15.4 The rusting problem

What is rusting?
This car was once new and shiny. But it has been corroded – broken down by reaction with something in the atmosphere. In time, it will all be dust.

The corrosion of iron and steel has a special name: rusting. The red-brown substance that forms is called rust.

An experiment to investigate rusting
1 Stand three identical nails in three test-tubes.
2 Now prepare the test-tubes as below, so that:
   - test-tube 1 contains dry air
   - test-tube 2 contains water but no air
   - test-tube 3 has both air and water.
3 Leave the test-tubes to one side for several days.

Result After several days, the nails in test-tubes 1 and 2 show no signs of rusting. But the nail in test-tube 3 has rust on it. This is because:
Rusting requires oxygen and water.

In fact the iron is oxidised, in this reaction:

$$4\text{Fe (s)} + 3\text{O}_2 (g) + 4\text{H}_2\text{O (l)} \rightarrow 2\text{Fe}_2\text{O}_3\cdot2\text{H}_2\text{O (s)}$$
iron + oxygen + water \rightarrow hydrated iron(III) oxide (rust)

Rusting and salt
- Iron rusts faster in salty water. (Salt speeds up the oxidation.)
- So this is a problem for ships … and for cars, where salt is sprinkled on roads in winter, to melt ice. It helps the cars to rust!

Stainless steel
Remember, the alloy stainless steel does not rust. But other steels do.
How to prevent rusting

Iron is the most widely used metal in the world – for everything from needles to ships. But rusting destroys things. How can you prevent it? There are two approaches.

1. Cover the iron

The aim is to keep out oxygen and water. You could use:

- **paint.** Steel bridges and railings are usually painted.
- **grease.** Tools and machine parts are coated with grease or oil.
- **another metal.** Iron is coated with zinc, by dipping it into molten zinc, for roofing. Steel is electroplated with zinc, for car bodies. Coating with zinc has a special name: galvanising.
  
  For food tins, steel is coated with tin by electroplating.

2. Let another metal corrode instead

During rusting, iron is oxidised: it loses electrons. Magnesium is more reactive than iron, which means it has a stronger drive to lose electrons. So when a bar of magnesium is attached to the side of a steel ship, or the leg of an oil rig, it will corrode instead of the iron.

Without magnesium: \[ \text{Fe} \rightarrow \text{Fe}^{2+} + 2e^- \]

With magnesium: \[ \text{Mg} \rightarrow \text{Mg}^{2+} + 2e^- \]

The magnesium dissolves. It has been sacrificed to protect the iron. This is called **sacrificial protection.**

The magnesium bar must be replaced before it all dissolves.

Note that zinc could also be used for this. See page 191 for more.

---

**Q**

1. What is rusting?
2. Which two substances cause iron to rust?
3. See if you can think of a way to prove that it is the oxygen in air, not nitrogen, that causes rusting.
4. Iron that is tin-plated does not rust. Why not?
5. You have a new bike. Suggest steps you could take to make sure it does not rust. Give a reason for each one.
6. **a** What does the sacrificial protection of iron mean?
   **b** Both magnesium and zinc can be used for it. Why?
   **c** But copper will not work. Explain why.
Everyone needs water
We all need water.
- **At home** we need it for drinking, cooking, washing things (including ourselves) and flushing toilet waste away.
- **On farms** it is needed as a drink for animals, and to water crops.
- **In industry**, they use it as a solvent, and to wash things, and to keep hot reaction tanks cool. (Cold-water pipes are coiled around the tanks.)
- **In power stations** it is heated to make steam. The steam then drives the turbines that generate electricity.

So where does the water come from?
Much of the water we use is taken from rivers. But some is pumped up from below ground, where water that has drained down through the soil lies trapped in rocks.

This underground water is called **groundwater**. A large area of rock may hold a lot of groundwater, like a sponge. This rock is called an **aquifer**.

Is it clean?
River water is not clean – even if it looks it! It will contain particles of mud, and animal waste, and bits of dead vegetation. But worst of all are the **microbes**: bacteria and other tiny organisms that can make us ill.

Over 1 billion people around the world have no access to clean water. They depend on dirty rivers for their drinking water. And over 2 million people, mainly children, die each year from **diarrhoea** and diseases such as **cholera** and **typhoid**, caused by drinking infected water.

Providing a water supply on tap
No matter where in the world you are, the steps in providing a clean safe water supply, on tap, are the same:

1. Find a clean source – a river or aquifer – to pump water from.
2. Remove as many solid particles from the water as you can.
   - You could make fine particles stick together and skim them off.
   - You could filter the water through clean gravel or sand.
3. Add something to kill the microbes in the water. (Usually chlorine.)
4. Store the water in a clean covered reservoir, ready for pumping to taps.

How well you can clean the water up depends on how dirty it is, and what kind of treatment you can afford!
A modern treatment plant
This diagram shows a modern water treatment plant. Follow the numbers to see how particles are removed and microbes killed.

2 A coagulant is added – a chemical to make small suspended particles stick together. It could be iron(III) sulfate, for example.

3 Next, air is blown through the water in flotation tanks, to make the coagulated particles float to the top. They are skimmed off.

4 The water is passed through a bed of fine sand to filter it.

5 It may go through further filters. For example more sand, or charcoal to remove bad tastes and smells.

6 Chlorine is added to kill the bacteria and other microbes.

7 A fluoride compound is added in some plants, to help fight tooth decay.

8 The water is pumped to the storage reservoir, ready for pumping to homes.

This treatment can remove even the tiniest particles. And chlorine can kill all the microbes. But the water may still have harmful substances dissolved in it. For example, nitrates from fertilisers, that can make babies ill.

It is possible to remove dissolved substances, using special membranes. But that is very expensive, and is not usually done. The best solution is to find the cleanest source you can, for your water supply.

If there is only dirty water to drink …
- Leave it to sit in a container for a while, to let particles settle.
- Scoop out the clearer water from the top of the container, and boil it for several minutes to kill the microbes.
- If you are not able to boil it, leave it sitting in a clear plastic container in the sun for several hours. This will kill most microbes!

Two tests for water
If a liquid contains water, it will …
- turn white anhydrous copper(II) sulfate blue
- turn blue cobalt chloride paper pink.
Both colour changes can be reversed by heating.

The test for pure water
If a liquid is pure water, it will also …
- boil at 100 °C, and
- freeze at 0 °C.

Q
1 What is: a groundwater? b an aquifer? c a microbe? (Check the glossary?)
2 What is a coagulant used for, in water treatment plants?
3 Why is chlorine such an important part of the treatment?
4 A fluoride compound may be added to water. Why?
5 Some water can be harmful even after treatment. Explain.
6 You need a drink of water – but there is only dirty river water. What will you do to clean it?
Living in space

The International Space Station
Right now, about 350 km above you, a large satellite is orbiting the Earth. On board are scientists: at least three. They could be asleep as you read this, or listening to music, or taking exercise. But most of the time they are doing experiments.

The satellite is the International Space Station (ISS). It is a floating lab, where scientists from different countries carry out a range of experiments. These can be more exciting than usual, since everything is weightless!

Where do they get their oxygen?
Inside the space station, the air is like that on the Earth. The main gas is nitrogen, which does not get used up. But the oxygen does – and the scientists would die without a steady supply. There is no oxygen outside the space station. So where do they get it?

- **From the electrolysis of water** A special polymer is used as the electrolyte. The overall reaction is:
  \[2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2\]
  The scientists breathe the oxygen. The hydrogen is vented to space.

- **From 'oxygen candles'** These are a back-up. They contain sodium chlorate (NaClO₃) mixed with iron powder. When the mixture is lit, the sodium chlorate starts breaking down to sodium chloride and oxygen. Some of the oxygen in turn reacts with the iron, giving iron oxide – and this reaction gives out the heat needed to keep the main reaction going.

- **From oxygen cylinders** These are for emergencies only! (It costs too much to deliver oxygen cylinders from the Earth.)

The carbon dioxide that accumulates in the air is collected, and vented to space. (In future it may be kept to grow plants.)
What about water?
The scientists would die without water too. So where does the water come from, to drink and for electrolysis? Mostly from their own bodies!
All urine is collected. So is the water vapour in the air (from the scientists’ breath) and any waste water from washing. It is filtered through many kinds of filter, to remove dissolved substances, and treated to kill bacteria. In fact this water ends up much purer than our drinking water down here on the Earth! As a back-up, some containers of water are stored on board.
Note that the scientists use very little water for washing, since it is so precious. They usually have a wipe with a damp cloth.

Keeping the lights on
The other essential is electricity. Easy! Solar panels on the ‘wings’ of the space station convert sunlight to electricity. Some of this is used to charge batteries, for the hours when the sun is hidden. (The space station orbits the Earth once every 90 minutes, so the scientists enjoy 16 sunrises and sunsets each day!)
The electricity is used for electrolysis, and lighting, and laptops, and music players. Cooking does not take much. The food is mostly dried ready-made meals, sent up from the Earth. Add water, and warm in the oven!

A self-contained unit
This diagram sums up the life support systems, in the space station:

The systems developed for the space station could be very useful one day, if more of us have to move into space!

Who owns the ISS?
- The ISS is jointly owned by the space agencies of the USA, Russia, Japan, and Canada, and the European Space Agency. They all send scientists to it.
- Other countries may join in before the project ends (around 2020 or later).
Checkup on Chapter 15

Revision checklist

Core curriculum
Make sure you can …
- name the gases in clean air, and give the percentages for the two main gases present
- explain why oxygen is so important to us
- describe an experiment to find the % of oxygen in air
- name the fossil fuels and give examples of their use as fuels
- name four common pollutants in air
  - give the source, for each
  - describe the harm they do
- explain what rusting is
- say which substances must be present for rusting to occur
- describe an experiment to investigate the conditions needed for rusting
- give examples of ways to prevent rusting, by keeping oxygen and moisture away
- give examples of how we use water in homes, on farms, in industry, and in power stations
- describe the steps in the treatment of water, to give a clean safe water supply

Extended curriculum
Make sure you can also …
- describe the separation of gases from the air, using fractional distillation
- list the harmful gases produced in car engines
  - explain what catalytic converters are
  - name the metals they usually use as catalysts
  - explain how nitrogen oxides and carbon monoxide are converted to harmless gases in them

Questions

Core curriculum

1 Copy and complete:
Air is a ............of different gases. 99% of it consists of the two elements ......... and .......... . Some of the remaining 1% consists of two compounds, ........... and ............. . The rest is made up of elements called the ............. . These all belong to Group .... of the Periodic Table. The gas we depend on most is ........... This gas combines with glucose in our body cells, releasing energy. The process is called ............. . This gas is also used in combination with ........... in torches for welding and cutting metal.

2 Air is a mixture of different gases.
   a Which gas makes up about 78% of the air?
   b Only one gas in the mixture will allow things to burn in it. Which gas is this?
   c Which noble gas is present in the greatest quantity, in air?
   d i Which gas containing sulfur is a major cause of air pollution?
      ii What harmful effect does this gas have?
   e Name two other gases that contribute to air pollution, and say what harm they do.

3 The rusting of iron wool gives a way to find the percentage of oxygen in air, using this apparatus:
   After five days the water level had risen by 2.5 cm, and the iron had rusted to iron(III) oxide.
   a Write a balanced equation for the reaction between iron wool and oxygen.
   b The iron wool was dampened with water before being put in the tube. Why?
   c Why does the water rise up the tube?
   d What result does the experiment give, for the percentage of oxygen in air?
   e What sort of result would you get if you doubled the amount of iron wool?
4 Oxygen and nitrogen, the two main gases in air, are both slightly soluble in water. A sample of water was boiled, and the gases collected. The water vapour was allowed to condense and the remaining gases were measured. In a 50 cm³ sample of these gases, 18 cm³ were oxygen.
   a  i  What % of the dissolved air was oxygen?
   ii  How does this compare to the % of oxygen in the atmosphere?
   b  About what % of atmospheric air is nitrogen?
   c  Which gas, nitrogen or oxygen, is more soluble in water?

5 This diagram shows one stage in the treatment of water to make it ready for piping to homes:

   - water in (to be cleaned)
   - stones
   - sand
   - water out

   a  Name the process being carried out here.
   b  The water entering this stage has already been treated with a coagulant, aluminium sulfate. What does a coagulant do?
   c  Which kinds of impurities will the above process: i remove?  ii fail to remove?
   d  The next stage in treatment is chlorination. i  What does this term mean?
   ii  Why is this process carried out?
   e  In some places the water is too acidic to be piped to homes. What could be added to reduce the acidity level?
   f  At the end of treatment, another element may be added to water, for dental reasons, in the form of a salt. Which element is this?

Extended curriculum

6 Nitrogen and oxygen are separated from air by fractional distillation. Oxygen boils at −183°C and nitrogen at −196°C.
   a  Write the chemical formulae of these two gases.
   b  What state must the air be in, before fractional distillation can be carried out?
   c  Very low temperatures are required for b. How are these achieved?
   d  Explain, using their boiling points, how the nitrogen and oxygen are separated.
   e  Name one other gas obtained in the process.

7 Modern cars are fitted with catalytic converters. An outline of one is shown below:

   catalysts: rhodium, platinum, palladium

   oxides of nitrogen, carbon monoxide, unburnt hydrocarbons

   less harmful gases to the atmosphere

   a  i  Where in the car is the catalytic converter?
   ii  What is the purpose of a catalytic converter?
   iii  Which type of elements are rhodium, platinum, and palladium?
   b  Look at the gases that enter the converter.
   i  How and where are the oxides of nitrogen formed?
   ii  Where do the unburnt hydrocarbons come from?
   c  The gases below enter the catalytic converter. Name substances i – iv, to show what the gases are converted into.

<table>
<thead>
<tr>
<th>gases in</th>
<th>converted to</th>
</tr>
</thead>
<tbody>
<tr>
<td>oxides of nitrogen</td>
<td>i</td>
</tr>
<tr>
<td>carbon monoxide</td>
<td>ii</td>
</tr>
<tr>
<td>unburnt hydrocarbons</td>
<td>iii</td>
</tr>
<tr>
<td></td>
<td>and iv</td>
</tr>
</tbody>
</table>

8 In the catalytic converters fitted to modern cars, carbon monoxide and oxides of nitrogen in the exhaust gas are converted to other substances.
   a  i  Why is carbon monoxide removed?
   ii  Give one harmful effect of nitrogen dioxide.
   b  What is meant by a catalytic reaction?
   c  In one reaction in a catalytic converter, nitrogen monoxide (NO) reacts with carbon monoxide to form nitrogen and carbon dioxide. Write a balanced equation for this reaction.

9 Underwater steel pipelines need to be protected from corrosion. One method is to attach a block of a second metal to the pipeline.
   a  i  What is the key factor in choosing the second metal?
   ii  Name a suitable metal.
   iii  Write a half-equation to show what happens to this metal when it is attached to the pipeline.
   b  What name is given to this type of protection?
16.1 Hydrogen, nitrogen, and ammonia

Hydrogen: the lightest element
Hydrogen is the lightest of all the elements. It is so light that there is none in the air: it has escaped from the Earth’s atmosphere.

But out in space, it is the most common element in the universe. Inside the sun, hydrogen atoms fuse to form helium atoms. The energy given out provides the Earth with heat and light. We could not live without it.

Making hydrogen in the lab
Hydrogen is made in the lab by using a metal to drive it out or displace it from dilute acid. Zinc and dilute sulfuric acid are the usual choice.

The apparatus is shown on the right, below. The reaction is:

\[
\text{Zn (s)} + \text{H}_2\text{SO}_4 (aq) \rightarrow \text{ZnSO}_4 (aq) + \text{H}_2 (g)
\]

The properties of hydrogen
1. It is the lightest of all gases – about 20 times lighter than air.
2. It is colourless, with no smell.
3. It combines with oxygen to form water.
   A mixture of the two gases will explode when lit. The reaction is:
   \[
   2\text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2\text{H}_2\text{O (l)}
   \]
   It gives out so much energy that it is used to fuel space rockets.
   The same overall reaction takes place in hydrogen fuel cells, without burning, and gives energy in the form of electricity (page 121).
4. Hydrogen is more reactive than copper, as you can see from the panel.
   So it will take oxygen from copper(II) oxide, reducing it to copper.
   The hydrogen is itself oxidised:
   \[
   \text{CuO (s)} + \text{H}_2 (g) \rightarrow \text{Cu (s)} + \text{H}_2\text{O (l)}
   \]

Nitrogen
Nitrogen is a colourless, odourless, unreactive gas, that makes up nearly 80% of the air. You breathe it in – and breathe it out again, unchanged.

But you also take in nitrogen in the proteins in your food. Your body uses these to build muscle, bone, skin, hair, blood, and other tissues. In fact you are nearly 3% nitrogen, by mass!

The properties of nitrogen
1. It is a colourless gas, with no smell.
2. It is only slightly soluble in water.
3. It is very unreactive compared with oxygen.
4. But it will react with hydrogen to form ammonia:
   \[
   \text{N}_2 (g) + 3\text{H}_2 (g) \rightleftharpoons 2\text{NH}_3 (g)
   \]
   This reversible reaction is the first step in making nitric acid, and nitrogen fertilisers. There is more about it in the next unit.
5 Nitrogen also combines with oxygen at high temperatures to form oxides: nitrogen monoxide (NO) and nitrogen dioxide (NO₂).

The reactions occur naturally in the air during lightning – and also inside hot car engines, and power station furnaces. The nitrogen oxides are acidic, and cause air pollution, and acid rain. (See page 214.)

Ammonia
Ammonia is a gas with the formula NH₃. It is a very important compound, because it is used to make fertilisers. It is made in industry by reacting nitrogen with hydrogen. The details are in the next unit.

Making ammonia in the lab
You can make ammonia in the lab by heating any ammonium compound with a strong base. The base displaces ammonia from the compound.

For example:

\[
2\text{NH}_4\text{Cl (s)} + \text{Ca(OH)}_2 (s) \rightarrow \text{CaCl}_2 (s) + 2\text{H}_2\text{O (l)} + 2\text{NH}_3 (g)
\]

ammonium calcium calcium water ammonia chloride hydroxide chloride

This reaction can be used as a test for ammonium compounds. If an unknown compound gives off ammonia when heated with a strong base, it must be an ammonium compound.

