

## IGCSE SEPARATE SCIENCES

### TOPIC C14: ORGANIC CHEMISTRY

#### REVISION NOTES

Organic chemistry is the chemistry of a huge number of compounds containing carbon. Carbon atoms are in group 4 which means they form up to four bonds with other elements. They also have the very special property of being able to bond to itself many times forming long chains or rings of carbon atoms. The chemicals that make up living organisms are all organic compounds.

#### Names of organic compounds

All organic compounds are named using a system based on the structure of the molecule. The first part of the name gives you the number of carbon atoms in the chain

1C =meth

2C =eth

3C =prop

4C =but

The second part of the name gives you the type of compound it is and enables you to predict how it will react (the functional group)

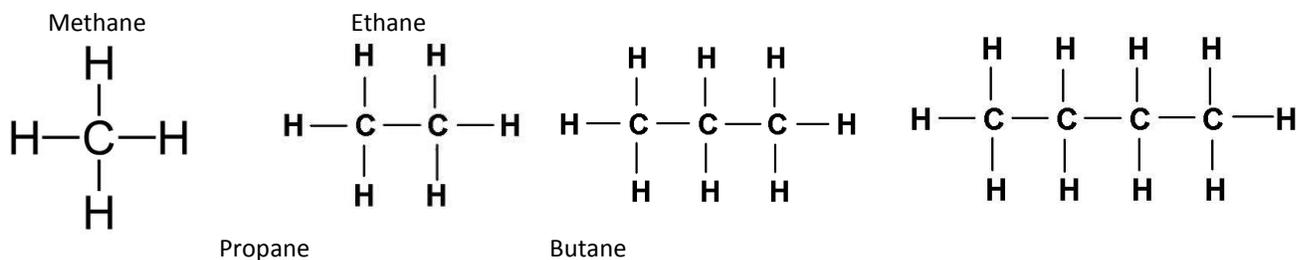
-ane = alkane

-ene =alkene

-anol = alcohol

-anoic acid =carboxylic acid

e.g



#### Fuels

Hydrocarbons (organic compounds of carbon and hydrogen only) are very good fuels. They can burn in air reacting with oxygen to produce carbon dioxide and water. The reaction gives out a lot of heat energy it is a very exothermic reaction. If oxygen is limited carbon monoxide can be formed instead of carbon dioxide. This is dangerous as carbon monoxide is very poisonous.

The fuels obtained from petroleum (crude oil) are examples of fossil fuels. **Fossil fuels** are made from the remains of dead plants and animals buried under many layers over millions of years. Fossil fuels are **non-renewable** because they take so long to make they can't be replaced as they are used. Examples of fossil fuels are:

Coal a solid fuel. It can be burnt in power stations to generate electricity.

Fuels obtained from petroleum such as petrol, diesel and kerosene are liquid fuels. These are used for vehicles: cars, lorries and planes

Natural gas (methane) a gaseous fuel this can be used in power stations to generate electricity it can be also used in homes for cooking.

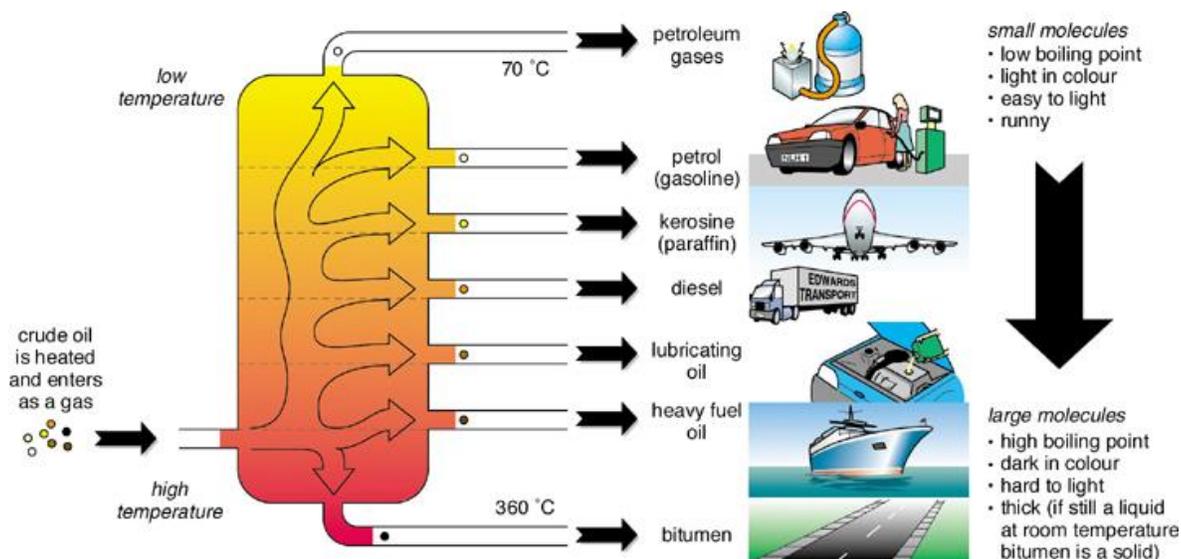
When solid fuels are in a powdered form they can burn very quickly. Coal dust in mines can cause explosions. Similarly dust in grain stores can have the same effect.

