How we use petroleum

Over 13 billion litres of petroleum are used around the world every day.

Around half the petroleum pumped from oil wells is used for transport. It provides the fuel for cars, trucks, planes, and ships. You won't get far without it!

Most of the rest is burned for heat, in factories, homes, and power stations, as above. In a power station, the heat is used to turn water to steam, to drive turbines.

A small % is used as the starting chemicals to make many other things: plastics, shampoo, paint, thread, fabric, detergents, makeup, medical drugs, and more.

Many of the things you use every day were probably made from petroleum. Toothbrush, comb, and shampoo just for a start!

A non-renewable resource

Petroleum is still forming, very slowly, under the oceans. But we are using it up much faster than it can form, which means it will run out one day.

So petroleum is called a **non-renewable resource**.

It is hard to tell when it will run out. At the present rate of use, some experts say the world's reserves will last about 40 more years. What will we do then?

▲ A platform for pumping petroleum from under the ocean.

Q

1. The other name for petroleum is … ?
2. Why is petroleum called a *fossil fuel*?
3. What is a *hydrocarbon*?
4. What is petroleum made of?
5. Explain why petroleum is such a valuable resource.
6. Petroleum is called a *non-renewable* resource. Why?
7. What do you think we will use for fuel, when petroleum runs out?

17.2 Refining petroleum

What does *refining* mean?

Petroleum contains *hundreds* of different hydrocarbons. But a big mixture like this is not very useful.

So the first step is to separate the compounds into groups with molecules of a similar size. This is called **refining** the petroleum. It is carried out by **fractional distillation**.

Refining petroleum in the lab

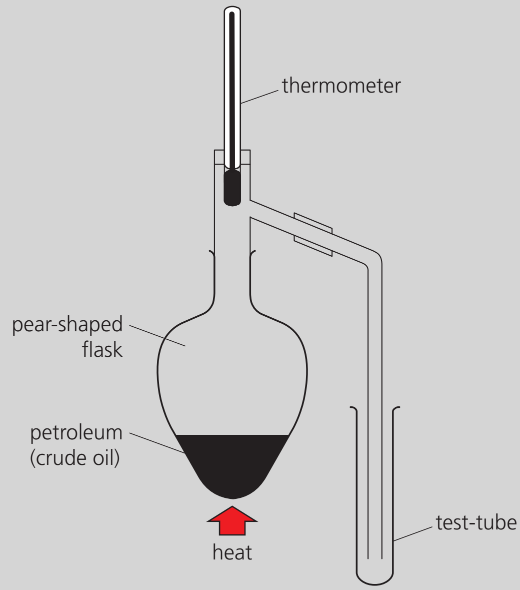
The apparatus on the right can be used to refine petroleum in the lab.

1 As you heat the petroleum, the compounds start to evaporate. The ones with smaller lighter molecules go first, since it takes less energy to free these from the liquid.

2 As the hot vapours rise, so does the thermometer reading. The vapours condense in the cool test-tube.

3 When the thermometer reading reaches 100 °C, replace the first test-tube with an empty one. The liquid in the first test-tube is your first **fraction** from the distillation.

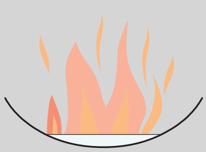
4 Collect three further fractions in the same way, replacing the test-tube at 150 °C, 200 °C, and 300 °C.



Comparing the fractions

Now compare the fractions – how runny they are, how easily they burn, and so on. You can burn samples on a watch glass, like this:

fraction 1



It catches fire easily. The flame burns high, which shows that the liquid is **volatile** – it evaporates easily.

fraction 2

This catches fire quite easily. The flame burns less high – so this fraction is less volatile than fraction 1.

fraction 3

This seems less volatile than fraction 2. It does not catch fire so readily or burn so easily – it is not so **flammable**.

fraction 4

This one does not ignite easily. You need to use a wick to keep it burning. It is the least flammable of the four.

This table summarizes the results:

Fraction	Boiling point range	How easily does it flow?	How volatile is it?	How easily does it burn?	Size of molecules
1	up to 100 °C	very runny	volatile	very easily	small
2	100 – 150 °C	runny	less volatile	easily	
3	150 – 200 °C	not very runny	even less volatile	not easily	
4	200 – 300 °C	viscous (thick and sticky)	least volatile	only with a wick	large

The trends the fractions show

Those results show that, the larger the molecules in a hydrocarbon:

– the higher its boiling point will be
– the less volatile it will be
– the less easily it will flow (or the more viscous it will be)
– the less easily it will burn.

These trends help to dictate what the different fractions will be used for, as you will see below.

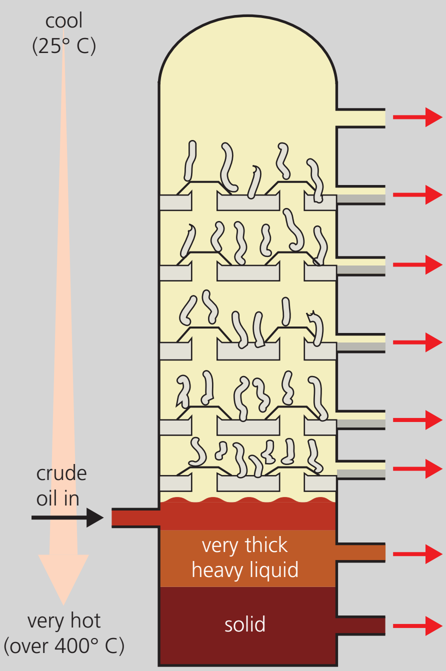
▲ The new road surface is bitumen mixed with fine gravel.

In the petroleum refinery

In a refinery, the fractional distillation is carried out in a tower that is kept very hot at the base, and cooler towards the top. Look at the drawing.

Petroleum is pumped in at the base. The compounds start to boil off. Those with the smallest molecules boil off first, and rise to the top of the tower. Others rise only part of the way, depending on their boiling points, and then condense.

The table shows the fractions that are collected.



Name of fraction	Number of carbon atoms	What fraction is used for	
refinery gas	C_1 to C_4	bottled gases for cooking and heating	boiling points and viscosity increase
gasoline (petrol)	C_5 to C_6	fuel for cars	
naphtha	C_6 to C_{10}	starting point or **feedstock** for many chemicals and plastics	
paraffin (kerosene)	C_{10} to C_{15}	fuel for aircraft, oil stoves, and lamps	
diesel oil (gas oil)	C_{15} to C_{20}	fuel for diesel engines	
fuel oil	C_{20} to C_{30}	fuel for power stations, ships, and for home heating systems	
lubricating fraction	C_{30} to C_{50}	oil for car engines and machinery; waxes and polishes	
bitumen	C_{50} upwards	for road surfaces and roofs	

As the molecules get larger, the fractions get less runny, or more viscous: from gas at the top of the tower to solid at the bottom. They also get less flammable. So the last two fractions in the table are not used as fuels.

Q

1 Which two opposite processes take place, during fractional distillation?

2 A group of compounds collected during fractional distillation is called a ……… ?

3 What does it mean? **a** volatile **b** viscous

4 List four ways in which the properties of different fractions differ.

5 Name the petroleum fraction that: **a** is used for petrol **b** has the smallest molecules **c** is the most viscous **d** has molecules with 20 to 30 carbon atoms

17.3 Cracking hydrocarbons

After fractional distillation …

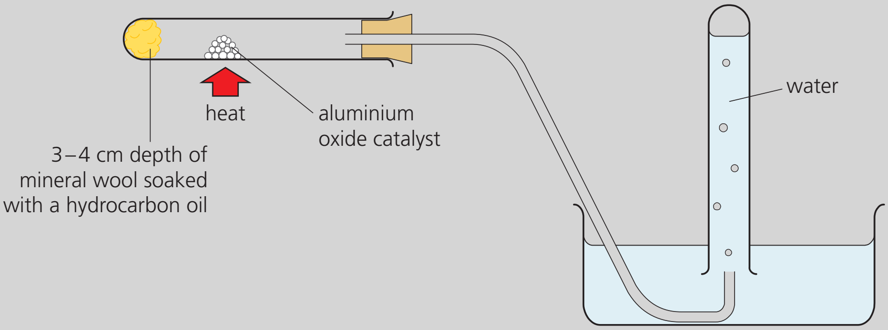
Petroleum is separated into fractions by fractional distillation. But that is not the end of the story. The fractions all need further treatment before they can be used.

1 They contain impurities – mainly sulfur compounds. If left in the fuels, these will burn to form harmful sulfur dioxide gas.
2 Some fractions are separated further into single compounds, or smaller groups of compounds. For example the gas fraction is separated into methane, ethane, propane, and butane. (We buy butane in canisters.)
3 Part of a fraction may be **cracked**.
Cracking breaks molecules down into smaller ones.

▲ This sulfur was obtained from sulfur compounds removed from natural gas.

Cracking a hydrocarbon in the lab

This experiment is carried out using a hydrocarbon oil from petroleum. The product is a gas, collected over water in the inverted test-tube:



The moment heating is stopped, the delivery tube must be lifted out of the water. Otherwise water will get sucked up into the hot test-tube.
Now compare the reactant and product:

	The reactant	The product
Appearance	thick colourless liquid	colourless gas
Smell	no smell	pungent smell
Flammability	difficult to burn	burns readily
Reactions	few chemical reactions	many chemical reactions

So the product is quite different from the reactant. Heating has caused the hydrocarbon to break down. A **thermal decomposition** has taken place. Note that:

- the reactant had a high boiling point and was not flammable – which means it had large molecules, with long chains of carbon atoms.
- the product has a low boiling point and is very volatile – so it must have small molecules, with short carbon chains.
- the product must also be a hydrocarbon, since nothing new was added.

So the molecules of the starting hydrocarbon have been cracked.
And since the product is reactive, it could be a useful chemical.

▲ Some of the naphtha fraction from refining will be piped to the cracking plant.

Cracking in the refinery

In the refinery, cracking is carried out in a similar way.

- The long-chain hydrocarbon is heated to vaporize it.
- The vapour is usually passed over a hot catalyst.
- Thermal decomposition takes place.

▲ Plastic furniture: it all began with cracking.

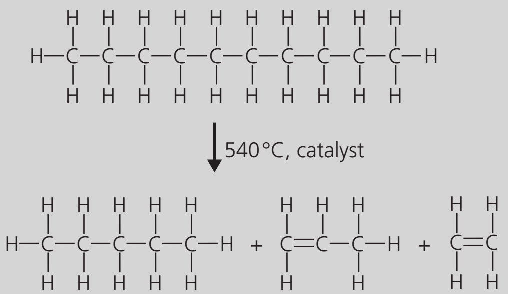
Why cracking is important

- Cracking helps you make the best use of petroleum. Suppose you have too much of the naphtha fraction, and too little of the gasoline fraction. You can crack some naphtha to get molecules the right size for petrol.
- Cracking *always* produces short-chain compounds with a carbon–carbon double bond. This bond makes the compounds **reactive**. So they can be used to make plastics and other substances.

Examples of cracking

1 **Cracking the naphtha fraction** Compounds in the naphtha fraction are often cracked, since this fraction is used as the feedstock for making many useful chemicals. This is the kind of reaction that occurs:

decane, $C_{10}H_{22}$ from naphtha fraction



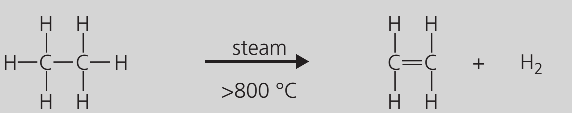
pentane, C_5H_{12} suitable for petrol

propene, C_3H_6

ethene, C_2H_4

So decane has been broken down into three smaller molecules. The propene and ethene molecules have carbon–carbon double bonds. These two compounds belong to the **alkene** family, and they are very reactive.

2 **Cracking ethane** Ethane has very short molecules – but even it can be cracked, to give ethene and hydrogen:



ethane   ethene   hydrogen

The hydrogen can be used to make ammonia – see page 226.

▲ Decane is one of the hydrocarbons in **white spirit**, a solvent used to thin oil-based paint, and clean paintbrushes.

Q

1. What happens during cracking?
2. Cracking is a *thermal decomposition*. Explain why.
3. Describe the usual conditions needed for cracking a hydrocarbon in the petroleum refinery.
4. What is *always* produced in a cracking reaction?
5. Explain why cracking is so important.
6. **a** A straight-chain hydrocarbon has the formula C_5H_{12}. Draw the structural formula for its molecules.
   b Now show what might happen when the compound is cracked.

17.4 Families of organic compounds

What their names tell you

There are *millions* of organic compounds. That could make organic chemistry confusing – but to avoid this, the compounds are named in a very logical way.

The rest of this chapter is about some families of organic compounds. **For these families, the name of the organic compound tells you:**

- **which family it belongs to**
- **how many carbon atoms are in it.**

Look at these two tables:

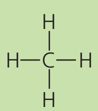
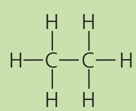
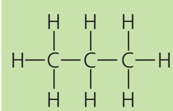
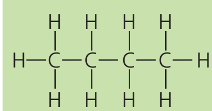
If the name ends in ...	... the compound belongs to this family ...	Example
-ane	the alkanes	ethane, C_2H_6
-ene	the alkenes	ethene, C_2H_4
-ol	the alcohols	ethanol, C_2H_5OH
-oic acid	the carboxylic acids	ethanoic acid, CH_3COOH

This in the name ...	... means this many carbon atoms ...	Example from the alkane family
meth-	1	methane, CH_4
eth-	2	ethane, C_2H_6
prop-	3	propane, C_3H_8
but-	4	butane, C_4H_{10}
pent-	5	pentane, C_5H_{12}
hex-	6	hexane, C_6H_{14}

▲ Natural gas burning at a cooker hob: it is mainly methane, the simplest alkane.

The alkanes: the simplest family

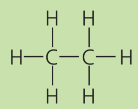
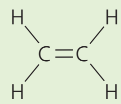
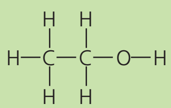
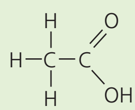
Here again are the first four members of the alkane family. Note that methane is the simplest member. What patterns do you notice?

Compound	methane	ethane	propane	butane
Formula	CH_4	C_2H_6	C_3H_8	C_4H_{10}
Structural formula				
Number of carbon atoms in the chain	1	2	3	4
Boiling point/°C	−164	−187	−42	−0.5

boiling point increases with chain length

Comparing families

This table shows one member from each of the four families. Compare them.

Family	A member	Structural formula	Comments
alkanes	ethane, C_2H_6		• The alkanes contain only carbon and hydrogen, so they are **hydrocarbons**. • The bonds between their carbon atoms are all **single bonds**.
alkenes	ethene, C_2H_4		• The alkenes are **hydrocarbons**. • All alkenes contain **carbon – carbon double bonds**. • The C=C bond is called their **functional group**.
alcohols	ethanol, C_2H_5OH		• The alcohols are not hydrocarbons. • They are like the alkanes, but with an **OH group**. • The OH group is their functional group.
carboxylic acids	ethanoic acid, CH_3COOH		• The carboxylic acids are not hydrocarbons. • All carboxylic acids contain the **COOH group**. • The COOH group is their functional group.

Functional groups

A functional group is the part of a molecule that largely dictates how the molecule will react.

For example, all the alkenes have similar reactions because they all have the same functional group, the C=C bond.

Homologous series

Look back at the alkanes in the table at the bottom of page 250. They form a **homologous series**. In a homologous series:

- All the compounds fit the same general formula.
  For the alkanes the general formula is $\mathbf{C}_n\mathbf{H}_{2n+2}$, where n is a number.
  For methane n is 1, giving the formula CH_4.
  For ethane n is 2, giving C_2H_6.
  For propane n is 3, giving C_3H_8.
- The chain length increases by 1 each time.
- As the chain gets longer, the compounds show a gradual change in properties. For example, their boiling points rise, and they burn less easily.

