e) *Soaps, Detergents, and Emulsions* page 18
- (f) *Proteins* page 21
- (g) *Oxidation of Food* page 25
- (h) *Fragrances* page 32
- (i) *Skin Care* page 34

Unit 3 - Chemistry in Society

- (a) Getting the Most from Reactants
- (b) Controlling the Rate
- (c) Chemical Energy
- (d) Equilibria
- (e) Chemical Analysis

Unit 4 - Researching Chemistry

- (a) Common Chemical Apparatus
- (b) General Practical Techniques
- (c) Reporting Experimental Work

Assessment

- There is a **final exam** for Higher Chemistry. It is split into **two papers**:
 - Paper 1: Multiple Choice, 25, marks, 40 mins
 - Paper 2: Written Answers, 95, marks, 2 h 20 min
 - 75 marks of written answer questions
- There is an **Assignment** (essay on a Chemistry topic) to write for National 5 Chemistry.
 - The Assignment is **externally marked** by an SQA marker (NOT your teacher)
 - The Assignment contains **20 marks**, but these are scaled to 30 marks such that the assignment is worth 20 % of the total marks.
 - You have unlimited **time to research** and gather data for your Assignment.
 - You can **2 h** to write the Assignment.

(a) Systematic Carbon Chemistry

Alkanes

Names end in -ane

Start of name represents the number of carbon atoms (these names are also given in the data booklet page 9)

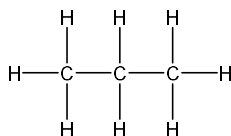
Number of carbons	Name
1	Methane
2	Ethane
3	Propane
4	Butane
5	Pentane
6	Hexane
7	Heptane
8	Octane

They are saturated - the carbon to carbon bonds are all single bonds

General formula: C_nH_{2n+2}

e.g. Propane

- Full structural formula:



- Shortened structural formula: $CH_3CH_2CH_3$
- Molecular formula: C_3H_8

Branched Chained Structures - Systematic Naming Rules:

The longest chain is the main chain and the last part of the name.

Numbering of the main chain starts from the end that gives the lower overall number position for side groups (branches).

Side branch names end in 'yl' and depend on the number of carbon atoms in them: methyl for 1 carbon, ethyl for 2 carbons, propyl for 3 carbons, etc.

Prefixes 'di', 'tri' etc... are used when the same branch is present more than once

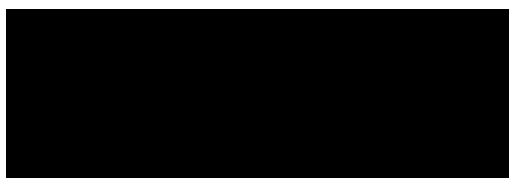
Alphabetical order is used if different side branches appear in the same structure e.g. ethyl before methyl

Hyphens are used before or after numbers that come next to letters within a name e.g. 2-ethyl-3-methyl.....

Commas are used between numbers if there is more than one of the same side branch e.g. 2,3,3-trimethyl..... (remember if there are 2 branches on one carbon you must write the position number twice)

e.g. 3-methylpentane

- Full structural formula:



- Shortened structural formula: $\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$
- Molecular formula: C_6H_{14}

Branches are shown in brackets

Straight chained and branched chained alkanes are isomers of each other

Alkenes

Names end in -ene

Start of name represents the number of carbon atoms (some of these names are also given in the data booklet page 9)

Number of carbons	Name
2	Ethene
3	Propene
4	Butene
5	Pentene
6	Hexene
7	Heptene
8	Octene

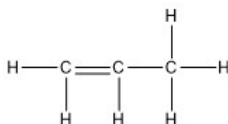
Alkenes are made up of chains of carbon atoms that contain at least one double bond

They are unsaturated - this means that the molecule contains at least one double (or triple) carbon to carbon bond

General formula: C_nH_{2n}

e.g. Propene

- Full structural formula:



- Shortened structural formula: $\text{CH}_2=\text{CHCH}_3$
- Molecular formula: C_3H_6

Naming

When naming alkenes the position of the double bond **MUST** be given

Numbering of a molecule starts at the end closest to the double bond - the double bond takes priority over branches

e.g. 4-methylpent-2-ene

The number for the double bond is the number of the carbon where the bond starts

e.g.

But-1-ene

But-2-ene



These structures are isomers of each other as the double bond is in a different position

Isomers

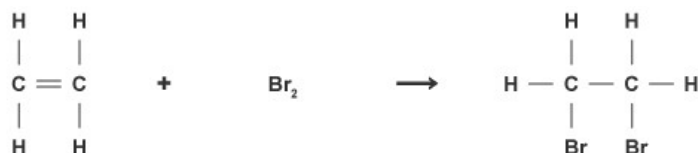
Isomers are compounds with the same molecular formula but different structural formulae. Isomers may belong to a different homologous series and usually have different physical properties.

Addition reactions

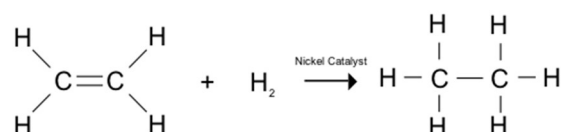
The chemical test for unsaturation - a double bond (e.g. an alkene) is it decolourises bromine water
Alkenes undergo addition reactions: the addition of a small molecule across a double bond.

e.g.

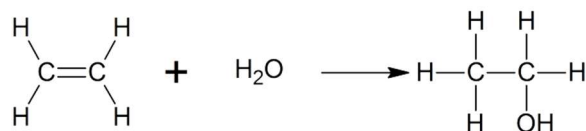
Alkene + Bromine (Br₂) → dibromoalkane (bromination)



Alkene + Hydrogen (H₂) → Alkane (hydrogenation)



Alkene + Water (H₂O) → Alcohol (hydration)



Other small molecules include HX (X = halogen) e.g. HBr, HCl, HI

Summary:

Homologous Series	General Formula	Saturated or Unsaturated	Decolourises bromine?
Alkanes	C _n H _{2n+2}	Saturated	No
Alkene	C _n H _{2n}	Unsaturated	Yes

Physical Properties

A physical property is something that can be observed and measured (e.g. boiling point and melting point).

As alkanes, alkenes or cycloalkanes increase in size (increase in number of carbon atoms) there is a gradual increase in the melting points and boiling points.

Molecules with more carbons have **stronger forces of attraction between the molecules** therefore it takes more energy to separate these molecules. These molecules have stronger **intermolecular forces**.

(b) Alcohols

Homologous series with a similar chemical structure to alkanes however one of the hydrogen atoms is replaced with an -OH group.

Functional group = **Hydroxyl group** (-OH group)

Name ends in -ol

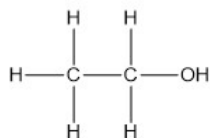
Start of name represents the number of carbon atoms (some of these names are also given in the data booklet pg 9)

Number of carbons	Name
1	Methanol
2	Ethanol
3	Propan-1-ol
4	Butan-1-ol
5	Pentan-1-ol
6	Hexan-1-ol
7	Heptan-1-ol
8	Octan-1-ol

General formula: $C_nH_{2n+2}O$ or $C_nH_{2n+1}OH$

e.g. Ethanol

- Full structural formula:



- Shortened structural formula: $\text{CH}_3\text{CH}_2\text{OH}$
- Molecular formula: $\text{C}_2\text{H}_5\text{OH}$ or $\text{C}_2\text{H}_6\text{O}$

Naming

The position of the OH group **MUST** be stated. The number carbon the OH is attached to goes in front of the -ol in the name, the lowest possible number is used:

e.g.

These structures are isomers as the OH is in a different position.

Types of alcohols

Alcohols can be divided into 3 types depending on the position of the -OH. The three types are primary, secondary and tertiary.

Type	Primary	Secondary	Tertiary
Position of -OH	Joined to the end of the carbon chain (attached to carbon with 1 other carbon bonded)	Joined to an intermediate carbon atom (attached to a carbon with 2 other carbons bonded)	Joined to an intermediate carbon atom which also has a branch attached (attached to a carbon with 3 other carbons bonded)
Characteristic group of atoms	$\begin{array}{c} \text{H} \\ \\ \text{R}-\text{C}-\text{H} \\ \\ \text{OH} \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{R}-\text{C}-\text{R}^1 \\ \\ \text{OH} \end{array}$	$\begin{array}{c} \text{R}^2 \\ \\ \text{R}-\text{C}-\text{R}^1 \\ \\ \text{OH} \end{array}$

Properties of alcohols

Alcohols containing two hydroxyl groups are called diols.