It is possible to make methane from decaying animal and plant matter. This is renewable and is called biogas.

### Petrochemicals

Petroleum (crude oil) is a mixture of hydrocarbons (compounds containing carbon and hydrogen only). The hydrocarbons in crude oil can be separated by fractional distillation using a fractionating column. The oil is heated and the different hydrocarbons become gases and move up the column. The ones with higher boiling points will rise further before turning back into a liquid. The shorter the hydrocarbon molecule the higher the boiling point. Each group of compounds is called a fraction.

The fractions are shown in the diagram:



### Homologous series

A **homologous series** is a group of organic compounds that have the same general formula and similar chemical properties. They react in a similar way because they have similar bonds; they have the same **functional group**. Their physical properties show a gradual change as the carbon chain gets longer the:

- Boiling point increases
- They become less flammable (don't set fire as easily)
- They get more viscous (don't pour as easily)
- They get less volatile (don't evaporate as easily)

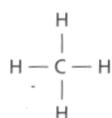
All organic compounds are made up of covalently bonded molecules. The molecules are held together by weak forces called Van der Waals forces.

### Alkanes

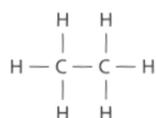
Alkanes are an homologous series with the general formula  $C_nH_{2n+2}$ . They are hydrocarbons and are found mainly in crude oil. Like all organic compounds they can be represented by molecular formulae or graphical formulae. Alkanes are **saturated hydrocarbons** as they only have carbon to carbon single bonds. A **molecular formula** shows the number of carbon and hydrogen atoms in a molecule. For example ethane  $C_2H_6$ .

A **graphical formula** shows how the atoms are actually joined together e.g. ethane  $H_3C-CH_3$ .

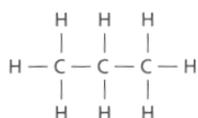
Below shows some common alkanes and their molecular and graphical formulas:



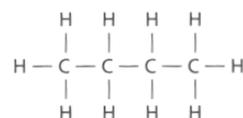
methane  
CH<sub>4</sub>



ethane  
C<sub>2</sub>H<sub>6</sub>



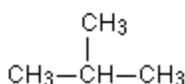
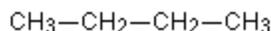
propane  
C<sub>3</sub>H<sub>8</sub>



butane  
C<sub>4</sub>H<sub>10</sub>

### Some common alkanes

The first three alkanes have carbon atoms joined in a line even if propane is drawn in an L-shape the carbons are still in line. With butane however its possible to draw a different arrangement. These are example of isomers.

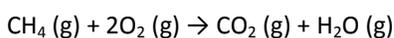


**Isomers** have the same molecular formula but different structural formula. They behave similarly chemically but their physical properties can be different. Generally the more branched the molecule the lower the boiling point.

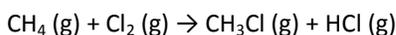
### Chemical properties of alkanes

They are generally unreactive however they do burn exothermically making them good fuels. For example methane is the main part of natural gas. All alkanes form carbon dioxide and water when they are burned in a plentiful supply of air. If the oxygen is in short supply carbon monoxide and soot (carbon) can be formed.

Methane + oxygen → carbon dioxide + water



The only other reaction of alkanes is with chlorine. In the presence of sunlight one of the hydrogens in the alkane can be replaced by a chlorine atom this is called a **substitution reaction**.



Chloroethane and hydrogen chloride are formed.