The properties of ammonia
1. It is a colourless gas with a strong, choking smell.
2. It is less dense than air.
3. It reacts with hydrogen chloride gas to form a white smoke.
   The smoke is made of tiny particles of solid ammonium chloride:
   \[
   \text{NH}_3 (g) + \text{HCl (g)} \rightarrow \text{NH}_4\text{Cl (s)}
   \]
   This reaction can be used to test whether a gas is ammonia.
4. It is very soluble in water. (It shows the fountain effect.)
5. The solution in water is alkaline – it turns red litmus blue.
6. Since ammonia solution is alkaline, it reacts with acids to form salts. For example with nitric acid it forms ammonium nitrate:
   \[
   \text{NH}_3 (aq) + \text{HNO}_3 (aq) \rightarrow \text{NH}_4\text{NO}_3 (aq)
   \]

1  How can hydrogen be made using zinc and dilute sulfuric acid?
   See if you can suggest a different metal and acid, for making it. (Use the reactivity series?)
2  a  Why is hydrogen able to react with copper(II) oxide?
   b  Which type of reaction is this?
3  Which is more reactive, nitrogen or oxygen?
4  Two examples of displacement reactions have been given in this unit. What is a displacement reaction?
5  Write a word equation for the reaction of powdered sodium hydroxide with ammonium sulfate.

▲ The fountain experiment. The flask contains ammonia. It dissolves in the first drops of water that reach the top of the tube, so a fountain of water rushes up to fill the vacuum. (Any very soluble gas will show this effect.)
### Making ammonia in industry

#### It's a key chemical
Ammonia is a very important chemical, because it is needed to make fertilisers – and we depend on fertilisers to grow enough food. It is made from nitrogen and hydrogen. The reaction is reversible.

#### The Haber process
The process used to make ammonia is called the Haber process.

1. **Gases mixed and scrubbed**
2. **Compressor**
3. **Converter**
4. **Cooler**
5. **Storage tanks**

- **1** The reactants are nitrogen and hydrogen. The nitrogen is obtained from air, and the hydrogen by reacting natural gas (methane) with steam, or by cracking hydrocarbons. See the details on the right. The two gases are mixed, and scrubbed (cleaned) to remove impurities.
- **2** The gas mixture is compressed. More and more gas is pumped in, until the pressure reaches 200 atmospheres.
- **3** The compressed gas flows to the converter – a round tank with beds of hot iron at 450°C. The iron catalyses the reversible reaction:
  \[ \text{N}_2 (g) + 3\text{H}_2 (g) \rightleftharpoons 2\text{NH}_3 (g) \]
  But only 15% of the mixture leaving the converter is ammonia.
- **4** The mixture is cooled until the ammonia condenses to a liquid. The nitrogen and hydrogen are recycled to the converter for another chance to react. Steps 3 and 4 are continually repeated.
- **5** The ammonia is run into tanks, and stored as a liquid under pressure.

#### Obtaining the reactants

**Nitrogen**
Air is nearly 80% nitrogen, and 20% oxygen. The oxygen is removed by burning hydrogen:
\[ 2\text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2\text{H}_2\text{O} (l) \]
That leaves mainly nitrogen, and a small amount of other gases.

**Hydrogen**
- It is usually made by reacting natural gas (methane) with steam:
  \[ \text{CH}_4 (g) + 2\text{H}_2\text{O} (g) \rightarrow \text{CO}_2 (g) + 4\text{H}_2 (g) \]
- It can also be made by cracking hydrocarbons from petroleum. For example:
  \[ \text{C}_2\text{H}_6 (g) \rightarrow \text{C}_2\text{H}_4 (g) + \text{H}_2 (g) \]
Improving the yield of ammonia

The reaction between nitrogen and hydrogen is reversible, and the forward reaction is exothermic: it gives out heat.

\[
\text{N}_2 (g) + 3\text{H}_2 (g) \xrightarrow{\text{exothermic}} 2\text{NH}_3 (g)
\]

Since the reaction is reversible, a mixture of the two gases will never react completely. The yield will never be 100%.

But the yield can be improved by changing the reaction conditions, to shift equilibrium towards the product.

The graph on the right shows how the yield changes with temperature and pressure.

The chosen conditions

**The temperature and pressure**  As you can see, the highest yield on the graph is at \(X\), at 350°C and 400 atmospheres.

But the Haber process uses 450°C and 200 atmospheres, at \(Y\) on the graph. Why? Because at 350°C, the reaction is too slow. 450°C gives a better rate.

And second, a pressure of 400 atmospheres needs very powerful pumps, and very strong and sturdy pipes and tanks, and a lot of electricity. 200 atmospheres is safer, and saves money.

So the conditions inside the converter do not give a high yield. But then the ammonia is removed, so that more will form. And the unreacted gases are recycled, for another chance to react. So the final yield is high.

**The catalyst**  Iron speeds up the reaction. But it does not change the yield!

More about the raw materials

The panel on the opposite page shows how the raw materials are obtained. Air and water are easy to find. But you need natural gas (methane), or hydrocarbons from petroleum (crude oil), to make hydrogen.

So ammonia plants are usually built close to natural gas terminals or petroleum refineries. In fact many petroleum and gas companies now make ammonia, as a way to increase their profits.

---

**Q**

1. Ammonia is made from nitrogen and hydrogen.
   a. How are the nitrogen and hydrogen obtained?
   b. What is the process for making ammonia called?
   c. Write an equation for the reaction.
2. Look at the catalyst beds in the diagram on page 226.
   a. What is in them?
   b. Why are they arranged this way?
3. a. Explain why high pressure and low temperature help the yield, in making ammonia. (Check Unit 9.6?)
   b. 400 atmospheres and 250°C would give a high yield. Why are these conditions not used in the Haber process?
   c. What is the % yield of ammonia at 200 atmospheres and 450°C? (Use the graph.)
   d. What happens to the unreacted gases?
What plants need
A plant needs carbon dioxide, light, and water. It also needs several different elements. The main ones are nitrogen, potassium, and phosphorus.

Plants need nitrogen for making chlorophyll, and proteins.

Potassium helps them to produce proteins, and to resist disease.

Phosphorus helps roots to grow, and crops to ripen.

Plants obtain these elements from compounds in the soil, which they take in through their roots as solutions. The most important one is nitrogen. Plants take it in as nitrate ions and ammonium ions.

Fertilisers
Every crop a farmer grows takes compounds from the soil. Some get replaced naturally. But in the end the soil gets worn out. New crops will not grow well. So the farmer has to add fertilisers.

A fertiliser is any substance added to the soil to make it more fertile.

Animal manure is a natural fertiliser. Synthetic fertilisers are made in factories, and sprinkled or sprayed on fields. Here are some examples.

- ammonium nitrate, NH₄NO₃
- ammonium sulfate, (NH₄)₂SO₄
- potassium sulfate, K₂SO₄
- ammonium phosphate, (NH₄)₃PO₄

Nutrition for plants: these granules are made of animal manure, a natural fertiliser.

Getting ready to apply fertiliser to fields. (Sometimes spelled fertilizer!)
Examples of reactions to make synthetic fertilisers

1. Ammonia reacts with nitric acid to give ammonium nitrate. This fertiliser is an excellent source of nitrogen:
   \[ \text{NH}_3 \text{(aq)} + \text{HNO}_3 \text{(aq)} \rightarrow \text{NH}_4\text{NO}_3 \text{(aq)} \]
   ammonia     nitric acid     ammonium nitrate

2. Ammonia reacts with sulfuric acid to give ammonium sulfate:
   \[ 2\text{NH}_3 \text{(aq)} + \text{H}_2\text{SO}_4 \text{(aq)} \rightarrow (\text{NH}_4)_2\text{SO}_4 \text{(aq)} \]
   ammonia     sulfuric acid     ammonium sulfate

It’s not all good news

Fertilisers help to feed the world. We could not grow enough crops without them. But there are drawbacks – as usual!

In the river Fertilisers can seep into rivers from farmland. In the river, they help tiny water plants called algae to grow. These can cover the water like a carpet. When they die, bacteria feed on them, at the same time using up the oxygen dissolved in the water. So fish suffocate.

In the water supply From rivers, the nitrate ions from fertilisers can end up in our water supply. They are converted to nitrite ions in our bodies. These combine with haemoglobin in blood, in place of oxygen, so the blood carries less oxygen around the body. This can cause illness, especially in infants. Their skin may take on a blue tinge.

So farmers should use fertilisers carefully. They should try to keep them away from river banks – and not spread them in wet weather.

What % of it is nitrogen?

Ammonium nitrate is rich in nitrogen. What % of it is nitrogen? Find out like this:

\[ \text{Formula: } \text{NH}_4\text{NO}_3 \]
\[ A_1 \text{ : } N = 14, \text{ H } = 1, \text{ O } = 16 \]
\[ M = (14 \times 2) + (4 \times 1 ) + (16 \times 3) = 80 \]
\[ \% \text{ of this that is nitrogen} \]
\[ = \frac{28}{80} \times 100\% \]
\[ = 35\% \]

Q

1. You can buy a mixture of fertilisers called NPK fertiliser. It contains elements plants need. Why do you think it is called NPK?
2. Nitrogenous fertilisers are fertilisers that contain nitrogen. Name three nitrogenous fertilisers.
3. Fertilisers can harm river life. Explain how.
4. The box in the margin above will remind you how to work out % composition.
   a) Find the % of nitrogen in ammonium sulfate. (A₂ : S = 32)
   b) Which would provide more nitrogen: 1 kg of ammonium nitrate or 1 kg of ammonium sulfate?
   c) Make sure not to add it in the rainy season. Why not?
16.4 Sulfur and sulfur dioxide

Where is sulfur found?
Sulfur is a non-metal. It is quite a common element in the Earth’s crust.
- It is found, as the element, in large underground beds in several countries, including Mexico, Poland and the USA. It is also found around the rims of volcanoes.
- It occurs as a compound in many metal ores. For example in the lead ore galena, which is lead(II) sulfide, PbS.
- Sulfur compounds also occur naturally in the fossil fuels: coal, petroleum (crude oil) and natural gas.

Extracting the sulfur
From oil and gas  Most sulfur is now obtained from the sulfur compounds found in petroleum and natural gas. These compounds are removed to help reduce air pollution.

For example natural gas is mainly methane. But it can have as much as 30% hydrogen sulfide. This is separated from the methane. Then it is reacted with oxygen, with the help of a catalyst, to give sulfur:

$$2\text{H}_2\text{S} (g) + \text{O}_2 (g) \rightarrow 2\text{S} (s) + 2\text{H}_2\text{O} (l)$$

hydrogen sulfide + oxygen → sulfur + water

From sulfur beds  About 5% of the sulfur we use comes from the underground sulfur beds. Superheated water is pumped down to melt the sulfur and carry it to the surface. (It melts at 115°C.)

The properties of sulfur
1. It is a brittle yellow solid.
2. It has two different forms or allotropes, as shown on the right.
3. Because it is molecular, it has quite a low melting point.
4. Like other non-metals, it does not conduct electricity.
5. Like most non-metals, it is insoluble in water.
6. It reacts with metals to form sulfides. For example with iron it forms iron(II) sulfide:
   $$\text{Fe} (s) + \text{S} (s) \rightarrow \text{FeS} (s)$$
   You can see photos of this reaction on page 46.
7. It burns in oxygen to form sulfur dioxide:
   $$\text{S} (s) + \text{O}_2 (g) \rightarrow \text{SO}_2 (g)$$

Uses of sulfur
- Most sulfur is used to make sulfuric acid.
- It is added to rubber, for example for car tyres, to toughen it. This is called vulcanizing the rubber.
- It is used in making drugs, pesticides, dyes, matches, and paper.
- It is used in making cosmetics, shampoos, and body lotions.
- It is added to cement to make sulfur concrete. This is not attacked by acid. So it is used for walls and floors in factories that use acid.

A molecule of sulfur. It has 8 atoms – so the molecular formula of sulfur is $S_8$. But it is just called $S$ in equations.

A crystal of rhombic sulfur, the allotrope that is stable at room temperature.

If you heat rhombic sulfur slowly to above 96°C, the molecules rearrange themselves. The result is needle-shaped crystals of monoclinic sulfur.
Sulfur dioxide

Sulfur dioxide (SO₂) is a gas. It forms when sulfur burns in air.

1. It is a colourless gas, heavier than air, with a strong, choking smell.
2. Like most non-metal oxides, it is an acidic oxide. It dissolves in water, forming sulfurous acid, H₂SO₃:
   \[ \text{H₂O (l) + SO₂ (g) \rightarrow H₂SO₃ (aq)} \]
   This breaks down easily again to sulfur dioxide and water.
3. It acts as a bleach when it is damp or in solution. This is because it removes the colour from coloured compounds by reducing them.
4. It can kill bacteria.

Sulfur dioxide as a pollutant

Coal and petroleum contain sulfur compounds – even after petroleum is treated to remove them. Some coals contain a high % of sulfur.

When these fuels are burned in power stations, and factory furnaces, the sulfur compounds are oxidised to sulfur dioxide.

This escapes into the air, where it can cause a great deal of harm. It can attack your lungs, giving breathing problems. It also dissolves in rain to give acid rain. This attacks buildings and metal structures, and can kill fish and plants. (See page 214.)

Uses of sulfur dioxide

- Its main use is in the manufacture of sulfuric acid.
- It is used to bleach wool, silk, and wood pulp for making paper.
- It is used as a sterilizing agent in making soft drinks and jam, and in drying fruit. It stops the growth of bacteria and moulds.

Q

1. Name three sources of sulfur in the Earth’s crust.
2. Sulfur has quite a low melting point. Why is this?
3. Sulfur has two allotropes. What does that mean?
4. Sulfur reacts with iron to form iron(II) sulfide. Is this a redox reaction? Explain your answer.
5. a. Sulfur dioxide is an acidic oxide. Explain.
   b. What problems does this property cause, if sulfur dioxide escapes into the air from power stations?
6. Sulfur dioxide is a heavy gas. Do you think this contributes to air pollution? Explain your answer.
### 16.5 Sulfuric acid

#### Making sulfuric acid by the Contact process

More sulfuric acid is made than any other chemical! Most of it is made by the **Contact process**. The raw materials are:

- **sulfur, air, and water** ... or
- **sulfur dioxide, air, and water**.

The sulfur dioxide is obtained when sulfide ores, such as lead and zinc ores, are roasted in air to extract the metal from them.

Starting with sulfur, the steps in the Contact process are:

<table>
<thead>
<tr>
<th>Step</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S (s) + O₂ (g) → SO₂ (g)</td>
</tr>
<tr>
<td>2</td>
<td>SO₂ (g) + O₂ (g) → SO₃ (g)</td>
</tr>
<tr>
<td>3</td>
<td>SO₂ (g) + O₂ (g) → SO₃ (g)</td>
</tr>
<tr>
<td>4</td>
<td>SO₃ (g) + 2H₂O (l) → H₂SO₄ (l)</td>
</tr>
</tbody>
</table>

#### Things to note about the Contact process

- The reaction in step 3 is **reversible**. The sulfur trioxide continually breaks down again. So the mixture is passed over four separate beds of catalyst, to give the reactants further chances to react.

- Sulfur trioxide is removed between the last two beds of catalyst (using step 4) in order to increase the yield.

- The reaction in step 3 is **exothermic**. So yield rises as temperature falls. But the catalyst will not work below 400°C, and it works better at higher temperatures. So 450°C is a compromise.

- To keep the temperature down to 450°C, heat must be removed from the catalyst beds. So pipes of cold water are coiled around them to carry heat away. The heat makes the water boil. The steam is used to generate electricity for the plant, or for heating buildings.

- In step 4, the sulfur trioxide is dissolved in concentrated acid instead of water, because with water, a thick, dangerous mist of acid forms.

---

**Pressure in the Contact process**

In step 3:

\[
2\text{SO}_2 + \text{O}_2 \rightleftharpoons 2\text{SO}_3
\]

3 molecules 2 molecules

- So increasing the pressure will increase the yield of sulfur trioxide. (Page 127 explains why.)
- But in practice, the pressure is increased only a little (to less than two atmospheres).
Concentrated sulfuric acid was added to two teaspoons of sugar – and this is the result. It turned the sugar into carbon. Think what it could do to flesh!

The teacher’s sulfate. The white stick they call chalk is not really chalk – it is calcium sulfate.

Concentrated sulfuric acid – danger!
- Concentrated sulfuric acid is a dehydrating agent. It removes water.
- It ‘likes’ water so much that it removes hydrogen and oxygen atoms from other substances. For example from sugar (sucrose, C_{12}H_{22}O_{11}), leaving just carbon.
- Look at the photo above.
- When it is mixed with water, the reaction gives out a great deal of heat.

Uses of sulfuric acid
Sulfuric acid is one of the world’s most important chemicals. It has thousands of uses in industry. Its main uses are in making:
- fertilisers such as ammonium sulfate
- paints, pigments, and dyestuffs
- fibres and plastics
- soaps and detergents.
It is also the acid used in car batteries.

Dilute sulfuric acid
In the lab, dilute sulfuric acid is made by adding the concentrated acid to water. And never the other way round – because so much heat is produced that the acid could splash out and burn you.

Dilute sulfuric acid shows the usual reactions of acids:
1. acid + metal → salt + hydrogen
2. acid + metal oxide or hydroxide → salt + water
3. acid + carbonate → salt + water + carbon dioxide

Its salts are called sulfates. And reactions 2 and 3 are neutralisations: water is produced as well as a salt.

For example dilute sulfuric acid reacts with iron like this:

\[
\text{H}_2\text{SO}_4 (aq) + \text{Fe (s)} \rightarrow \text{FeSO}_4 (aq) + \text{H}_2 (g)
\]

sulfuric acid iron(II) sulfate hydrogen

And with copper(II) oxide like this:

\[
\text{H}_2\text{SO}_4 (aq) + \text{CuO (s)} \rightarrow \text{CuSO}_4 (aq) + \text{H}_2\text{O (l)}
\]

sulfuric acid copper(II) oxide copper(II) sulfate water

Unit 9.6 will help you answer these questions.
1. For making sulfuric acid, name:
   a. the process
   b. the raw materials
   c. the catalyst
2. a. The reaction between sulfur dioxide and oxygen is reversible. What does that mean?
   b. Suggest a reason why a catalyst is needed.
   c. At 500°C, the catalyst makes sulfur trioxide form even faster. Why is this temperature not used?
3. Explain how these help to increase the yield of sulfur trioxide, in the Contact process:
   a. Several beds of catalyst are used.
   b. The sulfur trioxide is removed by dissolving it.
4. Identify two oxidation reactions in the manufacture of sulfuric acid.
5. a. Write word equations for the reactions of zinc metal, zinc oxide (ZnO) and zinc carbonate (ZnCO_{3}) with dilute sulfuric acid.
   b. Now write a balanced equation for each reaction in a.
**Carbon, the element**

Some carbon is found in the Earth’s crust as the free element, in two forms: **diamond** and **graphite**. Diamond is a hard, clear solid. Graphite is a dark, greasy solid. So diamond and graphite are **allotropes** (different forms of the same element).