Alcohols containing three hydroxyl groups are called triols.

Name	Full structural formula	Systematic name
glycol (diol)	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$	Ethane-1,2-diol
glycerol (triol)	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$	Propane-1,2,3-triol

As the number of hydroxyl groups increases the boiling points tend to increase. This is because hydroxyl groups are polar, and this leads to more hydrogen bonding hence more energy is needed to break them. Remember stronger intermolecular forces mean higher melting points, increased viscosity (thickness) and increased solubility in water.

(c) Carboxylic Acids

Functional group = Carboxyl group (-COOH group)

Name ends in -oic acid

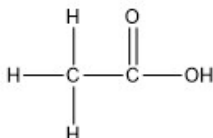
Start of name represents the number of carbon atoms (some of these names are also given in the data booklet pg 9)

Number of carbons	Name
1	Methanoic acid
2	Ethanoic acid
3	Propanoic acid
4	Butanoic acid
5	Pentanoic acid
6	Hexanoic acid
7	Heptanoic acid
8	Octanoic acid

General formula: $C_nH_{2n}O_2$

e.g. Ethanoic acid

- Full structural formula:



- Shortened structural formula: CH_3COOH
- Molecular formula: $\text{C}_2\text{H}_4\text{O}_2$

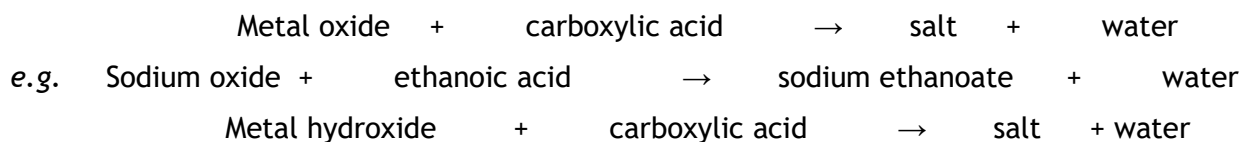
Naming

When naming the -COOH carbon **MUST** be counted as one of the carbons

When numbering the -COOH carbon is always carbon 1

Carboxylic acids reactions

Carboxylic acids can react with bases:



e.g. Sodium hydroxide + methanoic acid → sodium methanoate + water

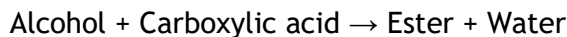
Metal carbonate + carboxylic acid → salt + water + carbon dioxide

e.g. Calcium carbonate + propanoic acid → calcium propanoate + water + carbon dioxide

(d) Esters, Fats and Oils

Esters

Esters are formed by reacting an alcohol with a carboxylic acid. This is known as an esterification reaction which is an example of a condensation reaction (two molecules are joined with the elimination of a small molecule - water).



Alcohols contain the functional group -OH (hydroxyl group) and are characterised by the name ending in -ol

Carboxylic acids contain the functional group -COOH (carboxyl group) and are characterised by the name ending in -anoic acid.

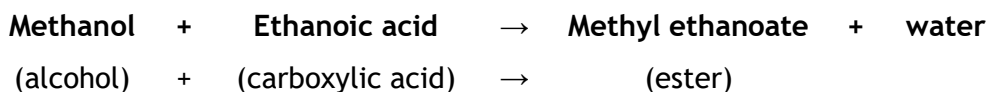
Esters contain the functional group -COO- (ester link).

Naming Esters

The first part of the name comes from the alcohol and ends in '-yl'

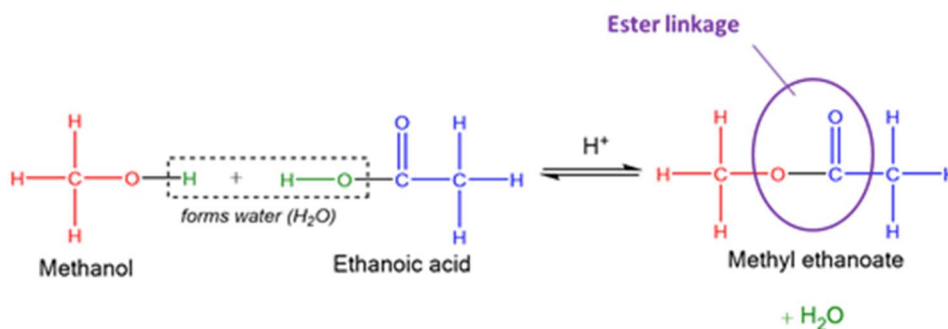
The second part of the name comes from the carboxylic acid and ends in '-oate'

e.g.

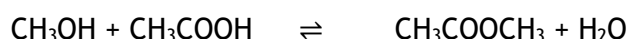


Drawing Esters

The rate of reaction is increased by heating the reaction mixture and using concentrated sulphuric acid as a catalyst (H^+ ions). The reaction is reversible.

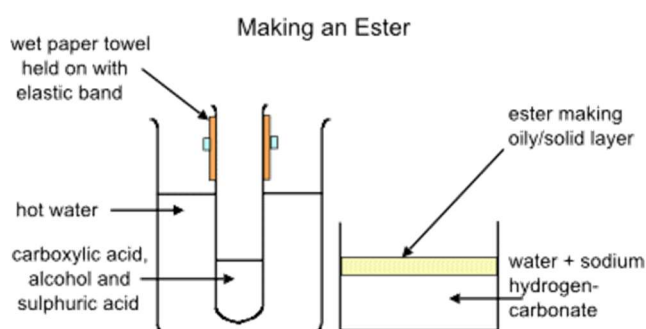


Shortened Structural Formula:



Making Esters - Condensation reaction

- Esters are made in a lab by the condensation reaction between an alcohol and a carboxylic acid.
- Equal quantities of the reactants (alcohol and carboxylic acid) are added to a test tube.
- Concentrated sulphuric acid is added as a catalyst.
- A wet paper towel is put around the top of the test tube to act as a condenser.
- The tube is placed in a beaker of hot water/water bath (not heated with a Bunsen since alcohols are flammable).
- Reaction mixture is poured onto sodium hydrogen carbonate solution to neutralise the concentrated sulphuric acid and any unreacted carboxylic acid.
- Evidence the ester has formed: 1) distinct smell 2) two layers are formed



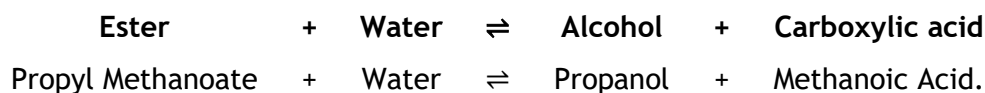
Uses of Esters

Esters are used as flavourings and fragrances as many have pleasant, fruity smells. Esters are also used as solvents for non-polar compounds that do not dissolve in water. (Remember, like dissolves like, therefore esters are also non-polar).

Hydrolysis of Esters

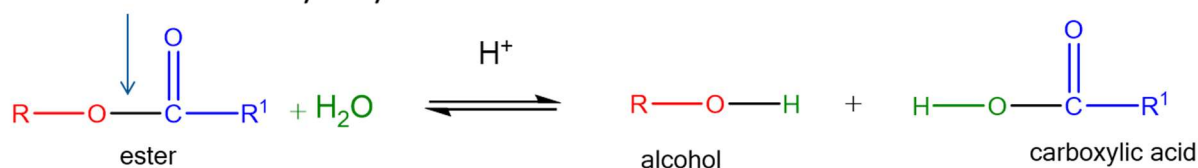
The reaction between a carboxylic acid and an alcohol to make an ester is reversible.

In hydrolysis reactions large molecules are broken down into smaller molecules by reaction with water.
e.g.



Hydrolysis is the opposite to condensation. The C-O bond formed when an ester is made is broken when an ester is hydrolysed.