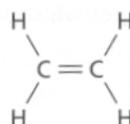
The reaction doesn't stop there if there is plenty of chlorine it can continue:

- $\text{CH}_3\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_2\text{Cl}_2 + \text{HCl}$
- $\text{CH}_2\text{Cl}_2 + \text{Cl}_2 \rightarrow \text{CHCl}_3 + \text{HCl}$
- $\text{CHCl}_3 + \text{Cl}_2 \rightarrow \text{CCl}_4 + \text{HCl}$

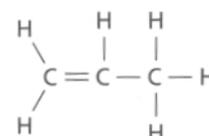
### Alkenes

Alkenes are **unsaturated hydrocarbons** they have at least one carbon-carbon double bond in the molecule.

Examples of alkenes include ethene and propene shown here:



ethene  
C<sub>2</sub>H<sub>4</sub>

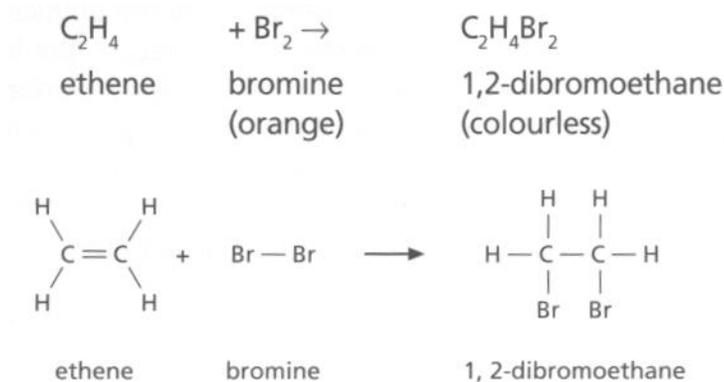


propene  
C<sub>3</sub>H<sub>6</sub>

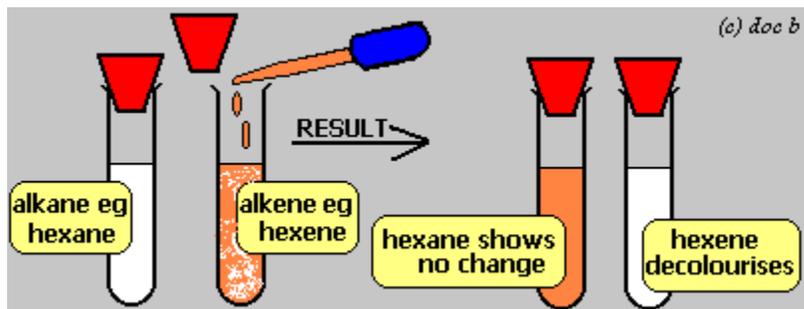
Alkenes burn in the same way as alkanes but they also undergo a type of reaction called an **addition reaction**. This makes them more reactive than alkanes. In an addition reaction the double bond is broken and used to bond with something else. Common addition reactions are with bromine, hydrogen, water and themselves

#### Addition reactions with bromine

When alkenes are added to bromine water the bromine molecule adds to the alkene forming a bromo-alkane. The bromine water turns from orange to colorless.

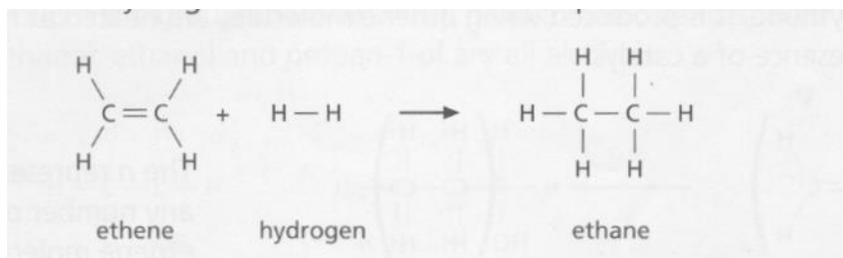


As saturated compounds do not react with bromine water so bromine water is used to test for unsaturation (double bonds).



