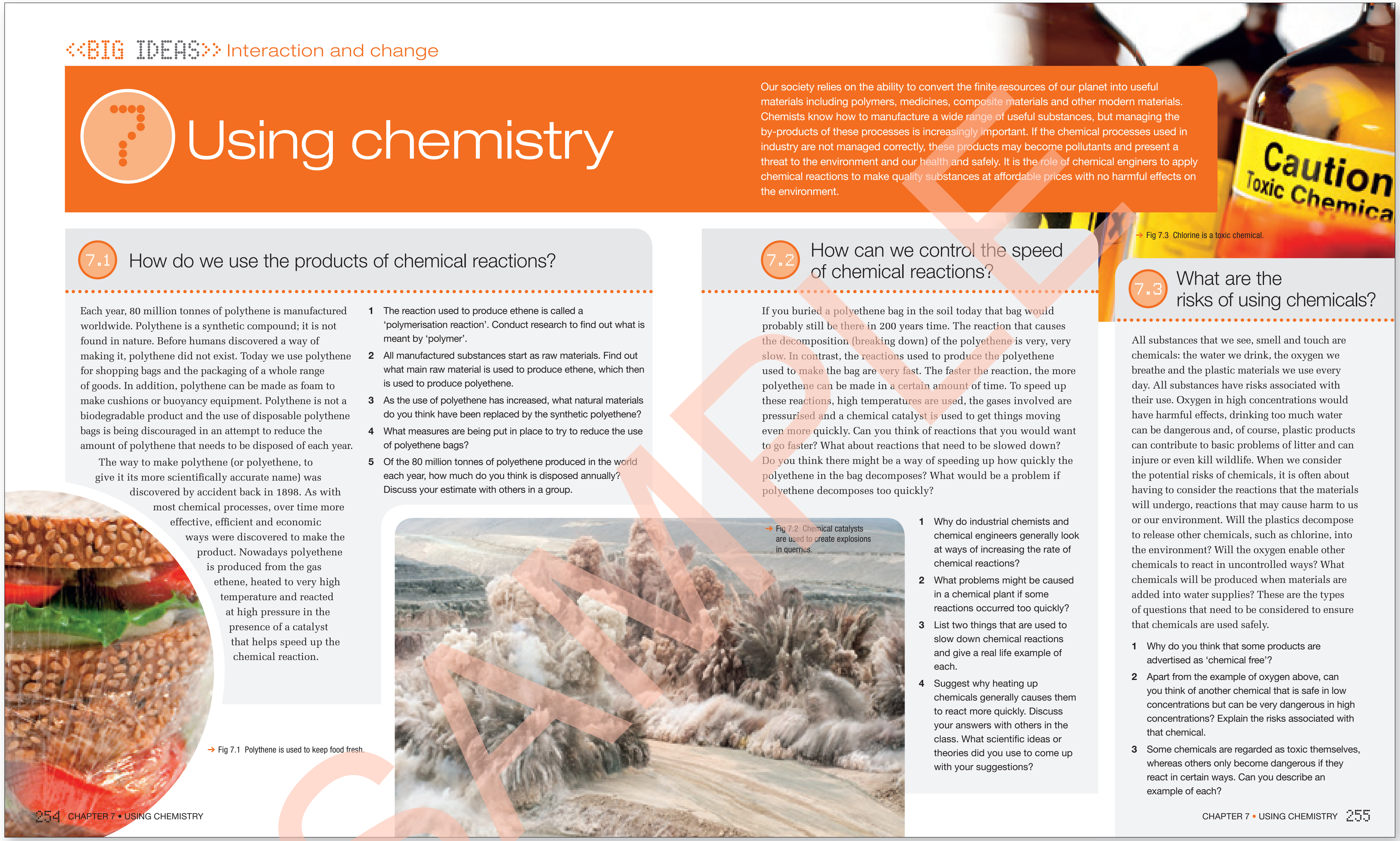
Each unit within this chapter is introduced using an engaging image and supported by text and questions. Discussions around the image, text and/or questions should assist teachers in ascertaining prior knowledge and provide students with an idea of where the chapter is heading. This is designed to promote an inquiry approach to learning and reduce the 'why?' questions.

Curriculum guidance

Big idea	Previous curriculum content	Year 10 curriculum content
Interaction and change: substances change and new substances are produced by rearranging atoms through atomic interactions and energy transfer	Chemical reactions involve rearranging atoms to form new substances; during a chemical reaction, mass is not created or destroyed (Year 9) Chemical reactions, including combustion and the reactions of acids, are important in both non-living and living systems and involve energy transfer (Year 9)	Different types of chemical reactions are used to produce a range of products and can occur at different rates

Big ideas

In Year 9, students studied chemical reactions in terms of the rearrangement of atoms to form new products. Combustion reactions and acid reactions were studied in relation to the Law of Conservation of Mass. This chapter extends this understanding to examine the changes that occur to chemicals as they interact with each other and how this can be used in a range of situations, such as the production of metals, polymers and pharmaceuticals. Future applications, such as aspects of nanotechnology, are also examined. By understanding the types of reactions occurring,



<<BIG IDEAS>> Interaction and change

7 Using chemistry

Our society relies on the ability to convert the finite resources of our planet into useful materials including polymers, medicines, composite materials and other modern materials. Chemists know how to manufacture a wide range of useful substances, but managing the by-products of these processes is increasingly important. If the chemical processes used in industry are not managed correctly, these products may become pollutants and present a threat to the environment and our health and safely. It is the role of chemical engineers to apply chemical reactions to make quality substances at affordable prices with no harmful effects on the environment.