**Carbon compounds**

There are *thousands* of carbon compounds in nature: in living things, in the soil, in the oceans, and in the atmosphere (carbon dioxide). You are around 75% water by mass – and around 20% carbon!

**The carbon cycle**

Carbon moves between compounds in the atmosphere, living things, the soil, and the ocean, in a non-stop journey called **the carbon cycle**:

- **Charcoal**: a form of graphite made by heating coal or wood in a little air.

**Note about the carbon cycle**

- Carbon moves between the atmosphere, ocean, and living things, in the form of carbon dioxide.
- Carbon dioxide is ...
  - removed from the atmosphere by **photosynthesis**, and **dissolving** in the ocean
  - added to it by **respiration**, and the **combustion** (burning) of fuels that contain carbon.

---

**Two opposite reactions**

**Respiration**, which goes on in your body, is the opposite of **photosynthesis** in plant leaves. You can compare their equations on the next page.
Removing carbon dioxide from the atmosphere

- **By photosynthesis** In this process, carbon dioxide and water react in plant leaves, to give glucose and oxygen. Chlorophyll, a green pigment in leaves, is a catalyst for the reaction. Sunlight provides the energy:

  \[
  6\text{CO}_2 (g) + 6\text{H}_2\text{O} (l) \xrightarrow{\text{light, chlorophyll}} \text{C}_6\text{H}_12\text{O}_6 (s) + 6\text{O}_2 (g)
  \]

  The plant uses the glucose to make the other carbon compounds it needs. Then animals eat the plants. So the carbon compounds get passed along the food chain. Many of them end up in your dinner!

  Note that photosynthesis also goes on in **phytoplankton**, tiny plants that float in the ocean. These are eaten by fish and other organisms. So carbon is passed along food chains in the ocean too.

- **By dissolving** Some carbon dioxide from the air dissolves in the ocean. It provides carbonate ions, which shellfish use along with calcium ions from the water, to build their shells. (Shells are made of calcium carbonate.) Fish also use them in building their skeletons.

  But only a certain % of carbon dioxide will dissolve. A balance is reached between its concentration in the air and the ocean.

Adding carbon dioxide to the atmosphere

- **By respiration** This is the process that takes place in our cells (and in the cells of plants and other animals) to provide energy:

  \[
  \text{C}_6\text{H}_12\text{O}_6 (aq) + 6\text{O}_2 (g) \rightarrow 6\text{CO}_2 (g) + 6\text{H}_2\text{O} (l) + \text{energy}
  \]

  We get the glucose from food. The energy keeps us warm, and allows us to move, and enables other reactions to go on in our bodies.

- **By the combustion of fuels** Natural gas or **methane** burns like this:

  \[
  \text{CH}_4 (g) + 2\text{O}_2 (g) \rightarrow \text{CO}_2 (g) + 2\text{H}_2\text{O} (l) + \text{energy}
  \]

The carbon cycle and fossil fuels

In the ocean, the remains of dead organisms fall to the ocean floor, and are buried. Over millions of years their soft parts turn into petroleum (oil) and natural gas. (Hard shells turn into limestone rock.)

Meanwhile, trees and other vegetation get buried in warm swamps. Over millions of years, they turn into coal.

In this way, carbon dioxide from the air ends up in the fossil fuels. And when we burn these, it is released again.

---

**Q**

1. What is the carbon cycle?
2. Compare respiration and the combustion of methane.
   a. What is similar about the two reactions?
   b. What do we use the energy from respiration for?
   c. What do we use the energy from burning fuels for?
3. Now compare respiration and photosynthesis. What do you notice about these reactions?
4. See if you can draw a circular flowchart that shows:
   - how carbon dioxide from the air gets locked up as compounds in petroleum and natural gas
   - and how it is released again, millions of years later.
5. One part of the carbon cycle does not occur naturally (that is, without help from humans). Which part?
6. What part do you play in the carbon cycle?
16.7 Some carbon compounds

Carbon dioxide

The gas carbon dioxide (CO₂) occurs naturally in air. It is also a product in these three reactions:

1. The combustion of carbon compounds in plenty of air. For example, when natural gas (methane) burns in plenty of air, the reaction is:
   \[ CH_4 (g) + 2O_2 (g) \rightarrow CO_2 (g) + 2H_2O (l) \]

2. The reaction between glucose and oxygen, in your body cells:
   \[ C_6H_{12}O_6 (aq) + 6O_2 (g) \rightarrow 6CO_2 (g) + 6H_2O (l) \]
   This is called respiration. You breathe out the carbon dioxide.

3. The reaction between dilute acids and carbonates. For example between hydrochloric acid and marble chips (calcium carbonate):
   \[ CaCO_3 (s) + 2HCl (aq) \rightarrow CaCl_2 (aq) + CO_2 (g) + H_2O (l) \]

Properties of carbon dioxide

1. It is a colourless gas, with no smell.
2. It is much heavier than air.
3. Things will not burn in it. We say it does not support combustion.
4. It is slightly soluble in water, forming carbonic acid, H₂CO₃.

Carbon monoxide

Carbon monoxide (CO) forms when carbon compounds burn in too little oxygen. For example, when methane burns in insufficient oxygen:

\[ 2CH_4 (g) + 3O_2 (g) \rightarrow 2CO (g) + 4H_2O (l) \]

It is a deadly poisonous gas. It binds to the haemoglobin in red blood cells, and prevents it from carrying oxygen around the body. So victims die from oxygen starvation.

Carbon monoxide has no smell, which makes it hard to detect. So it is important to have gas heaters and boilers checked regularly, to make sure the air supply is not blocked by soot.

Carbonates

Carbonates are compounds that contain the carbonate ion, CO₃²⁻. One example is calcium carbonate, CaCO₃, which occurs naturally as limestone, chalk and marble. These are the main properties of carbonates:

1. They are insoluble in water – except for sodium, potassium, and ammonium carbonates, which are soluble.
2. They react with acids to form a salt, water, and carbon dioxide.
3. Most of them break down on heating, to an oxide and carbon dioxide:
   \[ CaCO_3 (s) \rightarrow CaO (s) + CO_2 (g) \]
   calcium carbonate calcium oxide carbon dioxide
   (limestone) (lime)

But sodium and potassium carbonates do not break down, since the compounds of these reactive metals are more stable. (See page 189.)
Methane

Methane is the compound CH₄.

- It is found in gas deposits in the ocean floor and on land, as natural gas. We use natural gas as a fuel.
- It also forms wherever bacteria break down plant material, in the absence of oxygen. For example in paddy fields, and swamps, and landfill sites (rubbish dumps).
- Some animals give out methane as waste gas. They include cattle, sheep, goats, camel, and buffalo. Bacteria in their stomachs help to break down grass and other food, giving methane as one product.

Organic compounds

Methane is an organic compound. Organic compounds all contain carbon, and most contain hydrogen. Some contain elements like sulfur and nitrogen too. Many are found in, or derived from, living things.

Methane is the simplest organic compound. There are millions more – far more than all the inorganic (non-organic) compounds. They include:

- the proteins, carbohydrates, and fats in your body
- the hundreds of different compounds in petroleum and coal
- the plastics and medical drugs made from the compounds in petroleum.

The study of these carbon compounds is called organic chemistry.

The next two chapters in this book are about organic chemistry.

---

**Q**

1. Give the word equation for the combustion of natural gas:
   - a in a gas boiler, when the boiler is working well.
   - b in a gas boiler, when the air inlet is partly blocked with soot.

2. Gas boilers should be checked regularly, to make sure air flows through the burner properly. Why?

3. a Write an equation to show what happens when lead(II) carbonate is heated.
   - b What is this type of reaction called? (Page 189?)

4. a Name three sources of methane, CH₄.
   - b Which do you think is the main source?

5. Is it organic, or inorganic?
   - a sodium chloride
   - b water
Carbon dioxide and methane are greenhouse gases

Carbon dioxide and methane are both **greenhouse gases**. That means they absorb heat in the atmosphere, and prevent it from escaping into space.

This is how greenhouse gases work:

1. The sun sends out energy as light and UV rays.

2. These warm the Earth, which reflects some of the energy away again, as heat.

3. Some of this heat escapes from the atmosphere.

4. But some is absorbed by greenhouse gases in the atmosphere. So the air, and Earth, are warmed.

There are several greenhouse gases. Carbon dioxide and methane are the two main ones we add to the atmosphere, through human activity. There is much more carbon dioxide than methane in the atmosphere. But the levels of both are rising:

- The level of carbon dioxide is rising because we burn more fossil fuel each year. The carbon dioxide from this goes into the atmosphere. It cannot escape into space, and the ocean can dissolve only some of it.

- The level of methane is rising because there is an increase in animal farming, and rice farming, around the world – and more and more landfill sites.

We need greenhouse gases. Without them, we would freeze to death at night, when the sun was not shining. But many scientists think the level of greenhouse gases is now so high that it is causing global warming.

**Global warming**

Measurements show that average temperatures around the world are rising. We call this **global warming**.

Why is it happening? Some scientists say it is a natural change, like similar changes in the past.

However, a panel of scientists from around the world examined all the data, and concluded that greenhouse gases are **almost certainly** the main cause.

They picked out carbon dioxide as the main culprit. The rise in average temperatures over time appears to match the rise in carbon dioxide levels over time. Compare the two graphs on the right.
Climate change

Air temperature affects rainfall, and cloud cover, and wind patterns. So as average temperatures rise, climates around the world change too. Scientists try to predict what will happen, using computer models. They cannot make really good predictions yet, because they do not fully understand the links between weather, and clouds, and the ocean. But they do predict that:

- some places with quite a lot of rain will become very dry, and other places will get much wetter.
- melting land-ice in the Arctic and Antarctica will cause sea levels to rise, so low-lying countries will be at risk of flooding.
- storms, floods, and wildfires will be more frequent and severe.
- species that cannot adapt to the changing climate will die out.
- more drought is likely, which will lead to famine – so more people will become refugees.

Most experts agree that climate change is already underway.

What can we do?

If global warming is a natural change, we can do nothing to stop it. We can only prepare for the consequences.

If we are causing global warming by burning fossil fuels, we still cannot stop it, because the level of carbon dioxide already in the air is enough to cause a further temperature rise. All we can do is cut back heavily on new emissions of carbon dioxide, to stop warming getting out of control.

- Many people are trying to cut back on using fossil fuel, for example by using public transport or bikes, or walking, rather than going by car.
- Many countries have set targets for switching to clean ways to get electricity, such as windpower and solar power.
- Scientists are looking at ways to reduce the amount of carbon dioxide entering the atmosphere. For example by capturing it from power station chimneys, and burying it deep underground.

Some countries are starting to prepare for climate change. The poorest countries are likely to suffer most, since they do not have enough money to cope well with floods, drought, and other disasters.

1. a We need greenhouse gases. Why?  
   b So why are they becoming a problem?
2. The two main greenhouse gases we are adding to the atmosphere are …?
3. Global warming could lead to the extinction of some species of living things. Explain why.
4. The more carbon dioxide in the air, the more will dissolve in the ocean. (A balance is reached.)
   a Which type of oxide is carbon dioxide: acidic or basic?
   b i How might the pH of the ocean be affected by our burning of fossil fuels? Explain.
   ii Do you think this could cause problems? Explain.
Limestone

Limestone: from sea creatures
Most of the creatures that live in the sea have shells or skeletons made of calcium carbonate. When they die, their remains fall to the sea floor. Slowly, over millions of years, the layers of shells and bones become limestone rock. (The soft parts of sea organisms become oil and gas.) Over millions of years, powerful forces raised some sea beds upwards, draining them to form land. That explains why plenty of limestone is found inland, miles from the sea!

Making use of limestone
Around 5 billion tonnes of limestone are quarried from the Earth’s crust every year. This is what it is used for:

<table>
<thead>
<tr>
<th>石灰石, CaCO₃</th>
<th>破碎石灰石</th>
<th>石灰, CaO</th>
<th>生石灰, Ca(OH)₂</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>用途</strong></td>
<td><strong>用途</strong></td>
<td><strong>用途</strong></td>
<td><strong>用途</strong></td>
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<tr>
<td>用于</td>
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<td>用于</td>
<td>用于</td>
</tr>
<tr>
<td>提取铁矿石</td>
<td>制作水泥</td>
<td>中和酸性土壤</td>
<td>中和酸性土壤</td>
</tr>
<tr>
<td>铁矿石</td>
<td>铁矿石</td>
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<td>铁矿石</td>
</tr>
<tr>
<td>破碎</td>
<td>加水</td>
<td>粉碎</td>
<td>生石灰, Ca(OH)₂</td>
</tr>
<tr>
<td>加热</td>
<td>石灰</td>
<td>石灰</td>
<td>生石灰, Ca(OH)₂</td>
</tr>
</tbody>
</table>

Lime
When limestone is heated, it breaks down to lime (or quicklime):

\[ \text{CaCO}_3 (s) \rightleftharpoons \text{CaO} (s) + \text{CO}_2 (g) \]

This is thermal decomposition.

The drawing shows a lime kiln. The kiln is heated. Limestone is fed in at one end. Lime comes out the other. The reaction is reversible. So the calcium oxide and carbon dioxide could combine again. But air is blown through the kiln to carry the carbon dioxide away before it has a chance to react.
Slaked lime

Slaked lime forms when water is added to lime. The reaction is exothermic, so the mixture hisses and steams. Conditions are controlled so that the slaked lime forms as a fine powder:

\[
\text{CaO (s)} + \text{H}_2\text{O (l)} \rightarrow \text{Ca(OH)}_2 (s)
\]

(calcium oxide) (calcium hydroxide (lime) (slaked lime))

Slaked lime is used to neutralise acidity in soil, and in lakes. In the lab, we use it to test for carbon dioxide. Limewater is a weak solution of calcium hydroxide, which is sparingly soluble in water. (See the test on page 285.)

Cement

Cement is made by mixing limestone with clay, heating the mixture strongly in a kiln, adding gypsum (hydrated calcium sulfate), and grinding up the final solid to give a powder.

Flue gas desulfurisation

Flue gas desulfurisation means the removal of sulfur dioxide from the waste gases at power stations, before they go out the flue (chimney).

It is usually carried out using a runny mixture of powdered limestone, or slaked lime, and water. The mixture is sprayed through the waste gases, or the gases are bubbled through it.

When slaked lime is used, the reaction that removes the sulfur dioxide is:

\[
\text{Ca(OH)}_2 (s) + \text{SO}_2 (g) \rightarrow \text{CaSO}_3 (s) + \text{H}_2\text{O (l)}
\]

(calcium hydroxide sulfurdioxide calcium sulfite water)

Then the calcium sulfite can be turned into hydrated calcium sulfate:

\[
2\text{CaSO}_3 (s) + \text{O}_2 (g) + 4\text{H}_2\text{O (l)} \rightarrow 2\text{CaSO}_4 \cdot 2\text{H}_2\text{O (s)}
\]

(calcium sulfite oxygen water hydrated calcium sulfate)

Hydrated calcium sulfate is known as gypsum. It is used in making cement, plaster board, plaster for broken limbs, and other products. So the company that owns the power station can sell it, to earn some money.

Q

1. How was limestone formed?
2. a. How is lime made? Write the equation.
   b. Why is it important to remove the carbon dioxide?
   c. How is the carbon dioxide removed, in a lime kiln?
3. How is slaked lime made? Write the equation.
4. Give two uses each for lime and slaked lime.
5. Limewater is a solution of slaked lime. It is used for …?
6. Slaked lime is more soluble in water than limestone is. Which of the two might be a better choice, for controlling soil acidity in a rainy area? Explain your choice.
7. a. Explain the term flue gas desulfurisation.
   b. Name a material used for this process.
   c. Calcium sulfite from the process is often turned into gypsum. What is gypsum, and why do they make it?
Checkup on Chapter 16

Revision checklist

Core curriculum
Make sure you can ...

☐ say how these can be prepared in the lab:
  hydrogen ammonia
  and give two reactions for each of them
☐ give the equation for the reversible reaction
  between nitrogen and hydrogen
☐ name the three main elements plants need from
  the soil, and say why they need them
  – explain what fertilisers are
  – say why they are needed
  – and give examples of salts that act as fertilisers
☐ describe two problems associated with fertilisers
☐ give equations for three different types of reaction
  that produce carbon dioxide (including respiration)
☐ give three sources of methane
☐ explain what a greenhouse gas is, and how it works
☐ name two greenhouse gases
☐ explain these terms:
  global warming climate change
☐ say that many scientists (but not all) believe that
  carbon dioxide plays a key role in climate change
☐ describe how limestone is converted to lime and
  slaked lime, and give equations
☐ give at least two uses each for limestone, lime and
  slaked lime
☐ explain what flue gas desulphurisation means, and
  describe how it is carried out
☐ say what gypsum is, and give some uses for it

Extended curriculum
Make sure you can also ...

☐ explain why ammonia is an important chemical
☐ say how the raw materials (nitrogen and hydrogen)
  are obtained, for making ammonia
☐ state the conditions used in the manufacture of
  ammonia, and explain the choice of conditions
☐ name three sources of sulfur
☐ state three uses of sulfur dioxide
☐ describe the Contact process for making sulfuric
  acid, starting with sulfur, and state the conditions
☐ give the typical acid properties of dilute sulfuric acid
☐ sketch the carbon cycle, and give equations for
  these three reactions linked to the carbon cycle:
  respiration, combustion of a fuel such as methane,
  and photosynthesis

Questions

Core curriculum

1 An NPK fertiliser contains the three main elements
  that plants need, for healthy growth.
  a Name the three elements.
  b Describe how each element helps plants.
  c Which of the three elements are provided by the
    following fertilisers?
    i ammonium phosphate
    ii potassium nitrate
    iii ammonium sulfate
  d Write a formula for each fertiliser in c.

2 a Copy the diagram below. Then fill in:
  i the common names of the substances
  ii their chemical formulae

   calcium carbonate
   calcium hydroxide (solution)
   calcium hydroxide (solid)
   calcium oxide
   add water

  b Beside each arrow say how the change is carried
    out. One example is shown.
  c Give three reasons why limestone is an
    important raw material.