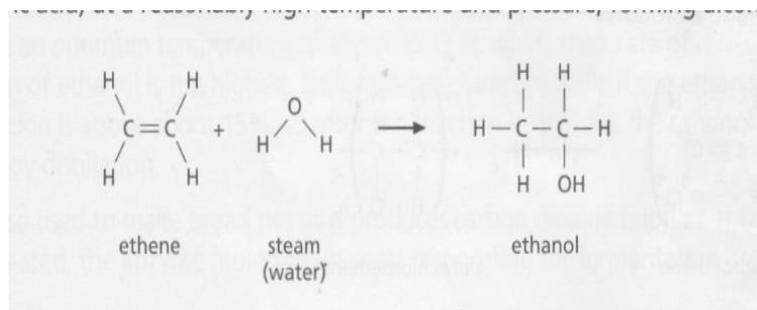
#### Addition with hydrogen

They react with hydrogen in the presence of a nickel catalyst to form alkanes. This reaction is called Hydrogenation. It is used in the manufacture of margarine.



#### Addition of water

Another important addition reaction is the reaction of ethene with steam under pressure with a phosphoric acid catalyst forming ethanol.

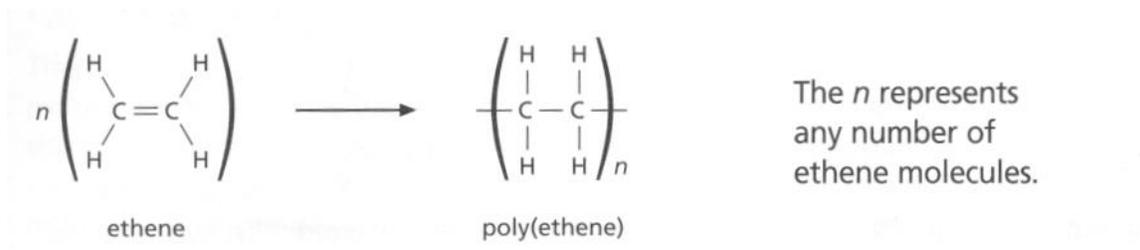


## Cracking

When crude oil is separated into fractions by fractional distillation not enough petrol is produced to supply the demand. More petrol is produced by breaking up the molecules of longer chain oil fractions such as naphtha in the process called cracking. The naphtha is heated and passed over a catalyst usually aluminium oxide. The molecule breaks into parts forming more petrol (an alkane) and an alkene. Alkenes are also very useful as they are used to make plastics

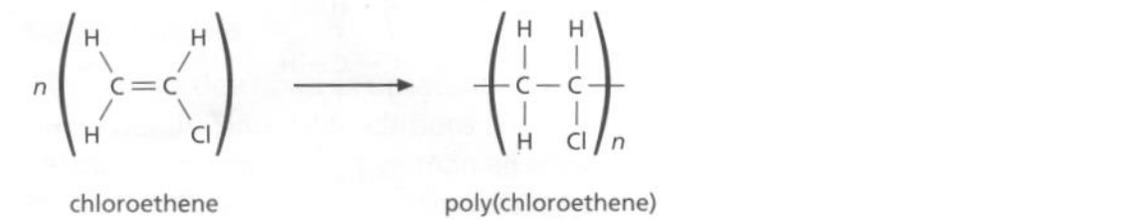
## Plastics and polymers

The alkenes formed in cracking are very useful because they are used to make plastics. The alkenes are heated under pressure with a catalyst and the alkenes double bonds open up causing them to join together to form very long chain molecules called polymers (see before). Ethene produces the plastic polyethene or polythene. This is called **addition polymerisation**



Ethene is called the monomer as the monomer is the molecule that joins together to make the polymer. Plastics are a type of polymer called addition polymers because they are formed from double bonds breaking apart and adding together.

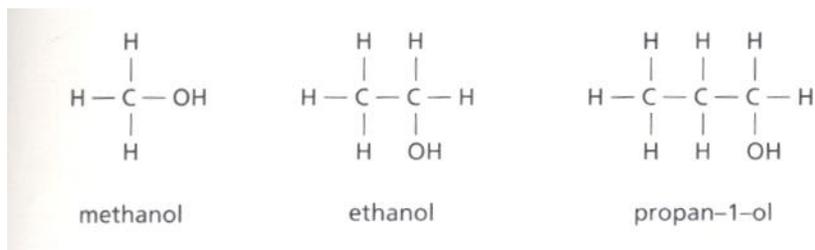
Another example of an important plastic made by addition polymerization is poly chloroethane



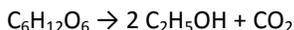
Plastics are extremely useful for many things because they are light, cheap, resist corrosion, can be dyed different colours and can be moulded into different shapes. However plastics do not break down easily and this can lead to pollution problems. Also the production of plastic needs oil which is non-renewable it is important that plastics are recycled if possible.