As you will see later, all four families in this unit form homologous series.

In a homologous series ...

As the chain gets longer:

- melting and boiling points rise
- viscosity increases – the compounds flow less easily
- flammability decreases – the compounds burn less easily.

Q

1 *Propanol* is an organic compound.
  a How many carbon atoms does it contain?
  b Which family does it belong to?
  c See if you can draw a structural formula for it.

2 Draw a structural formula for the alkane called *hexane*.

3 An alkane has 32 carbon atoms in each molecule. Give its formula.

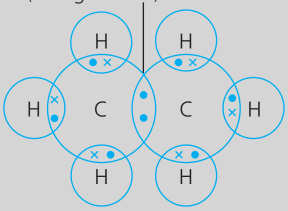
4 Try to draw the structural formula for *propanoic acid*.

17.5 The alkanes

Alkanes: a reminder

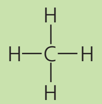
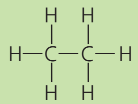
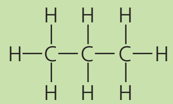
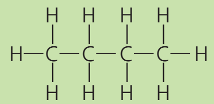
This is what you have learned about the alkanes so far:

- The alkanes are the simplest family of organic compounds.
- They are hydrocarbons: they contain only carbon and hydrogen.
- Their carbon – carbon bonds are all single bonds.
- They form a homologous series, with the general formula $\mathbf{C}_n\mathbf{H}_{2n+2}$.



▲ The bonding in ethane.

This table shows the first four members of the alkane family. What patterns do you notice?

Compound	methane	ethane	propane	butane
Formula	CH_4	C_2H_6	C_3H_8	C_4H_{10}
Structural formula				
Number of carbon atoms in the chain	1	2	3	4
Boiling point/°C	−164	−87	−42	−0.5

boiling point increases with chain length

Key points about the alkanes

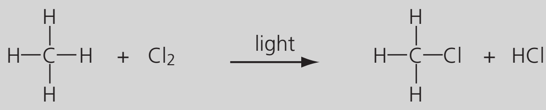
1. They are found in petroleum and natural gas. Petroleum contains alkanes with up to 70 carbon atoms. Natural gas is mainly methane, with small amounts of ethane, propane, butane, and other compounds.
2. The first four alkanes are gases at room temperature. The next twelve are liquids. The rest are solids. Boiling points increase with chain length because attraction between the molecules increases – so it takes more energy to separate them.
3. Since all their carbon – carbon bonds are single bonds, the alkanes are called **saturated**. Look at the bonding in ethane on the right above.
4. Generally, the alkanes are quite unreactive.
5. But alkanes do burn well in a good supply of oxygen, forming carbon dioxide and water vapour, and giving out plenty of heat. So they are used as **fuels**. Methane burns the most easily. Like this:

   $CH_4\,(g) + 2O_2\,(g) \longrightarrow CO_2\,(g) + 2H_2O\,(l)$ + heat energy
6. If there is not enough oxygen, the alkanes undergo **incomplete combustion**, giving poisonous carbon monoxide. For example:

   $2CH_4\,(g) + 3O_2\,(g) \longrightarrow 2CO\,(g) + 4H_2O\,(l)$ + less heat energy

▲ Butane is used as fuel for cooking and heating, in many homes.

7 Alkanes also react with chlorine in sunlight. For example:



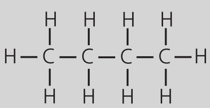
methane chloromethane

This is called a **substitution** reaction, because a chlorine atom takes the place of a hydrogen atom. If there is enough chlorine, all four hydrogen atoms will be replaced, one by one. Look at the panel on the right.

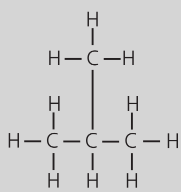
The reaction can be explosive in sunlight. But it will not take place in the dark, because it is also a **photochemical reaction**: light energy is needed to break the bonds in the chlorine molecules, to start the reaction off.

> **Chlorine and methane**
>
> The hydrogen atoms can be replaced one by one:
>
> | | |
> |---|---|
> | chloromethane | CH_3Cl |
> | dichloromethane | CH_2Cl_2 |
> | trichloromethane | $CHCl_3$ |
> | tetrachloromethane | CCl_4 |
>
> All four are used as solvents. But they can cause health problems, so are being used less and less.

Isomers



butane
boiling point 0 °C



2-methylpropane
boiling point −10 °C

Compare these alkane molecules. Both have the same formula, C_4H_{10}. But they have different structures. The first has a **straight** or unbranched chain. In the second, the chain is **branched**.

The two compounds are **isomers**.
Isomers are compounds with the same formula, but different structures.

The more carbon atoms in a compound, the more isomers it has. There are 75 isomers with the formula $C_{10}H_{22}$, for example.

Since isomers have different structures, they also have slightly different properties. For example branched isomers have lower boiling points, because the branches make it harder for the molecules to get close. So the attraction between them is less strong, and less heat is needed to overcome it.

▲ Branched-chain hydrocarbons burn less easily than their straight-chain isomers. So they are used in petrol to control combustion and stop engine 'knock' – and especially for racing cars.

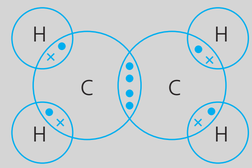
Q

1. Describe the bonding in ethane. A drawing will help!
2. Why are alkanes such as methane and butane used as fuels? See if you can give *at least* two reasons.
3. Butane burns in a similar way to methane. See if you write a balanced equation for its combustion.
4. **a** The reaction of chlorine with methane is called a *substitution* reaction. Why?
   b What special condition is needed, for this reaction?
5. Ethane reacts with chlorine, in a substitution reaction.
   a Draw the structural formula for each compound that can form, as the reaction proceeds. (Isomers too!)
   b Write the formula for each compound in **a**.
6. The compound C_5H_{12} has *three* isomers.
   a Draw the structures of these three isomers.
   b Their boiling points are 9.5, 28, and 36 °C. Match these to your drawings, and explain your choice.

17.6 The alkenes

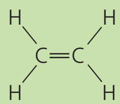
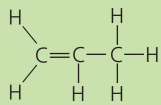
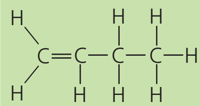
The alkene family

- The alkenes are hydrocarbons.
- They form a homologous series, with the general formula $\mathbf{C_nH_{2n}}$.
- They all contain the C=C double bond. This is their functional group, and largely dictates their reactions. Look at the bonding in ethene.
- Because they contain C=C double bonds, they are called **unsaturated**. (Alkanes have only single carbon – carbon bonds, so are **saturated**.)



▲ The bonding in ethene.

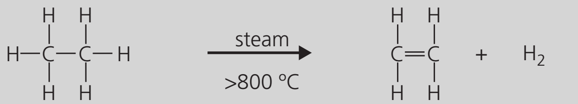
Here are the first three members of the family. Note how ethene is drawn:

Compound	ethene	propene	but-1-ene
Formula	C_2H_4	C_3H_6	C_4H_8
Structural formula			
Number of carbon atoms	2	3	4
Boiling point/°C	−102	−47	−6.5

Do you agree that these compounds fit the general formula $\mathbf{C_nH_{2n}}$?

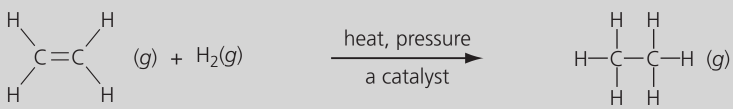
Key points about the alkenes

1 The alkenes are made from alkanes by cracking. For example ethene is formed by cracking ethane. Hydrogen is also produced:



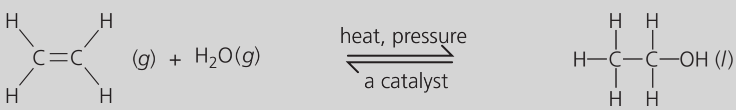
ethane ethene hydrogen

2 Alkanes are much more reactive than alkanes, because the double bond can break, to add on other atoms. For example, ethene can add on hydrogen again, to form ethane:



ethene ethane

It also adds on water (as steam) to form ethanol, an alcohol:



ethene ethanol

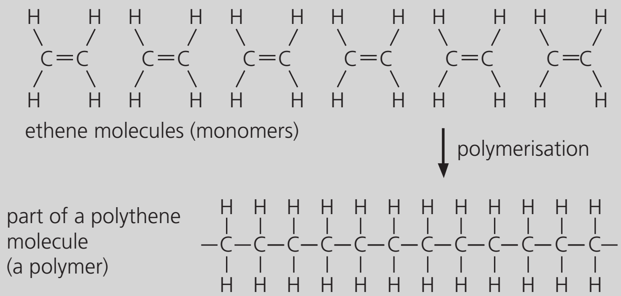
These reactions are called **addition reactions**. Can you see why? **An addition reaction turns an unsaturated alkene into a saturated compound.**

▲ Ethanol is a good solvent. It also kills many germs, so it is used in disinfectant gels for wiping your hands, in hospital.

Polymerisation

Alkene molecules undergo a very useful **addition reaction,** where they add on *to each other* to form compounds with very long carbon chains.

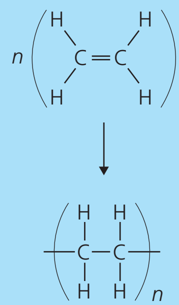
The alkene molecules are called **monomers**. The long-chain compounds that form are called **polymers**. The reaction is called **polymerisation**. For example ethene polymerises like this:



The product is **poly(ethene)** or **polythene**. The chain can be many thousands of carbon atoms long!

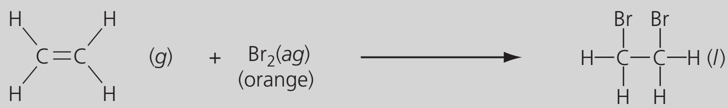
The short way to show it …

You can show polymerisation in a short way, like this. *n* stands for a very large number.



A test for unsaturation

You can use **bromine water** to test whether a hydrocarbon is unsaturated. It is an orange solution of bromine in water. If a C=C bond is present, an addition reaction takes place and the colour disappears. For example:



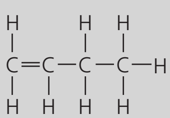
ethene (colourless) — 1,2–dibromoethane (colourless)

▲ Polythene is used to make plastic bottles, plastic bags, plastic sheeting …

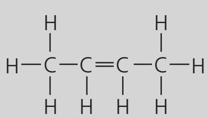
Isomers in the alkene family

In alkenes, the chains can branch in different ways, *and* the double bonds can be in different positions.

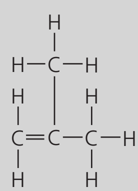
Compare the three compounds below. All three have the formula C_4H_8, but they have different structures. So they are isomers.



but-1-ene



but-2-ene



2-methylpropene

Now look at the numbers in their three names. What do these tell you?

Q

1 a Name the two simplest alkenes.
b Now draw their structural formulae.

2 What makes alkenes react so differently from alkanes?

3 Ethene can *polymerise*. What does that mean?

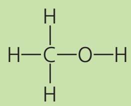
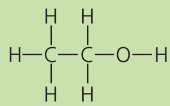
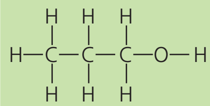
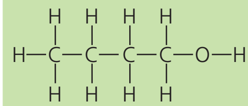
4 a Propene is *unsaturated*. What does that mean?
b Write an equation for its reaction with bromine.

5 How would you turn propene into:
a propane? **b** propanol?

17.7 The alcohols

What are alcohols?

The **alcohols** are the family of organic compounds that contain the **OH** group. This table shows the first four members:

Alcohol	methanol	ethanol	propan-1-ol	butan-1-ol
Formula	CH_3OH	C_2H_5OH	C_3H_7OH	C_4H_9OH
Structural formula				
Number of carbon atoms	1	2	3	4
Boiling point/°C	65	78	87	117

Note that:

- they form a homologous series, with the general formula $\mathbf{C_nH_{2n+1}OH}$.
- their OH functional group means they will all react in a similar way.
- two of the names above have -1- in. This tells you that the OH group is attached to a carbon atom at one end of the chain.

▲ Ethanol is used as a solvent for perfume. Why?

Ethanol, an important alcohol

- Ethanol is the alcohol in alcoholic drinks.
- It is a good solvent. It dissolves many substances that do not dissolve in water.
- It evaporates easily – it is **volatile**. That makes it a suitable solvent to use in glues, printing inks, perfumes, and aftershave

Two ways to make ethanol

Ethanol is made in two ways, one biological and one chemical.

1 By fermentation – the biological way

Ethanol is made from glucose using yeast, in the absence of air:

$$C_6H_{12}O_6\,(aq) \xrightarrow[\text{in yeast}]{\text{enzymes}} 2C_2H_5OH\,(aq) + 2CO_2\,(g) + \text{energy}$$

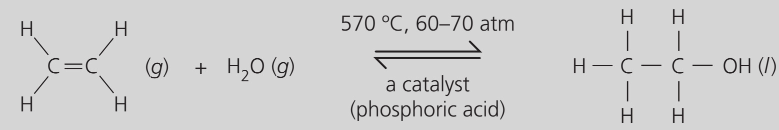
glucose → ethanol + carbon dioxide

- Yeast is a mass of living cells. The enzymes in it catalyse the reaction. (See page 142.)
- The process is called **fermentation**, and it is exothermic.
- Ethanol can be made in this way from any substance that contains sugar, starch, or cellulose. (These break down to glucose.) For example it can be made from sugarcane, maize, potatoes, and wood.
- The yeast stops working when the % of ethanol reaches a certain level, or if the mixture gets too warm.
- The ethanol is separated from the final mixture by fractional distillation.

▲ Corn (maize) is widely grown in the USA to make ethanol, for car fuel. Fuel made from plant material, using yeast or bacteria, is called **biofuel**.

2 By the hydration of ethene – the chemical way

Hydration means water is added on. This is an **addition reaction**.



ethene ethanol

- The reaction is reversible, and exothermic.
- High pressure and a low temperature would give the best yield. But in practice the reaction is carried out at 570 °C, to give a decent rate of reaction.
- A catalyst is also used, to speed up the reaction.

Ethanol as a fuel

Ethanol burns well in oxygen, giving out plenty of heat:

$$C_2H_5OH\ (l) + 3O_2\ (g) \longrightarrow 2CO_2\ (g) + 3H_2O\ (l) + \text{heat}$$

It is increasingly used as a fuel for car engines because:

- it can be made quite cheaply from waste plant material
- many countries have no petroleum of their own, and have to buy it from other countries; it costs a lot, so ethanol is an attractive option
- ethanol has less impact on carbon dioxide levels than fossil fuels do.

▲ Traffic in Rio de Janeiro in Brazil: running mainly on ethanol made from sugar cane.

Ethanol and global warming

Like the fossil fuels, ethanol does produce carbon dioxide when it burns. This is a greenhouse gas, linked to global warming. But ethanol has less impact on carbon dioxide levels in the atmosphere, because …

… although carbon dioxide is given out when ethanol burns …

… it is taken in by plants being grown to make more ethanol.

By contrast, the carbon dioxide given out when fossil fuels burn was taken in from the atmosphere many millions of years ago.

The drawbacks

More and more crops are being grown to make ethanol, for cars.

- But that takes up a lot of land.
- It means less land to grow crops for food.
- A shortage of food crops means a rise in food prices.
- When food prices rise, it affects poor people the most.

Many people are against growing crops to make ethanol. They say: *Feed people*, not cars!