3 Limestone is calcium carbonate, CaCO₃. It is
  quarried on a huge scale.
  a Which elements does it contain?
  b Much of the quarried limestone is turned into
    lime (CaO) for the steel industry.
    i What is the chemical name for lime?
    ii Describe how it is made from limestone.
  c Powdered limestone is used to improve the
    water quality in acidified lakes.
    i How might the lakes have become acidified?
    ii Why is limestone added?
    iii The limestone is used in powdered form, not
      lumps. Why? Try for more than one reason.
  d List other important uses of limestone.
4 Powdered limestone is used to treat the waste gases from power stations that burn coal and petroleum. The equation for the reaction that takes place is:

\[ \text{CaCO}_3 (s) + \text{SO}_2 (g) \rightarrow \text{CaSO}_3 (s) + \text{CO}_2 (g) \]

a i Name the gas that is removed by this reaction.
ii Why is it important to remove this gas?
b Why are large lumps of limestone not used?
c The process is called flue gas desulfurisation. Explain clearly what this means.
d The calcium sulfite is usually turned into gypsum, which has the formula \( \text{CaSO}_4\cdot2\text{H}_2\text{O} \).
   i What is the full chemical name for gypsum?
   ii Which type of chemical reaction occurs when \( \text{CaSO}_3 \) is converted into \( \text{CaSO}_4 \)?
   iii Give two uses for gypsum.
e Name two chemicals that could be used to make calcium sulfate by precipitation.

Extended curriculum

5 This is about the manufacture of ammonia.

a Which two gases react to give ammonia?
b Why are the two gases scrubbed?
c Why is the mixture passed over iron?
d What happens to the unreacted nitrogen and hydrogen?
e In manufacturing ammonia, is the chosen pressure high, low, or moderate? Explain why.

6 Nitrogen and hydrogen are converted to ammonia in the Haber process:

\[ \text{N}_2 (g) + 3\text{H}_2 (g) \rightarrow 2\text{NH}_3 (g) \]

Below is the energy level diagram for the reaction.

a What does this diagram tell you?
b Explain why high temperatures are not used in the manufacture of ammonia.
c The reaction is reversible, and reaches equilibrium. Explain very clearly what the two terms in italics mean.
d i What effect does a catalyst have on an equilibrium reaction?
   ii Which catalyst is used in the Haber process?
   iii What effect does this catalyst have on the % yield of ammonia?

d i Sulfuric acid is made by the Contact process.
The first stage is to make sulfur trioxide, like this:

\[ 2\text{SO}_2 (g) + \text{O}_2 (g) \rightarrow 2\text{SO}_3 (g) \]

The energy change in the reaction is \(-97 \text{ kJ/mol}\).

a Name the catalyst used in this reaction.
b Is the reaction exothermic, or endothermic?
c What are the reaction conditions for making sulfur trioxide?
d Will the yield of sulfur trioxide increase, decrease, or stay the same, if the temperature is raised? Explain your answer.
e Describe how sulfur trioxide is changed into concentrated sulfuric acid.

8 Below is a flow chart for the Contact process:

![Flow chart]

a Name the substances A, B, C, D, E, and F.
b Why is a catalyst used?
c Write a chemical equation for the reaction that takes place on the catalyst.
d The production of substance F is very important. Why? Give three reasons.
e Copy out the flow chart, and write in the full names of the different substances.

9 Dilute sulfuric acid has typical acid properties. An excess of it is added to test-tubes W, X, Y and Z, which contain these powdered substances:

W copper(II) oxide  X magnesium
Y calcium hydroxide  Z sodium carbonate

a In which test-tubes will you observe fizzing?
b In which test-tube will a coloured solution form?
c In which of the test-tubes does neutralisation take place?
d Name the four salts obtained, after reaction.
e Write balanced equations for the four reactions.
17.1 Petroleum: a fossil fuel

The fossil fuels
The fossil fuels are petroleum (or crude oil), coal, and natural gas. They are called fossil fuels because they are the remains of plants and animals that lived millions of years ago.

Petroleum formed from the remains of dead organisms that fell to the ocean floor, and were buried under thick sediment. High pressures slowly converted them to petroleum, over millions of years.

Natural gas is mainly methane. It is often found with petroleum. It is formed in the same way. But high temperatures and high pressures caused the compounds to break down to gas.

Coal is the remains of lush vegetation that grew in ancient swamps. The dead vegetation was buried under thick sediment. Pressure and heat slowly converted it to coal, over millions of years.

What is in petroleum?
Petroleum is a smelly mixture of hundreds of different compounds. They are organic compounds, which means they contain carbon, and usually hydrogen.

In fact most are hydrocarbons - they contain only carbon and hydrogen. These drawings show molecules of three different hydrocarbons:

This is a molecule of pentane, C₅H₁₂. It has a straight chain of 5 carbon atoms.

This is a molecule of cyclohexane, C₆H₁₂. Here a chain of 6 carbon atoms form a ring.

This is a molecule of 3-methyl pentane, C₇H₁₄. Here 6 carbon atoms form a branched chain.

A formula drawn out in this way is called a structural formula.

Notice how the carbon atoms are bonded to each other, to make the spine of each molecule. The hydrogen atoms are bonded to the carbon atoms. In petroleum you will find hydrocarbon molecules of different shapes and sizes, with different numbers of carbon atoms, from 1 to over 70.
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?

---

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?
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:

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

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.

<table>
<thead>
<tr>
<th>Name of fraction</th>
<th>Number of carbon atoms</th>
<th>What fraction is used for</th>
</tr>
</thead>
<tbody>
<tr>
<td>refinery gas</td>
<td>C₁ to C₄</td>
<td>bottled gases for cooking and heating</td>
</tr>
<tr>
<td>gasoline (petrol)</td>
<td>C₅ to C₆</td>
<td>fuel for cars</td>
</tr>
<tr>
<td>naphtha</td>
<td>C₆ to C₁₀</td>
<td>starting point or feedstock for many chemicals and plastics</td>
</tr>
<tr>
<td>paraffin (kerosene)</td>
<td>C₁₀ to C₁₅</td>
<td>fuel for aircraft, oil stoves, and lamps</td>
</tr>
<tr>
<td>diesel oil (gas oil)</td>
<td>C₁₅ to C₂₀</td>
<td>fuel for diesel engines</td>
</tr>
<tr>
<td>fuel oil</td>
<td>C₂₀ to C₃₀</td>
<td>fuel for power stations, ships, and for home heating systems</td>
</tr>
<tr>
<td>lubricating fraction</td>
<td>C₃₀ to C₅₀</td>
<td>oil for car engines and machinery; waxes and polishes</td>
</tr>
<tr>
<td>bitumen</td>
<td>C₅₀ upwards</td>
<td>for road surfaces and roofs</td>
</tr>
</tbody>
</table>

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
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.

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:

<table>
<thead>
<tr>
<th>The reactant</th>
<th>The product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>thick colourless liquid</td>
</tr>
<tr>
<td>Smell</td>
<td>no smell</td>
</tr>
<tr>
<td>Flammability</td>
<td>difficult to burn</td>
</tr>
<tr>
<td>Reactions</td>
<td>few chemical reactions</td>
</tr>
</tbody>
</table>

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:

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.
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.

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
- 540°C, catalyst
- 5 C_{5}H_{12}, pentane, suitable for petrol
- 5 C_{3}H_{6}, propene, and C_{2}H_{4}, ethene

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:

- H_{2}C=C_{2}H_{4}, ethene
- 800 °C
- H_{2}, hydrogen

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

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_{5}H_{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:

<table>
<thead>
<tr>
<th>If the name ends in ...</th>
<th>... the compound belongs to this family ...</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>-ane</td>
<td>the alkanes</td>
<td>ethane, C₂H₆</td>
</tr>
<tr>
<td>-ene</td>
<td>the alkenes</td>
<td>ethene, C₂H₄</td>
</tr>
<tr>
<td>-ol</td>
<td>the alcohols</td>
<td>ethanol, C₂H₅OH</td>
</tr>
<tr>
<td>-oic acid</td>
<td>the carboxylic acids</td>
<td>ethanoic acid, CH₃COOH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>This in the name ...</th>
<th>... means this many carbon atoms ...</th>
<th>Example from the alkane family</th>
</tr>
</thead>
<tbody>
<tr>
<td>meth-</td>
<td>1</td>
<td>methane, CH₄</td>
</tr>
<tr>
<td>eth-</td>
<td>2</td>
<td>ethane, C₂H₆</td>
</tr>
<tr>
<td>prop-</td>
<td>3</td>
<td>propane, C₃H₈</td>
</tr>
<tr>
<td>but-</td>
<td>4</td>
<td>butane, C₄H₁₀</td>
</tr>
<tr>
<td>pent-</td>
<td>5</td>
<td>pentane, C₅H₁₂</td>
</tr>
<tr>
<td>hex-</td>
<td>6</td>
<td>hexane, C₆H₁₄</td>
</tr>
</tbody>
</table>

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?

<table>
<thead>
<tr>
<th>Compound</th>
<th>methane</th>
<th>ethane</th>
<th>propane</th>
<th>butane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>CH₄</td>
<td>C₂H₆</td>
<td>C₃H₈</td>
<td>C₄H₁₀</td>
</tr>
</tbody>
</table>
| Structural formula | H
   H-C-H
   H | H
   H-C-H
   H | H
   H-C-C-H
   H   H | H
   H-C-C-C-H
   H   H   H |
| Number of carbon atoms in the chain | 1 | 2 | 3 | 4 |
| Boiling point/°C | −164 | −187 | −42 | −0.5 |

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

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.

Comparing families

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

<table>
<thead>
<tr>
<th>Family</th>
<th>A member</th>
<th>Structural formula</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>alkanes</td>
<td>ethane, C₂H₆</td>
<td><img src="image" alt="Ethane" /></td>
<td>・The alkanes contain only carbon and hydrogen, so they are hydrocarbons.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>・The bonds between their carbon atoms are all single bonds.</td>
</tr>
<tr>
<td>alkenes</td>
<td>ethene, C₂H₄</td>
<td><img src="image" alt="Ethene" /></td>
<td>・The alkenes are hydrocarbons.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>・All alkenes contain carbon – carbon double bonds.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>・The C=C bond is called their functional group.</td>
</tr>
<tr>
<td>alcohols</td>
<td>ethanol, C₂H₅OH</td>
<td><img src="image" alt="Ethanol" /></td>
<td>・The alcohols are not hydrocarbons.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>・They are like the alkanes, but with an OH group.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>・The OH group is their functional group.</td>
</tr>
<tr>
<td>carboxylic acids</td>
<td>ethanoic acid, CH₃COOH</td>
<td><img src="image" alt="Ethanoic acid" /></td>
<td>・The carboxylic acids are not hydrocarbons.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>・All carboxylic acids contain the COOH group.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>・The COOH group is their functional group.</td>
</tr>
</tbody>
</table>

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 CₙH₂ₙ₊₂, where n is a number.
  For methane n is 1, giving the formula CH₄.
  For ethane n is 2, giving C₂H₆.
  For propane n is 3, giving C₃H₈.
・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.
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 $C_nH_{2n+2}$.

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

<table>
<thead>
<tr>
<th>Compound</th>
<th>methane</th>
<th>ethane</th>
<th>propane</th>
<th>butane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>CH$_4$</td>
<td>C$_2$H$_6$</td>
<td>C$_3$H$_8$</td>
<td>C$<em>4$H$</em>{10}$</td>
</tr>
<tr>
<td>Structural formula</td>
<td><img src="image" alt="Structural formula for methane" /></td>
<td><img src="image" alt="Structural formula for ethane" /></td>
<td><img src="image" alt="Structural formula for propane" /></td>
<td><img src="image" alt="Structural formula for butane" /></td>
</tr>
<tr>
<td>Number of carbon atoms in the chain</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Boiling point/°C</td>
<td>−164</td>
<td>−87</td>
<td>−42</td>
<td>−0.5</td>
</tr>
</tbody>
</table>

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:

$$\text{CH}_4 (g) + 2\text{O}_2 (g) \rightarrow \text{CO}_2 (g) + 2\text{H}_2\text{O} (l) + \text{heat energy}$$

6. If there is not enough oxygen, the alkanes undergo incomplete combustion, giving poisonous carbon monoxide. For example:

$$2\text{CH}_4 (g) + 3\text{O}_2 (g) \rightarrow 2\text{CO} (g) + 4\text{H}_2\text{O} (l) + \text{less heat energy}$$
7. Alkanes also react with chlorine in sunlight. For example:

\[
\begin{align*}
\text{H}_2\text{C}-\text{H} + \text{Cl}_2 & \xrightarrow{\text{light}} \text{H}_2\text{C}-\text{Cl} + \text{HCl} \\
\text{methane} & \text{chloromethane}
\end{align*}
\]

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.

### Isomers

- **butane**
  - boiling point 0 °C
- **2-methylpropane**
  - boiling point –10 °C

Compare these alkane molecules. Both have the same formula, C\(_4\)H\(_{10}\). 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.

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**.

The compound C\(_2\)H\(_6\) 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.
The alkenes

The alkene family

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

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

<table>
<thead>
<tr>
<th>Compound</th>
<th>ethene</th>
<th>propene</th>
<th>but-1-ene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>( \text{C}_2\text{H}_4 )</td>
<td>( \text{C}_3\text{H}_6 )</td>
<td>( \text{C}_4\text{H}_8 )</td>
</tr>
<tr>
<td>Structural formula</td>
<td><img src="image" alt="Structure of ethene" /></td>
<td><img src="image" alt="Structure of propene" /></td>
<td><img src="image" alt="Structure of but-1-ene" /></td>
</tr>
<tr>
<td>Number of carbon atoms</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Boiling point/°C</td>
<td>-102</td>
<td>-47</td>
<td>-6.5</td>
</tr>
</tbody>
</table>

Do you agree that these compounds fit the general formula \( \text{C}_n\text{H}_{2n} \)?

**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:

   ![Reaction of ethane to form ethene and hydrogen](image)

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:

   ![Reaction of ethene to form ethane](image)

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

   ![Reaction of ethene to form ethanol](image)

These reactions are called **addition reactions**. Can you see why?

An addition reaction turns an unsaturated alkene into a saturated compound.
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!

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:

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 C₄H₈, but they have different structures. So they are isomers.

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:

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>methanol</th>
<th>ethanol</th>
<th>propan-1-ol</th>
<th>butan-1-ol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>CH₃OH</td>
<td>C₂H₅OH</td>
<td>C₃H₇OH</td>
<td>C₄H₉OH</td>
</tr>
<tr>
<td>Structural formula</td>
<td>H-(\text{OC})H</td>
<td>H-(\text{OC})H</td>
<td>H-(\text{OC})H</td>
<td>H-(\text{OC})H</td>
</tr>
<tr>
<td>Number of carbon atoms</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Boiling point/°C</td>
<td>65</td>
<td>78</td>
<td>87</td>
<td>117</td>
</tr>
</tbody>
</table>

Note that:
- they form a homologous series, with the general formula \(\text{C}_n\text{H}_{2n+1}\text{OH}\).
- 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, 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:

\[
\text{C}_6\text{H}_{12}\text{O}_6 \text{ (aq)} \xrightarrow{\text{enzymes in yeast}} 2\text{C}_2\text{H}_5\text{OH (aq)} + 2\text{CO}_2 \text{ (g)} + \text{energy}
\]

- 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 in 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.
2 By the hydration of ethene – the chemical way

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

![Chemical reaction diagram]

- 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:

\[
C_2H_5OH (l) + 3O_2 (g) \rightarrow 2CO_2 (g) + 3H_2O (l) + \text{heat}
\]

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.

**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!**

---

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.
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:

<table>
<thead>
<tr>
<th>Name of acid</th>
<th>methanoic</th>
<th>ethanoic</th>
<th>propanoic</th>
<th>butanoic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>HCOOH</td>
<td>CH₃COOH</td>
<td>C₂H₅COOH</td>
<td>C₃H₇COOH</td>
</tr>
</tbody>
</table>
| Structural formula | \[
\begin{align*}
\text{HCOOH} & : \text{H} & - & \text{O} & - & \text{OH} \\
\text{CH₃COOH} & : \text{H} & - & \text{C} & - & \text{O} & - & \text{OH} \\
\text{C₂H₅COOH} & : \text{H} & - & \text{C} & - & \text{C} & - & \text{O} & - & \text{OH} \\
\text{C₃H₇COOH} & : \text{H} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{O} & - & \text{OH}
\end{align*}
\]
| 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 $C_nH_{2n}O_2$. 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:

\[
\text{H}_2\text{C}\\text{C}\\text{O}\\\text{H} + \text{O} \rightarrow \text{H}\\text{C}\\text{C}\\text{O}\\\text{H}
\]

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 Mn²⁺ ions, with a colour change. The acid provides the H⁺ ions for the reaction:

   \[
   \text{MnO}_4^- + 8\text{H}^+ + 5e^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}
   \]

   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:

$$\text{CH}_3\text{COOH} \text{ (aq)} \xrightarrow{\text{some molecules}} \text{CH}_3\text{COO}^- \text{ (aq)} + H^+ \text{ (aq)}$$

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:

$$\text{H}^+ \text{ (aq)} + \text{NaOH} \text{ (aq)} \rightarrow \text{H}_2\text{O} \text{ (l)}$$

   or $\text{CH}_3\text{COOH} \text{ (aq)} + \text{NaOH} \text{ (aq)} \rightarrow \text{CH}_3\text{COONa} \text{ (aq)} + \text{H}_2\text{O} \text{ (l)}$

   Like all salts, sodium ethanoate is an ionic compound.

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:

$$\text{H}^+ \text{ (aq)} + \text{C}_3\text{H}_7\text{OH} \text{ (l)} \xrightarrow{\text{conc. H}_2\text{SO}_4} \text{CH}_3\text{COOC}_3\text{H}_7 \text{ (l)} + \text{H}_2\text{O} \text{ (l)}$$

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 as 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.