## Alcohols

Alcohols are another homologous series. They all contain the functional group  $\text{-OH}$  (the functional group is the group that determines the chemical properties). Methanol, ethanol and propan-1-ol are all alcohols. Ethanol is a good organic solvent and it is used in alcoholic drinks. It is also a very good fuel. When it burns it produces carbon dioxide and water and it produces a very clean flame.



There are two main ways of making ethanol. One is to react ethene with steam (see earlier) and the other is by using fermentation of sugars by yeast cells.

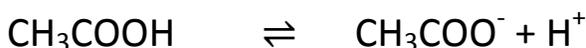


Sine fermentation relies on the enzymes in yeast the best temperature is about 35°C. Yeast cells die if the concentration of ethanol is more than 15% so after the reaction has finished the mixture needs to be distilled to separate the ethanol.

### Organic acids (carboxylic acids)

An example is ethanoic acid CH<sub>3</sub>COOH. Ethanoic acid is formed by the oxidation of ethanol. This is why alcoholic drinks go sour if they are left in the air for a long time. Ethanol is can be oxidized more quickly if it added to acidified (acid added like sulfuric acid) potassium manganate (VII). The potassium manganite (VII) changes colour from purple to colourless. Ethanol is also oxidized to ethanoic acid by heating with a mixture of potassium dichromate VI and sulfuric acid. The solution changes from orange to green

Carboxylic acids are weak acids, typically solutions are around pH3 (yellow-orange-pink with universal indicator). This means that they are only partly dissociated into ions in solution. The solutions of ethanoic acid in water conduct electricity because of the ions produced.



Ethanoic acid

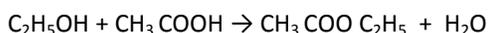
Ethanoate ion

hydrogen ion (proton)

Ethanoic acid (and other carboxylic acids) show the typical acid reactions. They changes blue litmu red and they react with:

- **Metals** to form salts and hydrogen e.g.
  - ethanoic acid + magnesium → magnesium ethanoate + hydrogen
  - $2CH_3COOH + Mg \rightarrow (CH_3COO)_2Mg + H_2$
- **Alkali bases** to form a carboxylic acid salt and water e.g.
  - ethanoic acid + potassium hydroxide → potassium ethanoate + water
  - $CH_3COOH + KOH \rightarrow CH_3COOK + H_2O$
- **Insoluble bases** to form salt and water e.g.
  - zinc oxide + ethanoic acid → zinc ethanoate + water
  - $ZnO + 2CH_3COOH \rightarrow (CH_3COO)_2Zn + H_2O$
- **Carbonate and hydrogen carbonate bases** to produce a carboxylic acid salt, water and carbon dioxide e.g.
  - ethanoic acid + sodium hydrogen carbonate → sodium ethanoate + water + carbon dioxide
  - $CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$
  - OR propanoic acid + sodium carbonate → sodium propanoate + water + carbon dioxide
  - $2CH_3CH_2COOH + Na_2CO_3 \rightarrow 2CH_3CH_2COONa + H_2O + CO_2$

**Carboxylic acids also react with alcohols** to form members of another homologous series called **esters**. Concentrated sulfuric acid acts as a catalyst.

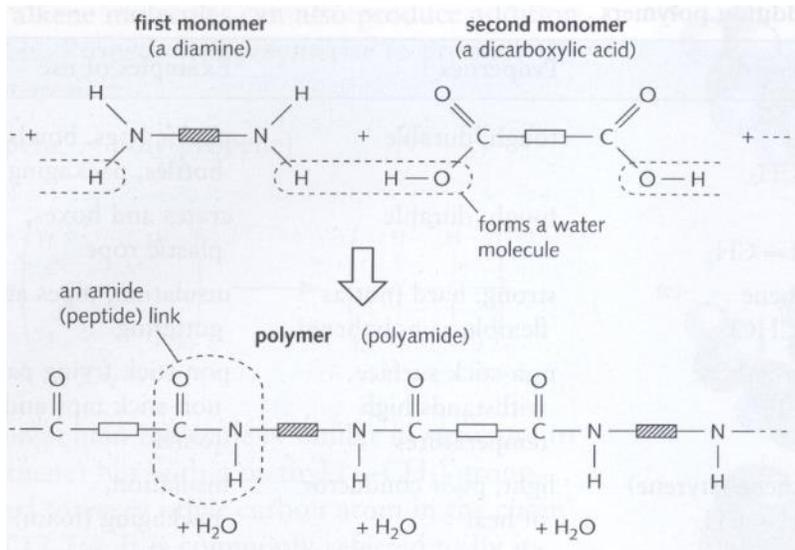


Esters are usually sweet smelling and widely used as fragrances (e.g. perfumes) and food flavorings.