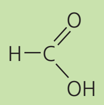
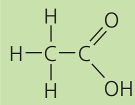
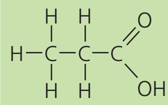
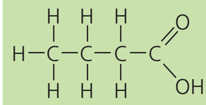
Q

1. All alcohols react in a similar way. Why?
2. Draw the structural formula for ethanol.
3. Give three uses of ethanol.
4. In Brazil, sugarcane is used to make ethanol. Name the process used, and say what the catalyst is.
5. **a** Write a word equation for the combustion (burning) of: **i** ethanol **ii** methane
   b Compare the equations. What do you notice?
6. There is another isomer with the same formula as propan-1-ol. Draw its structure, and suggest a name.

17.8 The carboxylic acids

The carboxylic acid family

Now we look at the family of organic acids: the carboxylic acids.
Here are the first four members of the family:

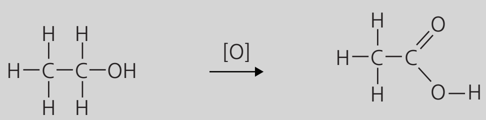
Name of acid	methanoic	ethanoic	propanoic	butanoic
Formula	HCOOH	CH_3COOH	C_2H_5COOH	C_3H_7COOH
Structural formula				
Number of carbon atoms	1	2	3	4
Boiling point/°C	101 °C	118 °C	141 °C	164 °C

- The family forms a homologous series with the general formula $\mathbf{C_nH_{2n}O_2}$. Check that this fits with the formulae in the table above.
- The functional group **COOH** is also called the **carboxyl group**.

We focus on ethanoic acid in the rest of this unit. But remember that other carboxylic acids behave in a similar way, because they all contain the carboxyl group.

Two ways to make ethanoic acid

Ethanoic acid is made by oxidising ethanol:



The oxidation can be carried out in two ways.

1 By fermentation – the biological way

When ethanol is left standing in air, bacteria bring about its oxidation to ethanoic acid. This method is called **acid fermentation**.

Acid fermentation is used to make vinegar (a dilute solution of ethanoic acid). The vinegar starts as foods such as apples, rice, and honey, which are first fermented to give ethanol.

2 Using oxidising agents – the chemical way

Ethanol is oxidised much faster by warming it with the powerful oxidising agent potassium manganate(VII), in the presence of acid. The manganate(VII) ions are themselves reduced to Mn^{2+} ions, with a colour change. The acid provides the H^+ ions for the reaction:

$$\underset{\text{purple}}{MnO_4^-} + 8H^+ + 5e^- \longrightarrow \underset{\text{colourless}}{Mn^{2+}} + 4H_2O$$

Potassium dichromate(VI) could also be used as the oxidising agent. As you saw on page 99, this gives a colour change from orange to green.

▲ Organic chemistry at the dinner table. Vinegar (on the left) is mainly a solution of ethanoic acid in water. Olive oil, on the right, is made of **esters**.
(See page 275 for more about oils.)

Ethanoic acid: typical acid reactions

Ethanoic acid shows typical acid reactions.

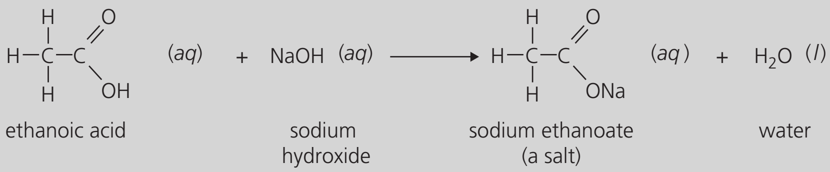
1 A solution of ethanoic acid turns litmus red.

2 A solution of ethanoic acid contains H^+ ions, because some of the ethanoic acid molecules dissociate in water, like this:

$$\underset{\text{ethanoic acid}}{CH_3COOH\ (aq)} \xrightarrow{\text{some molecules}} \underset{\text{ethanoate ions}}{CH_3COO^-\ (aq)} + \underset{\text{hydrogen ions}}{H^+\ (aq)}$$

Since only *some* molecules dissociate, ethanoic acid is a **weak acid**.

3 Ethanoic acid reacts with metals, bases, and carbonates, to form **salts**. It reacts with sodium hydroxide like this:

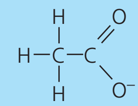


or $CH_3COOH\ (aq) + NaOH\ (aq) \longrightarrow CH_3COONa\ (aq) + H_2O\ (l)$

Like all salts, sodium ethanoate is an ionic compound.

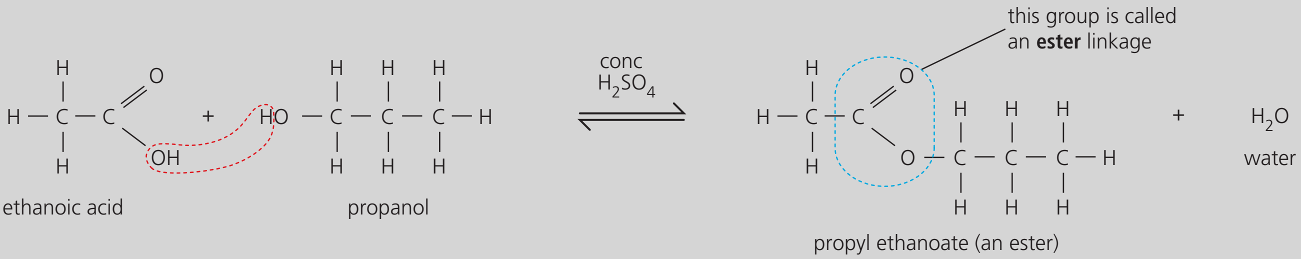
The ethanoate ion

This is its structural formula:



Esters

Ethanoic acid also reacts with alcohols, to give compounds called **esters**. The alcohol molecule is reversed below, to help you see what is happening:



or $CH_3COOH\ (l) + C_3H_7OH\ (l) \xrightleftharpoons{\text{conc. } H_2SO_4} CH_3COOC_3H_7\ (l) + H_2O\ (l)$

Note these points:

- Two molecules have joined to make a larger molecule, with the loss of a small molecule, water. So this is called a **condensation reaction**.
- The reaction is reversible, and sulfuric acid acts a catalyst.
- The alcohol part comes *first* in the name – but second in the formula.
- Propyl ethanoate smells of pears. In fact many esters have attractive smells and tastes. So they are added to shampoos and soaps for their smells, and to ice cream and other foods as flavourings.

▲ The smell and taste of the apple come from natural esters. Synthetic esters are used in the shampoo.

Q

1 What is the functional group of the carboxylic acids?

2 Copy and complete. (Page 152 may help!)

carboxylic acid + metal $\rightarrow$ ________ + ________

carboxylic acid + alkali $\rightarrow$ ________ + ________

carboxylic acid + alcohol $\rightleftharpoons$ ________ + ________

3 Carboxylic acids are *weak* acids. Explain why.

4 Draw structural formulae to show the reaction between ethanol and ethanoic acid, and name the products.

5 What is a *condensation reaction*?

6 Esters are important compounds in industry. Why?

Checkup on Chapter 17

Revision checklist

Core curriculum

Make sure you can …

- ☐ name the fossil fuels and say how they were formed
- ☐ explain what a *hydrocarbon* is
- ☐ explain why petroleum has to be refined, and:
  - – describe the refining process
  - – name the different fractions
  - – say what these fractions are used for
- ☐ explain what *cracking* is, and why it is so useful, and give the equation for the cracking of ethane
- ☐ say what a *structural formula* is, and draw structural formulae for
  methane ethane ethene ethanol ethanoic acid
- ☐ say what family a compound belongs to, from its structural formula or its name
- ☐ give the functional groups for the alkenes, alcohols, and carboxylic acids
- ☐ describe alkanes as unreactive except for burning, and give an equation for the combustion of methane
- ☐ explain what *unsaturated* means and describe a test to identify an unsaturated hydrocarbon
- ☐ describe how ethene monomers add on to each other to form the polymer poly(ethene)
- ☐ describe the two ways of making ethanol
- ☐ give at least two uses for ethanol
- ☐ give the reaction for the combustion of ethanol
- ☐ give at least two advantages of ethanol as a fuel

Extended curriculum

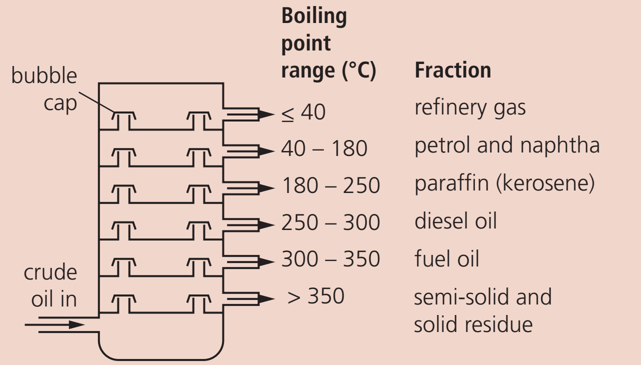
Make sure you can also …

- ☐ name, and draw the structural formulae for, the four simplest members of each family: alkanes, alkenes, alcohols, and carboxylic acids
- ☐ give the general properties of a homologous series
- ☐ explain what *isomers* are, and draw examples
- ☐ describe the substitution reactions of alkanes with chlorine
- ☐ describe the addition reactions of alkenes with hydrogen and steam
- ☐ describe the two ways to make ethanoic acid
- ☐ explain why ethanoic acid is a weak acid
- ☐ give examples of reactions to show that ethanoic acid is a typical acid
- ☐ describe the reaction of ethanoic acid with an alcohol, and name the products that form

Questions

Core curriculum

1 Petroleum is separated into fractions, like this:



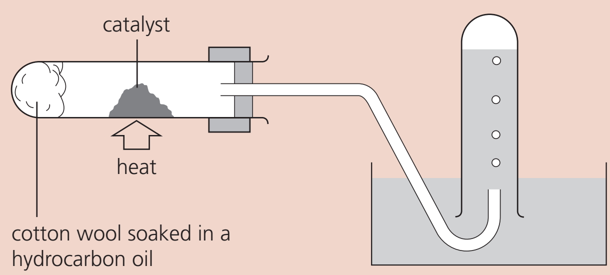
a **i** What is this process called?
ii It uses the fact that different compounds have different ……… ………. What is missing?

b **i** Is naphtha just one compound, or a group of compounds? Explain.
ii Using the terms *evaporation* and *condensation*, explain how naphtha is produced.

c Give one use for each fraction obtained.

d A hydrocarbon has a boiling point of 200 °C.
i Are its carbon chains shorter, or longer, than those found in naphtha?
ii Is it more viscous, or less viscous, than the compounds found in naphtha?

2



A hydrocarbon can be cracked in the lab using the apparatus above.

a What is cracking?

b Which two things are needed, to crack the hydrocarbon?

c The first tube of collected gas is discarded. Why? (What else is in the heated tube?)

d At the end of the experiment, the delivery tube must be removed from the water immediately. Why is this?

e Ethane, C_2H_6, can be cracked to give ethene, C_2H_4, and hydrogen. Write an equation for this.

3 Answer these questions about the alkanes.

a Which two elements do alkanes contain?

b Which alkane is the main compound in natural gas?

c After butane, the next two alkanes in the series are *pentane* and *hexane*. How many carbon atoms are there in a molecule of:

i pentane? **ii** hexane?

d Will pentane react with bromine water? Explain.

e Alkanes burn in a good supply of oxygen. Name the gases formed when they burn.

f Write the word equation for the complete combustion of pentane in oxygen.

g Name a harmful substance formed during *incomplete* combustion of pentane in air.

4 When ethanol vapour is passed over heated aluminium oxide, a dehydration reaction occurs, and the gas ethene is produced.

a Draw a diagram of suitable apparatus for carrying out this reaction in the lab.

b What is meant by a *dehydration reaction*?

c Write an equation for this reaction, using the structural formulae.

d **i** What will you see if the gas that forms is bubbled through bromine water?

ii You will not see this if ethanol vapour is passed through bromine water. Why not?

5 **a** Which of these could be used as monomers for addition polymers? Explain your choice.

i ethene, $CH_2{=}CH_2$

ii ethanol, C_2H_5OH

iii propane, C_3H_8

iv styrene, $C_6H_5CH{=}CH_2$

v chloropropene, $CH_3CH{=}CHCl$

b Suggest a name for each polymer obtained.

Extended curriculum

6 The saturated hydrocarbons form a homologous series with the general formula C_nH_{2n+2}.

a What is a *homologous series*?

b Explain what the term *saturated* means.

c Name the series described above.

d **i** Give the formula and name for a member of this series with two carbon atoms.

ii Draw its structural formula.

e **i** Name a homologous series of *unsaturated* hydrocarbons, and give its general formula.

ii Give the formula and name for the member of this series with two carbon atoms.

iii Draw the structural formula for the compound.

7 Ethanol is a member of a homologous series.

a Give two general characteristics of a homologous series.

b **i** Which homologous series is ethanol part of?

ii What is the general formula for the series?

iii What does *functional group* mean?

iv What is the functional group in ethanol's homologous series?

c Write down the formula of ethanol.

d **i** Draw the structural formula for the fifth member of the series, pentan-1-ol.

ii Draw the structural formula for an isomer of pentan-1-ol.

iii Describe how pent-1-ene could be made from pentan-1-ol.

iv Name the organic product formed when pentan-1-ol is oxidised using acidified potassium manganate(VII).

8 Ethanoic acid is a member of the homologous series with the general formula $C_nH_{2n}O_2$.

a Name this series.

b What is the functional group of the series?

c Ethanoic acid is a *weak* acid. Explain what this means, using an equation to help you.

d Ethanoic acid reacts with carbonates.

i What would you *see* during this reaction?

ii Write a balanced equation for the reaction with sodium carbonate.

e **i** Name the member of the series for which $n = 3$, and draw its structural formula.

ii Give the equation for the reaction between this compound and sodium hydroxide.

9 Ethanoic acid reacts with ethanol in the presence of concentrated sulfuric acid.

a Name the organic product formed.

b Which type of compound is it?

c How could you tell quickly that it had formed?

d What is the function of the sulfuric acid?

e The reaction is *reversible*. What does this mean?

f Write an equation for the reaction.

10 Hex-1-ene is an unsaturated hydrocarbon. It melts at −140 °C and boils at 63 °C. Its empirical formula is CH_2. Its relative molecular mass is 84.

a **i** To which family does hex-1-ene belong?

ii What is its molecular formula?

b **i** Hex-1-ene reacts with bromine water. Write an equation to show this reaction.

ii What is this type of reaction called?

iii What would you *see* during the reaction?

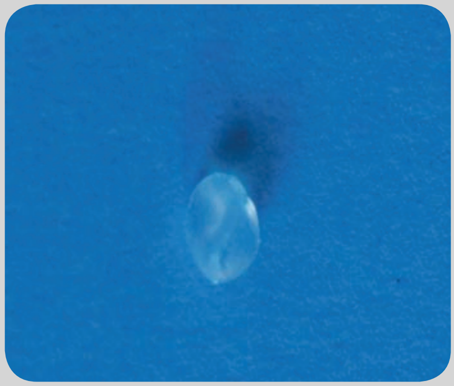
18.1 Introducing polymers

What is a polymer?

A polymer is any substance containing very large molecules, formed when lots of small molecules join together.

For example, look what happens when ethene molecules join:

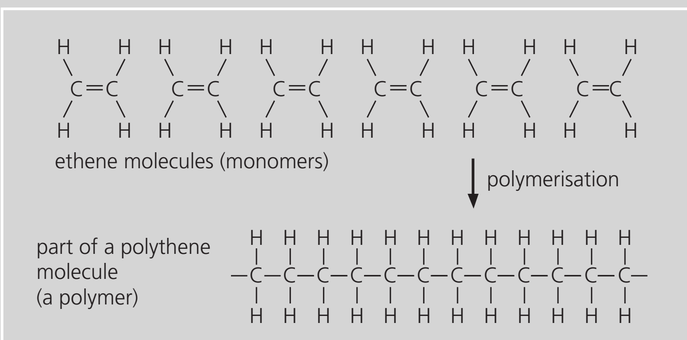
This test tube contains ethene gas. When ethene is heated to 50 °C, at a few atmospheres pressure, and over a special catalyst …



… it turns into a liquid that cools to a waxy white solid. This is found to contain very long molecules, made by the ethene molecules joining.