$\Delta$ 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 $\Rightarrow$ ______ + ______

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?
Questions

Core curriculum

1. Petroleum is separated into fractions, like this:

<table>
<thead>
<tr>
<th>Boiling point range (°C)</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 40</td>
<td>refinery gas</td>
</tr>
<tr>
<td>40 – 180</td>
<td>petrol and naphtha</td>
</tr>
<tr>
<td>180 – 250</td>
<td>paraffin (kerosene)</td>
</tr>
<tr>
<td>250 – 300</td>
<td>diesel oil</td>
</tr>
<tr>
<td>300 – 350</td>
<td>fuel oil</td>
</tr>
<tr>
<td>&gt; 350</td>
<td>semi-solid and solid residue</td>
</tr>
</tbody>
</table>

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, C₂H₆, can be cracked to give ethene, C₂H₄, 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$_2$H$_5$OH
   iii propane, C$_3$H$_8$
   iv styrene, C$_6$H$_5$CH=CH$_2$
   v chloroprene, CH$_2$CH=CHCl
   b Suggest a name for each polymer obtained.

Extended curriculum

6 The saturated hydrocarbons form a homologous series with the general formula C$_n$H$_{2n+2}$.
   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$_n$H$_{2n}$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 $-140^\circ$C and boils at $63^\circ$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?
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.