## Macromolecules

Macromolecules are large molecules built up of small units (monomers). Plastics mentioned earlier are examples. These are addition polymers and are synthetic (man-made). Another type of polymerization is condensation polymerization. **Condensation polymers** can be formed from two or more different monomers joining together or from only one monomer. When the monomers join a molecule of water is produced at each join. Starch formed from glucose is a condensation polymer (this is a natural polymer – not man-made). Other examples of polymers:-

**Nylon** is a synthetic condensation polymer produced from two different monomers. One of the monomers has an amide group ( $\text{NH}_2$ ) and the other has a carboxylic acid group ( $-\text{COOH}$ ). Each time a link is made a molecule of water is lost. The link formed is called an amide (or peptide link) so the resulting polymer is a polyamide (polypeptide)



Nylon fibers can be made in the laboratory

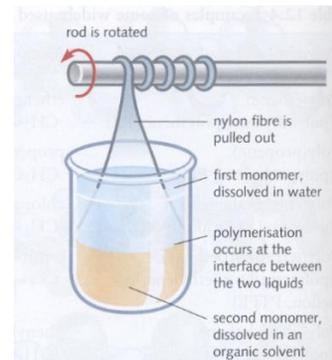
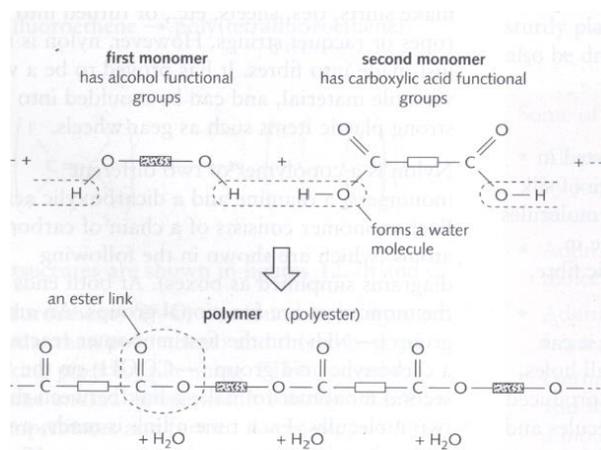
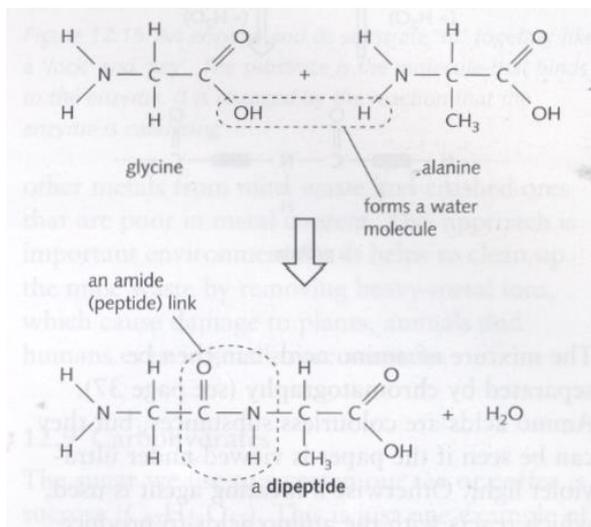


Figure 12.8 Nylon is a polyamide and can be made in the laboratory.

**Polyester** is another synthetic condensation polymer used as a fiber. An example is Terylene. It is made from two monomers one monomer has an alcohol group at each end and the other has a carboxylic acid group at each end. When the monomers react an ester link is formed.