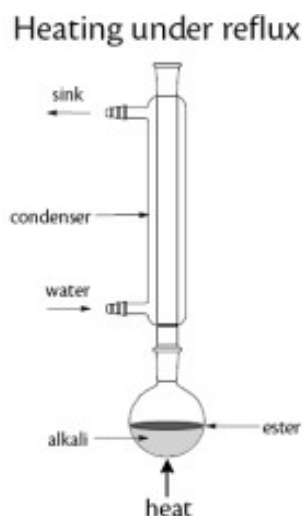
Bond that is broken in hydrolysis



Acid catalysed (H^+) hydrolysis is reversible. Alkali catalysed hydrolysis is not reversible.

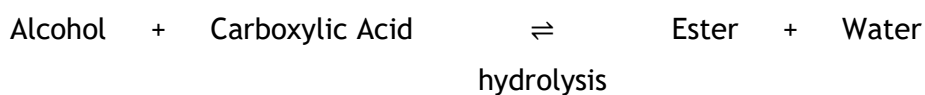
For the hydrolysis of Esters, they are heated under reflux: heating the mixture with a condenser attached.

This ensures volatile compounds do not escape and allows the reaction to take place at a higher temperature.



Ester Summary

Condensation



- Uses of Esters: Flavouring, fragrances, solvents
- Properties of Esters: Volatile (can easily vaporise), flammable, distinctive smells
- Catalyst for forming Esters: Sulfuric acid (H⁺)

Table of Esters showing the alcohol and carboxylic acid used to make them:

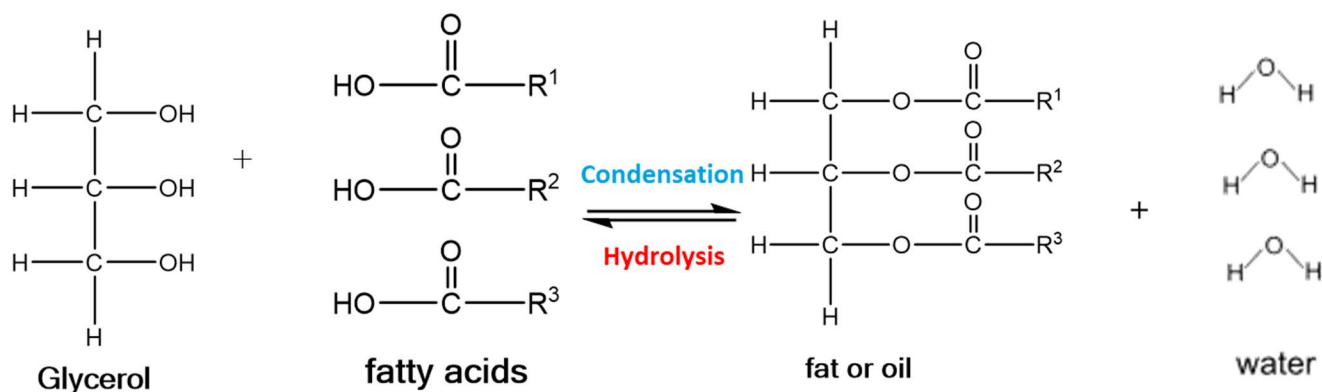
Ester name	Shortened Molecular Formula	Alcohol used	Carboxylic acid used
Methyl butanoate	C₃H₇COO CH ₃	Methanol	Butanoic acid
Benzyl butanoate	C₃H₇COO CH ₂ C ₆ H ₅	Benzyl alcohol	Butanoic acid
Benzyl ethanoate	CH₃COO CH ₂ C ₆ H ₅	Benzyl alcohol	Ethanoic acid
Octyl ethanoate	CH₃COO C ₈ H ₁₇	Octanol	Ethanoic acid
Propyl ethanoate	CH₃COO C ₃ H ₇	Propanol	Ethanoic acid
Ethyl methanoate	HCOO C ₂ H ₅	Ethanol	Methanoic acid
Propyl pentanoate	C₄H₉COO C ₃ H ₇	Propanol	Pentanoic acid

Bold shows the ester link (-COO).

Fats and Oils

Fat and oils are used in our diets to provide us with energy. They are essential for the transport and storage of fat-soluble vitamins. Fats are classed as solids and oils are classed as liquids. Fats and oils are insoluble in water and very volatile (as they are esters).

Edible fats and edible oils are esters formed from the condensation reaction of glycerol (an alcohol - propane-1,2,3-triol) with three fatty acid molecules (carboxylic acids). Each molecule of the alcohol condenses with 3 molecules of fatty acid.



R¹, R² and R³ are long carbon chains which can be the same or different.

Glycerol has three-OH groups and can form three ester links with fatty acid molecules. The product is called a triglyceride.

One mole of glycerol combines with three moles of fatty acid (see diagram above).

Structure of Fatty Acids

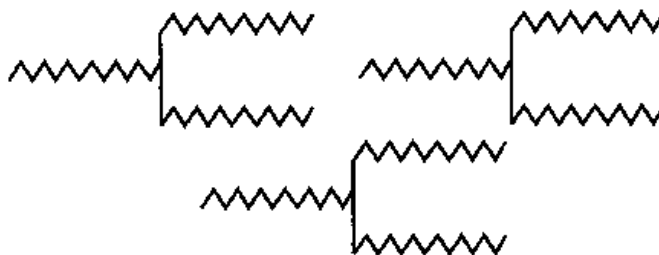
Fatty acid molecules are saturated or unsaturated straight-chain carboxylic acids usually with long chains of carbon atoms. They contain an even number of carbon atoms.

The structure of the fatty acid which combines with the glycerol affects whether an oil or fat is formed and its properties.

- Fats tend to be formed from saturated fatty acids
- Oils tend to be formed from unsaturated fatty acids
- There is a higher degree of unsaturation in oils than fats, this could be tested with bromine solution being decolourised.

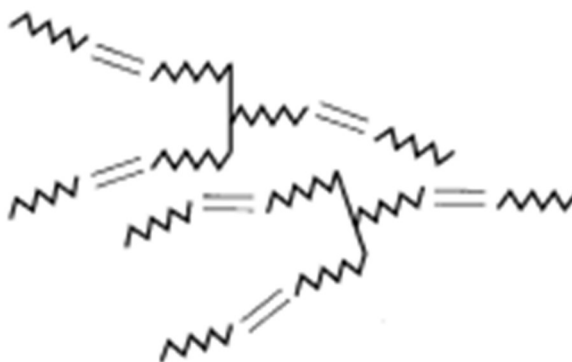
Fats

Saturation (single carbon to carbon bonds) means efficient packing therefore stronger van der Waals interactions = higher melting point than oils (more energy required to separate the molecules),, therefore they are solids.



Oils

Unsaturation (at least one carbon to carbon double bond) means a distorted structure that can't pack as closely and weaker van der Waals interactions = lower melting point than fats (less energy required to separate the molecules), therefore they are liquids.



Unsaturated compounds such as oils quickly decolourise bromine solution. Whereas, saturated compounds such as fat do not.

The bromine molecules add across the carbon-carbon double bond in an addition reaction. The greater the number of double bonds of a substance, the more bromine solution can be decolourised.

Degree of Unsaturation in Fats and Oils - Bromine solution

When an oil is shaken with bromine water, the brown colour of bromine water decolourised. This indicates the presence of double bonds in the oil molecules.

If a fat is dissolved in an organic solvent such as hexane and then shaken with bromine water, no decolourisation occurs with some fats and only slight or slow decolourisation with others.

This indicates that fats may contain no double bonds or fewer double bonds than oils.

It is possible to titrate fats/oils against bromine water and to determine the volume (and hence the number of moles) of bromine needed to react with all of the double bonds in 1 mole of the fat/oil molecules. The greater the number of drops (the longer the titration), the more unsaturated the oil. The end-point is when all of the double bonds have been used up and a trace of bromine (brown colour) remains (no further decolourisation).

Each double bond will react with 1 molecule of bromine or each mole of double bonds will react with 1 mole of bromine.

Degree of Unsaturation in Fats and Oils - Iodine

Another titrimetric measurement is called the iodine number or value. The degree of saturation in a fat or oil can also be determined by the Iodine Number.

The iodine reacts with the C=C bonds, so the greater the iodine number, the greater the number of double bonds.

[It is then possible to calculate the amount of iodine that reacted with the original fat or oil and the answer called the iodine value is usually expressed as grams iodine/100 grams of fat or oil. The higher the value, the more unsaturated the fat or oil.]

