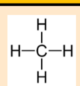
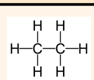
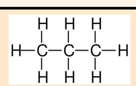
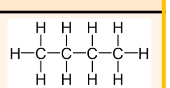
Organic Chemistry

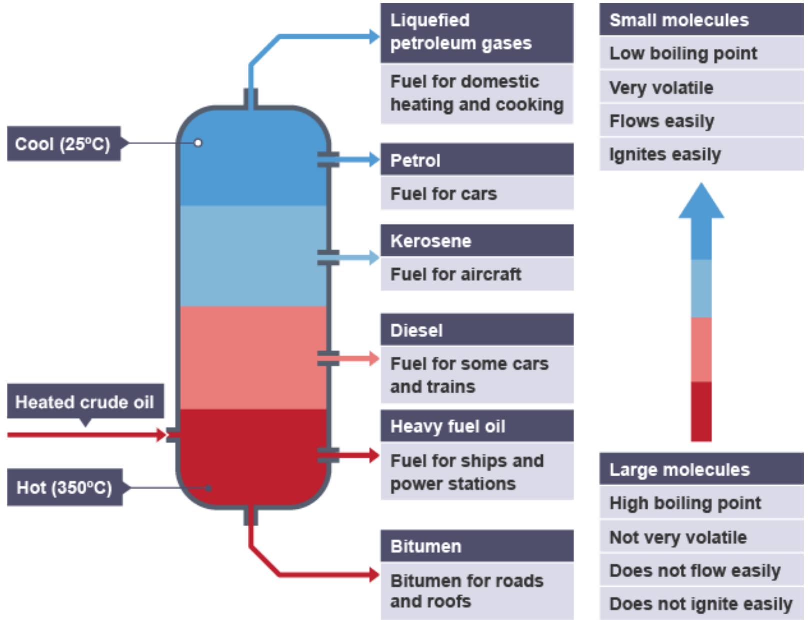
1. Hydrocarbons

Crude oil is a **finite** resource found in rocks. Crude oil is the remains of an ancient biomass consisting mainly of **plankton** that was buried in mud. Crude oil is a mixture of a very large number of compounds. Most of the compounds in crude oil are **hydrocarbons**, which are molecules made up of hydrogen and carbon atoms only.

Most of the hydrocarbons in crude oil are hydrocarbons called **alkanes**. Alkanes are hydrocarbons that contain **no double bonds** between the carbon atoms. We say they are **saturated.**

An **homologous series** is a family of molecules that all have the same **general formula** and have chemical properties that are similar.
The general formula for the homologous series of alkanes is $\mathbf{C_nH_{2n+2}}$. Each alkane differs from the one before as it has an extra CH_2 added to it. The lines in the structural formula diagrams represent **covalent bonds.**

Alkane	Molecular formula	Structural formula
Methane	CH_4	
Ethane	C_2H_6	
Propane	C_3H_8	
Butane	C_4H_{10}	



2. Fractional Distillation

Fractional distillation separates the **fractions** (parts of the mixture) of crude oil based on their chain lengths. The fractions can be processed to produce **fuels** and **feedstock** (raw materials for an industrial process) for the petrochemical industry.

During the fractional distillation of crude oil:
- Crude oil is heated until it vaporises and then enters a tall **fractionating column**, which is hot at the bottom and gets cooler towards the top
- **Vapours** from the oil rise through the column
- Vapours **condense** when they become cool enough
- Liquids are led out of the column at different heights.

Small hydrocarbon molecules have weak **intermolecular forces**, so they have low boiling points. They do not condense, but leave the column as gases. Long hydrocarbon molecules have stronger intermolecular forces, so they have high boiling points. They leave the column as hot liquid bitumen.