And it is really useful. It can be used to make toys, dustbins, tables and chairs, water pipes, buckets, crates, washing-up bowls and so on.

The reaction that took place is:



The drawing shows six ethene molecules adding together. In fact many thousands add together, giving molecules with very long chains. These very large molecules are called **macromolecules**.

A polymer is a substance made of macromolecules.

The polymer made from ethene is called **poly(ethene)** or **polythene**. Poly- means *many*. The reaction is called a **polymerisation**.

In a polymerisation reaction, thousands of small molecules join to give macromolecules. The small molecules are called monomers. The product is called a polymer.

Synthetic polymers

Polythene is a **synthetic polymer**. *Synthetic* means it is made in a factory. Other synthetic polymers include nylon, Terylene, lycra, chewing gum, and plastics such as polystyrene and perspex. Hair gels and shower gels contain water-soluble polymers.

▲ Hair gel: a water-soluble polymer. When you put it on, the water in it evaporates so the gel gets stiff.

Natural polymers

Polythene was first made in 1935. But for billions of years, nature has been busy making natural polymers. Look at these examples:

Starch is a polymer made by plants. The starch molecules are built from molecules of **glucose**, a sugar. We eat plenty of starch in rice, bread, and potatoes.

Plants also use glucose to make another polymer called **cellulose**. Cotton T-shirts and denim jeans are almost pure cellulose, made by the cotton plant.

Your skin, hair, nails, bones and muscles are mostly polymers, made of macromolecules called **proteins**. Your body builds these up from **amino acids**.

The wood in trees is about 50% cellulose. Paper is made from wood pulp, so this book is mainly cellulose. The polymer in your hair and nails, and in wool and silk, and animal horns and claws, is called **keratin**. The polymer in your skin and bones is called **collagen**.

So – you contain polymers, you eat polymers, you wear polymers, and you use polymers. Polymers play a big part in your life!

The reactions that produce polymers

All polymers, natural and synthetic, consist of macromolecules, formed by small molecules joined together.

But these macromolecules are not all made in the same way. There are two types of reaction: **addition polymerisation** and **condensation polymerisation**. You can find out more about these in the next two units.

▲ Wood: over 75% cellulose. This wood may end up as paper.

Q

1 What is:

a a macromolecule? **b** a polymer?

c a natural polymer? **d** a synthetic polymer?

e polymerisation?

2 Name the natural polymer found in:

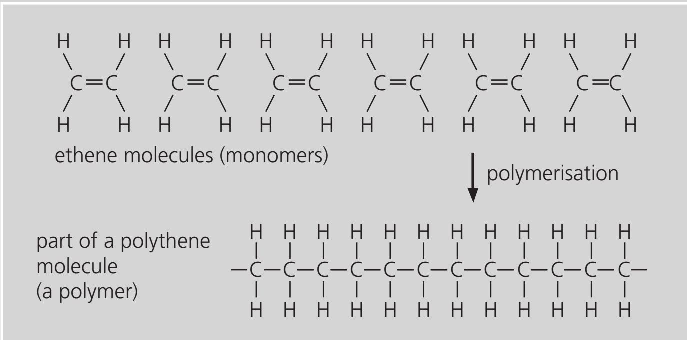
a your hair **b** this book

3 Name at least three items you own, that are made of polymers.

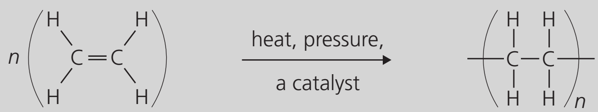
18.2 Addition polymerisation

Another look at the polymerisation of ethene

Here again is the reaction that produces polythene:



The reaction can be shown in a short form like this:



where n stands for a large number. It could be many thousands. The catalyst for the reaction is usually a mixture of titanium and aluminium compounds.

It's an addition reaction

The reaction above takes place because the double bonds in ethene break, allowing the molecules to add on to each other. So this is called **addition polymerisation**.

In addition polymerisation, double bonds in molecules break and the molecules add on to each other.

The monomer

The small starting molecules in a polymerisation are called **monomers**. In the reaction above, ethene is the monomer.

For addition polymerisation to take place, the monomers must have C=C double bonds.

The chain lengths in polythene

In polythene, all the macromolecules are long chains of carbon atoms, with hydrogen atoms attached. So they are all similar. But they are not all identical. The chains are not all the same length. That is why we can't write an exact formula for polythene.

By changing the reaction conditions, the *average* chain length can be changed. But the chains will never be all the same length.

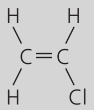
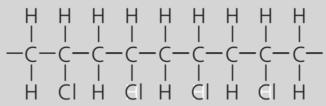
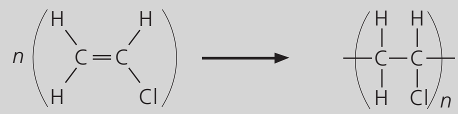
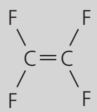
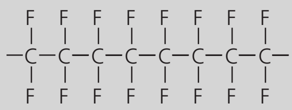
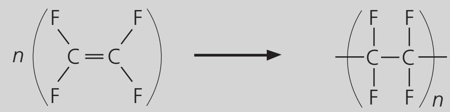
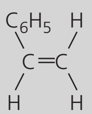
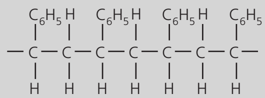
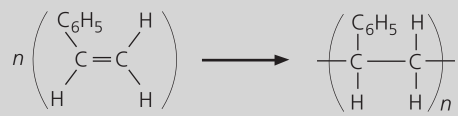
The relative atomic mass (M_r) of an ethene molecule is 28. The *average* M_r of the macromolecules in a sample of polyethene can be 500 000 or more. In other words, when making polythene, at least 17 000 ethene molecules join, on average!

▲ Polythene for packaging is made and sold as pellets like these. Later they will be heated to soften or melt them, and turned into plastic bottles and bags.

▲ To make a bottle, polythene pellets are melted. A little molten polymer is fed into a mould. A jet of air forces it into the shape of the mould. Then the mould is opened – and out comes a bottle!

Making other polymers by addition

Look at the polymers in this table. You have probably heard of them all. They are all made by addition polymerisation. Compare them:

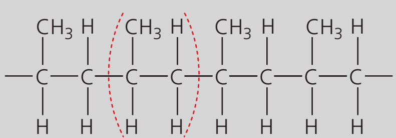
The monomer	Part of the polymer molecule	The equation for the reaction
 chloroethene (vinyl chloride)	 poly(chloroethene) or polyvinyl chloride (PVC)	 *n* stands for a large number!
 tetrafluoroethene	 poly(tetrafluoroethene) or Teflon	
 phenylethene (styrene)	 poly(phenylethene) or poly(styrene)	

Identifying the monomer

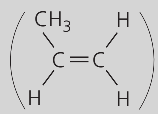
If you know the structure of the addition polymer, you can work out what the monomer was. Like this:

- Identify the repeating unit. (It has two carbon atoms side by side, in the main chain.) You could draw brackets around it.
- Then draw the unit, but put a double bond between the two carbon atoms. That is the monomer.

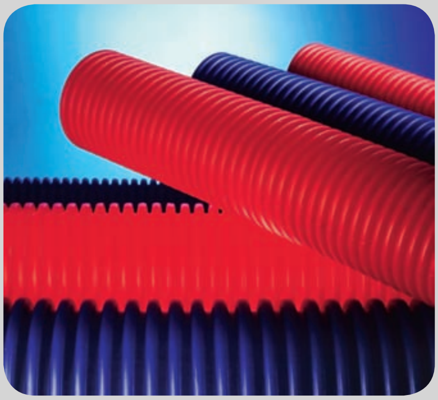
For example:



This shows part of a molecule of **poly(propene)**. The unit within brackets is the repeating unit.



So this is the monomer that was used. It is the alkene **propene**. Note the C=C double bond.



▲ PVC is light and flexible so is widely used for hoses and water pipes, and as an insulating cover for electrical wiring.

Q

1 Why was *addition polymerisation* given that name?

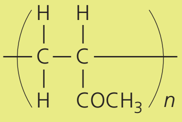
2 **a** What is a *monomer*?

b Could methane (CH_4) be used as a monomer for addition polymerisation? Explain your answer.

3 It is not possible to give an exact formula for the macromolecules in polythene. Why not?

4 Draw a diagram to show the polymerisation of:
a ethene **b** chloroethene **c** phenylethene

5 A polymer has the general formula shown on the right. Draw the monomer that was used to make it.



18.3 Condensation polymerisation

Condensation polymerisation

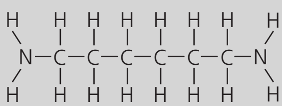
In addition polymerisation, there is only one monomer.
Double bonds break, allowing the monomer molecules to join together.
But in condensation polymerisation, no double bonds break. Instead:

- two *different* monomers join.
- each has *two functional groups* that take part in the reaction.
- the monomers join at their functional groups, by getting rid of or **eliminating** small molecules.

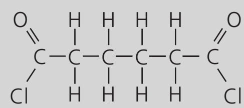
Let's look at two examples.

1 Making nylon

Below are the two monomers used in making nylon. We will call them **A** and **B**, for convenience:



A 1,6-diaminohexane

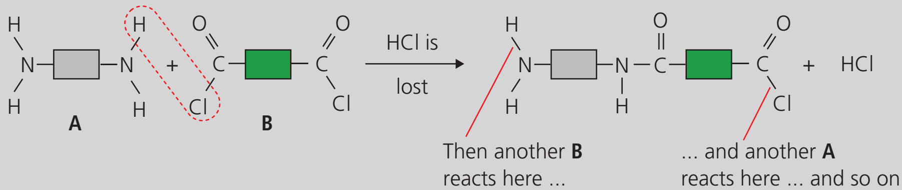


B hexan-1,6-dioyl chloride

A has an NH_2 group *at each end*. **B** has a COCl group *at each end*.
Only these functional groups take part in the reaction.
So we can show the rest of the molecules as blocks, for simplicity.

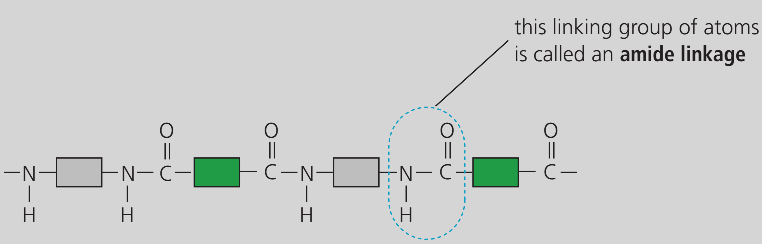
The reaction

This shows the reaction between the two monomer molecules:



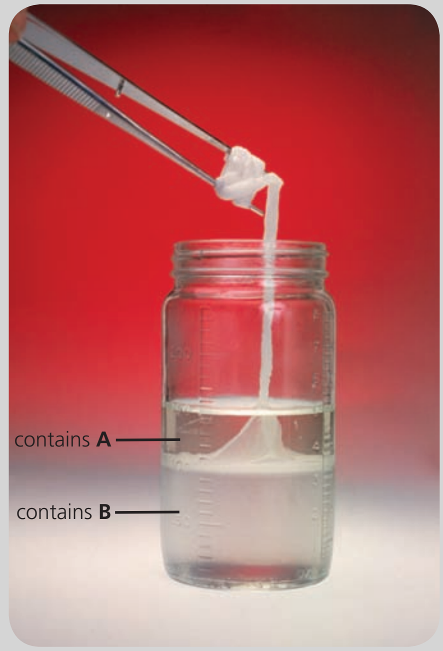
So the nitrogen atom at one end of **A** has joined to the carbon atom at one end of **B**, by eliminating a molecule of hydrogen chloride.

The reaction continues at the other ends of A and B. In this way, thousands of molecules join, giving a macromolecule of nylon. Here is part of it:



The group where the monomers joined is called the **amide** linkage. So nylon is called a **polyamide**. (Proteins have this link too, as you will see.)

Nylon can be drawn into tough strong fibres that do not rot away. So it is used for thread, ropes, fishing nets, car seat belts, and carpets.

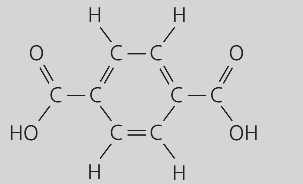


▲ Making nylon in the school lab. **A** is dissolved in water. **B** is dissolved in an organic solvent that does not mix with water. Nylon forms where the solutions meet.

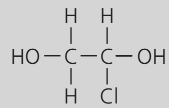
▲ Nylon thread: tough, strong, great for flying kites.

2 Making Terylene

Like nylon, Terylene is made by condensation polymerisation, using two different monomers. This time we call them **C** and **D**:



C benzene-1,4-dicarboxylic acid

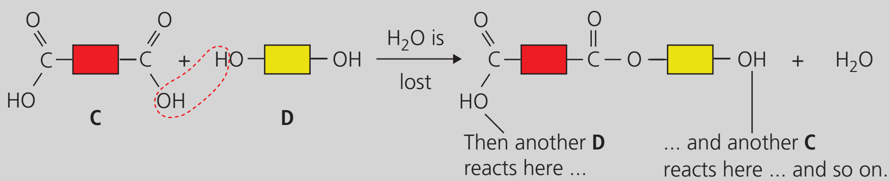


D ethane-1,2-diol

C has two COOH (carboxyl) groups, and **D** has two OH (alcohol) groups. Only these functional groups take part in the reaction.
So once again we can show the rest of the molecules as blocks.

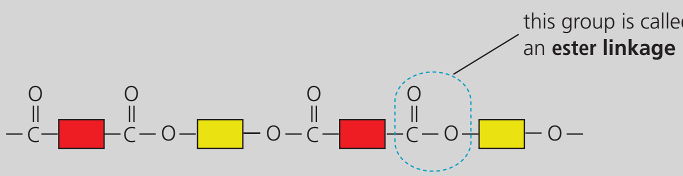
The reaction

This shows the reaction between the two monomer molecules:



So a carbon atom at one end of **C** has joined to an oxygen atom at one end of **D**, by eliminating a water molecule.

The reaction continues at the other ends of **C** and **D**. In this way thousands of molecules join, giving a macromolecule of Terylene. Here is part of it:

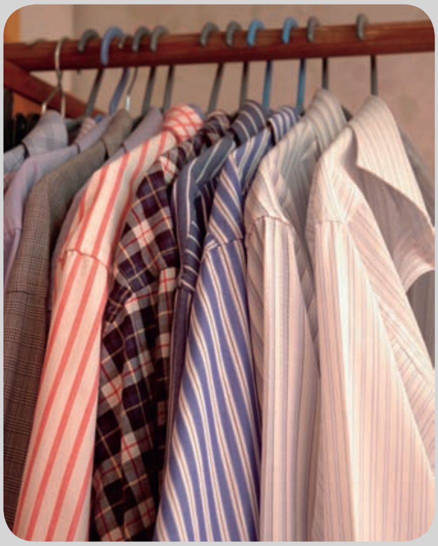


In fact the reaction is the same as the reaction between the acid and alcohol on page 259, giving an ester. (See the last section on that page.)

So the group where the monomers have joined is called an **ester linkage**. Terylene is called a **polyester**.

Terylene is used for shirts and other clothing, and for bedlinen. It is usually woven with cotton. The resulting fabric is more hard-wearing than cotton, and does not crease so easily. Terylene is also sold as polyester thread.

▲ Fibres of nylon and Terylene are made by pumping the melted polymer through a spinneret (like a shower head). As it comes out through the holes, the polymer hardens into long threads.