Calculation for Unsaturation

Saturated = No carbon-carbon double bond

Monounsaturated = 1 carbon-carbon double bond

Polyunsaturated = more than 1 carbon-carbon double bond

When calculating if a compound is saturated, monounsaturated or polyunsaturated consider only the side chain - ignore the COOH or COOR.

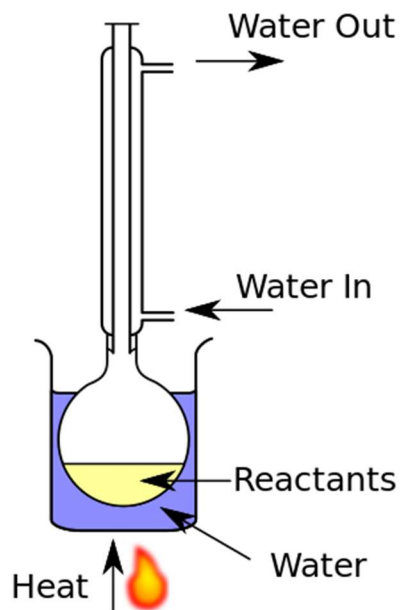
- It is saturated if it fits the general formula C_nH_{2n+1}
- If it is not saturated there is 1 double bond for each pair of hydrogens lost ($2 \times H$)

(e) Soaps, detergents and emulsions

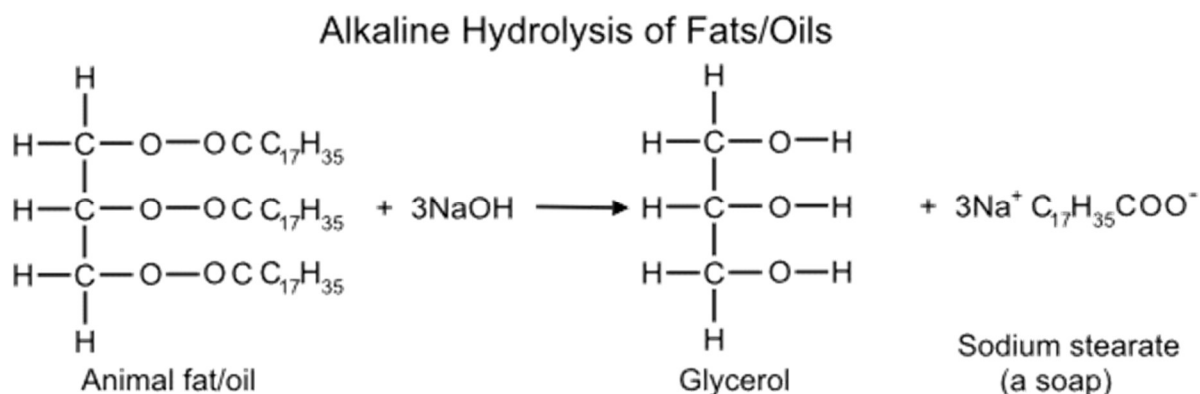
Soap

Soaps are formed by the alkaline hydrolysis (breaking up) of fats and oils by sodium or potassium hydroxide by boiling under reflux conditions. When they hydrolyse they produce glycerol and three carboxylic acids known as fatty acids. When hydrolysis is carried out under alkali conditions (NaOH) the fatty acid immediately reacts to form water soluble, ionic salts called soaps.

Reflux Apparatus:



Alkaline hydrolysis of fats and oils

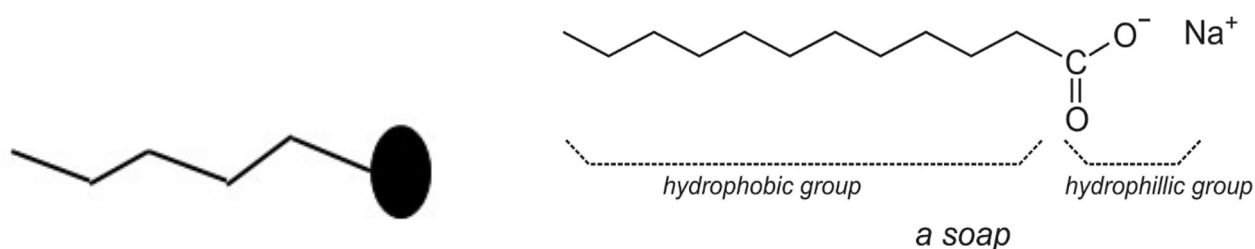


During hydrolysis, three molecules of soap are made per molecule of glycerol (3:1 ratio of fatty acid:glycerol).

The hydrolysis is carried out using alkalis (NaOH or KOH) as catalyst and the fatty acids formed are changed into sodium or potassium salts (soaps) such as sodium stearate, $\text{C}_{17}\text{H}_{35}\text{COO}^-\text{Na}^+$ in a neutralisation reaction. The soaps are ionic and water-soluble.

Structure of Soap

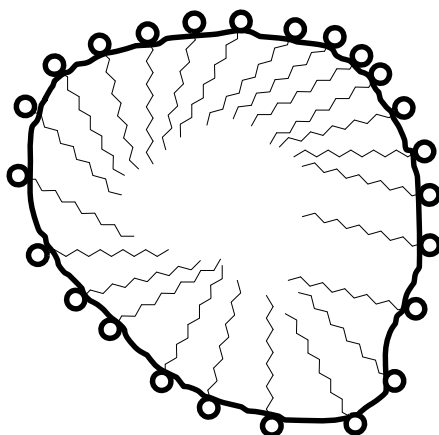
Soap can be illustrated using the diagrams below:



Hydrophobic part: The long, non-polar covalent hydrocarbon chain (on the fatty acid) gives rise to the hydrophobic (water hating) part of the soap. This part of the soap molecule is soluble in non-polar compounds such as oil and grease (like dissolves like).

Hydrophilic part: The ionic/polar group at the end of the soap molecule (usually termed the head) is hydrophilic (water loving). This means that the head of the soap molecule is soluble in ionic and polar compounds such as water but not in oil.

How Soap Works



Step 1: The soap/detergent is added to the water. The soap molecules arrange themselves in grease and water (hydrophobic tails in grease and hydrophilic head in water).

Step 2: Agitation/shaking/scrubbing begins to separate the grease from the surface. The process continues to form micelles (balls of grease droplets in water). The micelles are able to be washed away as they are suspended in water.

Detergents

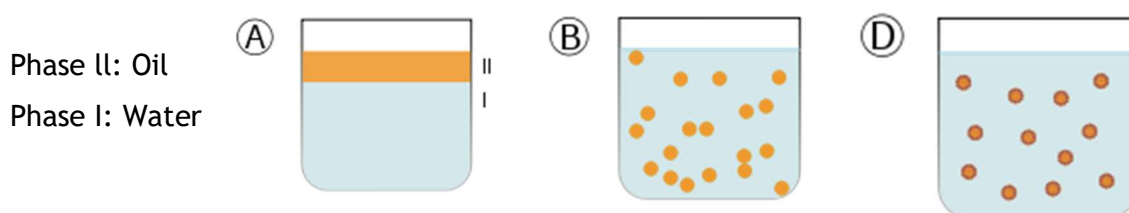
“Hard water,” is a term used to describe high levels of dissolved metal ions. When hard water is mixed with soap it forms a precipitate (scum), reducing cleansing action:

Soapless detergents are substances like detergents they also have a hydrophilic head and a hydrophobic tail. These remove oil and grease in the same way as soap. Soapless detergents do not form scum with hard water, therefore, detergents are used in hard water areas as they don't form scum.

Emulsions

An emulsion contains small droplets of one liquid dispersed in another liquid.

An emulsifier can be used to prevent non-polar and polar liquids separating into layers.

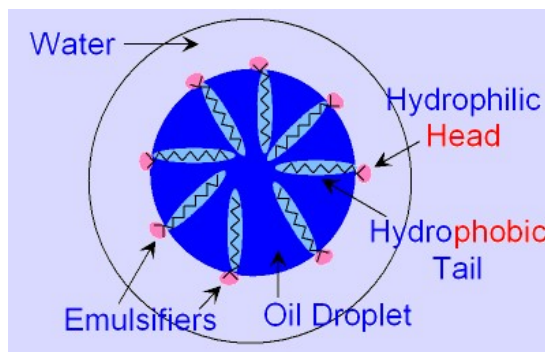


With the addition of an emulsifier (dark outline around particles) the interfaces between phase II (oil) and phase I (water) create a stabilised emulsion.