3 Properties of Hydrocarbons

The boiling point, viscosity and flammability of hydrocarbons depends on their chain length, as shown in the diagram above. These properties influence how hydrocarbons are used as fuels.
The combustion of hydrocarbon fuels releases energy. During combustion, the carbon and hydrogen in the fuels are oxidised.

hydrocarbon + oxygen → carbon dioxide + water

For example, the complete combustion of propane:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

4 Cracking of Hydrocarbons

Hydrocarbons can be broken down (**cracked**) to produce smaller, more useful molecules. Cracking can be done in two ways:
- **Catalytic cracking** needs a temperature of 550°C and a **catalyst** of aluminium oxide.
- **Steam cracking** uses a higher temperature of over 800°C and no catalyst

The products of cracking include alkanes and another type of hydrocarbon called **alkenes**. Alkenes are **unsaturated** and are more reactive than alkanes. They react with orange **bromine water** to turn it colourless. This is the test for alkenes.
For example, hexane can be cracked to form butane and ethene:

hexane → butane + ethene

$$C_6H_{14} \rightarrow C_4H_{10} + C_2H_4$$

Cracking is important for two main reasons:
1.It helps to match the supply of small fractions with the demand for them as fuels.
2. Alkenes are used to produce polymers and as starting materials for the production of many other chemicals.

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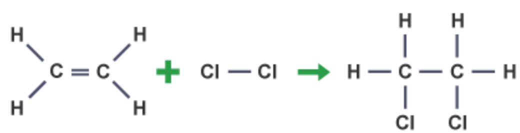
5. Alkenes

Alkenes are hydrocarbons with a double carbon-carbon bond, C=C , this is the their **functional group**. A functional group is the atoms that determine the reactions of organic compounds. The general formula for the homologous series of alkenes is $\mathbf{C_nH_{2n}}$ Alkene molecules are unsaturated because they contain two fewer hydrogen atoms than the alkane with the same number of carbon atoms.

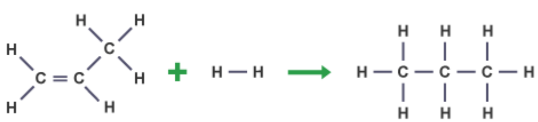
Alkenes react with **oxygen** in combustion reactions in the same way as other hydrocarbons, but they tend to burn in air with smoky flames because of **incomplete combustion.**

The functional group, C=C, allows alkenes to undergo **addition reactions** with halogens, hydrogen or water.

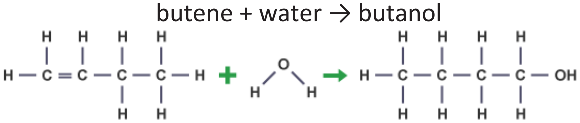
alkene + halogen → halogenoalkane
Chlorine, bromine or iodine can be added to an alkene. These reactions are usually spontaneous e.g.
ethene + chlorine → dichloroethane

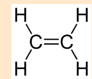
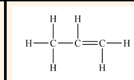
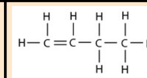
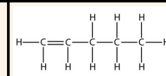


alkene + hydrogen → alkane
This is called **hydrogenation**, and it needs a **catalyst** e.g.
propene + hydrogen → propane



alkene + water (steam) → alcohol
This is called **hydration**. It needs a temperature of approximately 300°C and a catalyst. e.g.
butene + water → butanol



Alkene	Molecular formula	Structural formula
Ethene	C_2H_4	
Propene	C_3H_6	
Butene	C_4H_8	
Pentene	C_5H_{10}	

Alcohols continued…

Solubility in water
When the alcohols with the shortest hydrocarbon chains are added to water, they mix easily to produce a solution. However, the solubility decreases as the length of the alcohol molecule gets longer, so butanol is less soluble than propanol. It may not mix easily, and two distinct layers might be left in the container.

Oxidation of alcohols
Alcohols can be oxidised without **combustion** to produce **carboxylic acids**. E.g. ethanol can be oxidised to ethanoic acid using an **oxidising agent**.

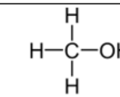
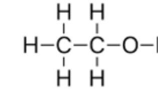
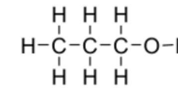
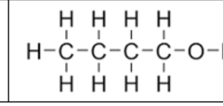
ethanol + oxidising agent → ethanoic acid + water

$$CH_3CH_2OH + 2[O] \rightarrow CH_3COOH + H_2O$$

Each of the two oxygen atoms provided by the oxidising agent are shown as [O]. Notice that the left-hand side of the ethanol molecule is unchanged. The reaction involves the -OH group on the right-hand side.