▲ Shirts made from Terylene woven with cotton.

Q

1. How many products are there, in condensation polymerisation?
2. In condensation polymerisation, each monomer molecule must have *two* functional groups. Explain why.
3. List the differences between condensation and addition polymerisation.
4. **a** Draw a diagram to show the reaction that produces nylon. (You can show the carbon chains as blocks.)
   b Circle the *amide linkage* in your drawing.
   c Nylon is called a *polyamide*. Why?
5. Draw part of a Terylene macromolecule in a simple way, using blocks as above. Circle the *ester linkage*.

18.4 Making use of synthetic polymers

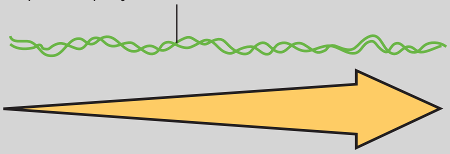
Plastics are synthetic polymers

Synthetic polymers are usually called **plastics**. (*Plastic* means *can be moulded into shape without breaking*, and this is true of all synthetic polymers while they are being made.) But when they are used in fabrics, and for thread, we still call them synthetic polymers.

Most plastics are made from chemicals found in the naphtha fraction of petroleum (pages 247 and 249). They are usually quite cheap to make.

▲ A synthetic polymer for sewing. (It is polyester.)

a pair of polymer molecules



as molecules get longer, the force of attraction between them increases

The properties of plastics

Most plastics have these properties:

1 They do not usually conduct electricity or heat.

2 They are unreactive. Most are not affected by air, water, acids, or other chemicals. This means they are usually safe for storing things in, including food.

3 They are usually light to carry – much lighter than wood, or stone, or glass, or most metals.

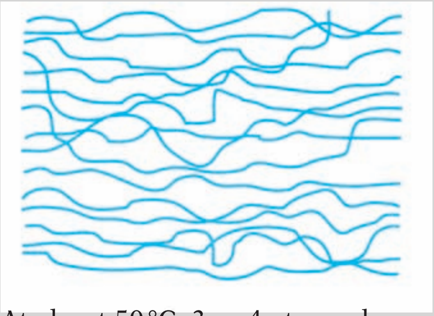
4 They don't break when you drop them. You have to hammer most rigid plastics quite hard, to get them to break.

5 They are strong. This is because their long molecules are attracted to each other. Most plastics are hard to tear or pull apart.

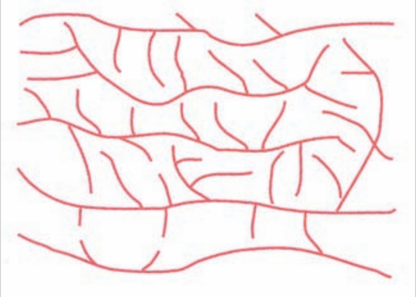
6 They do not catch fire easily. But when you heat them, some soften and melt, and some char (go black as if burned).

Changing the properties

By choosing monomers and reaction conditions carefully, you can make plastics with exactly the properties you want. For example, look at how you can change the properties of polythene:



At about 50 °C, 3 or 4 atmospheres pressure, and using a catalyst, you get long chains like these. They are packed close together so the polythene is quite **dense**.



At about 200 °C, 2000 atmospheres pressure, and with a little oxygen present, the chains will branch. Now they can't pack closely, so the polythene is far less dense.

So by choosing the right conditions, you can change the density of the polythene, and make it 'heavy' or 'light' to suit your needs.

The **high-density** polythene is hard and strong, which is why it is used for things like bowls and dustbins. The **low-density** polythene is ideal for things like plastic bags, and 'cling film' for wrapping food.

Uses for synthetic polymers

Given all those great properties, it is not surprising that plastics have thousands of uses. Here are some examples.

Polymer	Examples of uses
polythene	plastic bags and gloves, clingfilm (*low density*) mugs, bowls, chairs, dustbins (*high density*)
polychloroethene (PVC)	water pipes, wellingtons, hoses, covering for electricity cables
polypropene	crates, ropes
polystyrene	used as expanded polystyrene in fast-food cartons, packaging, and insulation for roofs and walls (to keep homes warm)
Teflon	coated on frying pans to make them non-stick, fabric protector, windscreen wipers, flooring
nylon	ropes, fishing nets and lines, tents, curtains
Terylene	clothing (especially mixed with cotton), thread

▲ Another use of nylon: for parasails like this one, and parachutes.

▲ Polystyrene is an insulator: it helps to prevent heat loss. So it is used under floors, and in fast-food cartons.

▲ Teflon – a slippery polymer. It is used to coat irons to help them glide, and on frying pans to stop food sticking.

Q

1 Look at the properties of plastics, on page 268. Which *three* properties do you think are the most important for:

a plastic bags? **b** kitchen bowls and utensils?
c water pipes? **d** fishing nets?
e hair dryers? **f** polystyrene fast-food containers?

2 What is *low-density* polythene, and how is it made?

3 Teflon is used to coat frying pans, to make them non-stick. So what properties do you think Teflon has? List them.

4 a What is *expanded polystyrene*?
b Give three uses of this material.

5 a Now make a table with these headings:

Item	*Properties of the plastic in it*	*Disadvantages of this plastic*	*Name of this plastic*

b i Fill in the first column of your table, giving three or four plastic items you own or use.
ii In the second column, give the properties you observe, for that plastic. (You are a scientist!) For example is the plastic rigid? Or flexible?
iii In the third column give any disadvantages you notice, for this plastic.
iv Then see if you can name it. If you can, well done!

18.5 Plastics: here to stay?

Plastics: the problem

There were only a few plastics around before the 1950s. Since then, dozens of new ones have been developed, and more are on the way.

Now it is hard to imagine life without them. They are used everywhere.

One big reason for their success is their unreactivity. But this is also a problem. They do not break down or rot away. Most of the plastics thrown out in the last 50 years are still around – and may still be here 50 years from now. A mountain of waste plastic is growing.

▲ Plastic bags – here today, still here tomorrow …

Polythene: the biggest problem

Polythene is the biggest problem. It is the most-used plastic in the world, thanks to its use in plastic bags and food packaging. Around 5 trillion polythene bags are made every year. (That's 5 million million.) Most are used only once or twice, then thrown away.

In many places, rubbish is collected and brought to **landfill sites**. The plastic bags fill up these sites. In other places, rubbish is not collected. So the plastic bags lie around and cause many problems. For example:

- they choke birds, fish and other animals that try to eat them. Or they fill up the animals' stomachs so that they cannot eat proper food, and starve to death. (Animals cannot digest plastics.)
- they clog up drains, and sewers, and cause flooding.
- they collect in rivers, and get in the way of fish. Some river beds now contain a thick layer of plastic.
- they blow into trees and onto beaches. So the place looks a mess. Tourists are put off – and many places depend on tourists.

Because of these problems, plastic bags have been banned in many places. For example in Bangladesh, Rwanda and several states in India.

▲ A stomach full of plastic means the bird will starve to death.

▲ Nice for visitors …

Recycling plastics

Some waste plastics do get reused. For example:

- some are melted down and made into new plastic bags, and things like soles for shoes, and fleeces.
- some are melted and their long chains cracked, to make small molecules that can be polymerised into new plastics.
- some are burned, and the heat is used to produce electricity.

But only a small % of waste plastic is reused in these ways. One problem is the many different types of plastic. These must be separated before reusing them, but that is not easy to do. Burning also poses problems, since some plastics give off poisonous gases.

▲ A degradeable plastic bag: it will break down along with the vegetable peelings and scrap paper inside.

Degradeable plastics

Degradeable polythene is already here. Some is **biodegradeable**: it contains additives such as starch that bacteria can feed on. Some is **photodegradeable**: it containts additives that break down in sunlight. In both cases, the result is that the polythene breaks down into tiny flakes.

The amount of additive can be varied for different purposes – for example to make rubbish sacks that will break down within weeks.

Bio-polymers: the future?

In future, the plastics you use could be **bio-polymers** – grown inside plants, or made in tanks by bacteria.

For example, one strain of bacteria can feed on sugar from crops such as maize, to produce polyesters.

Plants that can make plastics in their cells have already been developed. When the plants are harvested, the plastic is extracted using a solvent. Then the solvent is evaporated.

Work on bio-polymers is still at an early stage. But when oil runs out, we will be glad of bio-polymers. And they have two advantages for the environment: they are a renewable resource, and biodegradeable.

▲ This little cress plant has been genetically modified to produce a plastic in its cells.

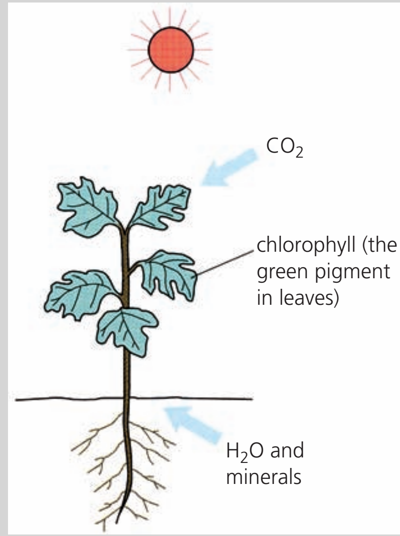
Q

1. Describe some negative effects of plastics on the environment.
2. Polythene is responsible for most of the environmental problems caused by plastics. Explain why.
3. Explain what these are, in your own words:
   a photodegradable polythene **b** bio-polymers
4. See if you can come up with some ideas, to help prevent pollution by plastic bags.

18.6 The macromolecules in food (part I)

What's in your food?

No matter what kind of food you eat, its main ingredients are the same: **carbohydrates**, **proteins** and **fats**. All three are made of macromolecules. And plants can produce them all.



▲ A plant: a natural chemical factory.

Plants: the polymer factories

1 Plants take in carbon dioxide from the air, and water from the soil.

2 Using energy from sunlight, and **chlorophyll** as a catalyst, they turn them into glucose and oxygen, in a process called **photosynthesis**:

$$\underset{\text{carbon dioxide}}{6CO_2\,(g)} + \underset{\text{water}}{6H_2O\,(l)} \longrightarrow \underset{\text{glucose (a sugar)}}{C_6H_{12}O_6\,(s)} + \underset{\text{oxygen}}{6O_2\,(g)}$$

3 Then they turn the glucose molecules into macromolecules of starch and cellulose, by polymerisation. These natural polymers are called **carbohydrates**. Plants use cellulose to build stems and other structures. They use starch as an energy store.

4 Using glucose, and minerals from the soil, they also produce macromolecules of **proteins** and **fats**.

Enzymes in plant cells act as catalysts, for the reactions in **3** and **4**.

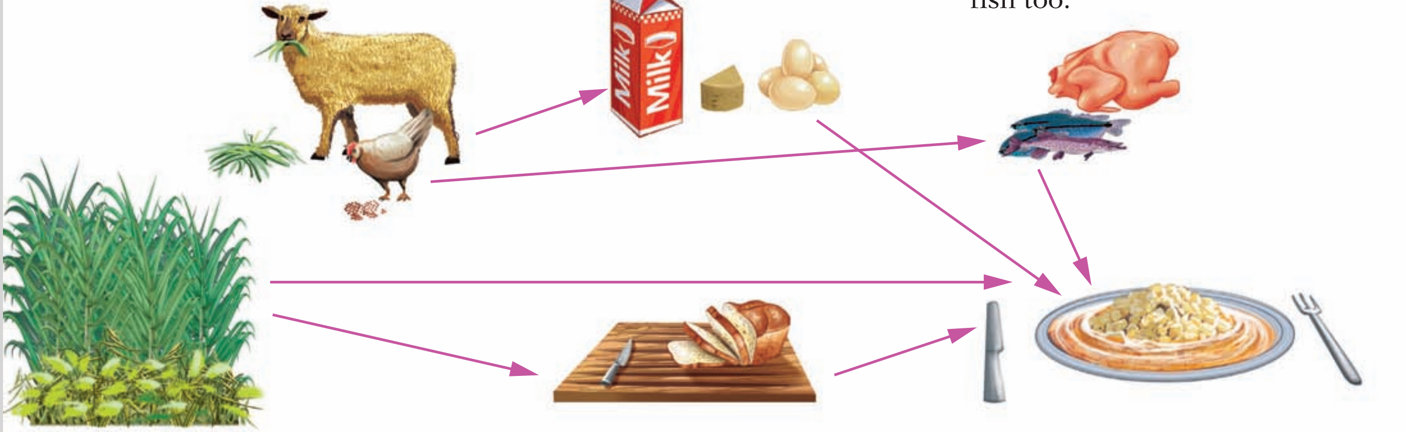
From plants to you

This is how the macromolecules from plants reach you:

1 Animals eat plants, and seeds of plants. They digest them, and build their own carbohydrates, proteins, and fats from them.

2 You eat animal carbohydrates, proteins, and fats, in animal produce such as eggs, milk, and cheese.

3 You eat them in meat and fish too.



4 You also eat parts of plants. For example maize, rice, potatoes and other vegetables, and fruit, …

5 … and things like bread and pasta, made from plant products.

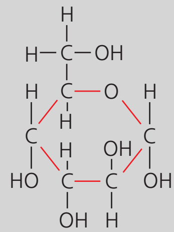
6 During digestion, you break the macromolecules back down to their building blocks. You use some for energy, and the rest to build up new carbohydrates, proteins, and fats.

We will now look more closely at the carbohydrates, proteins, and fats that plants produce, in this unit and the next one.

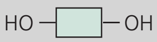
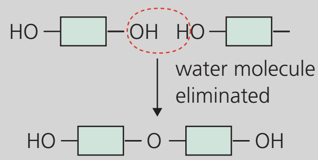
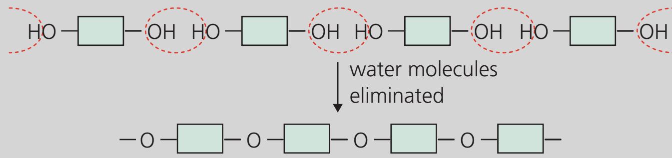
Carbohydrates

Carbohydrates contain just carbon, hydrogen and oxygen. Glucose is called a **simple carbohydrate**. It is also called a **monosaccharide**, which means *a single sugar unit*.

The structure of a glucose molecule is shown on the right. Now let's see how glucose molecules join:



◀ A molecule of glucose, $C_6H_{12}O_6$.

1	2	3
1 We can draw a glucose molecule like this, showing the two groups that react: 	**2** Two glucose molecules can join like this, giving maltose, a **disaccharide**: 	**3** Hundreds or thousands can join in the same way, giving **starch**, a **complex carbohydrate**. It is also called a **polysaccharide**: 

In reaction 2, two molecules join, eliminating a small molecule (water). So it is a condensation reaction. Reaction 3 is a **condensation polymerisation**, so starch is a **polymer**.

▲ It can do something we can't do: digest cellulose. Grass is mainly cellulose.

Cellulose

Cellulose is also a polysaccharide. Its molecules are built from at least 1000 glucose units. But they are joined differently than those in starch, so cellulose has quite different properties.

The cell walls in plants are made of cellulose. So we eat cellulose every time we eat cereals, vegetables, and fruit. We can't digest it, but it helps to clean out our digestive systems. We call it **fibre**.

The importance of carbohydrates

Your body *can* digest starch. It breaks it back down to glucose. It uses some of this for respiration, which provides you with energy (page 235).

It builds the rest into a complex carbohydrate called **glycogen**, which acts as an energy store.

So carbohydrates are an important part of your diet. Rice, wheat, pasta, potatoes, and bananas are all rich in starch. Honey and fruit juices are rich in glucose.

▶ Before races, marathon runners eat plenty of carbohydrate to build up their glycogen levels.