This addition of an emulsifier allows two otherwise immiscible layers to be mixed uniformly, dispersing an equal amount of each throughout the entire volume. The mixture is able to exist as a stable (non-separating) emulsion for a reasonable time (known as shelf-life).

Emulsifiers in food

Emulsifiers for use in food can be made by reacting edible oils with glycerol. In the molecules formed, only one or two fatty acid groups are linked to each glycerol backbone. The hydroxyl groups present in the emulsifier are hydrophilic whilst the fatty acid chains are hydrophobic. The hydrophobic fatty acid chains dissolve in oil whilst the hydrophilic hydroxyl groups dissolve in water, forming a stable emulsion.



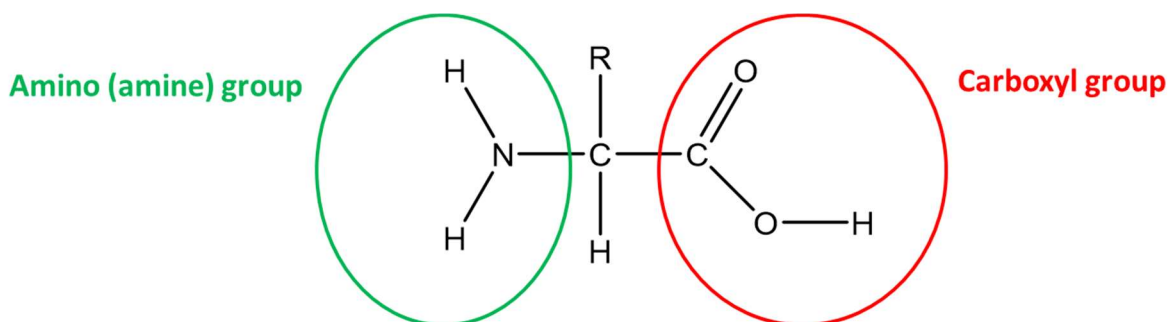
(f) Proteins

Function of Proteins

Proteins are the **major structural materials of animal tissue** and are also involved in the **maintenance and regulation of life processes**. Enzymes are proteins which act as biological catalysts.

Amino Acids

Amino acids are the building blocks from which proteins are formed. They contain an **amino (amine) group** (-NH₂) and a **carboxyl group** (-COOH) attached to the same carbon: the α -carbon.



R = a variable organic group or a hydrogen

There are 20 common amino acids out of which most proteins are made.

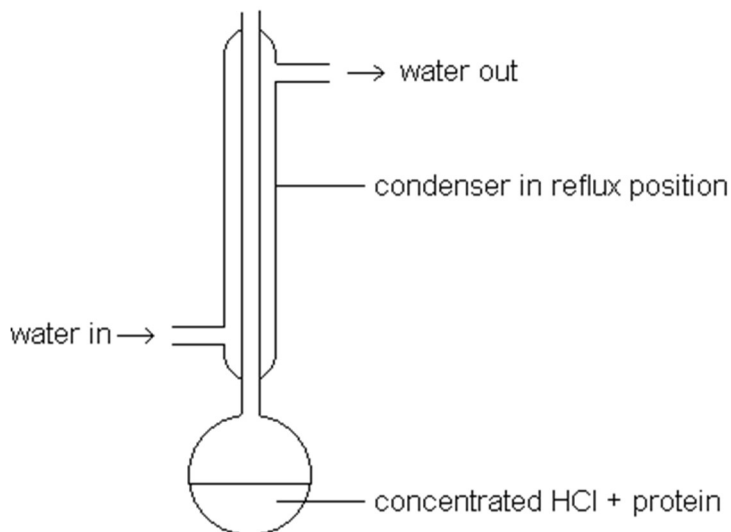
Our body can make amino acids. The amino acids that cannot be made in our body are called **essential amino acids**. These amino acids must be present in our **diet**.

Amide Links and Condensation Reaction

Proteins are made of many amino acids molecules linked together by **condensation reactions**. In these reactions, the **amino group** of one amino acid and the **carboxyl group** of another amino acid join, with the **elimination of water**.

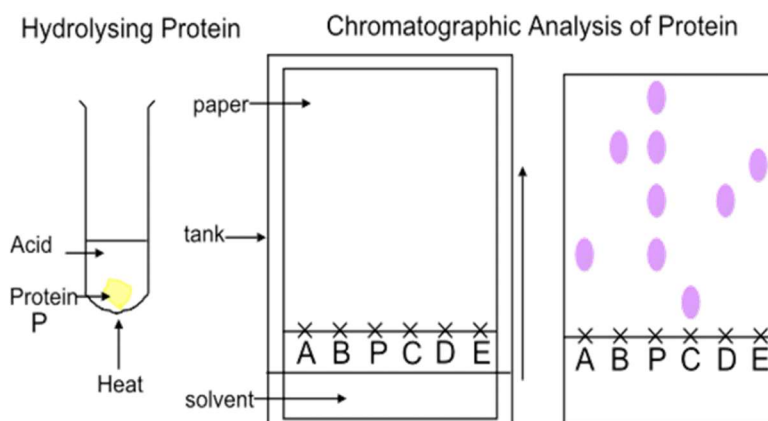
You can work out the structural formulae of the **amino acids** obtained from **hydrolysis** by looking at the structure of a section of the **protein**.

Hydrolysis set-up



Identifying Amino Acids using Chromatography

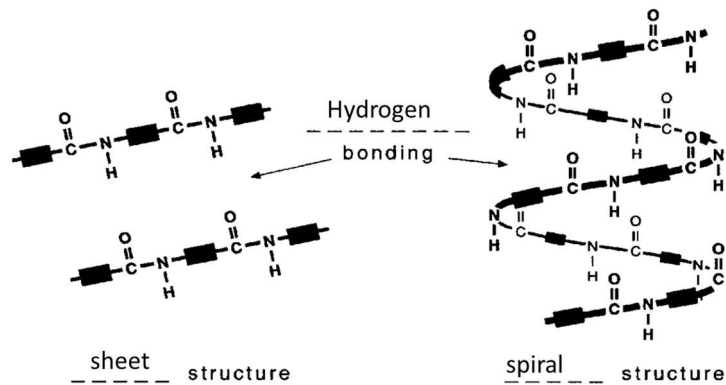
The amino acids present in a protein can be identified by first **hydrolysing** the protein then using **chromatography**.



- A, B, C, D and E are five known amino acids.
- P is the hydrolysed protein.
- P contains amino acids: A,B and D because those spots are present.
- The hydrolysed protein also contains another one amino acid.
- This can be identified by running another chromatogram with different known samples of pure amino acids.

Protein Shapes

Within proteins, the long-chain molecules form spirals, sheets, or other complex shapes. The chains are held in these forms by **intermolecular bonding (hydrogen bonding)** between the side chains of the constituent amino acids.



When proteins are heated, these intermolecular bonds are broken, allowing the proteins to **change their shape** and is said to be **denatured**. These changes alters the texture and appearance of the food when it is cooked.

(g) Oxidation of Food

Alcohols

Alcohols can be divided into **3 types** depending on the position of the -OH. The three types are **primary, secondary and tertiary**.

Type	Primary	Secondary	Tertiary
Position of -OH	Joined to the end of the carbon chain (attached to carbon with 1 other carbon bonded)	Joined to an intermediate carbon atom (attached to a carbon with 2 other carbons bonded)	Joined to an intermediate carbon atom which also has a branch attached (attached to a carbon with 3 other carbons bonded)
Characteristic group of atoms	$\begin{array}{c} \text{H} \\ \\ \text{R}-\text{C}-\text{H} \\ \\ \text{OH} \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{R}-\text{C}-\text{R}^1 \\ \\ \text{OH} \end{array}$	$\begin{array}{c} \text{R}^2 \\ \\ \text{R}-\text{C}-\text{R}^1 \\ \\ \text{OH} \end{array}$
[R, R ¹ and R ² stand for hydrocarbon groups]			

Properties of alcohols

Alcohol molecules are polar therefore hydrogen bonding exists (particularly smaller ones)

Smaller alcohol molecules are miscible (can mix with) with water, the molecules can form hydrogen bonds with one another.