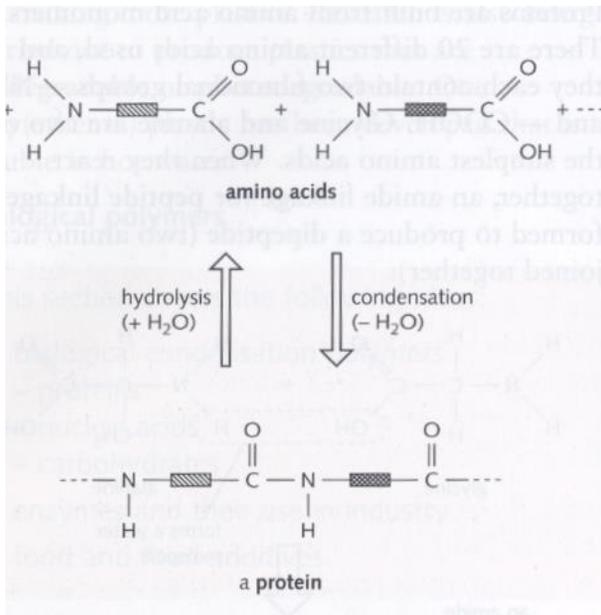




**Proteins** are natural condensation polymers made up from amino-acid monomers. Amino acids have an amine group at one end and a carboxylic acid group at the other end. When they react they form an amide link (peptide link) like in nylon. Two of the simplest amino acids are glycine and alanine

**Hydrolysis of proteins** is a method of analyzing proteins. The protein is broken down into amino acids (hydrolyzed) when it is heated with concentrated hydrochloric acid. This is the reverse of the condensation reaction. The amino acid mixture can be separated using chromatography. Amino acids are colourless so a locating agent is added to make them visible in ultra violet light. It is then possible to determine the amino acids presents from their relative distances moved.

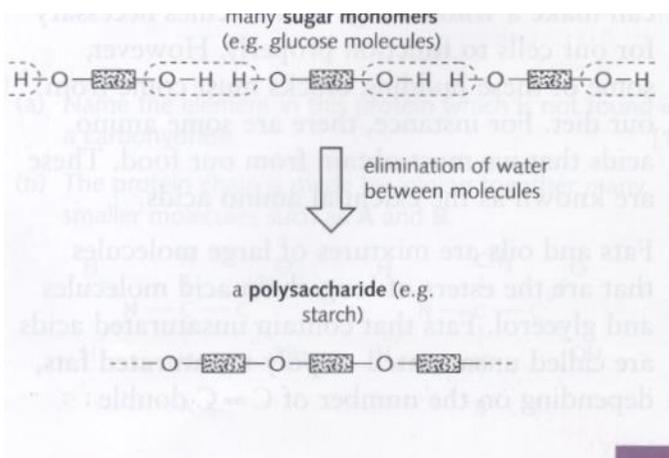
Note that hydrolysis reactions are the opposite of condensation. **Condensation** is the joining together of two molecule with the elimination of a small molecule (usually water). **Hydrolysis** is the breaking apart of a large molecule into two s



The buiret test for proteins detects the presence of the amide link (peptide link).

**Carbohydrates** are natural condensation polymers made up from simple sugars. Starch, cellulose and glycogen are all polymers of glucose. The simple sugar monomers are

called monosaccharides and the polymers are called polysaccharides. All monosaccharides have OH groups and its these groups that join together to make the polymer with the elimination of water.

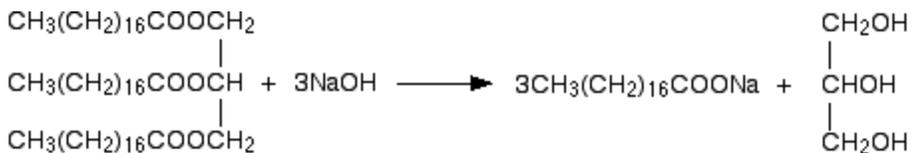


Polysaccharides can also be broken down in simple sugars by acid hydrolysis (warming with concentrated hydrochloric acid). The sugars present can be separated by chromatography and a locating agent is needed to detect the spots.

**Fats** are esters of the alcohol glycerol. Glycerol has three OH groups and each forms an ester with a carboxylic acid. These acids tend to have long chains and are often called fatty acids. Thus fats have the same link as polyesters such as terylene.

**Soaps** are formed from the hydrolysis of fats with sodium hydroxide. Animal or vegetable fat is heated with sodium hydroxide and the ester link is broken down.

fat + sodium hydroxide → soap + glycerol



a typical fat or oil

a typical sodium salt  
found in soap

glycerol

This process is called **saponification**