Q

1 All life depends on photosynthesis. Explain why.

2 Explain what it is, and name one example:
- **a** a carbohydrate **b** a monosaccharide
- **c** a disaccharide **d** a polysaccharide

3 In ways is cellulose:
- **a** like starch? **b** different from starch?

4 The cellulose in vegetables is good for us. Why?

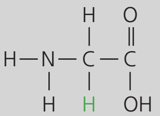
5 Name three foods you eat, that are rich in starch.

18.7 The macromolecules in food (part II)

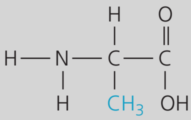
Proteins – built from amino acids

Proteins are **polymers**, built up from molecules of **amino acids**. Amino acids contain carbon, hydrogen, oxygen, and nitrogen, and some contain sulfur. The general structure of an amino acid molecule is shown on the right. Note the COOH and NH_2 functional groups.

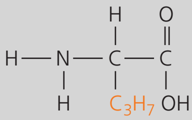
There are twenty common amino acids. Here are three of them – with the COOH bonds drawn vertically, to help you see how the amino acids join:



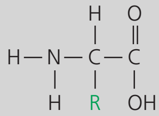
glycine



alanine



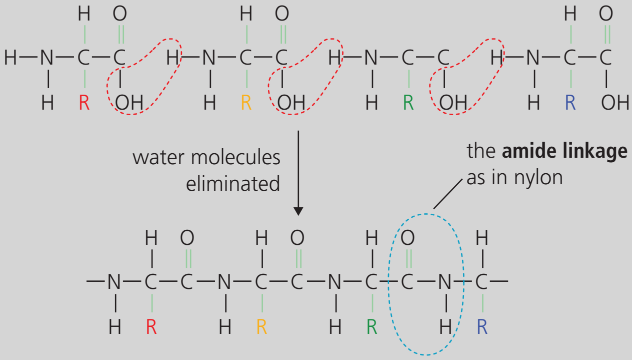
cysteine

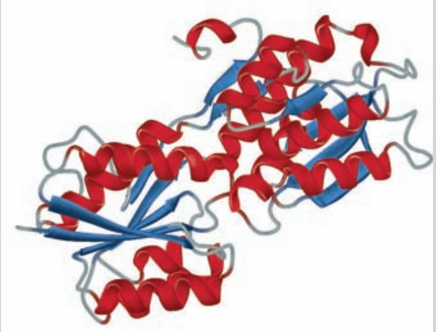


▲ An amino acid is a carboxylic acid with an amino (NH_2) group. R stands for the rest of the molecule.

How amino acids join up to make proteins

This shows four different amino acids combining:





▲ Proteins are large and complex. The chains are often coiled. The genes in the cells of plants and animals control which amino acids join up, and in what order.

From 60 to 6000 amino acid units can join to make a macromolecule of protein. They can be different amino acids, joined in different orders – so there are a huge number of proteins!

The reaction is a **condensation polymerisation**, with loss of water molecules. Note the **amide linkage**, as in nylon (page 266).

The importance of proteins in your food

When your body digests food, it breaks the proteins back down to amino acids. These then join up again to make proteins your body needs. For example all these substances in your body are proteins:

- the enzymes that act as catalysts for reactions in your body cells
- the collagen in your skin, bones, and teeth
- the keratin that forms your hair
- haemoglobin, the red substance in blood, that carries oxygen
- hormones, the chemicals that dictate how you grow and develop.

Your body needs all 20 amino acids to make these proteins. It *can* make 11 by itself. But there are 9 **essential amino acids** that it cannot make. To be healthy, you must eat foods that can provide these.

Rich in proteins

chicken and other meats
fish
cheese
yoghurt
milk
eggs
soya beans
lentils
beans and peas
spinach
nuts
seeds (such as sunflower seeds)

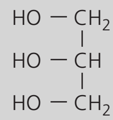
▲ Proteins from animals usually have all 20 amino acids. So do those from soya beans. But in other plant proteins, some essential amino acids are often missing.

Fats

Foods also contain natural **fats** and **oils** (liquid fats).

Complex carbohydrates, and proteins, are polymers. But fats are not made by polymerisation, so they are not polymers. They are esters: compounds formed from an **alcohol** and an **acid**.

- The alcohol is always **glycerol**, a natural alcohol with three OH groups. (Its chemical name is propan-1,2,3-triol.)
- The acids are natural carboxylic acids, usually with long carbon chains. They are called **fatty acids**. For example palmitic acid, $C_{15}H_{31}COOH$.

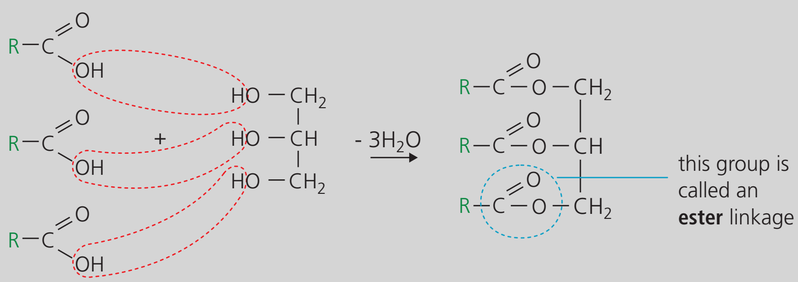


glycerol

◀ A molecule of glycerol.

How fats are formed

This shows the reaction between glycerol and a fatty acid. R stands for the long chain of carbon atoms with hydrogen atoms attached, in the acid:



3 molecules of a fatty acid + 1 molecule of glycerol ⟶ 1 macromolecule of a fat

This is a **condensation reaction**, with the elimination of water. Each OH group in a glycerol molecule can react with a *different* fatty acid, so you can get many different esters. Note the ester linkage, as in Terylene (page 267).

▲ Making palm oil. She will crush the boiled palm fruit to release the oil, and use it for cooking. Palm oil is a mixture of esters, mainly from palmitic acid.

The importance of fats in your food

In your body, fats and oils in food are broken down to fatty acids and glycerol. Some of these are used for energy. Some are combined into new fats, to make the membranes in your body cells. Some cells also store fat droplets. These cells form a layer under your skin, which keeps you warm.

So you need some fats in your diet. But runny **unsaturated fats** (containing carbon–carbon double bonds) are better for you than the hard, saturated, fats found in meat and cheese. Saturated fats have been linked to heart disease.

!

Rich in fats

meat
oily fish
butter, cheese, cream
avocados
nuts and seeds
vegetable oils (such as palm oil, olive oil, sunflower oil)
margarine and other spreads

▲ Fish oil and vegetable oils contain unsaturated fats. These are better for you than saturated fats.

Q

1. What is: **a** an amino acid? **b** a protein?
2. Describe in your own words a protein macromolecule.
3. Give three examples of the important roles proteins play in your body.
4. Name six foods that are rich in protein.
5. Show how palmitic acid reacts with propan-1,2,3-triol to give an ester found in palm oil.
6. What happens to fats when you eat them?
7. Compare the reactions that produce carbohydrates, proteins, and fats. What do they have in common?

18.8 Breaking down the macromolecules

What happens during digestion?

You saw earlier how the natural macromolecules in food were built up by condensation reactions, with the loss of water molecules.

The opposite happens when you eat them. In your mouth, stomach and small intestine, the macromolecules are broken down again, by reacting with water. This is called **hydrolysis**.

Hydrolysis is a reaction in which molecules are broken down by reaction with water.

▲ The hydrolysis of starch starts in your mouth, where the enzyme *amylase* in saliva start breaking it down.

Hydrolysis in the digestive system

This is what happens in your body, during digestion:

- **Starch** and any disaccharides get broken down to glucose. Your cells then use the glucose to provide energy, in a process called respiration. It is the reverse of photosynthesis:

  $C_6H_{12}O_6\ (aq) + 6O_2\ (g) \longrightarrow 6CO_2\ (g) + 6H_2O\ (l) + \text{energy}$

  glucose + oxygen ⟶ carbon dioxide + water + energy

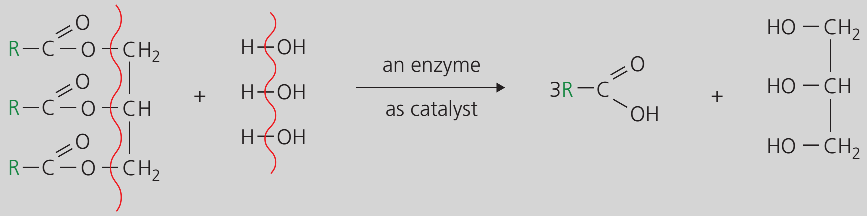
- **Proteins** get broken down to **amino acids** which your body then uses to build up the proteins it needs.
- **Fats** and **oils** (which are esters) get broken down into **glycerol** and **fatty acids**. These are used for energy, or to make new fats for cell membranes, or to be stored.

All the 'breaking down' reactions during digestion are hydrolyses.

▲ All the macromolecules will be broken down, with help from enzymes.

Example: hydrolysis of an ester during digestion

This shows the hydrolysis of an ester in a vegetable oil, in your digestive system. R represents long chains of carbon atoms:



an ester in a vegetable oil — water — fatty acid — glycerol

Compare it with the reaction shown on page 275. What do you notice?

Enzymes as catalysts

Enzymes act as catalysts, in building up the macromolecules in food. In digestion, other enzymes act as catalysts to break them down again. (Look at the hydrolysis above.) Enzymes called **amylases** act on starch, **lipases** act on fats and oils, and **proteinases** act on proteins.

▲ Getting ready for hydrolysis.

Hydrolysis in the lab

You can also carry out hydrolysis of starch, proteins and fats in the lab. This table shows the conditions, and the results for complete hydrolysis.

Macromolecule	Conditions for the hydrolysis	Complete hydrolysis gives …
starch	heat with dilute hydrochloric acid	glucose
proteins	boil with 6M hydrochloric acid for 24 hours	amino acids
fats	boil with dilute sodium hydroxide	glycerol plus the sodium salts of the fatty acids ($R-COO^- Na^+$)

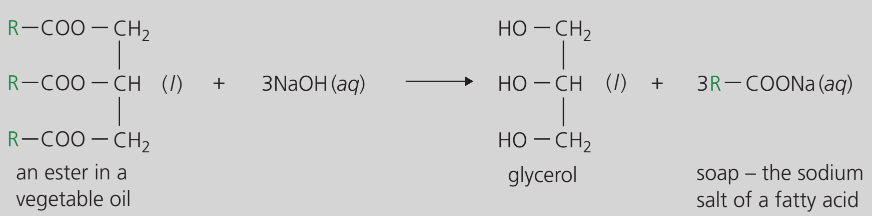
Note that:

- the products are the same as for digestion, except for fats, where you obtain sodium salts of the fatty acids.
- the hydrolyses in your digestive system take place in much milder conditions, at much lower temperatures, thanks to enzymes.
- if the hydrolysis of starch and proteins is *not* complete, you will obtain a mixture of molecules of different sizes. Partial hydrolysis of starch can give glucose, maltose (made of two glucose units), maltotriose (three glucose units), and dextrins (many glucose units).

You can use paper chromatography to identify the products of the hydrolyses, as shown in Unit 2.5. They are colourless, so you need to use locating agents.

Making soap from fats and oils

The sodium salts of fatty acids are used as **soap**. So soap is made in factories by boiling fats and oils with sodium hydroxide, as above. For example:



The soap you buy may be made from vegetable oil – like palm oil or coconut oil – or even from fish oil or animal fat. Chemicals are added to make it smell nice. These are usually artificial esters. (As you saw on page 259, many esters have attractive smells.)

▲ Sodium salts that keep you clean!

Q

1 **a** What does *hydrolysis* mean?
   b See if you can draw a diagram to show that the complete hydrolysis of starch to glucose, in the lab, is the opposite of a condensation polymerisation.
   c If you carry out an incomplete hydrolysis of starch in the lab, you get a mixture of products. Explain.

2 Hydrolysis of a protein in the lab will give a mixture of products. Explain why, and how to identify them.

3 Oils are broken down in your digestive system. And oils are used to make soaps, in industry.
   a What do these two processes have in common?
   b In what way are they different?

Checkup on Chapter 18

Revision checklist

Extended curriculum

Make sure you can …

- ☐ explain these terms:

  monomer *polymer* *polymerisation*
  macromolecule *natural polymer* *synthetic polymer*
- ☐ describe addition polymerisation, and
  - say what the key feature of the monomer is
  - draw part of a polymer molecule, formed from a given monomer
  - identify the monomer, for a given polymer
- ☐ name at least three polymers formed by addition polymerisation, and give uses for them
- ☐ describe condensation polymerisation, and
  - say what the key features of the monomers are
  - state the differences between condensation and addition polymerisation
- ☐ draw simple diagrams to show the monomers, and part of the macromolecule, for:

  nylon *Terylene*

  using blocks to represent carbon chains
- ☐ explain what the *amide* and *ester* linkages are, and identify them on a drawing
- ☐ give uses for nylon and Terylene
- ☐ give at least five general properties of plastics
- ☐ describe some of the environmental problems caused by plastics
- ☐ name and describe the three main groups of macromolecules in food
- ☐ explain what these are:

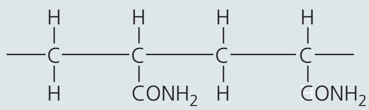
  amino acids *fatty acids* *glycerol* *esters*
- ☐ draw simple diagrams to show how these are formed by condensation polymerisation:

  starch *proteins*
- ☐ draw a simple diagram to show how fats are formed by a condensation reaction
- ☐ explain what *hydrolysis* is
- ☐ describe the products, when starch, proteins, and fats are broken down in your digestive system
- ☐ describe how the hydrolysis of starch, proteins, and fats is carried out in the lab, and name the products of complete hydrolysis
- ☐ describe how to carry out paper chromatography to identify products of hydrolysis
- ☐ explain how fats and oils are used to make soaps

Questions

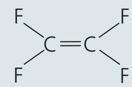
Extended curriculum

1 This diagram represents two units of an addition polymer called polyacrylamide:



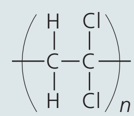
a Draw the structure of the monomer.
b Suggest a name for the monomer.
c Is the monomer saturated, or unsaturated?

2 The polymer 'Teflon' is obtained from the monomer tetrafluoroethene, which has this structure:



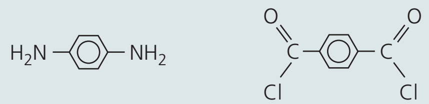
a Which feature of the monomer makes polymerisation possible?
b Which type of polymerisation occurs?
c Draw three units in the structure of the macromolecule that forms.
d Give the chemical name for this polymer.

3 The polymer poly(dichloroethene) has been used to make 'cling film', for covering food to keep it fresh. This shows the structure of the polymer:



a What does *n* represent?
b Name the monomer, and draw its structural formula.
c Which type of polymerisation takes place?
d One property of poly(dichlorothene) is its *low permeability* to moisture and gases.
  i See if you can explain what the term in italics means.
  ii That property is important in keeping food fresh. Why?
  iii Give three other *physical* properties a polymer would need, to be suitable for use as 'cling film'.
e Poly(dichloroethene) is *non-biodegradable*.
  i Explain the term in italics.
  ii Describe two environmental problems caused by the disposal of such plastics.

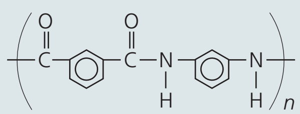
4 **Polyamides** are polymers made by condensation polymerisation. One polyamide was developed for use in puncture-resistant bicycle tyres.
The two monomers for it are:



The hexagon with the circle in the middle stands for a ring of 6 carbon atoms, with 3 double bonds.

a What is *condensation polymerisation*?
b Show in detail how the monomers join.
c Name the other product of the reaction.
d **i** In what way is this polymer similar to nylon? (See page 266.)
ii But its properties are different from those of nylon. Why?