As the number of **hydroxyl (-OH)** groups increases the boiling points tend to **increase**. This is because as there are more **polar hydroxyl** groups this leads to more **hydrogen bonding** hence more **energy** is needed to break them. Remember stronger intermolecular forces mean **higher melting points, higher viscosity (thickness) and greater solubility in water**.

Diols contain 2 hydroxyl groups.

Triols contain 3 hydroxyl groups.

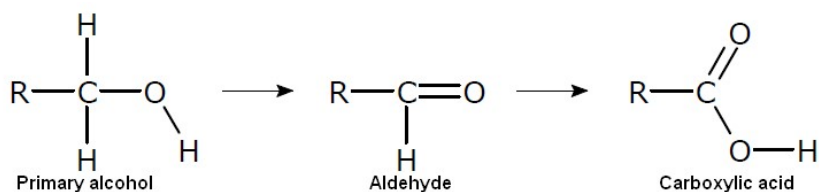
Name	Full structural formula	Systematic name
glycol (diol)	$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H} \end{array} $	Ethane-1,2-diol
glycerol (triol)	$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H} \end{array} $	Propane-1,2,3-triol

Oxidation of Alcohols

For carbon compounds:

- Oxidation is an increase in the oxygen to hydrogen ratio
- Reduction is a decrease in the oxygen to hydrogen ratio
- Primary alcohols are oxidised first to aldehydes then to carboxylic acids.
- Secondary alcohols are oxidised to ketones.
- Tertiary alcohols cannot be oxidised.

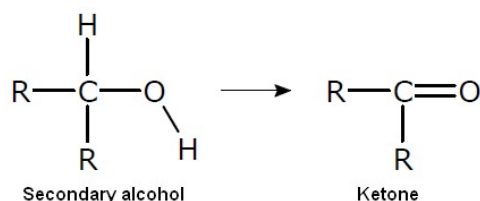
Primary Alcohols



The first stage of oxidation involves the **loss of hydrogen** to form an **aldehyde**.

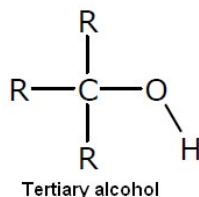
The second stage of oxidation involves the **gain of oxygen** to form a **carboxylic acid**.

Secondary Alcohols



The oxidation involves the **loss of hydrogen** to form a **ketone**.

Tertiary Alcohols



Tertiary alcohols do not undergo oxidation because they do not have a hydrogen atom attached to the same carbon atom as the hydroxyl group.

Oxidation: All of the oxidation products from primary and secondary alcohols contain the $>\text{C}=\text{O}$ group. This group is known as the **carbonyl group**.

For carbon compounds, oxidation results in an **increase in the oxygen to hydrogen ratio**.

[Reduction results in a decrease in the oxygen to hydrogen ratio]

	$\text{CH}_3\text{CH}_2\text{OH}$	\rightarrow	CH_3CHO	\rightarrow	CH_3COOH
O:H	1:6		1:4		2:4 = 1:2
	Ethanol		Ethanal		Ethanoic Acid

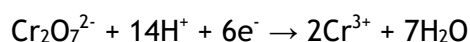
Oxidising Agents

In the laboratory, **acidified (VI) dichromate solution** or **hot copper (II) oxide** can be used to oxidise

- primary alcohols to aldehydes and then to carboxylic acids
- secondary alcohols to ketones

Acidified (VI) dichromate solution

Acidified potassium dichromate solution can be added to a test tube with an alcohol present, heated in a water bath. If the alcohol is oxidised the dichromate changes colour from **orange to blue-green** (the **dichromate is reduced and the alcohol oxidised**). A different smell may also be detected.

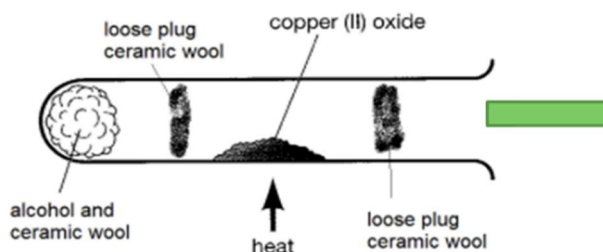


Hot copper (II) oxide

Alcohol vapours can be passed over heated **copper (II) oxide (CuO)**. During the reaction the **copper oxide is reduced to copper** and the alcohol is oxidised. A colour change would be observed from **black** → **brown solid**



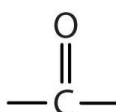
Set up



Using this experiment, you could test a **primary alcohol** such as **butan-1-ol** and a **secondary alcohol** such as **butan-2-ol**. Both reactions would show **black copper oxide** turn to a **brown solid**. However, the **primary alcohol** was oxidised to an **aldehyde** then a **carboxylic acid** which can be shown by the indicator/pH paper turning red.

Aldehydes

The functional group in an aldehyde is the **carbonyl group**.



Aldehyde names end in **-anal**.

General formula **C_nH_{2n}O**

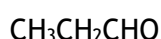
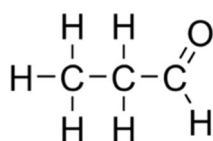
The name of an aldehyde does not contain a number to show where the functional group is because the functional group is always at the end of the chain with a hydrogen atom attached to it.

Naming and drawing aldehydes

When naming aldehydes, there is no need to indicate a number for the carbonyl functional group as the carbonyl group is always at the end of the carbon chain.

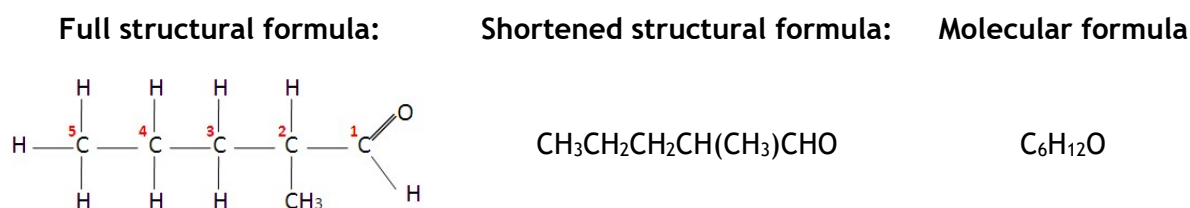
e.g. Propanal

Full structural formula: Shortened structural formula: Molecular formula



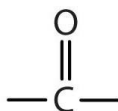
Aldehydes with **branches** can be drawn and named. When naming aldehydes with branches, the carbonyl (>C=O) functional groups take priority then branches are numbered after this point. When writing the shortened structural formula, the branch is written inside brackets.

e.g. 2-methylpentanal



Ketones

Ketones, like aldehydes, also contain a **carbonyl** group.



However, unlike aldehydes the **carbonyl** group **not located at the end of the carbon chain**.

Ketone names end in **-one**

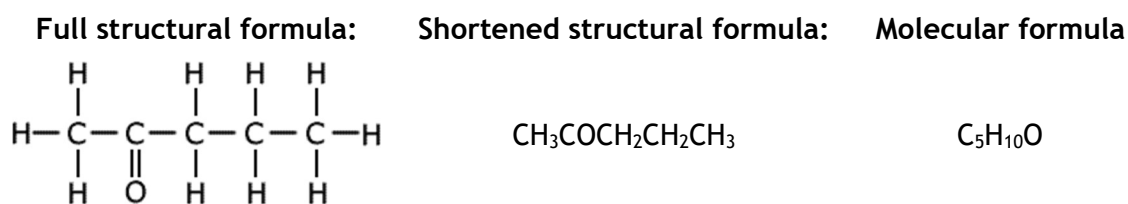
When naming ketones the position of the **carbonyl** functional group must be included in the name.