The reaction that took place is:

```
/ \ / \ / \ / \\
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.

---

**Q**

1. What is:
   - a macromolecule?
   - a polymer?
   - a natural polymer?
   - a synthetic polymer?
   - 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:

\[
\begin{align*}
\text{heat, pressure, a catalyst} & \rightarrow \text{polymerisation} \\
\text{ethene molecules (monomers)} & \rightarrow \text{part of a polythene molecule (a polymer)}
\end{align*}
\]

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

\[
\begin{align*}
\begin{array}{c}
\text{ethene molecules (monomers)} \\
\text{part of a polythene molecule (a polymer)}
\end{array}
\end{align*}
\]

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 polythene can be 500 000 or more. In other words, when making polythene, at least 17 000 ethene molecules join, on average!
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:

<table>
<thead>
<tr>
<th>The monomer</th>
<th>Part of the polymer molecule</th>
<th>The equation for the reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>H[\text{CH}2\text{Cl}] H</td>
<td>H-C-C-H [\text{Cl} ] H</td>
<td>(n\left(\text{H-C-C-Cl}\right)\rightarrow \left(\text{H-C-C-Cl}\right)/n)</td>
</tr>
<tr>
<td>(vinyl chloride)</td>
<td>poly(chloroethene) or polyvinyl chloride (PVC)</td>
<td>(n) stands for a large number!</td>
</tr>
<tr>
<td>F[\text{C} ] F</td>
<td>F-F-F-F-F-F-F-</td>
<td>(n\left(\text{F-C-F}\right)\rightarrow \left(\text{F-C-F}\right)/n)</td>
</tr>
<tr>
<td>tetrafluoroethene</td>
<td>poly(tetrafluoroethene) or Teflon</td>
<td></td>
</tr>
<tr>
<td>[\text{C}_6\text{H}_5\text{CH}2\text{H}]</td>
<td>[\text{C}_6\text{H}_5\text{CH}2\text{H}-]</td>
<td>(n\left(\text{C}_6\text{H}_5\text{CH}2\text{H}\right)\rightarrow \left(\text{C}_6\text{H}_5\text{CH}2\text{H}\right)/n)</td>
</tr>
<tr>
<td>phenylethene (styrene)</td>
<td>poly(phenylethene) or poly(styrene)</td>
<td></td>
</tr>
</tbody>
</table>

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:

\[
\left(\text{CH}_3\text{CH}2\text{H}\right)_{\text{n}}
\]

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.

\(\text{PVC}\) is light and flexible so is widely used for hoses and water pipes, and as an insulating cover for electrical wiring.

### Questions

1. Why was addition polymerisation given that name?
2. **a** What is a monomer?  
   **b** Could methane (CH4) 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 has an NH₂ 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.
2 Making Terylene

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

\[
C \quad \text{benzene-1,4-dicarboxylic acid} \\
D \quad \text{ethane-1,2-diol}
\]

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:

\[
\begin{align*}
\text{C} & \quad \text{oxidation} \\
\text{D} & \quad \text{hydrogenation}
\end{align*}
\]

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.

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.

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.

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.

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

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

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.
   b 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?
   b iii In the third column give any disadvantages you notice, for this plastic.
   b iv Then see if you can name it. If you can, well done!
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.

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.
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.

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 contains 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.

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 photodegradeable polythene   b bio-polymers
4 See if you can come up with some ideas, to help prevent pollution by plastic bags.
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.

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:
\[
6\text{CO}_2 (g) + 6\text{H}_2\text{O} (l) \rightarrow C_6\text{H}_12\text{O}_6 (s) + 6\text{O}_2 (g)
\]
carbon water glucose oxygen
dioxide (a sugar)
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.

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

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.
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:

1. We can draw a glucose molecule like this, showing the two groups that react:

   ![Glucose molecule](image1)

2. Two glucose molecules can join like this, giving maltose, a disaccharide:

   ![Maltose molecule](image2)

3. Hundreds or thousands can join in the same way, giving starch, a complex carbohydrate. It is also called a polysaccharide:

   ![Starch molecule](image3)

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.

**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.

**Questions**

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 what 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.
The macromolecules in food (part II)

18.7 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 NH₂ 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**

### 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.

Business

- 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, \( \text{C}_{15}\text{H}_{31}\text{COOH} \).

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:

\[
\begin{align*}
\text{HO} &- \text{CH}_2 \\
\text{HO} &- \text{CH} \\
\text{HO} &- \text{CH}_2 \\
\text{R} - \text{C} &\equiv \text{O} \\
\text{HO} - \text{CH}_2 & - 3\text{H}_2\text{O} \\
\text{R} - \text{C} &\equiv \text{O} - \text{CH} \\
\text{R} - \text{C} &\equiv \text{O} - \text{CH}_2 \\
\text{R} - \text{C} &\equiv \text{O} - \text{CH}_2
\end{align*}
\]

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).

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.
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.

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:
  \[
  \text{C}_6\text{H}_{12}\text{O}_6 \text{ (aq)} + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy}
  \]
  glucose + oxygen → carbon + water + energy
dioxide

- **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.

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:

\[
\begin{align*}
\text{an ester in a} & \quad \text{water} \quad \text{fatty acid} \\
\text{vegetable oil} & \quad \text{glycerol}
\end{align*}
\]

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.
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.

<table>
<thead>
<tr>
<th>Macromolecule</th>
<th>Conditions for the hydrolysis</th>
<th>Complete hydrolysis gives …</th>
</tr>
</thead>
<tbody>
<tr>
<td>starch</td>
<td>heat with dilute hydrochloric acid</td>
<td>glucose</td>
</tr>
<tr>
<td>proteins</td>
<td>boil with 6M hydrochloric acid for 24 hours</td>
<td>amino acids</td>
</tr>
<tr>
<td>fats</td>
<td>boil with dilute sodium hydroxide</td>
<td>glycerol plus the sodium salts of the fatty acids ((R^-\text{COO}^-\text{Na}^+))</td>
</tr>
</tbody>
</table>

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:

\[
\begin{align*}
R^-\text{COO}^-\text{CH}_2 & \quad R^-\text{COO}^-\text{CH} (\text{I}) + 3\text{NaOH}(aq) \quad \text{HO}^-\text{CH} (\text{I}) + 3R^-\text{COONa}(aq) \\
R^-\text{COO}^-\text{CH}_2 & \quad \text{an ester in a vegetable oil} \quad \text{glycerol} \quad \text{soap – the sodium salt of a fatty acid}
\end{align*}
\]

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.)

What does hydrolysis mean?
- 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.
- If you carry out an incomplete hydrolysis of starch in the lab, you get a mixture of products. Explain.

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

Oils are broken down in your digestive system. And oils are used to make soaps, in industry.
- What do these two processes have in common?
- In what way are they different?
Checkup on Chapter 18

Questions

Extended curriculum

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

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{CONH}_2 \\
\text{H} \\
\end{array}
\]

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:

\[
\begin{array}{c}
\text{F} \\
\text{F} \\
\text{C} \\
\text{C} \\
\end{array}
\]

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:

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{C} \\
\text{C} \\
\text{Cl} \\
\text{Cl} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{Cl} \\
\end{array}\]

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(dichloroethene) 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:

\[
\begin{align*}
\text{H}_2\text{N} & \quad \text{O} \\
\text{O} & \quad \text{Cl} \\
\text{Cl} & \quad \text{O}
\end{align*}
\]

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:

\[
\begin{align*}
\text{O} & \quad \text{C} \\
\text{C} & \quad \text{N} \\
\text{H} & \quad \text{N} \\
\text{O} & \quad \text{O}
\end{align*}
\]

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?
c ii What are the products of the hydrolysis?
c iii How can the products be separated?

6 One very strong polymer has this structure:

\[
\begin{align*}
\text{O} & \quad \text{C} \\
\text{C} & \quad \text{O} \\
\text{CH}_2 & \quad \text{CH}_2
\end{align*}
\]

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?
e 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:

\[
\begin{align*}
\text{O} & \quad \text{O} \\
\text{O} & \quad \text{O}
\end{align*}
\]

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.

\[
\begin{align*}
\text{H}_2\text{C} & \quad \text{OOC(C}_{17}\text{H}_{35}) \\
\text{HC} & \quad \text{OOC(C}_{15}\text{H}_{31}) \\
\text{H}_2\text{C} & \quad \text{OOC(C}_{14}\text{H}_{29})
\end{align*}
\]

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!

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!

---

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.
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 cm³ 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/L. 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.
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.

The results
For X:
Initial level of acid in the burette 0.0 cm³
Final level 22.2 cm³
Volume of acid used 22.2 cm³

For Y:
Initial level of acid in the burette 22.2 cm³
Final level 37.5 cm³
Volume of acid used 15.3 cm³

Analysis of the results
The same volume of each cleaner was used. The sodium hydroxide in X neutralised 22.2 cm³ of acid. The sodium hydroxide in Y neutralised 15.3 cm³ of acid. This means that solution ...

My conclusion
These results ...

To improve the reliability of the results
I would ...

Q1 In this experiment, was there:
   a an independent variable? If so, what was it?
   b a dependent variable? If so, what was it?

Q2 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.

Q3 Why is an indicator needed, for titrations?

Q4 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?

Q5 Now complete the student's Analysis of the results.

Q6 Complete the Conclusion, by saying whether or not the results supported the hypothesis.

Q7 How would you improve the reliability of the results?

Q8 How would you modify the experiment, to compare liquid scale-removers for kettles? (They contain acid.)

Q9 Next week the student will do an experiment to see whether neutralisation is exothermic or endothermic. Which item below will the student definitely use?

A B C D E F

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

<table>
<thead>
<tr>
<th>To make ...</th>
<th>Place in flask ....</th>
<th>Add ....</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon dioxide</td>
<td>calcium carbonate (marble chips)</td>
<td>dilute hydrochloric acid</td>
<td>( \text{CaCO}_3 (s) + 2\text{HCl} (aq) \rightarrow \text{CaCl}_2 (aq) + \text{H}_2\text{O} (l) + \text{CO}_2 (g) )</td>
</tr>
<tr>
<td>hydrogen</td>
<td>pieces of zinc</td>
<td>dilute hydrochloric acid</td>
<td>( \text{Zn} (s) + 2\text{HCl} (aq) \rightarrow \text{ZnCl}_2 (aq) + \text{H}_2 (g) )</td>
</tr>
<tr>
<td>oxygen</td>
<td>manganese(IV) oxide (as a catalyst)</td>
<td>hydrogen peroxide</td>
<td>( 2\text{H}_2\text{O}_2 (aq) \rightarrow 2\text{H}_2\text{O} (l) + \text{O}_2 (g) )</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Method</th>
<th>Place in flask ....</th>
<th>Add ....</th>
<th>g</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>upward displacement of air</td>
<td></td>
<td></td>
<td>over water</td>
<td>gas syringe</td>
</tr>
<tr>
<td>downward displacement of air</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the gas is heavier than air</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the gas is lighter than air</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the gas is sparingly soluble in water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>you want to measure the volume accurately</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Apparatus

<table>
<thead>
<tr>
<th>Method</th>
<th>Apparatus</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>upward displacement of air</td>
<td>gas jar</td>
<td>carbon dioxide, CO(_2), sulfur dioxide, SO(_2), hydrogen chloride, HCl</td>
</tr>
<tr>
<td>downward displacement of air</td>
<td>gas jar</td>
<td>ammonia, NH(_3), hydrogen, H(_2), oxygen, O(_2)</td>
</tr>
<tr>
<td>over water</td>
<td></td>
<td>carbon dioxide, CO(_2), hydrogen, H(_2), oxygen, O(_2)</td>
</tr>
<tr>
<td>gas syringe</td>
<td>gas syringe</td>
<td>any gas</td>
</tr>
</tbody>
</table>

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.
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.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Description and test details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ammonia, NH₃</strong></td>
<td>Ammonia is a colourless alkaline gas with a strong sharp smell.</td>
</tr>
<tr>
<td>Properties</td>
<td></td>
</tr>
<tr>
<td>Test</td>
<td>Hold damp indicator paper in it.</td>
</tr>
<tr>
<td>Result</td>
<td>The indicator paper turns blue. (You may also notice the sharp smell.)</td>
</tr>
<tr>
<td><strong>Carbon dioxide, CO₂</strong></td>
<td>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:</td>
</tr>
<tr>
<td>Properties</td>
<td>CO₂ (g) + Ca(OH)₂ (aq) → CaCO₃ (s) + H₂O (l)</td>
</tr>
<tr>
<td>Test</td>
<td>Bubble the gas through limewater.</td>
</tr>
<tr>
<td>Result</td>
<td>Limewater turns cloudy or milky.</td>
</tr>
<tr>
<td><strong>Chlorine, Cl₂</strong></td>
<td>Chlorine is a green poisonous gas which bleaches dyes.</td>
</tr>
<tr>
<td>Properties</td>
<td>Hold damp indicator paper in the gas, in a fume cupboard.</td>
</tr>
<tr>
<td>Test</td>
<td>Indicator paper turns white.</td>
</tr>
<tr>
<td><strong>Hydrogen, H₂</strong></td>
<td>Hydrogen is a colourless gas which combines violently with oxygen when lit.</td>
</tr>
<tr>
<td>Properties</td>
<td>Collect the gas in a tube and hold a lighted splint to it.</td>
</tr>
<tr>
<td>Test</td>
<td>The gas burns with a squeaky pop.</td>
</tr>
<tr>
<td><strong>Oxygen, O₂</strong></td>
<td>Oxygen is a colourless gas. Fuels burn much more readily in it than in air.</td>
</tr>
<tr>
<td>Properties</td>
<td>Collect the gas in a test-tube and hold a glowing splint to it.</td>
</tr>
<tr>
<td>Test</td>
<td>The splint immediately bursts into flame.</td>
</tr>
</tbody>
</table>

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.
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.

<table>
<thead>
<tr>
<th>Cation</th>
<th>Test</th>
<th>If the cation is present</th>
<th>Ionic equation for the reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ammonium (\text{NH}_4^+)</td>
<td>Add a little dilute sodium hydroxide solution. Heat gently.</td>
<td>Ammonia gas is given off. (It turns litmus red.)</td>
<td>(\text{NH}_4^+ (aq) + \text{OH}^- (aq) \rightarrow \text{NH}_3 (g) + \text{H}_2\text{O} (l))</td>
</tr>
<tr>
<td>copper(II) (\text{Cu}^{2+})</td>
<td>Add dilute sodium hydroxide or ammonia solution.</td>
<td>A pale blue precipitate forms. But it dissolves on adding more ammonia, giving a deep blue solution.</td>
<td>(\text{Cu}^{2+} (aq) + 2\text{OH}^- (aq) \rightarrow \text{Cu(OH)}_2 (s))</td>
</tr>
<tr>
<td>iron(II) (\text{Fe}^{2+})</td>
<td>Add dilute sodium hydroxide or ammonia solution.</td>
<td>A pale green precipitate forms.</td>
<td>(\text{Fe}^{2+} (aq) + 2\text{OH}^- (aq) \rightarrow \text{Fe(OH)}_2 (s))</td>
</tr>
<tr>
<td>iron(III) (\text{Fe}^{3+})</td>
<td>Add dilute sodium hydroxide or ammonia solution.</td>
<td>A red-brown precipitate forms.</td>
<td>(\text{Fe}^{3+} (aq) + 3\text{OH}^- (aq) \rightarrow \text{Fe(OH)}_3 (s))</td>
</tr>
<tr>
<td>aluminium (\text{Al}^{3+})</td>
<td>Add dilute sodium hydroxide or ammonia solution.</td>
<td>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.</td>
<td>(\text{Al}^{3+} (aq) + 3\text{OH}^- (aq) \rightarrow \text{Al(OH)}_3 (s))</td>
</tr>
<tr>
<td>zinc (\text{Zn}^{2+})</td>
<td>Add dilute sodium hydroxide or ammonia solution.</td>
<td>A white precipitate forms. It dissolves again on adding more sodium hydroxide or ammonia, giving a colourless solution.</td>
<td>(\text{Zn}^{2+} (aq) + 2\text{OH}^- (aq) \rightarrow \text{Zn(OH)}_2 (s))</td>
</tr>
<tr>
<td>calcium (\text{Ca}^{2+})</td>
<td>Add dilute sodium hydroxide solution.</td>
<td>A white precipitate forms. It will not dissolve on adding excess sodium hydroxide.</td>
<td>(\text{Ca}^{2+} (aq) + 2\text{OH}^- (aq) \rightarrow \text{Ca(OH)}_2 (s))</td>
</tr>
<tr>
<td></td>
<td>Add dilute ammonia solution.</td>
<td>No precipitate, or very slight white precipitate.</td>
<td></td>
</tr>
</tbody>
</table>

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 \(\text{Cu(NH}_3\text{)}_4^{2+}\) is an example. (See below.)
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:

<table>
<thead>
<tr>
<th>Precipitate</th>
<th>Indicates presence of …</th>
<th>Ionic equation for the reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>white</td>
<td>chloride ions, Cl(^{-})</td>
<td>(\text{Ag}^{+} (aq) + \text{Cl}^{-} (aq) \rightarrow \text{AgCl} (s))</td>
</tr>
<tr>
<td>cream</td>
<td>bromide ions, Br(^{-})</td>
<td>(\text{Ag}^{+} (aq) + \text{Br}^{-} (aq) \rightarrow \text{AgBr} (s))</td>
</tr>
<tr>
<td>yellow</td>
<td>iodide ions, I(^{-})</td>
<td>(\text{Ag}^{+} (aq) + \text{I}^{-} (aq) \rightarrow \text{AgI} (s))</td>
</tr>
</tbody>
</table>

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:
  \[\text{Ba}^{2+}(aq) + \text{SO}_4^{2-} (aq) \rightarrow \text{BaSO}_4 (s)\]

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:
  \[8\text{Al} (s) + 3\text{NO}_3^{-} (aq) + 5\text{OH}^{-} (aq) + 2\text{H}_2\text{O} (l) \rightarrow 3\text{NH}_3 (g) + 8\text{AlO}_2^{-} (aq)\]

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:
  \[2\text{H}^{+} (aq) + \text{CO}_3^{2-} (aq) \rightarrow \text{CO}_2 (g) + \text{H}_2\text{O} (l)\]

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

Questions

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 \((\text{NH}_4\text{NO}_3)\) 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:

<table>
<thead>
<tr>
<th>Name of ion</th>
<th>Concentration (milligrams/dm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>calcium</td>
<td>55</td>
</tr>
<tr>
<td>chloride</td>
<td>37</td>
</tr>
<tr>
<td>hydrogen carbonate</td>
<td>248</td>
</tr>
<tr>
<td>magnesium</td>
<td>19</td>
</tr>
<tr>
<td>nitrate</td>
<td>0.05</td>
</tr>
<tr>
<td>potassium</td>
<td>1</td>
</tr>
<tr>
<td>sodium</td>
<td>24</td>
</tr>
<tr>
<td>sulfate</td>
<td>13</td>
</tr>
</tbody>
</table>

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 cm³?

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.
Answers to the numerical questions in this book

page 33  6 C 6 p 6 e 6 n;  O 8 p 8 e 8 n;  Mg 12 p 12 e 12 n;
Al 13 p 13 e 13 n;  Cu 29 p 29 e 35 n
page 44  3 b i 60 ii 34 iii 0 iv 10 v 146
page 45  9 a i 38 ii 40
page 71  2 127 3 32 b 254 c 16 d 71 e 58 f 46 – all relative
molecular mass g 132, relative formula mass
page 73  1 a 95 g b 35.5 g c 47.5 g d 75% carbon 25% hydrogen
3 a 90% b 1.5 g
page 75  10 a 18 b 17 c 46 d 80 e 98 f 36.5 g 142
11 a 40 b 239 c 78 d 58.5 e 170 f 132 g 138 h 278
12 a 27.2 g i 2.72 g b 50 g e 80%
13 a 17.5% b 12185 kg ii 375 kg e 91.7%.
page 77  4 a 1 g b 127 g c 35.5 g d 71 g 5 a 32 g b 64 g e 136 g
7 a 9 moles b 3 moles a 8 a 6.02 x 1023 b 35.5 g
page 79  1 b 2 c i 32 g ii 8 g 2 b CuCO3, 124 g; CuO, 80 g;
CO2, 44 g; c i 11 g ii 20 g
page 81  3 24 dm3 a 168 dm3 b 12 dm3 c 0.024 dm3 (24 cm³)
5 a 12 dm3 b 2.4 dm3 6 a 12 dm3 b 12 dm3 7 a 12 dm3 b 6 dm3
page 83  1 a 1 mole b 1 mol c 2 a 2 mol/dm3 d 1.5 mol/dm3
3 a 0.5 dm³ (500 cm³) b 0.005 dm³ (5 cm³) 4 a 20 g b 0.5 g
5 a 0.5 moles per litre b 0.25 moles per litre
page 85  1 a 4 b 4 g i 3 FeS ii 4 SO3
page 87  4 CH 5 C2H6 a C3H8 b C4H10 7 P2O5
page 89  2 76.7% iii 63.4% 4 172 g iv 588%
page 90  1 b 160 g c 2000 moles d 2 moles e 4000 moles f 224 kg
2b 0.5 moles e i 11.2 g i i 8.8 g iii 4.8 dm³ or 4800 cm³ 3 a i 4 moles
ii 19 moles b 4.75 moles c 114 dm³ d 227 g e 502.2 dm³
page 91  4 a 0.5 moles b 25 cm³ c 75 cm³ d 50 cm³
5 a 1.4 g b 0.025 moles c 0.25 moles d Fe²⁺ e 0.6 dm³
6 a 106.5 g b 3 moles c 1 mole d AlCl3 e 0.1 mol/dm³
7 a 45.5 cm³ b 41.7 cm³ c 62.5 cm³
8 a P2O5 b 41.3 g c P4O10 d P4O6 (or P₂O₅)
9 a Zn₃P₂ b 24.1% 10 a 64 g b 4 moles c 2 moles d MnO₂
e 632.2g 11 a N₂H₄ b C₂N₂ c N₂O₄ d C₄H₆O₄ 12 b CH₄ a is
C₄H₆ b is C₂H₆ 13 b is 217 g B 20.1 g of mercury, 1.6 g of oxygen
94.5% 14 a 0.0521 moles b 4.375 g c 87.5%
page 117  4 – 486 kJ/mol
page 128  2 b drop of 4°C for ammonium nitrate, rise of 20°C for
calcium chloride d i 17°C for NH₄NO₃ 65°C for CaCl₂ ii 23°C for
NH₄NO₃ 35°C for CaCl₂ iii 21°C for NH₄NO₃ 45°C for CaCl₂
page 129  4 d 55.6 kJ 5 c i 2220 kJ/mol ii 2801 kJ/mol
d – 581 kJ/mol
page 133  3 a i 29 cm³ ii 39 cm³ b 1.5 minutes c i 5 cm³ of hydrogen per minute d 0 cm³ of hydrogen per minute
page 135  1 a i 60 cm³ ii 60 cm³
page 137  1 a experiment 1, 0.55 g; experiment 2, 0.95 g
b experiment 1, 0.33 g per minute; experiment 2, 0.5 g per minute
page 146  2 c i 14 cm³ of hydrogen/minute ii 9 cm³ of hydrogen/minute iii 8 cm³ of hydrogen/minute e 40 cm³ f 5 minutes
page 147  5 i 0.5 g
page 163  2 50 cm³ 3 1.6 mol/dm³
page 165  8 c 0.014 moles d 0.007 moles e 0.742g f 1.258 g
f 0.07 moles g 10 moles

page 180  2b Accept rough values around melting point 40°C,
boiling point 725°C c i 5 ii 37 iii 1
page 193  8 c i 2.45 volts ii 0.65 volts
page 209  3 c i 990 kg ii 0.25%
page 222  3 d 20.8%
page 223  4 a i 36% ii It is greater. b 78%
page 227  3 c 28%
page 229  4 a 21.2%
page 289  7 b ii 2.75 milligrams

Questions from past exam papers

page 296  13 e 80
page 298  2 b i 7.7% ii 1:1 iii empirical formula is CH,
molecular formula is C₆H₆.

page 299  5 a i

<table>
<thead>
<tr>
<th>composition by mass</th>
<th>copper</th>
<th>iron</th>
<th>sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of moles of atoms</td>
<td>0.075</td>
<td>0.075</td>
<td>0.15</td>
</tr>
<tr>
<td>simplest molar ratio of atoms</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

ii CuFe2

page 299  7 b i 100 ii 56 iii 12.5 kg

page 301  13 a energy to break bonds = 436 + 158 = +594 kJ
energy released in forming bonds = 2 x 562 = -1124 kJ
energy in - energy out = -530 kJ, so the reaction is exothermic

page 302  15 d i 0.033 moles ii 0.033 moles iii 5.67 g iv 70.6%

page 305  3 a

<table>
<thead>
<tr>
<th>time/s</th>
<th>volume of oxygen/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>catalyst W</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>40</td>
<td>32</td>
</tr>
<tr>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>80</td>
<td>37</td>
</tr>
<tr>
<td>100</td>
<td>37</td>
</tr>
</tbody>
</table>

page 306  5 b 47 ± 1 g/100 g of water

page 307  9 b and c

<table>
<thead>
<tr>
<th>Burette readings/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
</tr>
<tr>
<td>final reading</td>
</tr>
<tr>
<td>initial reading</td>
</tr>
<tr>
<td>difference</td>
</tr>
</tbody>
</table>
About the Cambridge IGCSE Chemistry exam

The exam papers
For your Cambridge IGCSE Chemistry exam, you must take three papers out of six. Look at this list.

- **Everyone must take this:**
  - Paper 1, multiple choice questions (45 minutes, 30% of the total marks)

- **Then one from these two:**
  - Paper 2, for the Core syllabus (1 hour 15 minutes, 50% of the total marks)
  - Paper 3, for the Extended syllabus (1 hour 15 minutes, 50% of the total marks)

- **And one from these three:**
  - Paper 4 Coursework (20% of total marks)
  - Paper 5 Practical test (1 hour 15 minutes, 20% of the total marks)
  - Paper 6 Alternative to Practical written paper (1 hour, 20% of the total marks)

Notice that Paper 1 carries 30% of the total marks for the exam. Your choice of Papers 2 or 3 carries 50%. Your remaining paper carries 20%.

Getting ready for the exam
- First, do you know which papers you will take? If you are not sure, ask your teacher.
- For Paper 3 (Extended) you will need to revise everything in this book, except the extra material on the yellow pages.
- For Paper 2 (Core), you can ignore all the material with a red line beside it, and the extra material.
- The CD with this book has lots of material to help you revise, including tests, revision advice, and sample exam papers with real questions from past papers. Check it out!

Doing past exam questions
Doing questions is a great way to revise. And before your exam, it is really important to work through questions from past papers.

The next eighteen pages of this book have real questions from past exams, for Papers 2, 3 and 6.
- If you are taking Paper 2 in the exam, you can ignore the Paper 3 questions.
- If you are taking Paper 3, you should concentrate on the Paper 3 questions but you may also find the Paper 2 questions helpful.
- The Paper 6 questions are for everyone. Even if you are not taking Paper 6 in the exam, you will find that these questions help with the other papers.

Note that answers for all the numerical questions in this book, including exam questions, are on page 290. Your teacher can provide answers for all the other questions, from both the book and CD, so that you can check your progress.

Good luck with your revision!
1 a The table gives some information about five elements, A, B, C, D and E. Copy and complete the table by writing either metal or non-metal in the last column.

<table>
<thead>
<tr>
<th>element</th>
<th>properties</th>
<th>metal or non-metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>shiny solid which conducts electricity</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>reddish brown liquid with a low boiling point</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>a form of carbon which is black in colour and conducts electricity</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>white solid which is an insulator and has a high melting point</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>dull yellow solid which does not conduct heat</td>
<td></td>
</tr>
</tbody>
</table>

b Describe how metallic character changes across a Period.

c Sodium is in Group I of the Periodic Table.
i Draw a diagram to show the full electronic structure of sodium.

\[ \text{Na} \rightarrow \text{Na}^+ + \text{...} \]

ii Complete the equation to show what happens when a sodium atom forms a sodium ion.

\[ \text{Na} \rightarrow \text{Na}^+ + \text{...} \]


d Complete these sentences about properties of the Group I elements using words from the list. acidic basic decrease hard increase lithium potassium soft

The Group I elements are relatively ........... metals which ........... in reactivity going down the Group. Sodium reacts more violently with water than ........... The Group I metals all form ........... oxides.

2 Lavandulol is found in lavender plants.
The formula of lavandulol is shown on the right.

a Which is the alcohol functional group in this formula?

b Is lavandulol a saturated or unsaturated compound? Give a reason for your answer.