A similar polymer has been developed as a fabric for fireproof clothing. Its structure is:



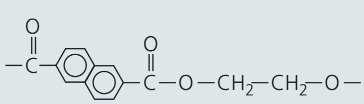
e Draw the structures of the two monomers that could be used to make this polymer.

5 Many synthetic polymers contain the amide linkage.
a Draw the structure of the amide linkage.
b Which important natural macromolecules also contain the amide linkage?

The substances in **b** will undergo hydrolysis in the laboratory, in the presence of acid.

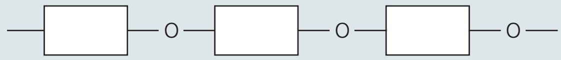
c **i** What does *hydrolysis* mean?
ii What are the products of the hydrolysis?
iii How can the products be separated?

6 One very strong polymer has this structure:



a Which type of polymerisation produced it?
b Which type of linkage joins the monomers?
c Draw the structures of the two monomers from which this polymer could be made.
d Compare the structure above with that for Terylene (page 267). What may be responsible for the greater strength of this polymer?
e **i** Which *natural* macromolecules have the same linkage as this polymer?
ii Hydrolysis of these macromolecules, using an alkali, gives a useful product. Name it.

7 Starch is a carbohydrate. It is a natural polymer. This shows part of a starch macromolecule:



a What is a *macromolecule*?
b What is a *carbohydrate*?
c Which type of polymerisation gives starch?
d What do the blocks represent, above?
e **i** Draw a diagram showing the structure of the monomer for starch. (Use a block.)
ii Name this monomer.
f Starch is also called a *polysaccharide*. Why?
g Starch can be broken down by hydrolysis.
i Describe two ways in which the hydrolysis is carried out. (One occurs in your body.)
ii One takes place at a far lower temperature than the other. What makes this possible?

8 In the lab, *partial* hydrolysis of starch gives a mixture of colourless products. They can be identified using chromatography. A locating agent is needed.
a Draw diagrams showing at least two of the products. (Use blocks like those in question **7**.)
b What is a *locating agent* and why is it needed?
c Outline the steps in carrying out the chromatography. (Page 25 may help.)

9 Soaps are salts of fatty acids.
a Name one fatty acid.
b In which way is a fatty acid different from ethanoic acid? In which way is it similar?
c Below is one example of a compound found in vegetable oil, and used to make soap.

$$\begin{array}{l} H_2C - OOC(C_{17}H_{35}) \\ \quad | \\ \ HC - OOC(C_{15}H_{31}) \\ \quad | \\ H_2C - OOC(C_{14}H_{29}) \end{array}$$

i This compound is an *ester*. Explain that term.
ii To make soap, the oil is usually reacted with a sodium compound. Which one?
iii Which type of reaction takes place?
d **i** The reaction in c will give *four* different products. Write down their formulae.
ii Which ones can be used as soap?
iii One product is an alcohol. Name it.
iv In which way is this product similar to ethanol? In which way is it different?
e Name three vegetable oils used to make soap.

19.1 Chemistry: a practical subject

The lab: the home of chemistry

All the information in this book has one thing in common. It is all based on real experiments, carried out in labs around the world, over the years – and even over the centuries. The lab is the home of chemistry!

How do chemists work?

Like all scientists, chemists follow the **scientific method**. This flowchart shows the steps. The handwritten notes are from a student.

1 You observe something that makes you ask yourself a question.
Kitchen cleaner X is better at removing grease than kitchen cleaner Y. Why?

↓

2 Come up with a **hypothesis** – a reasonable statement that you can test. You might need to do some research in books or on the internet, to help you.
Sodium hydroxide is used in kitchen cleaners to help remove grease.
The labels on X and Y say they contain sodium hydroxide.
My hypothesis: X may contain more sodium hydroxide than Y does.

↓

3 Plan an experiment to test the hypothesis.
I plan to do a titration to test my hypothesis. See the details in the next unit.

↓

4 Carry out the experiment, and record the results.
See the results in the next unit.

↓

5 Analyse the results.
You can help me do this, in the next unit.

↓

6 Did the results support your hypothesis?
See the next unit.

↓

7 Share your conclusions with other people.
The teacher wants to see them!

▲ Step into the lab, and try the scientific method ….

Planning an experiment: the variables

Suppose you want to investigate how the rate of a reaction changes with temperature.

- The temperature is under your control. So it is called the **independent variable**. It is the *only* thing *you* change as you do the experiment.
- If the rate changes as you change the temperature, the rate is a **dependent variable**. It **depends on** the temperature.

In many experiments you do, there will be an independent variable. You control it – and keep everything else unchanged.

That golden rule …
When you investigate something in the lab, **change only one thing at a time**, and see what effect it has.

The skills you use

When you plan and carry out an experiment, you use many different skills:

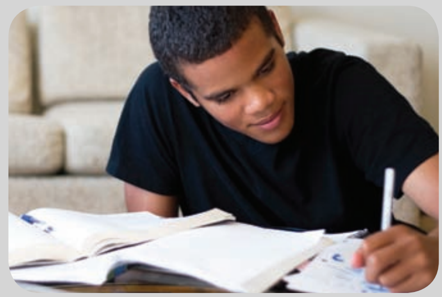
Thinking Use your brain before, during, and after the experiment. That is what brains are for. (They really like being used.)

Observing This is a very important skill. Chemists have made some amazing discoveries just by watching very carefully.

Using apparatus and techniques Weigh things, measure out volumes of liquids, measure temperature, do titrations, prepare crystals ….

Working accurately Sloppy work will ruin an experiment. Follow the instructions. Measure things carefully. Think about safety too.

Doing some maths You often have to do some calculations using your results. And drawing a graph can help you see what is going on.



Writing up You may have to write a report on your experiment, and give conclusions. And say how the experiment could be improved?

The experiments you do

Often, you will not get a chance to plan an experiment for yourself. Instead, the teacher will tell you what to do. So you might miss out steps **1**–**3** in the flowchart on page 280.

But even if you pick up at step **4**, you are still using the scientific method, and gaining practice in it. And you are following in the footsteps of many famous scientists, who have changed our lives by their careful work in the lab.

One day, you may become a scientist yourself. Even a famous one!

Q

1 Do you think this counts as a *hypothesis*?
- **a** I am late for class again.
- **b** If I add more yeast, the fermentation may go faster.
- **c** December follows November.
- **d** The rate of photosynthesis may change with temperature.

2 Explain in your own words what an *independent variable* is.

3 Which would be the independent variable, in an experiment to test the statement in **1b**?

4 Do you think the scientific method would be useful to:
a a doctor? **b** a detective?
Explain your answer.

19.2 Example of an experiment

Comparing those kitchen cleaners

In step **2** of the scientific method in the last unit, a student put forward a hypothesis. Here you can read how the student tested the hypothesis. But the report is not quite finished. That is *your* task.

An experiment to compare the amount of sodium hydroxide in two kitchen cleaners

Introduction

I noticed that kitchen cleaner X is better at removing grease than kitchen cleaner Y is. The labels show that both kitchen cleaners contain sodium hydroxide. This chemical is used in many cleaners because it reacts with grease to form soluble sodium salts, which go into solution in the washing-up water.

My hypothesis

Kitchen cleaner X may contain more sodium hydroxide than kitchen cleaner Y does.

Planning my experiment

I plan to titrate a sample of each cleaner against dilute hydrochloric acid, using methyl orange as indicator. This is a suitable method because the sodium hydroxide in the cleaner will neutralise the acid. The indicator will change colour when neutralisation is complete.

To make sure it is a fair test, I will use exactly the same volume of cleaner, and the same concentration of acid, and the same number of drops of indicator each time, and swirl the flask in the same way. The only thing I will change is the type of cleaner.

I will wear safety goggles, since sodium hydroxide and hydrochloric acid are corrosive.

The experiment

25 cm^3 of cleaner X were measured into a conical flask, using a pipette. 5 drops of methyl orange were added, and the solution turned yellow.

A burette was filled to the upper mark with hydrochloric acid of concentration 1 mol/dm^3. The initial level of the acid was noted.

The acid was allowed to run into the conical flask. The flask was continually and carefully swirled. As the acid dripped in, the solution showed flashes of pink. When the end point was near the acid was added drop by drop. When the solution changed from yellow to pink, the titration was stopped. The final level of the acid was recorded.

The experiment was repeated with cleaner Y.

▲ The colour of the solution has changed: the titration is complete.

The results

For X:		For Y:	
Initial level of acid in the burette	0.0 cm^3	Initial level of acid in the burette	22.2 cm^3
Final level	22.2 cm^3	Final level	37.5 cm^3
Volume of acid used	22.2 cm^3	Volume of acid used	15.3 cm^3

Analysis of the results

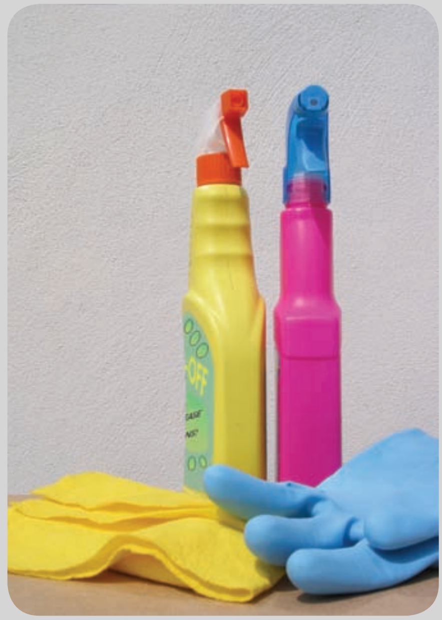
The same volume of each cleaner was used. The sodium hydroxide in X neutralised 22.2 cm^3 of acid. The sodium hydroxide in Y neutralised 15.3 cm^3 of acid. This means that solution ...

My conclusion

These results ...

To improve the reliability of the results

I would ...



▲ One is better at removing grease. Might it have a higher concentration of sodium hydroxide?

In the question section below, you will have the chance to complete the student's analysis and conclusions, and come up with suggestions for ensuring that the results were reliable.

Q

1 In this experiment, was there:
- **a** an independent variable? If so, what was it?
- **b** a dependent variable? If so, what was it?

2 a Look at the apparatus below. Which pieces did the student use in the experiment? Give their letters and names.
- **b** When measuring out solutions for titration, a pipette is used instead of a measuring cylinder. Why is this?
- **c** Why is a conical flask used rather than a beaker, for the titration?
- **d** Why are burettes used for titrations?
- **e** Which is *more* accurate for measuring liquids?
  i a burette **ii** a pipette
  Explain clearly why you think so.

3 Why is an indicator needed, for titrations?

4 a Suggest another indicator the student could have used, in place of methyl orange. (Hint: page 149.)
- **b** What colour change would be observed at the end-point, for the indicator you suggested?

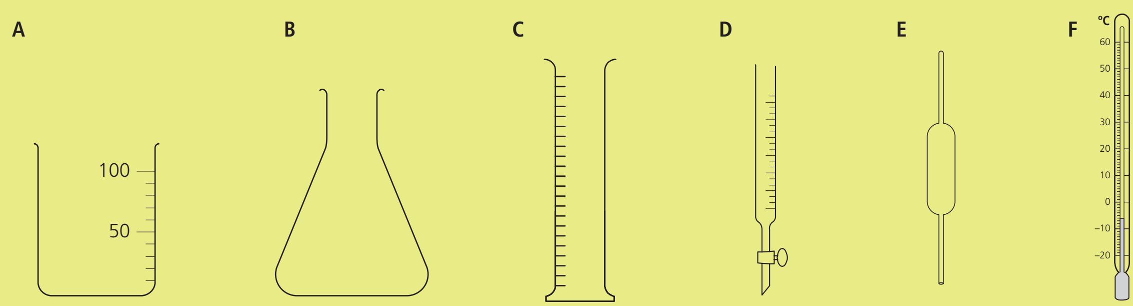
5 Now complete the student's *Analysis of the results*.

6 Complete the *Conclusion*, by saying whether or not the results supported the hypothesis.

7 How would you improve the reliability of the results?

8 How would you modify the experiment, to compare liquid scale-removers for kettles? (They contain acid.)

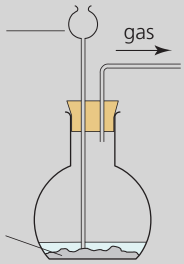
9 Next week the student will do an experiment to see whether neutralisation is exothermic or endothermic. Which item below will the student *definitely* use?

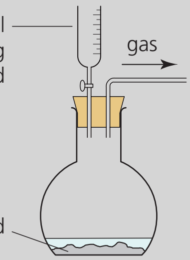


19.3 Working with gases in the lab

Preparing gases in the lab

You might have to prepare a gas in the lab, one day. The usual way to make a gas is to displace it from a solid or solution, using apparatus like this. The table below gives some examples.





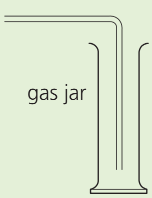
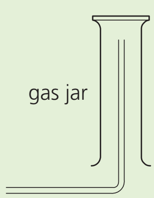
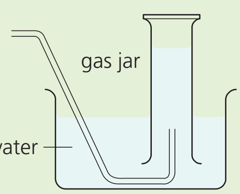
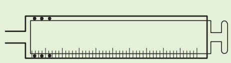
To make …	Place in flask ….	Add ….	Reaction
carbon dioxide	calcium carbonate (marble chips)	dilute hydrochloric acid	$CaCO_3\ (s) + 2HCl\ (aq) \longrightarrow CaCl_2\ (aq) + H_2O\ (l) + CO_2\ (g)$
hydrogen	pieces of zinc	dilute hydrochloric acid	$Zn\ (s) + 2HCl\ (aq) \longrightarrow ZnCl_2\ (aq) + H_2\ (g)$
oxygen	manganese(IV) oxide (as a catalyst)	hydrogen peroxide	$2H_2O_2\ (aq) \longrightarrow 2H_2O\ (l) + O_2\ (g)$

But to make ammonia, you can heat any ammonium compound with a base such as sodium hydroxide or calcium hydroxide – using both reactants in solid form.

Collecting the gases you have prepared

The table below shows four ways of collecting a gas you have prepared. The method depends on whether the gas is heavier or lighter than air, whether you need it dry, and what you want to do with it.

Using a measuring cylinder
- You can use a gas jar to collect a gas over water.
- But if you want to measure the volume of the gas, roughly, use a measuring cylinder instead.
- If you want to measure its volume accurately, use a gas syringe.

Method	upward displacement of air	downward displacement of air	over water	gas syringe
Use when …	the gas is heavier than air	the gas is lighter than air	the gas is sparingly soluble in water	you want to measure the volume accurately
Apparatus				
Examples	carbon dioxide, CO_2 sulfur dioxide, SO_2 hydrogen chloride, HCl	ammonia, NH_3 hydrogen, H_2	carbon dioxide, CO_2 hydrogen, H_2 oxygen, O_2	any gas

Tests for gases

You have a sample of gas. You think you know what it is, but you're not sure. So you need to do a test. Below are some tests for common gases. Each is based on particular properties of the gas, including its appearance, and sometimes its smell.

Gas	Description and test details
Ammonia, NH_3	
Properties	Ammonia is a colourless alkaline gas with a strong sharp smell.
Test	Hold damp indicator paper in it.
Result	The indicator paper turns blue. (You may also notice the sharp smell.)
Carbon dioxide, CO_2	
Properties	Carbon dioxide is a colourless, weakly acidic gas. It reacts with **limewater** (a solution of calcium hydroxide in water) to give a white precipitate of calcium carbonate: $CO_2\ (g) + Ca(OH)_2\ (aq) \longrightarrow CaCO_3\ (s) + H_2O\ (l)$
Test	Bubble the gas through limewater.
Result	Limewater turns cloudy or milky.
Chlorine, Cl_2	
Properties	Chlorine is a green poisonous gas which bleaches dyes.
Test	Hold damp indicator paper in the gas, *in a fume cupboard*.
Result	Indicator paper turns white.
Hydrogen, H_2	
Properties	Hydrogen is a colourless gas which combines violently with oxygen when lit.
Test	Collect the gas in a tube and hold a lighted splint to it.
Result	The gas burns with a squeaky pop.
Oxygen, O_2	
Properties	Oxygen is a colourless gas. Fuels burn much more readily in it than in air.
Test	Collect the gas in a test-tube and hold a glowing splint to it.
Result	The splint immediately bursts into flame.