6. Alcohols

Alcohols contain the functional group –OH.

Name	Formula	Structural formula
Methanol	CH_3OH	
Ethanol	CH_3CH_2OH (C_2H_5OH)	
Propanol	$CH_3CH_2CH_2OH$ (C_3H_7OH)	
Butanol	$CH_3CH_2CH_2CH_2OH$ (C_4H_9OH)	

Ethanol can be produced by **fermentation** which is an **anaerobic** process in **yeast**:
glucose → ethanol + carbon dioxide
The typical conditions needed for fermentation include:
- sugars **dissolved** in water, and mixed with yeast
- an air lock to allow carbon dioxide out, while stopping air getting in
- warm **temperature**, 25-35°C

Uses of alcohols:
Methanol is used as a chemical **feedstock**. It's **toxic**, so it's added to industrial ethanol (methylated spirits) to prevent people from drinking it. Ethanol is the alcohol present in alcoholic drinks. It is also used as a **fuel** and a **solvent**. Propanol and butanol are also used as solvents and fuels.

Combustion
ethanol + oxygen → carbon dioxide + water

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

When less oxygen is present, **incomplete combustion** will occur, producing H_2O and either CO_2 or CO.

Reactions with sodium
sodium + ethanol → sodium ethoxide + hydrogen

$$2Na + 2C_2H_5OH \rightarrow 2C_2H_5ONa + H_2$$

Methanol, propanol and butanol undergo similar reactions.

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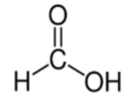
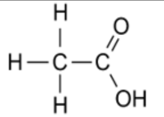
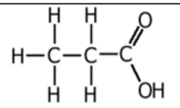
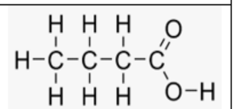
7. Carboxylic Acids

Carboxylic acids have the functional group –COOH.

Carboxylic acid	Formula	Structural formula
Methanoic acid	HCOOH	
Ethanoic acid	CH_3COOH	
Propanoic acid	CH_3CH_2COOH (C_2H_5COOH)	
Butanoic acid	$CH_3CH_2CH_2COOH$ (C_3H_7COOH)	

The carboxylic acids have the **typical properties of acids** due to the –COOH functional group. For example, they:

- **dissolve** in water to form **acidic solutions** with **pH** values less than 7
- react with **metals** to form a **salt** and hydrogen
- react with **bases** to form a salt and water
- react with **carbonates** to form a salt, water and carbon dioxide.

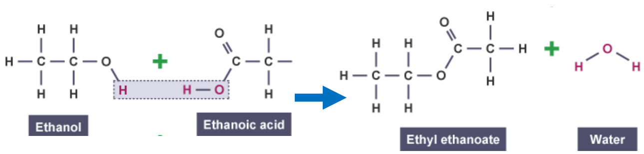
Carboxylic acids can react with alcohols to make **esters**. Esters are **organic compounds** which all contain the **functional group** -COO-. Esters have fruity smells and can be used as **solvents**.

The general equation for the formation of an ester is:

alcohol + carboxylic acid → ester + water

For example:

ethanol + ethanoic acid → ethyl ethanoate + water

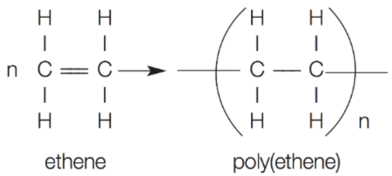


Carboxylic Acids continued…

Carboxylic acids are weak acids. This means that their solutions do not contain many hydrogen ions compared with a solution of a strong acid with the same **concentration**. The pH of a weak acid will be higher than the pH of a strong acid, with the same concentrations. In a solution of a strong acid, the molecules are fully ionised, but in a weak acid, very few of the molecules are **ionised**.