c State the names of the two products formed when lavandulol is burnt in excess oxygen.

d Lavandulol can be extracted from lavender flowers by distillation using the apparatus shown below. The lavandulol is carried off in small droplets with the steam.

\[ \text{lavandulol} \rightarrow \text{water} \]

i State the name of the piece of apparatus labelled A.

ii What is the temperature of the water at point X in the diagram?

iii The lavandulol and water are collected in the beaker. What information in the diagram shows that lavandulol is less dense than water?

e Lavender flowers contain a variety of different pigments (colourings). A student separated these pigments using paper chromatography. The results are shown in the diagram below.

\[ \text{chromatography paper} \]

i Copy the diagram and put an X to show where the mixture of pigments was placed at the start of the experiment.

ii How many pigments have been separated?

iii Draw a diagram to show how the chromatography apparatus was set up. Label

- the solvent
- the origin line
During chromatography, the solvent evaporates and then diffuses through the chromatography jar. What do you understand by diffusion? [1]

Ethanol can be used as a solvent in chromatography. Draw the formula for ethanol showing all atoms and bonds. [1]

Which two of the following statements about ethanol are true?
- It is a carboxylic acid.
- It is a product of the fermentation of glucose.
- It is an unsaturated compound.
- It is formed by the catalytic addition of steam to ethene. [1]

Cambridge IGCSE Chemistry 0620 Paper 2 Q3 November 2006

The diagram shows the structures of some substances containing carbon.

a Answer these questions using the letters A–F.
   i Which one of these structures is ionic? [1]
   ii Which one of them represents ethanol? [1]
   iii Which one of these structures represents a gas which turns limewater milky? [1]
   iv Which one of these structures is an unsaturated hydrocarbon? [1]

b Describe a chemical test for an unsaturated hydrocarbon. Give the result of the test. [2]

c State the chemical name of structure B. [1]

d Structure F has several uses. Which one of the following is a correct use of structure F?
   - for cutting metals
   - as a lubricant
   - for filling balloons
   - as an insulator [1]

The structures A to E are compounds. What do you understand by the term compound? [1]

e State the type of bonding in structure A. [1]

Cambridge IGCSE Chemistry 0620 Paper 2 Q1 June 2008

The table shows observations about the reactivity of various metals with dilute hydrochloric acid.

<table>
<thead>
<tr>
<th>metal</th>
<th>observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>calcium</td>
<td>many bubbles produced rapidly with much spitting</td>
</tr>
<tr>
<td>copper</td>
<td>no bubbles formed</td>
</tr>
<tr>
<td>iron</td>
<td>a few bubbles produced very slowly</td>
</tr>
<tr>
<td>magnesium</td>
<td>many bubbles produced rapidly with no spitting</td>
</tr>
</tbody>
</table>

a Put the metals in order of increasing reactivity. [1]

b Zinc is between iron and magnesium in reactivity. Suggest what observations will be made when zinc reacts with dilute hydrochloric acid. [1]

C Magnesium is extracted by the electrolysis of molten magnesium chloride.

d In some old magnesium manufacturing plants, coal gas is blown over the surface of the magnesium. The list shows the main substances in coal gas.
   carbon monoxide  ethene  hydrogen
   hydrogen sulfide  methane

i Draw the structure of ethene showing all atoms and bonds. [1]

ii Suggest two hazards of using coal gas by referring to two specific substances in the list. [2]

e Carbon monoxide can be removed from coal gas by mixing it with steam and passing the mixture over a catalyst of iron(III) oxide at 400 °C.

\[
CO + H_2O \rightarrow CO_2 + H_2
\]

i Write a word equation for this reaction. [1]

ii What does the symbol \( \rightarrow \) mean? [1]

iii Iron(III) oxide reacts with acids to form a solution containing iron(III) ions. Describe a test for aqueous iron(III) ions. Give the result. [2]

Cambridge IGCSE Chemistry 0620 Paper 2 Q2 June 2009
5 Hydrogen chloride can be made by burning hydrogen in chlorine.
   a Complete the equation for this reaction.
   \[ \text{H}_2 + \text{..............} \rightarrow \text{.... HCl} \] **[2]**
   b Draw a dot and cross diagram for a molecule of hydrogen chloride. Show all the electrons. *Use o for an electron from a hydrogen atom. Use x for an electron from a chlorine atom.* **[2]**
   c Hydrochloric acid is formed when hydrogen chloride gas dissolves in water. Suggest the pH of hydrochloric acid. Choose from this list.
   pH1 pH7 pH9 pH13 **[1]**
   d Complete the equation for the reaction of hydrochloric acid with zinc.
   \[ \text{zinc} + \text{hydrochloric acid} \rightarrow \text{zinc chloride} + \text{.............} \] **[1]**
   e Describe how dry crystals of zinc chloride can be obtained from a solution of zinc chloride. **[2]**
   f A student electrolysed molten zinc chloride. State the name of the product formed at
   i the anode, ii the cathode. **[2]**
   Cambridge IGCSE Chemistry 0620 Paper 2 Q7 June 2009

6 When Group I elements react with water, hydrogen gas is given off. The diagram shows the reaction of lithium, potassium and sodium with water.

   a Which one of these three elements A, B or C is lithium? **[1]**
   b i Balance the equation for the reaction of sodium with water by completing the lefthand side.
      \[ \text{........Na} + \text{........H}_2\text{O} \rightarrow \text{2NaOH} + \text{H}_2 \] **[1]**
      ii Apart from fizzing, describe two things that you would see when sodium reacts with water. **[2]**
   c iii After the sodium had reacted with the water, the solution was tested with red litmus paper.
      What colour did the litmus paper turn? Give a reason for your answer. **[2]**
   d iv Which two of the following statements about sodium are true?
      *It is made by reducing sodium oxide with carbon.*
      *It reacts with chlorine to form sodium chloride.*
      *It reacts readily with oxygen.*
      *It only conducts electricity when molten.* **[2]**
   Cambridge IGCSE Chemistry 0620 Paper 2 Q6 June 2009

7 The table shows the concentration of some ions present in seawater.

<table>
<thead>
<tr>
<th>name of ion</th>
<th>formula of ion</th>
<th>concentration of ion in g/dm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>bromide</td>
<td>Br⁻</td>
<td>0.07</td>
</tr>
<tr>
<td>calcium</td>
<td>Ca²⁺</td>
<td>0.04</td>
</tr>
<tr>
<td>chloride</td>
<td>Cl⁻</td>
<td>19.1</td>
</tr>
<tr>
<td>magnesium</td>
<td>Mg²⁺</td>
<td>1.2</td>
</tr>
<tr>
<td>potassium</td>
<td>K⁺</td>
<td>0.3</td>
</tr>
<tr>
<td>sodium</td>
<td>Na⁺</td>
<td>10.6</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td></td>
<td>0.8</td>
</tr>
</tbody>
</table>

   a Which negative ion has the highest concentration in seawater? **[1]**
   b Name the ion with the formula SO₄²⁻. **[1]**
   c Which two ions in the table are formed from Group I elements? **[1]**
   d When seawater is evaporated a number of different compounds are formed. State the name of the compound present in the greatest quantity. **[1]**
   e Names the four ions in the table which move to the cathode when seawater is electrolysed. **[2]**
   f When concentrated seawater is electrolysed, chlorine is formed at one of the electrodes.
      i To which Period in the Periodic Table does chlorine belong? **[1]**
      ii Draw the electronic structure of a chlorine molecule. Show only the outer electrons. **[2]**
   g Drinking water can be obtained by purifying seawater. Explain why distillation rather than filtration is used to purify seawater for drinking. **[2]**
   Cambridge IGCSE Chemistry 0620 Paper 2 Q3 June 2008
8 Iron is extracted from its ore in a blast furnace.
   a State the name of the ore from which iron is extracted. [1]
   b The diagram shows a blast furnace.

   i Which one of the raw materials is added to the blast furnace to help remove the impurities from the iron ore? [1]
   ii The impurities are removed as a slag. Which letter on the diagram shows the slag? [1]
   c Carbon monoxide is formed in the blast furnace by reaction of coke with oxygen.
      i Complete the equation for this reaction. 
      ...... C + ............... → ...... CO [2]
      ii State the adverse affect of carbon monoxide on human health. [1]
   d In the hottest regions of the blast furnace the following reaction takes place.
      \[
      \text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 2\text{Fe} + 3\text{CO}
      \]
      Which two of these five sentences correctly describe this reaction?
      The iron oxide gets reduced.
      The reaction is a thermal decomposition.
      The carbon gets oxidised.
      The carbon gets reduced.
      Carbon neutralises the iron oxide. [1]
   e Aluminium cannot be extracted from aluminium oxide in a blast furnace. Explain why aluminium cannot be extracted in this way. [2]
   f i State the name of the method used to extract aluminium from its oxide ore. [1]
      ii State one use of aluminium. [1]

9 Calcium carbonate, \( \text{CaCO}_3 \), is the raw material used in the manufacture of lime, \( \text{CaO} \).
   a i Describe how lime is manufactured from calcium carbonate. [1]
      ii Write a symbol equation for this reaction. [1]
      iii State one large scale use of lime. [1]
   b A student investigated the speed of reaction of calcium carbonate with hydrochloric acid using the apparatus shown below.
      i Name the pieces labelled A to C. [3]
      ii The equation for the reaction is
         \[
         \text{CaCO}_3 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{CO}_2 + \text{H}_2\text{O}
         \]
         Write the word equation for this reaction. [2]
      iii The student carried out the reaction at \( 40^\circ\text{C} \) using large pieces of calcium carbonate.
         The results are shown below. At what time did the reaction stop? [1]
      iv The student repeated the experiment using the same mass of powdered calcium carbonate. All other conditions were kept the same. Copy the grid above and sketch the graph for the reaction with calcium carbonate powder. [2]
      v How does the speed of reaction change when
         – the concentration of hydrochloric acid is decreased,
         – the temperature is increased? [2]
10 The apparatus below can be used to measure the energy released when a liquid fuel is burnt. The amount of energy released is calculated from the increase in temperature of a known amount of water.

![Diagram of apparatus]

a i Explain how this experiment shows that the burning of ethanol is exothermic. [1]
ii Complete the word equation for the complete combustion of ethanol.
ethanol + oxygen → .......... + .......... [2]

b Ethanol is a fuel containing carbon. Name two other commonly used fuels containing carbon. [2]

c Give the formula of the functional group present in ethanol. [1]

d The can contains water. Describe a chemical test for water. Give the result of the test. [2]

e The iron can used in this experiment rusts easily.
   i Describe a method which can be used to prevent iron from rusting. [1]
   ii Rust contains hydrated iron(III) oxide. What do you understand by the term hydrated? [1]
   iii Iron is a transition metal. State two typical properties of transition metals. [2]

11 Some coal dust was heated with copper(II) oxide using the apparatus shown below.

![Diagram of apparatus]

a Coal contains carbon and various hydrocarbons. Carbon reduces the copper(II) oxide when heated.
   i What do you understand by reduction? [1]
   ii At the end of the experiment a reddish-brown solid remained in the tube. State its name. [1]
   iii The reddish brown solid conducts electricity. How could you show that it does so? [2]

b During the experiment, water collected on the cooler parts of the test-tube.
   i Suggest where the hydrogen in the water comes from. [1]
   ii Water is a liquid. Describe the arrangement and motion of the particles in a liquid. [2]

Cambridge IGCSE Chemistry 0620 Paper 2 Q5 November 2007

12 Some sunglasses are made from glass which darkens in bright sunlight. The glass contains tiny crystals of silver chloride and copper(I) chloride.

a In bright sunlight, in the presence of copper(I) chloride, the silver chloride breaks down to solid silver which darkens the glass.

\[ \text{Ag} (s) + e^- \rightarrow \text{Ag} (s) \]

Name the particle with the symbol \( e^- \). [1]

b Silver is a metal. State two physical properties which are characteristic of all metals. [2]

c In bright sunlight, the copper(I) chloride in the sunglasses is converted to copper(II) chloride. What do the roman numerals (I) and (II) show in these copper compounds? Choose one from the number of copper atoms in the compounds, the number of neutrons in the compounds, whether the copper is in the solid, liquid or gaseous state, the oxidation state of the copper in the compounds. [1]

d Describe a test for aqueous copper(II) ions. Give the result of the test. [3]

e Give a common use of copper. [1]

Cambridge IGCSE Chemistry 0620 Paper 2 Q5 June 2007

13 This question is about compounds.

a What do you understand by the term compound? [1]

b Copy and complete the table below to show the formulae and uses of some compounds. [6]

<table>
<thead>
<tr>
<th>compound</th>
<th>relative number of atoms present</th>
<th>formula</th>
<th>use</th>
</tr>
</thead>
<tbody>
<tr>
<td>calcium oxide</td>
<td>( \text{Ca} = 1 ) ( \text{O} = 1 )</td>
<td>( \text{CaO} )</td>
<td></td>
</tr>
<tr>
<td>sodium chloride</td>
<td>( \text{Na} = 1 ) ( \text{Cl} = 1 )</td>
<td>( \text{table salt} )</td>
<td></td>
</tr>
<tr>
<td>calcium carbonate</td>
<td>( \text{Ca} = 1 ) ( \text{C} = 1 ) ( \text{O} = 3 )</td>
<td>( \text{NH}_4\text{NO}_3 )</td>
<td>in fertilisers</td>
</tr>
</tbody>
</table>

c Calculate the relative formula mass of \( \text{NH}_4\text{NO}_3 \). [1]

Cambridge IGCSE Chemistry 0620 Paper 2 Q4 November 2006
14 The list shows part of the reactivity series.

<table>
<thead>
<tr>
<th>metal</th>
<th>observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>magnesium</td>
<td>Gives off a few bubbles of gas with hot water. Dissolves very slowly.</td>
</tr>
<tr>
<td>calcium</td>
<td>Gives off bubbles steadily with cold water. Dissolves slowly.</td>
</tr>
<tr>
<td>strontium</td>
<td></td>
</tr>
</tbody>
</table>

b Equal sized pieces of magnesium, strontium and calcium are placed in water. Some observations about these reactions are shown in the table. Complete the box for strontium.

c When water is added to calcium carbide, acetylene and calcium hydroxide are formed. State a use for acetylene.

d A solution of calcium hydroxide is alkaline.

i Complete and balance the equation for the reaction of calcium hydroxide with hydrochloric acid.

\[ \text{Ca(OH)}_2 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{H}_2\text{O} \]

ii What type of chemical reaction is this?

\[ \text{Ca(OH)}_2 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{H}_2\text{O} \]

15 Petroleum is a mixture of hydrocarbons. It is separated into fractions such as petrol, paraffin and diesel.

a Name the process used to separate the fractions.

b Name two other fractions which are obtained from petroleum.

c Give one use for the paraffin fraction.

d Many of the compounds from petroleum are alkanes. Which two of these are alkanes?

\[ \text{CH}_2=\text{CH}_2, \text{CH}_3\text{CH}_2\text{CH}_3 \]

e Use words from the list below to complete the following sentence.

\[ \text{ethane} \text{ ethene} \text{ hydrogen} \text{ nitrogen} \]

\[ \text{oxgyen} \text{ reactive} \text{ unreactive} \text{ water} \]

Alkanes such as .......... are generally .......... but they can be burnt in .......... to form carbon dioxide and .......... [4]

f Alkanes are saturated hydrocarbons. What do you understand by i saturated, ii hydrocarbon? [2]

Cambridge IGCSE Chemistry 0620 Paper 2 Q3 June 2009

16 a Choose from the list of compounds to answer questions i to v. Each compound can be used once, more than once, or not at all.

\[ \text{calcium carbonate} \text{ carbon dioxide} \text{ hydrogen chloride} \text{ iron(III) oxide} \text{ lead(II) bromide} \text{ methane} \text{ sodium hydroxide} \]

Name the compound which

i is a transition metal compound, [1]

ii produces brown fumes at the anode when electrolysed, [1]

iii is used to manufacture lime, [1]

iv forms an alkaline solution in water, [1]

v is the main constituent of natural gas. [1]

b At a high temperature iron(III) oxide is reduced by carbon: \[ \text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 2\text{Fe} + 3\text{CO} \]

i Explain how the equation shows that iron(III) oxide is reduced by carbon. [1]

ii Copy and complete these sentences about the extraction of iron using words from the list.

\[ \text{bauxite} \text{ blast} \text{ converter} \text{ hematite} \text{ lime} \text{ limestone} \text{ sand} \text{ slag} \]

Iron is extracted from .......... by mixing the ore with coke and .......... in a .......... furnace. The iron ore is reduced to iron. Impurities in the ore react with calcium oxide to form .......... [4]

Cambridge IGCSE Chemistry 0620 Paper 2 Q1 June 2009
1. Use your copy of the periodic table to help you answer these questions.
   a. Predict the formula of each of the following compounds.
      i. barium oxide
      ii. boron oxide
   b. Give the formula of the following ions.
      i. sulfide
      ii. gallium
   c. Draw a diagram showing the arrangement of the valency electrons in one molecule of the covalent compound nitrogen trichloride. Use x to represent an electron from a nitrogen atom. Use o to represent an electron from a chlorine atom.
   d. Potassium and vanadium are elements in Period IV.
      i. State two differences in their physical properties.
      ii. Give two differences in their chemical properties.
   e. Fluorine and astatine are halogens. Use your knowledge of the other halogens to predict the following:
      i. the physical state of fluorine at r.t.p.
      ii. the physical state of astatine at r.t.p.
      iii. two similarities in their chemical properties.

2. Across the world, food safety agencies are investigating the presence of minute traces of the toxic hydrocarbon, benzene, in soft drinks.
   a. Sodium benzoate is a salt. It has the formula C₆H₅COONa. It can be made by neutralising benzoic acid using sodium hydroxide.
      i. Deduce the formula of benzoic acid.
      ii. Write a word equation for the reaction between benzoic acid and sodium hydroxide.
      iii. Name two other compounds that would react with benzoic acid to form sodium benzoate.
   b. Benzene contains 92.3% of carbon and its relative molecular mass is 78.
      i. What is the percentage of hydrogen in benzene?
      ii. Calculate the ratio of moles of C atoms : moles of H atoms in benzene.
      iii. Calculate its empirical formula and then its molecular formula.
   c. This shows the structural formula of Vitamin C.
      i. What is its molecular formula?
      ii. Name the two functional groups that are circled.

3. The following is a list of the electron distributions of atoms of unknown elements.

<table>
<thead>
<tr>
<th>element</th>
<th>electron distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2,6</td>
</tr>
<tr>
<td>B</td>
<td>2,8,4</td>
</tr>
<tr>
<td>C</td>
<td>2,8,8,2</td>
</tr>
<tr>
<td>D</td>
<td>2,8,18,8</td>
</tr>
<tr>
<td>E</td>
<td>2,8,18,8,1</td>
</tr>
<tr>
<td>F</td>
<td>2,8,18,18,7</td>
</tr>
</tbody>
</table>

a. Choose an element from the list for each of the following descriptions.
   i. It is a noble gas.
   ii. It is a soft metal with a low density.
   iii. It can form a covalent compound with element A.
   iv. It has a giant covalent structure similar to diamond.
   v. It is a diatomic gas with molecules of the type X₂.

b. Elements C and A can form an ionic compound.
   i. Draw a diagram that shows the formula of this compound, the charges on the ions, and the arrangement of the valency electrons around the negative ion. Use o to represent an electron from an atom of C. Use x to represent an electron from an atom of A.
   ii. Predict two properties of this compound.
4 The results of experiments on electrolysis using inert electrodes are given in the table.

<table>
<thead>
<tr>
<th>electrolyte</th>
<th>change at negative electrode</th>
<th>change at positive electrode</th>
<th>change to electrolyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>molten lead(II) bromide</td>
<td>lead formed</td>
<td>bromine formed</td>
<td>used up</td>
</tr>
<tr>
<td>a</td>
<td>potassium formed</td>
<td>iodine formed</td>
<td>used up</td>
</tr>
<tr>
<td>dilute aqueous sodium chloride</td>
<td>b</td>
<td>c</td>
<td>d</td>
</tr>
<tr>
<td>aqueous copper(II) sulfate</td>
<td>e</td>
<td>f</td>
<td>g</td>
</tr>
<tr>
<td>h</td>
<td>hydrogen formed</td>
<td>bromine formed</td>
<td>potassium hydroxide formed</td>
</tr>
</tbody>
</table>

Complete the table; the first line has been completed as an example.

Cambridge IGCSE Chemistry 0620 Paper 3 Q2 June 2009

5 An ore of copper is the mineral, chalcopyrite. This is a mixed sulfide of iron and copper.
   a Analysis of a sample of this ore shows that 13.80 g of the ore contained 4.80 g of copper, 4.20 g of iron and the rest sulfur.
   i Copy and complete the table.

<table>
<thead>
<tr>
<th>composition by mass /g</th>
<th>copper</th>
<th>iron</th>
<th>sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.80</td>
<td>4.20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ii Find the empirical formula of chalcopyrite. [1]

b Impure copper is extracted from the ore. This copper is refined by electrolysis.
   i Name
      A: the material used for the positive electrode (anode),
      B: the material used for the negative electrode (cathode),
      C: a suitable electrolyte.
   ii Write an ionic equation for the reaction at the negative electrode.
   iii One use of this pure copper is electrical conductors, another is to make alloys. Name the metal that is alloyed with copper to make brass. [1]

6 There are three types of giant structure—ionic, metallic and macromolecular.
   a Sodium nitride is an ionic compound. Draw a diagram that shows the formula of the compound, the charges on the ions, and the arrangement of the valency electrons around the negative ion. Use x to represent an electron from a sodium atom. Use o to represent an electron from a nitrogen atom. [3]
   b i Describe metallic bonding. [3]
   ii Use the above ideas to explain why metals are A: good conductors of electricity [1]
   B: metals are malleable. [2]
   c Silicon(IV) oxide has a macromolecular structure.
   i Describe the structure of silicon(IV) oxide (a diagram is not acceptable). [3]
   ii Diamond has a similar structure and consequently similar properties. Give two physical properties common to both diamond and silicon(IV) oxide. [2]

7 Calcium carbonate is an important raw material.
   a Name a rock made up of calcium carbonate. [1]
   b When calcium carbonate is heated strongly, it decomposes: CaCO₃ → CaO + CO₂
   i Calculate the relative formula mass of CaCO₃. [1]
   ii Calculate the relative formula mass of CaO. [1]
   iii 7.00 kg of calcium oxide was formed. What mass of calcium carbonate was heated? [2]
   c Calcium carbonate is used to control soil acidity.
   i Why is it important to control soil acidity? [1]
   ii Both calcium carbonate, insoluble in water, and calcium oxide, slightly soluble, are used to increase soil pH. Suggest two advantages of using calcium carbonate. [2]
   iii Give one use of calcium carbonate other than for making calcium oxide and controlling soil pH. [1]
8 Iron is a transition element.
   a Which three of the following six statements about transition elements are correct?
      i The metals are highly coloured e.g. yellow, green, blue.
      ii The metals have low melting points.
      iii Their compounds are highly coloured.
      iv Their compounds are colourless.
      v The elements and their compounds are often used as catalysts.
      vi They have more than one oxidation state. [3]

   b i In which Period in the Periodic Table is iron? [1]
   ii Use the Periodic Table to work out the number of protons and the number of
      neutrons in one atom of iron. [1]

c Iron is extracted in a blast furnace. The list below gives some of the substances used or
formed in the extraction.
   carbon monoxide  coke  iron ore  limestone  slag
   i Which substance is a mineral containing largely calcium carbonate? [1]
   ii Which substance is formed when impurities in the ore react with calcium oxide? [1]
   iii Which substance is also called hematite? [1]

d State two functions of the coke used in the blast furnace. [2]

e Most of the iron is converted into mild steel or stainless steel. Give one use for each. [2]

9 The first three elements in Group IV are carbon, silicon, germanium.
   a The element germanium has a diamond-type structure. Describe the structure of germanium.
      A diagram is acceptable. [2]
   b Unlike diamond, graphite is soft and is a good conductor of electricity.
      i Explain why graphite has these properties. [3]
      ii Give a use of graphite that depends on one of these properties.
   c Carbon dioxide and silicon(IV) oxide have similar formulae but different types of structure.
      i Give the formulae of these oxides. [1]
      ii How are their structures different? [2]
   d All these elements form compounds with hydrogen called hydrides. The saturated
      hydrides of carbon are the alkanes. Predict the formula of the hydride of germanium
      which contains two germanium atoms.

10 Zinc is extracted from zinc blende, ZnS.
   a Zinc blende is heated in air to give zinc oxide and sulfur dioxide.
      Most of the sulfur dioxide is used to make sulfur trioxide. This is used to manufacture sulfuric
      acid. Some of the acid is used in the plant, but most of it is used to make fertilisers.
      i Give another use of sulfur dioxide. [1]
      ii Describe how sulfur dioxide is converted into sulfur trioxide. [3]
      iii Name a fertiliser made from sulfuric acid. [1]
   b Some of the zinc oxide was mixed with an excess of carbon and heated to 1000 °C.
      Zinc distils out of the furnace.
      \[2\text{ZnO} + \text{C} \rightarrow 2\text{Zn} + \text{CO}_2\]
      \[
      \text{C} + \text{CO}_2 \rightarrow 2\text{CO}
      \]
      i Name the two changes of state involved in the process of distillation. [2]
      ii Why is it necessary to use an excess of carbon? [2]
   c The remaining zinc oxide reacts with sulfuric acid to give aqueous zinc sulfate.
      This is electrolysed with inert electrodes (the electrolysis is the same as that of
      copper(II) sulfate with inert electrodes). Ions present: \(\text{Zn}^{2+}(aq)\) \(\text{SO}_4^{2-}(aq)\) \(\text{H}^+(aq)\) \(\text{OH}^-\)(aq).
      i Zinc forms at the negative electrode (cathode). Write the equation for this
      reaction. [1]
      ii Write the equation for the reaction at the positive electrode (anode). [2]
      iii Complete this sentence:
         The electrolyte changes from aqueous zinc sulfate to .................. [1]
   d Give two uses of zinc. [2]

11 Aluminium is extracted by the electrolysis of a molten mixture that contains alumina, which
   is aluminium oxide, Al₂O₃.
   a The ore of aluminium is bauxite. This contains alumina, which is amphoteric, and iron(III)
   oxide, which is basic. The ore is heated with aqueous sodium hydroxide.
      Complete the following sentences.
      The i.......... dissolves to give a solution of ii.......... 
      The iii.......... does not dissolve and can be removed by iv.......... [4]
b Complete the labelling of the diagram.