Q

1 **a** Sketch the *complete* apparatus you will use to prepare and collect carbon dioxide. Label all the parts.
b How will you then test the gas to confirm that it is carbon dioxide?
c Write the equation for a positive test reaction.

2 **a** Hydrogen cannot be collected by upward displacement of air. Why not?
b Hydrogen burns with a squeaky pop. Write a balanced equation for the reaction that takes place.

3 **a** Name two substances you could use to make ammonia.
b Ammonia cannot be collected over water. Why not?
c The test for ammonia is …… ?

4 It is not a good idea to rely on smell, to identify a gas. Suggest at least two reasons why.

5 To measure the rate of the reaction between magnesium and hydrochloric acid, you will collect the hydrogen that forms. Which is better to use for this: a measuring cylinder over water, or a gas syringe? Give more than one reason.

19.4 Testing for ions in the lab

Time for detective work!

You have an unknown salt, and you want to find out what it is. This unit gives some tests you can do. But first, note these points:

- Positive ions are also called **cations**. Negative ions are called **anions**.
- In each test, *either* a precipitate forms *or* a gas you can test.

Tests for cations

This table shows tests for the ammonium ion, and several metal ions.

- To test for the ammonium ion you can use the unknown salt as a solid, or in aqueous solution. But for metal ions, use their aqueous solutions.
- To test for metal cations, you can use dilute sodium hydroxide or ammonia solution, since both provide hydroxide ions. But the results are not always the same, as you will see below.

Remember CAP!
Cations Are Positive.
They would go to the cathode (−).

Complex ions
- In complex ions, a metal ion is surrounded by several negative ions, or molecules.
- Many transition elements form complex ions.
- The copper ion $Cu(NH_3)_4^{2+}$ is an example. (See below.)

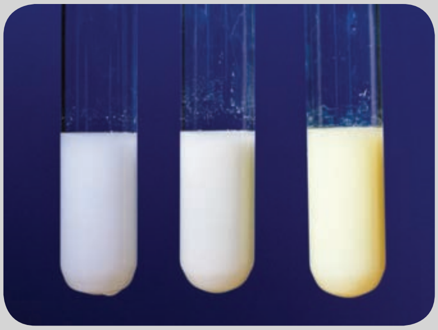
Cation	Test	If the cation is present	Ionic equation for the reaction
ammonium NH_4^+	Add a little dilute sodium hydroxide solution. Heat gently.	Ammonia gas is given off. (It turns litmus red.)	$NH_4^+\,(aq) + OH^-\,(aq) \longrightarrow NH_3\,(g) + H_2O\,(l)$
copper(II) Cu^{2+}	Add dilute sodium hydroxide or ammonia solution.	A pale blue precipitate forms. But it dissolves on adding more ammonia, giving a deep blue solution.	$Cu^{2+}\,(aq) + 2OH^-\,(aq) \longrightarrow Cu(OH)_2\,(s)$ The precipitate dissolves again in ammonia solution because a soluble complex ion forms: $[Cu(NH_3)_4]^{2+}\,(aq)$.
iron(II) Fe^{2+}	Add dilute sodium hydroxide or ammonia solution.	A pale green precipitate forms.	$Fe^{2+}\,(aq) + 2OH^-\,(aq) \longrightarrow Fe(OH)_2\,(s)$
iron(III) Fe^{3+}	Add dilute sodium hydroxide or ammonia solution.	A red-brown precipitate forms.	$Fe^{3+}\,(aq) + 3OH^-\,(aq) \longrightarrow Fe(OH)_3\,(s)$
aluminium Al^{3+}	Add dilute sodium hydroxide or ammonia solution.	A white precipitate forms. It dissolves again on adding excess sodium hydroxide, giving a colourless solution. But it *will not* dissolve if more ammonia is added instead.	$Al^{3+}\,(aq) + 3OH^-\,(aq) \longrightarrow Al(OH)_3\,(s)$ The precipitate dissolves in excess sodium hydroxide because aluminium hydroxide is amphoteric. The soluble aluminate ion forms: $(Al(OH)_4^-)$.
zinc Zn^{2+}	Add dilute sodium hydroxide or ammonia solution.	A white precipitate forms. It dissolves again on adding more sodium hydroxide *or* ammonia, giving a colourless solution.	$Zn^{2+}\,(aq) + 2OH^-\,(aq) \longrightarrow Zn(OH)_2\,(s)$ The precipitate dissolves again in sodium hydroxide because zinc hydroxide is amphoteric. The soluble zincate ion forms: $(Zn(OH)_4^{2-})$ It dissolves again in ammonia solution because a soluble complex ion forms: $[Zn(NH_3)_4]^{2+}$ (aq).
calcium Ca^{2+}	Add dilute sodium hydroxide solution.	A white precipitate forms. It will not dissolve on adding excess sodium hydroxide.	$Ca^{2+}\,(aq) + 2OH^-\,(aq) \longrightarrow Ca(OH)_2\,(s)$
	Add dilute ammonia solution.	No precipitate, or very slight white precipitate.	

Tests for anions

Halide ions (Cl^-, Br^-, I^-)

- To a small amount of the solution, add an equal volume of dilute nitric acid. Then add silver nitrate solution.
- Silver halides are insoluble. So if halide ions are present a precipitate will form. The colour tells you which one. Look at this table:

Precipitate	Indicates presence of ...	Ionic equation for the reaction
white	chloride ions, Cl^-	$Ag^+ (aq) + Cl^- (aq) \longrightarrow AgCl (s)$
cream	bromide ions, Br^-	$Ag^+ (aq) + Br^- (aq) \longrightarrow AgBr (s)$
yellow	iodide ions, I^-	$Ag^+ (aq) + I^- (aq) \longrightarrow AgI (s)$



▲ Halides are present. From left to right: chloride, bromide, iodide.

Sulfate ions (SO_4^{2-})

- To a small amount of the solution add an equal volume of dilute hydrochloric acid. Then add barium nitrate solution.
- Barium sulfate is insoluble. So if sulfate ions are present a **white** precipitate will form. The ionic equation for the reaction is:

$Ba^{2+}(aq) + SO_4^{2-} (aq) \longrightarrow BaSO_4 (s)$

▲ You need only a small amount of the unknown substance, in testing for cations and anions.

Nitrate ions (NO_3^-)

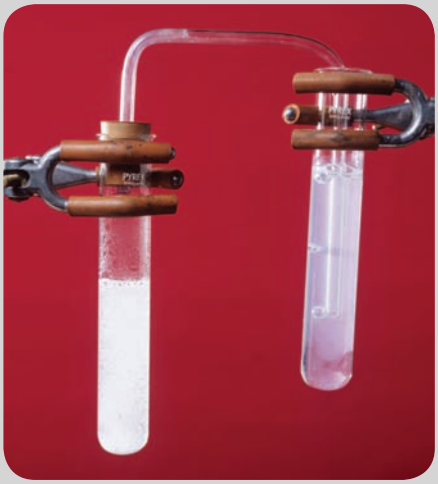
- To a small amount of the unknown solid or solution, add a little sodium hydroxide solution. Then add some small pieces of aluminium foil, and heat gently.
- If ammonia gas is given off, the unknown substance contained nitrate ions. The ionic equation for the reaction is:

$8Al (s) + 3NO_3^- (aq) + 5OH^- (aq) + 2H_2O (l) \longrightarrow 3NH_3 (g) + 8AlO_2^- (aq)$

Carbonate ions (CO_3^{2-})

- To a small amount of the unknown solid or solution, add a little dilute hydrochloric acid.
- If the mixture bubbles and gives off a gas that turns limewater milky, the unknown substance contained carbonate ions. The gas is carbon dioxide. The ionic equation for the reaction is:

$2H^+ (aq) + CO_3^{2-} (aq) \longrightarrow CO_2 (g) + H_2O (l)$



▶ The carbonate test: that is limewater on the right, and it is turning milky.

Q

1. The other name for a positive ion is … ?
2. Which two cations on page 286 cannot be identified using only sodium hydroxide? Which further test could be done?
3. Sodium hydroxide and ammonia solutions cannot be used to identify Na^+ or K^+ ions. Why not?
4. Silver nitrate is used in the test for halides. Why?
5. Nitrates are not tested by forming a precipitate. Why not?
6. Where do the OH^- ions come from, in the test for nitrate ions?
7. **a** Why is acid used, in testing for carbonates?
   b Limewater is also used in the test. What is limewater?

Checkup on Chapter 19

Revision checklist

For all students

Make sure you can …

☐ identify these common pieces of laboratory apparatus, and say what they are used for:

beaker *test-tube* *conical flask*
pipette *burette* *measuring cylinder*
gas jar *gas syringe* *condenser*
thermometer *filter funnel* *water trough*

☐ arrange these pieces of apparatus in order of accuracy (as here) for measuring out a volume of liquid:

beaker *measuring cylinder* *burette* *pipette*

☐ describe how to carry out these procedures:

– filtration
– simple distillation
– fractional distillation
– crystallisation
– paper chromatography
– titration

☐ describe the scientific method

☐ explain what these are:

independent variable *dependent variable*

☐ explain why measurements are often repeated, in experimental work

☐ describe how to prepare these gases in the lab:

hydrogen *oxygen* *carbon dioxide* *ammonia*

– and name suitable reactants to use
– give the equations for the reactions
– draw the apparatus

☐ give the test for these gases:

hydrogen *oxygen* *carbon dioxide*
ammonia *chlorine*

☐ give another term for: *cation* *anion*

☐ explain that in the tests for anions and cations, either a precipitate is formed, or a gas is given off

☐ describe tests to identify these cations:

Cu^{2+} Fe^{2+} Fe^{3+} Al^{3+} Zn^{2+} Ca^{2+} NH_4^+

☐ describe tests to identify these anions:

halide ions (Cl^-, Br^-, I^-) *sulfate ion*, SO_4^{2-}
nitrate ion, NO_3^- *carbonate ion*, CO_3^{2-}

Make sure you can also …

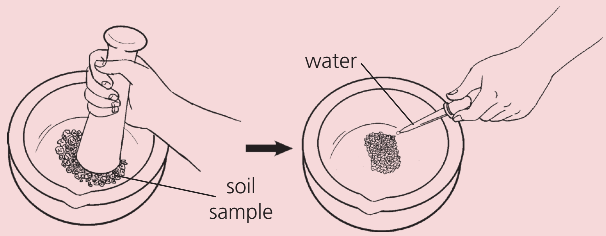
☐ describe a test for water (page 124)

☐ explain that melting and boiling points can be used to test whether a substance is pure (page 19)

Questions

For all students

1 A sample of soil from a vegetable garden was thoroughly crushed, and water added as shown:

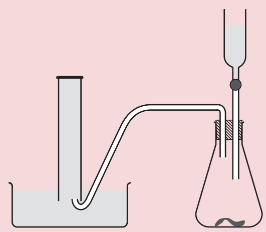


a Using a conical flask, filter funnel, filter paper, universal indicator, and dropping pipette, show how you would measure the pH of the soil.

b How would you check that the results for this sample were valid for the whole garden?

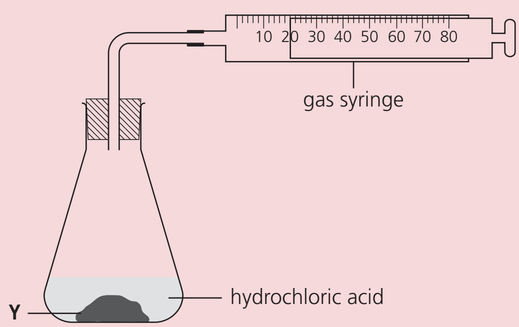
2 This apparatus is used to collect gases in the lab.

a Make a drawing of the apparatus, labelling the water, trough, measuring cylinder, delivery tube, flask, and dropping funnel.



b This apparatus can be used for preparing the gases hydrogen and carbon dioxide, but *not* sulfur dioxide. Explain why.

3 This apparatus is used to measure rate of a reaction.



a Suggest a suitable reagent to use as Y.

b Which other piece of apparatus is needed?

c Outline the procedure for this experiment.

d You must be careful not to use too much of the reagents. Why?

4 A sample of a potassium salt was contaminated with potassium chloride. These tests were carried out on the contaminated sample.

TEST A

Dilute nitric acid is added to the solid. The mixture bubbles. The gas given off turns limewater milky.

a **i** Name the gas given off.

ii Which anion is present in the potassium salt?

TEST B

An equal volume of barium nitrate solution is added to a solution of the solid. A precipitate forms.

b **i** What colour will the precipitate be?

ii Name the precipitate, and explain why it forms.

iii The precipitate will disappear if dilute nitric acid is added. Why?

TEST C

An equal volume of silver nitrate solution is added to a solution of the solid. A precipitate forms.

c **i** What colour will this precipitate be?

ii This precipitate confirms the presence of the impurity. Explain why.

d Give the formulae for both the potassium salt and the impurity.

5 Two solutions W and X are tested with universal indicator paper.

Solution W: the indicator paper turns red

Solution Y: the indicator paper turns orange

a **i** Which solution could have a pH of 1, and which could have a pH of 5?

ii Which type of solution is Y?

Further tests are carried out in test-tubes.

TEST A

A piece of magnesium is added to solution W.

b **i** What will you observe in the test-tube?

ii What is formed as a result of the reaction

iii How will solution Y compare, in this reaction?

TEST B

A solid, which is a sodium compound, is added to solution W. A gas is given off. It turns limewater milky.

c **i** What colour will the solid be?

ii Name the gas released.

iii Suggest a name for the solid.

TEST C

A few drops of barium nitrate solution are added to a solution of W. A white precipitate forms.

d **i** Name the white precipitate.

ii Identify solution W.

6 Ammonium nitrate (NH_4NO_3) is an important fertiliser. The ions in it can be identified by tests.

a Name the cation present, and give its formula.

b Which of these tests will confirm its presence?

A When aqueous sodium hydroxide is added to a solution of the compound, a white precipitate forms. This does not dissolve in excess sodium hydroxide.

B On heating the solid with solid sodium hydroxide, a gas is given off. It turns damp red litmus paper blue.

C On heating the solid with dilute hydrochloric acid, a gas is given off. It turns damp blue litmus paper red.

c Name the anion present, and give its formula.

d Which of these tests will confirm its presence?

A When dilute hydrochloric acid is added the solid fizzes, and releases a gas which relights a glowing splint.

B When a solution of barium ions is added to a solution of the compound, a white precipitate forms.

C When sodium hydroxide solution and aluminium foil are added to the solid, ammonia is given off after gentle heating.

7 A sample of mineral water contained these ions:

Name of ion	Concentration (milligrams / dm^3)
calcium	55
chloride	37
hydrogen carbonate	248
magnesium	19
nitrate	0.05
potassium	1
sodium	24
sulfate	13

a Make two lists, one for the anions and the other for the cations present in this mineral water.

b **i** Which metal ion is present in the highest concentration?

ii What mass of that metal would be present in a small bottle of water, volume 50 cm^3?

c Which of the ions will react with barium nitrate solution to give a white precipitate?

d Of the metal ions, only calcium can be identified by a precipitation test. Why is this?

e A sample of the water is heated with sodium hydroxide and aluminium foil. Ammonia gas could not be identified, even though the nitrate ion is present. Suggest a reason.