General formula = $\text{C}_n\text{H}_{2n}\text{O}$ ($n = 3$ or more)

Naming and drawing ketones

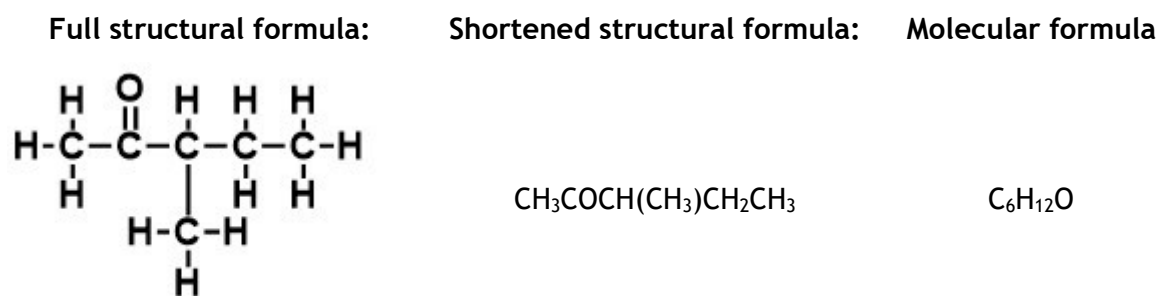
When naming ketones, it is necessary to specify the number of the carbonyl group.

e.g. Pentan-2-one



Ketones with **branches** can be drawn and named. When naming ketones with branches, the carbonyl (>C=O) functional groups take priority then branches are numbered after this point. When writing the shortened structural formula, the branch is written inside brackets.

e.g. 3-methylpentan-2-one

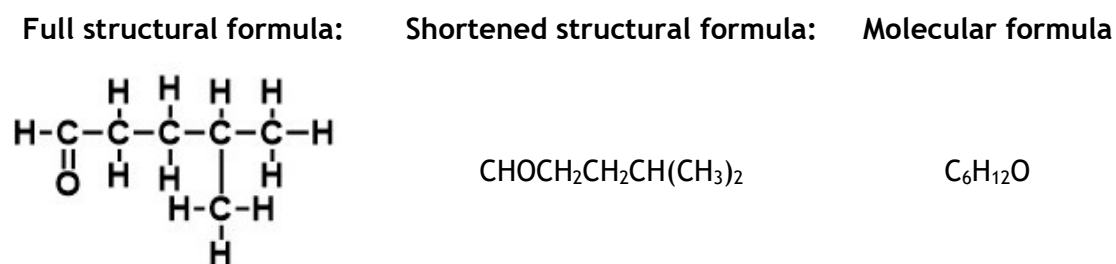


Isomers of aldehyde and ketones

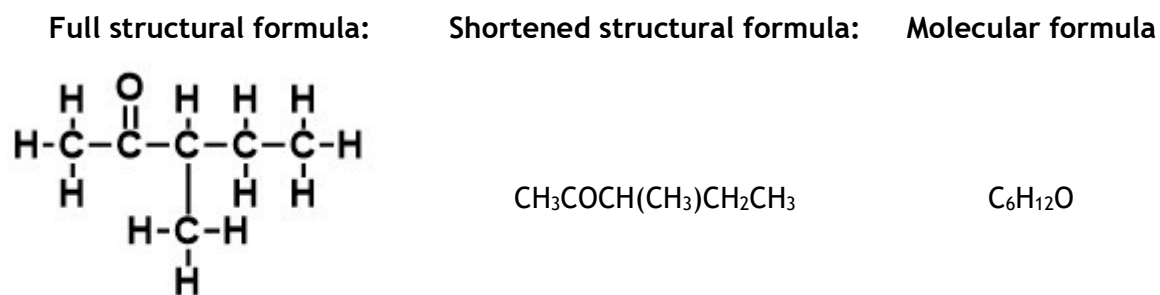
Aldehydes and ketones have the same general formula of $\text{C}_n\text{H}_{2n}\text{O}$ when n is greater than 3. They can therefore be isomers of one another.

e.g. The following compounds are isomers, they have the **same molecular formula** but have a **different structural formula**.

Name: 4-methylpentanal (aldehyde)



Name: 3-methylpentan-2-one (ketone)



Distinguishing between aldehydes and ketones

Aldehydes, but not ketones, can be oxidised to carboxylic acids. Oxidising agents can be used to differentiate between an aldehyde and a ketone.

With an aldehyde the following oxidising agents can be used test for the aldehyde, and observations made:

Oxidising agent	Observations	Explanation
Acidified potassium dichromate solution	Orange → Blue-green	$\text{Cr}_2\text{O}_7^{2-}(\text{aq})$ reduced to $\text{Cr}^{3+}(\text{aq})$
Fehling's solution	Blue solution → brick red precipitate	$\text{Cu}^{2+}(\text{aq})$ reduced to $\text{Cu}_2\text{O}(\text{s})$ i.e. $\text{Cu}^{2+} + \text{e}^- \rightarrow \text{Cu}^+$
Tollens' reagent	Colourless → Silver (formation of a silver mirror)	$\text{Ag}^+(\text{aq})$ reduced to $\text{Ag}(\text{s})$ i.e. $\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$

- Reminder:
 - Oxidising agents are themselves reduced in the reaction
 - Oxidation is loss of electrons
 - Reduction is gain of electrons

Antioxidants

Many flavours and aroma molecules are **aldehydes** and **ketones**. However, if these molecules are oxidised, they can change the taste and smell of the products. Example, oxidation of a primary alcohol will lead to forming a **carboxylic acid**. Oxygen from the air also reacts with edible oils giving the food a rancid flavour.

Antioxidants are molecules which will prevent these oxidation reactions taking place. A common example is ascorbic acid (Vitamin C) which will undergo oxidation and save the food from being oxidised. Are substances that are easily oxidised and oxidise in place of the compounds they have been added to protect.

Can be identified as the substance being oxidised in a redox equation.

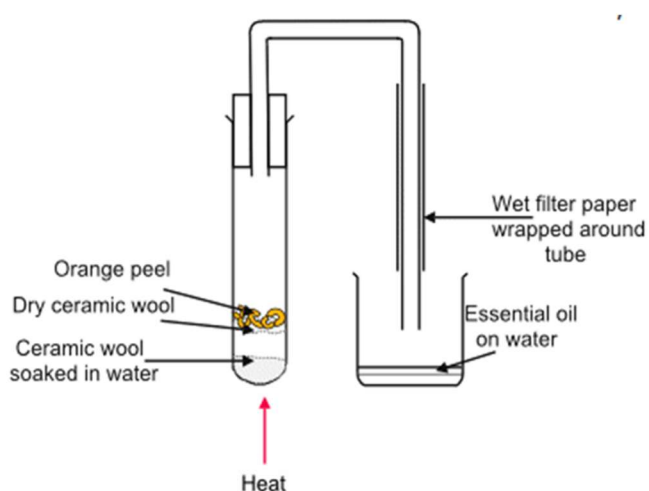
(h) Fragrances

Essential oils are concentrated extracts of the **volatile, non-water soluble (hydrophobic) aroma compounds from plants**. The oils have the aroma of the plant from which they are extracted. They include lavender, peppermint, orange, lemon, and eucalyptus oils.

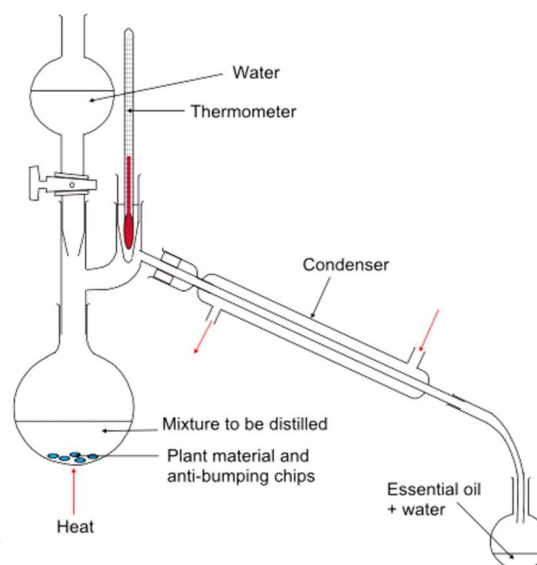
Essential oils are widely used in perfumes, cosmetic products, cleaning products and flavourings in food. They are extracted from plant sources by a process called **steam distillation**.