```
<table>
<thead>
<tr>
<th>waste gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon anode (+)</td>
</tr>
<tr>
<td>mixture of aluminium oxide and ii</td>
</tr>
<tr>
<td>iii</td>
</tr>
<tr>
<td>temperature is iv</td>
</tr>
</tbody>
</table>
```

c The ions involved in the electrolysis are $\text{Al}^{3+}$ and $\text{O}^{2-}$.

i Write an equation for the reaction at the cathode. [2]

ii Explain how carbon dioxide is formed at the anode. [2]

d Give an explanation for each of the following.

i Aluminium is used extensively in the manufacture of aircraft. [1]

ii Aluminium is used for food containers. [2]

iii Aluminium electricity cables have a steel core. [1]

Cambridge IGCSE Chemistry 0620 Paper 3 Q6 June 2007

12 a Four bottles were known to contain aqueous ammonia, dilute hydrochloric acid, sodium hydroxide solution and vinegar, which is dilute ethanoic acid. The bottles had lost their labels. The pH values of the four solutions were 1, 4, 10 and 13. Complete the table. [2]

<table>
<thead>
<tr>
<th>solution</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>aqueous ammonia</td>
<td></td>
</tr>
<tr>
<td>dilute hydrochloric acid</td>
<td></td>
</tr>
<tr>
<td>sodium hydroxide solution</td>
<td></td>
</tr>
<tr>
<td>vinegar</td>
<td></td>
</tr>
</tbody>
</table>

b The following apparatus was set up to investigate the electrical conductivity of dilute acids.

Dilute sulfuric acid is a strong acid. If it was replaced by a weak acid, what two differences in the observations would you expect to make? [2]

c When nitric acid is added to water the following reaction occurs.

$$\text{HNO}_3 + \text{H}_2\text{O} \rightarrow \text{NO}_3^- + \text{H}_3\text{O}^+$$

Give the name and the formula of the particle transferred from nitric acid to water. [2]

d This question is about the following oxides.

- aluminium oxide $\text{Al}_2\text{O}_3$
- calcium oxide $\text{CaO}$
- carbon dioxide $\text{CO}_2$
- carbon monoxide $\text{CO}$
- magnesium oxide $\text{MgO}$
- sulfur dioxide $\text{SO}_2$

i Which will react with hydrochloric acid but not with aqueous sodium hydroxide? [1]

ii Which will react with aqueous sodium hydroxide but not with hydrochloric acid? [1]

iii Which will react both with hydrochloric acid and aqueous sodium hydroxide? [1]

iv Which will react neither with hydrochloric acid nor with aqueous sodium hydroxide? [1]

Cambridge IGCSE Chemistry 0620 Paper 3 Q3 June 2006

13 Hydrogen reacts with the halogens to form hydrogen halides.

a Bond energy is the amount of energy, in kJ, that must be supplied (endothermic) to break one mole of a bond.

<table>
<thead>
<tr>
<th>bond</th>
<th>bond energy in kJ/mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H-H}$</td>
<td>+436</td>
</tr>
<tr>
<td>$\text{F-F}$</td>
<td>+158</td>
</tr>
<tr>
<td>$\text{H-F}$</td>
<td>+562</td>
</tr>
</tbody>
</table>

Use the above data to show that the following reaction is exothermic.

$$\text{H} \cdots \text{H} + \text{F} \cdots \text{F} \rightarrow 2\text{H} \cdots \text{F}$$ [3]

b They react with water to form acidic solutions.

- $\text{HCl} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{Cl}^-$
- $\text{HF} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{F}^-$

i Explain why water behaves as a base in both of these reactions. [2]

ii At equilibrium, only 1% of the hydrogen chloride exists as molecules, the rest has formed ions. In the other equilibrium, 97% of the hydrogen fluoride exists as molecules, only 3% has formed ions. What does this tell you about the strength of each acid? [2]

iii How would the pH of these two solutions differ? [1]

Cambridge IGCSE Chemistry 0620 Paper 32 Q7 June 2009
14 The reactivity series lists metals in order of reactivity. To find out which is more reactive, zinc or tin, this experiment could be carried out.

- Tin(II) nitrate(aq) is used as a solution.
  - If zinc surface is still shiny, it means NO REACTION (NR).
  - If zinc surface is covered with a grey deposit, it means REACTION (R).

The experiment could be carried out with other metals and the results recorded in a table. Then the order of reactivity can be deduced.

<table>
<thead>
<tr>
<th>aqueous solution</th>
<th>tin Sn</th>
<th>manganese Mn</th>
<th>silver Ag</th>
<th>zinc Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>tin(II) nitrate</td>
<td>R</td>
<td>NR</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>manganese(II) nitrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>silver(I) nitrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>zinc nitrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a The order was found to be:
- manganese most reactive
- zinc
- tin
- silver least reactive

Copy and complete this table of results from which the order was determined. [3]

ii Write the ionic equation for the reaction between tin atoms and silver(I) ions. [2]

iii The following is a redox reaction.

\[ Mn + Sn^{2+} \rightarrow Mn^{2+} + Sn \]

Indicate on the equation the change which is oxidation. Give a reason for your choice. [2]

iv Explain why experiments of this type cannot be used to find the position of aluminium in the reactivity series. [2]

b Potassium and calcium are very reactive metals at the top of the series. Because their ions have different charges, \( K^+ \) and \( Ca^{2+} \), their compounds behave differently when heated.

- Explain why the ions have different charges. [2]
- Their hydroxides are heated. If the compound decomposes, complete the word equation. If it does not decompose, write ‘no reaction’.
  - Potassium hydroxide \( \rightarrow \) .................
  - Calcium hydroxide \( \rightarrow \) ................. [2]

iii Complete the equations for the decomposition of their nitrates.

\[ 2KNO_3 \rightarrow \ldots \ldots + \ldots \ldots \]
\[ 2Ca(NO_3)_2 \rightarrow \ldots \ldots + \ldots \ldots + \ldots \ldots \]

Cambridge IGCSE Chemistry 0620 Paper 31 Q6 November 2008

15 The fractional distillation of crude oil usually produces large quantities of the heavier fractions. The market demand is for the lighter fractions and for the more reactive alkenes. The heavier fractions are cracked to form smaller alkanes and alkenes as in the following example.

\[ C_8H_{18} \rightarrow C_4H_{10} + C_4H_8 \]
- octane
- butane
- butenes

a i Write a different equation for the cracking of octane.

\[ C_8H_{18} \rightarrow \ldots \ldots + \ldots \ldots \]

ii The cracking of octane can produce isomers with the molecular formula \( C_4H_8 \). Draw the structural formulae of two of these isomers. [2]

b i Give the essential condition for the reaction between chlorine and butane. [1]

ii What type of reaction is this? [1]

iii This reaction produces a mixture of products. Give the names of two products that contain four carbon atoms per molecule. [2]

c Alkenes are more reactive than alkanes and are used to make a range of organic chemicals. Propene, \( CH_3-CH=CH_2 \), is made by cracking. Give the structural formula of the addition product when propene reacts with these.

i water

ii bromine

d Propene reacts with hydrogen iodide to form 2-iodopropane.

\[ CH_3-CH=CH_2 + HI \rightarrow CH_3-CHI-CH_3 \]

1.4 g of propene produced 4.0 g of 2-iodopropane. Calculate the percentage yield.

i moles of \( CH_3-CH=CH_2 \) reacted =

ii maximum moles of \( CH_3-CHI-CH_3 \) that could be formed =

\[ \text{mass of one mole of } CH_3-CHI-CH_3 = 170 \text{ g} \]

iii maximum mass of 2-iodopropane that could be formed =

iv percentage yield = [4]

Cambridge IGCSE Chemistry 0620 Paper 3 Q7 June 2006
16 The alcohols form a homologous series. The first four members are methanol, ethanol, propan-1-ol and butan-1-ol.

a One characteristic of a homologous series is that the physical properties vary in a predictable way. The table below gives the heats of combustion of the first three alcohols.

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Formula</th>
<th>Heat of combustion in kJ/mole</th>
</tr>
</thead>
<tbody>
<tr>
<td>methanol</td>
<td>CH₃OH</td>
<td>–730</td>
</tr>
<tr>
<td>ethanol</td>
<td>CH₃CH₂OH</td>
<td>–1370</td>
</tr>
<tr>
<td>propan-1-ol</td>
<td>CH₃CH₂CH₂OH</td>
<td>–2020</td>
</tr>
<tr>
<td>butan-1-ol</td>
<td>CH₃CH₂CH₂CH₂OH</td>
<td></td>
</tr>
</tbody>
</table>

i The minus sign indicates there is less chemical energy in the products than in the reactants. In what form is the energy given out? [1]

ii Is the reaction exothermic or endothermic? [1]

iii Complete the equation for the complete combustion of ethanol.

\[ \text{C}_2\text{H}_5\text{OH} + \text{O}_2 \rightarrow \text{...........} + \text{...........} \] [2]

iv Determine the heat of combustion of butan-1-ol by plotting the heats of combustion of the first three alcohols against the number of carbon atoms per molecule. Label your graph as on the right.

What is the heat of combustion of butan-1-ol in kJ/mol? [3]

v Describe two other characteristics of homologous series. [2]

b Give the name and structural formula of an isomer of propan-1-ol. [2]

c Methanol is made from carbon monoxide.

\[ \text{CO (g) + 2H}_2\text{(g) } \rightleftharpoons \text{CH}_3\text{OH (g)} \]

The forward reaction is exothermic.

i Describe how hydrogen is obtained from alkanes. [2]

ii Suggest a method of making carbon monoxide from methane. [2]

iii Which condition, high or low pressure, would give the maximum yield of methanol? Give a reason for your choice. [2]
1 The colours present in some blackcurrant sweets can be separated by chromatography. The colours are water-soluble dyes. The diagrams show how the colours can be extracted from the sweets.

a Name the pieces of apparatus labelled A to C. [3]

The apparatus below was used to carry out the chromatography.

b i Name the solvent used. [1]

ii Label, with an arrow, the origin on the diagram. [1]

c On a larger copy of this rectangle, sketch the chromatogram you would expect if two different colours were present in the sweets. [1]

Cambridge IGCSE Chemistry 0620 Paper 6 Q1 November 2008

2 Describe a chemical test to distinguish between each of the following pairs of substances.

Example: hydrogen and carbon dioxide

*test:* lighted splint

*result:* with hydrogen gives a pop

*result:* with carbon dioxide splint is extinguished

a zinc carbonate and zinc chloride [2]

b ammonia and chlorine [3]

c aqueous iron(II) sulfate and aqueous iron(III) sulfate [3]

Cambridge IGCSE Chemistry 0620 Paper 6 Q3 June 2009

3 A student investigated the addition of four different solids, A, B, C and D, to water. Five experiments were carried out.

Experiment 1

By using a measuring cylinder, 30 cm³ of distilled water was poured into a polystyrene cup and the initial temperature of the water was measured. 4 g of solid A was added to the cup and the mixture stirred with a thermometer. The temperature of the solution was measured after 2 minutes.

Experiment 2

Experiment 1 was repeated using 4 g of solid B.

Experiment 3

Experiment 1 was repeated using 4 g of solid C.

Experiment 4

Experiment 1 was repeated using 4 g of solid D.
Experiment 5
A little of the solution from Experiment 4 was added to a little of the solution from Experiment 2 in a test-tube. The observations were recorded.

**Observations**
a fast reaction
vigorous effervescence and bubbles produced

a. Copy out the table and use the thermometer diagrams for Experiments 1–4 to record the initial and final temperatures. Calculate and record the temperature difference in the table.

<table>
<thead>
<tr>
<th>expt</th>
<th>initial temperature / °C</th>
<th>final temperature / °C</th>
<th>difference / °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b. Draw a labelled bar chart of the results to Experiments 1, 2, 3, and 4 on graph paper.

Use the results and observations from Experiments 1 – 5 to answer the following questions.

c. i Which solid dissolves in water to produce an exothermic reaction? [1]
   ii Give a reason why you chose this solid. [1]

d. Which Experiment produced the largest temperature change? [1]

e. Predict the temperature change that would happen if
   i 8 g of solid B was used in Experiment 2, [1]
   ii 60 cm³ of water was used in Experiment 4. [1]
   iii Explain your answer to e ii. [2]

f. Suggest an explanation for the observations in Experiment 5. [2]

Cambridge IGCSE Chemistry 0620 Paper 6 Q4 November 2008

Hydrogen peroxide breaks down to form oxygen. The volume of oxygen given off can be measured using this apparatus.

Solids W and X both catalyse the breakdown of hydrogen peroxide. The syringe diagrams show the volume of oxygen formed every 20 seconds using these catalysts at 25 °C.

<table>
<thead>
<tr>
<th>time / s</th>
<th>using catalyst W</th>
<th>using catalyst X</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
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</tr>
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<td>40</td>
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<td>50</td>
<td>50</td>
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<tr>
<td>100</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

a. Copy the table. Use the gas syringe diagrams to complete it.

b. Plot a graph to show each set of results. Clearly label the curves. [6]

c. Which solid is the better catalyst in this reaction? Give a reason for your choice. [2]

d. Why is the final volume of oxygen the same in each experiment? [1]

e. Sketch a line on the grid to show the shape of the graph you would expect if the reaction with catalyst X was repeated at 40 °C. [2]

Cambridge IGCSE Chemistry 0620 Paper 6 Q6 June 2007
5 An experiment was carried out to determine the solubility of potassium chlorate at different temperatures. The solubility is the mass of potassium chlorate that dissolves in 100 g of water. The results obtained are shown in the table below.

<table>
<thead>
<tr>
<th>temperature / °C</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>solubility in g/100 g of water</td>
<td>14</td>
<td>17</td>
<td>20</td>
<td>24</td>
<td>29</td>
<td>34</td>
<td>40</td>
</tr>
</tbody>
</table>

a Draw a smooth line graph to show the solubility of potassium chlorate at different temperatures. Label your graph as shown below.

b Use your graph to determine the solubility of potassium chlorate at 70 °C. Show clearly on the graph how you obtained your answer. [2]
c What would be the effect of cooling a saturated solution of potassium chlorate from 60 °C to 20 °C? [2]

Cambridge IGCSE Chemistry 0620 Paper 6 Q6 November 2008

6 The diagram shows the formation of a solution of magnesium hydroxide from magnesium.

a Name the pieces of apparatus labelled A – C. [3]
b What type of chemical reaction is the burning of magnesium? [1]
c Suggest a pH for the solution of magnesium hydroxide. [1]

Cambridge IGCSE Chemistry 0620 Paper 6 Q1 November 2006

7 The diagram shows an experiment to pass electricity through lead bromide. Electricity has no effect on solid lead bromide.

a i Copy the diagram and clearly label the electrodes. [1]
   ii Suggest a suitable material to make the electrodes. [1]
b Give two observations expected when the lead bromide is heated to melting point. [2]
c State two different safety precautions when carrying out this experiment. [2]

Cambridge IGCSE Chemistry 0620 Paper 6 Q2 June 2008

8 Concentrated hydrochloric acid can be electrolysed using the apparatus shown.

a i Name the product at the positive electrode. [1]
   ii State a test for this product, and the result. [2]

Cambridge IGCSE Chemistry 0620 Paper 6 Q2 June 2007
A student investigated the reaction between potassium manganate(VII) and a metallic salt solution. Two experiments were carried out.

**Experiment 1**

a. About 1 cm³ of aqueous sodium hydroxide was added to a little of the salt solution A and the observation noted.

**observation** green precipitate formed

b. A burette was filled with potassium manganate(VII) solution up to the 0.0 cm³ mark. By using a measuring cylinder, 25 cm³ of solution A of the salt was placed into a conical flask. The flask was shaken to mix the contents. The potassium manganate(VII) solution was added to the flask, and shaken to mix thoroughly. Addition of potassium manganate(VII) solution was continued until there was a pale pink colour in the contents of the flask.

Copy the table of results below.

<table>
<thead>
<tr>
<th>Burette readings / cm³</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial reading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>final reading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>difference</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Use this burette diagram to record the volume and complete the column for Experiment 1 in the table.

**Experiment 2**

c. Experiment 1b was repeated using a different solution B of the salt, instead of solution A. Use the burette diagrams to record the volumes in the table and complete the table.

**d** About 1 cm³ of aqueous sodium hydroxide was added to a little of the solution in the flask and the observation noted.

**observation** red-brown precipitate

e. i. In which experiment was the greatest volume of potassium manganate(VII) solution used?[1]

ii. Compare the volumes of potassium manganate(VII) solution used in Experiments 1 and 2.[2]

iii. Suggest an explanation for the difference in the volumes.[2]

f. Predict the volume of potassium manganate(VII) solution which would be needed to react completely with 50 cm³ of solution B.[2]

g. Explain one change that could be made to the experimental method to obtain more accurate results.[2]

h. What conclusion can you draw about the salt solution from:

i. experiment 1a,[1]

ii. experiment 2d?[1]

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This label is from a container of ‘Bite Relief’ solution.

**BITE RELIEF**

**FOR FAST RELIEF FROM INSECT BITES AND STINGS**

Active ingredient: ammonia

Also contains water and alcohol

DIRECTIONS FOR USE: Use cotton wool to dab the solution on the affected area of the skin.

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a. Give a chemical test to show the presence of ammonia in Bite Relief solution.

Give the result of the test.[2]

b. What practical method could be used to separate the mixture of alcohol (b.p. 78 °C) and water (b.p. 100 °C)?[2]

c. Give a chemical test to show the presence of water. Give the result of the test.[2]

d. What would be the effect of touching the alcohol with a lighted splint?[1]