8. Addition Polymerisation

Alkenes can be used to make **polymers** such as poly(ethene) and poly(propene) by addition polymerisation. In addition polymerisation reactions, many small molecules (**monomers**) join together to form very large molecules (**polymers**). For example:



In addition polymers the repeating unit has the same atoms as the monomer because no other molecule is formed in the reaction.

9. Condensation Polymerisation

Condensation polymerisation involves monomers with two functional groups (OH, COOH, COO). When these types of monomers react they join together, usually losing small molecules such as water, and so the reactions are called condensation reactions. The simplest polymers are produced from two different monomers with two of the same functional groups on each monomer.

Example (notice the repeating units) –

ethanediol (2-alochol functional groups -OH)
$HO-CH_2-CH_2-OH$
(HO-☐-OH)

and

hexanedoic acid (2-carboxylic acid function groups -COOH)
$HOOC-CH_2-CH_2-CH_2-CH_2-COOH$
(HOOC-☐-COOH)

polymerise to produce a polyester:

n HO-☐-OH + HOOC-☐-COOH → ⟮O-☐-O-CO-☐-CO⟯$_n$ + 2nH_2O

10. Amino Acids

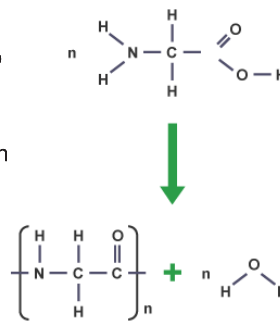
Amino acids are **molecules** which have at least two functional groups. All amino acids contain the $-NH_2$ group and also the carboxylic acid group -COOH. Amino acids are polymerised in cells to make **polypeptides** and **proteins**.

Amino acids react by **condensation polymerisation** so for every monomer which is added to the growing polymer chain, one molecule of water is also produced.

For example, glycine is the simplest amino acid. An equation for the formation of a polypeptide which is made only from glycine is:

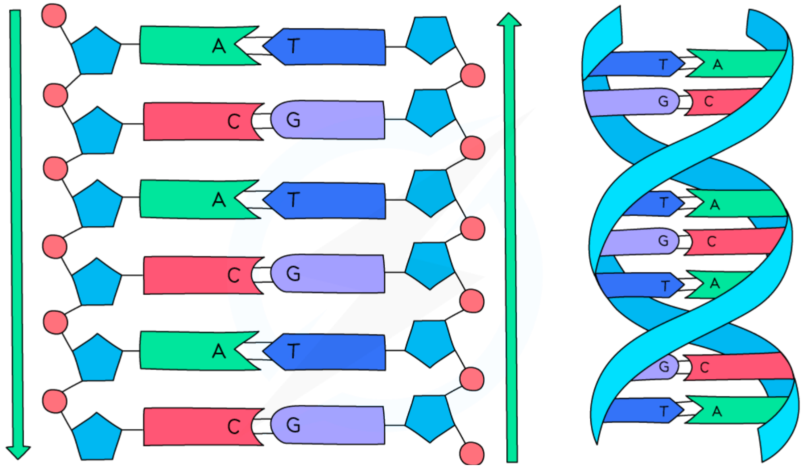
n glycine → poly(glycine) + water

$n\ H_2NCH_2COOH \rightarrow (-HNCH_2CO-)_n + n\ H_2O$

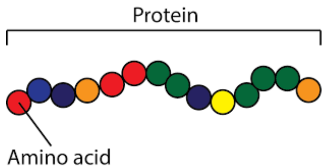


11. DNA and other Naturally Occurring Polymers *(separate Chemistry only)*

DNA (**deoxyribonucleic acid**) is a large molecule essential for life. DNA encodes genetic instructions for the development and functioning of living organisms and viruses. Most DNA molecules are two polymer chains, made from four different monomers called **nucleotides**, in the form of a **double helix**.



Proteins are biological polymers made inside cells. They are made from amino acid monomers and have a huge range of roles inside living things. For example, all **enzymes** are made from proteins.



Starch and cellulose are biological polymers which are made by plants. The monomers for both starch and cellulose are sugar molecules. Starch is used by plants as a way of storing energy as a complex **carbohydrate**. Cellulose is used to make the strong cell wall which gives plant cells (and therefore plants) strength.