Steam distillation

Method 1:



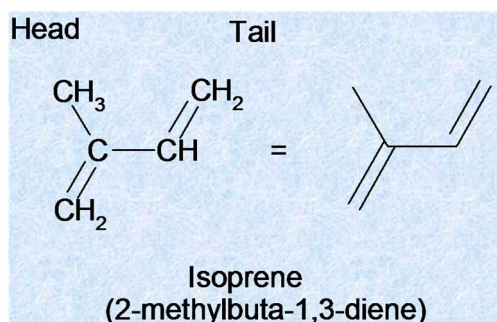
Method 2:



In this process it is important the oil is volatile, to ensure it evaporates and can be carried by the steam. Wet paper around a tube is used as a condenser is used in method A and a condenser is fitted to method B. Both set-ups have the same purpose, the condenser is used to cool the gas down to form a liquid mixture oil and water. As the two do not mix, they are easily separated.

Terpenes

Terpenes are key components in most essential oils. Terpenes are unsaturated compounds formed by joining together **isoprene (2-methylbuta-1,3-diene)** units. The molecular formula for these isoprene units is C_5H_8 .

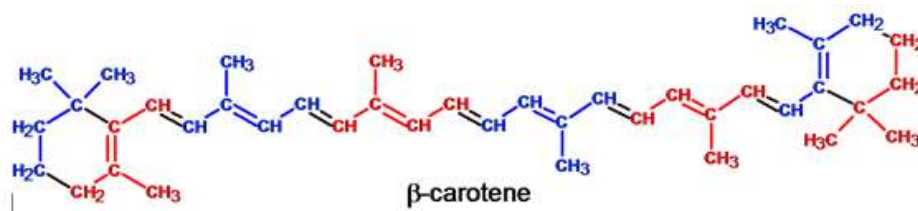


The general formula for terpenes is $(C_5H_8)_n$ where n is the number of linked **isoprene units**. This is called the isoprene rule. You need to **divide the total number of carbons by 5** to work out the number of **isoprene units**

The isoprene units may be linked together "head to tail" to form **linear terpene** or they may be arranged to form **cyclic terpenes**. The isoprene unit is one of nature's common building blocks.

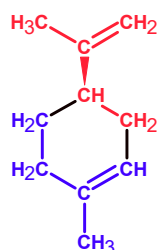
e.g.

β -carotene



It is found in carrots and is made up of **8 isoprene units**. (no. of carbons/5 = 40/5=8)

Limonene



Limonene

(skin of citrus fruits)

- Limonene is a cyclic terpene found in lemons
- It is made up of **2 isoprene units**.
- (10 carbons/5 = 2)

Oxidation of Terpenes

Terpenes can be **oxidised within plants** producing some of the compounds responsible for the **distinctive aroma of spices**.

Sometimes we would want to prevent the oxidation of terpenes because this can alter the properties and the smell. Being kept in brown bottles can help prevent oxidation. Brown glass bottles filter light, preventing chemicals degrading when exposed to light.

However, oxidation is not always negative. Some oxidised products help contribute to the fragrance of the spice or flavouring.

(i) Skin Care

Ultraviolet radiation (UV) is a **high-energy form of light** present in sunlight.

Exposure to UV light can result in **molecules gaining enough energy for bonds to be broken**.

This is the process responsible for **sunburn and skin cancer** also **contributes to aging of the skin**.

Sun-block products prevent UV light reaching the skin.

Radicals

When UV light breaks bonds, **free radicals are formed**.

Free radicals are the atoms formed which have **unpaired electrons** and, as a result, are **highly reactive**.

The mechanism of these free radical **chain reactions** involves 3 separate steps:

Initiation

Propagation

Termination

Summary of free radical chain reactions:

Initiation: Step that starts the reaction - breaking bond forming two free radicals (**2 free radicals on RHS**)

Propagation: Keeps the reaction going, more radicals form allowing the reaction to continue (hence **chain reaction**) (**1 free radical on each side**)

Termination: Radicals are needed for this process to work, two radicals colliding to form a stable compound therefore 'terminates' the process. (**2 free radicals on LHS**)

Free radical scavenger

Free radical scavengers are molecules which can **react with free radicals** to form **stable molecules and prevent chain reactions**.

Free radical scavengers are added to: cosmetics (e.g. anti-aging creams, vitamin C and E), food products (e.g. antioxidants, slow down oxidation), plastics.

Glossary

Word	Meaning
Alcohols	Organic compounds containing the hydroxyl (-OH) group.
Amide Link	A group of atoms, - CONH-, which joins amino acids in a protein. Sometimes called a peptide link.
Amino acid	The constituent molecules which join together to form proteins.
Antioxidants	Molecules which donate an electron to free-radicals, preventing the deterioration of food.
Carboxylic Acids	Organic compounds containing the carboxyl
Condensation Reaction	A reaction where two or more molecules join together and a small molecule, usually water is eliminated.
Emulsifier	a substance which will help maintain the mixing of two immiscible liquids into a relatively stable mixture called an emulsion.
Emulsion	a mixture of small droplets of one liquid such as oil dispersed in an another liquid such as water and kept there by an emulsifier.
Enzyme	A biological catalyst which speeds up natural processes.
Essential Amino Acids	Amino acids which are vital to the body but that can only be obtained from the diet.
Ester Link	A group of atoms of formula -COO- found in ester molecules and made from the combination of the carboxyl group and the alcohol group.
Esterification	A condensation reaction where an ester is made.
Fatty Acid	A carboxylic acid with between 4 and 24 (but usually 16 or 18) carbon atoms in the molecule and found in fats and oils. Only even numbers of carbon atoms are found.
Fibrous Protein	Where the sequences of amino acids are arranged to form long structures held together by internal hydrogen bonds.
Free Radical	Extremely reactive molecules with an unpaired electron.
Free Radical Scavenger	A molecule that can react with and remove free radicals.
Globular Protein	Where the chains of amino acids form folded coils with a significant number of the polar group (thus the hydrogen bonds) on the outside of the structure.

Glycerol	The trivial name for the alcohol propane-1,2,3-triol found in fats and oils.
Hydrolysis	a reaction where water is used to break chemical bonds. Literally splitting a substance using water.
Hydrolysis Reaction	A reaction where a bond is broken in a molecule using water. Here, protein chains are broken down into the component amino acid molecule by adding water across the amide link.
Hydrophilic	a substance which is attracted by water and so is soluble in water. Literally - water loving.
Hydrophobic	a substance which is repelled by water and so is insoluble in water. Literally - water hating.
Immiscible	Describes liquids which separate into two layers, even after being mixed. e.g. oil and water are immiscible
Initiation	The starting reaction of a chain reaction
Miscible	Describes two liquids which can dissolve completely so that only one layer exists e.g. ethanol and water are miscible
Non-Polar	Describes a molecule where any charges are insignificant or absent.
Oxidation	A reaction in which an organic compound has the oxygen to hydrogen ratio increased. Oxygen can be added or hydrogen can be removed.
Primary (1°) Alcohols	Alcohols in which the hydroxyl is bonded to carbon which is bonded to no more than one other carbon.
Propagation	A stage in a chain reaction where the numbers of radicals is maintained.
Protein	Naturally occurring compounds containing the elements carbon, hydrogen, oxygen and nitrogen.
Reaction	
Reduction	A reaction in which an organic compound has the oxygen to hydrogen ratio reduced. Oxygen can be removed or hydrogen can be added.
Reflux	Where liquid evaporate to form gases which are then re-condensed to continue reaction.
Secondary (2°) Alcohols	Alcohols in which the hydroxyl is bonded to a carbon which is bonded to two other carbons.
Soap	The sodium or potassium salts of long chain fatty acids e.g. sodium stearate or potassium oleate.
Solvent Extraction	A method to separate compounds based on their relative solubilities in two different immiscible liquids.

Surfactant	a material that can greatly reduce the surface tension of water when used in very low concentrations.
Termination	The last stage in a chain reaction, where all of the remaining radicals are used up.
Tertiary (3°) Alcohols	Alcohols in which the hydroxyl is bonded to a carbon which is bonded to three other carbons.
Titrate	A process using pipette and burette where volumes of reactants can be accurately measured.
Triglyceride	The chemical name for a fat or oil i.e. an ester of glycerol and three fatty acid molecules.
Trihydric alcohol	A molecule with three -OH groups in it.
Trihydric alcohol	A molecule with three -OH groups in it.
Unsaturated	Compounds which have double (or triple) covalent bonds between carbon atoms e.g. alkenes such as ethane.
Volatile	Describes a liquid which evaporates readily i.e. changes to a gas easily