7.1 How do we use the products of chemical reactions?

Each year, 80 million tonnes of polythene is manufactured worldwide. Polythene is a synthetic compound; it is not found in nature. Before humans discovered a way of making it, polythene did not exist. Today we use polythene for shopping bags and the packaging of a whole range of goods. In addition, polythene can be made as foam to make cushions or buoyancy equipment. Polythene is not a biodegradable product and the use of disposable polythene bags is being discouraged in an attempt to reduce the amount of polythene that needs to be disposed of each year.

The way to make polythene (or polyethene, to give it its more scientifically accurate name) was discovered by accident back in 1898. As with most chemical processes, over time more effective, efficient and economic ways were discovered to make the product. Nowadays polyethene is produced from the gas ethene, heated to very high temperature and reacted at high pressure in the presence of a catalyst that helps speed up the chemical reaction.

1 The reaction used to produce ethene is called a 'polymerisation reaction'. Conduct research to find out what is meant by 'polymer'.
2 All manufactured substances start as raw materials. Find out what main raw material is used to produce ethene, which then is used to produce polyethene.
3 As the use of polyethene has increased, what natural materials do you think have been replaced by the synthetic polyethene?
4 What measures are being put in place to try to reduce the use of polyethene bags?
5 Of the 80 million tonnes of polyethene produced in the world each year, how much do you think is disposed annually? Discuss your estimate with others in a group.

Fig 7.1 Polythene is used to keep food fresh.

7.2 How can we control the speed of chemical reactions?

If you buried a polyethene bag in the soil today that bag would probably still be there in 200 years time. The reaction that causes the decomposition (breaking down) of the polyethene is very, very slow. In contrast, the reactions used to produce the polyethene used to make the bag are very fast. The faster the reaction, the more polyethene can be made in a certain amount of time. To speed up these reactions, high temperatures are used, the gases involved are pressurised and a chemical catalyst is used to get things moving even more quickly. Can you think of reactions that you would want to go faster? What about reactions that need to be slowed down? Do you think there might be a way of speeding up how quickly the polyethene in the bag decomposes? What would be a problem if polyethene decomposes too quickly?

Fig 7.2 Chemical catalysts are used to create explosions in querries.

1 Why do industrial chemists and chemical engineers generally look at ways of increasing the rate of chemical reactions?
2 What problems might be caused in a chemical plant if some reactions occurred too quickly?
3 List two things that are used to slow down chemical reactions and give a real life example of each.
4 Suggest why heating up chemicals generally causes them to react more quickly. Discuss your answers with others in the class. What scientific ideas or theories did you use to come up with your suggestions?

Fig 7.3 Chlorine is a toxic chemical.

7.3 What are the risks of using chemicals?

All substances that we see, smell and touch are chemicals: the water we drink, the oxygen we breathe and the plastic materials we use every day. All substances have risks associated with their use. Oxygen in high concentrations would have harmful effects, drinking too much water can be dangerous and, of course, plastic products can contribute to basic problems of litter and can injure or even kill wildlife. When we consider the potential risks of chemicals, it is often about having to consider the reactions that the materials will undergo, reactions that may cause harm to us or our environment. Will the plastics decompose to release other chemicals, such as chlorine, into the environment? Will the oxygen enable other chemicals to react in uncontrolled ways? What chemicals will be produced when materials are added into water supplies? These are the types of questions that need to be considered to ensure that chemicals are used safely.

1 Why do you think that some products are advertised as 'chemical free'?
2 Apart from the example of oxygen above, can you think of another chemical that is safe in low concentrations but can be very dangerous in high concentrations? Explain the risks associated with that chemical.
3 Some chemicals are regarded as toxic themselves, whereas others only become dangerous if they react in certain ways. Can you describe an example of each?

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the products and the rate at which they are formed can be controlled. The potential hazards of using chemicals are examined in relation to their effects on surrounding systems.

Answers

7.1 How do we use the products of chemical reactions?

1 A polymer is a chain of smaller subunits called monomers, connected by covalent bonds.
2 Ethene (also known as ethylene) is produced from natural gas or crude oil using fractional distillation.
3 Polyethene is used to make foam and plastic. It would have replaced natural products such as rubber and cloth.
4 Many stores are now charging for the use of plastic bags or replacing them with cloth bags.
5 Students' results will vary.

7.2 How can we control the speed of chemical reactions?

1 Increasing the rate of a reaction increases the amount of product being produced and therefore the amount of money that can be made by a chemical company.
2 If an exothermic reaction occurs too quickly, large amounts of energy (heat and light) will be produced, which will be difficult to control.
3 Cooling things down or restricting the amount of a reactant will slow the rate of a chemical reaction. Examples of this include cooling a patient's body during an operation (reducing the rate of cellular respiration in cells) and reducing the amount of pollution, which will restrict the amount of acid rain being formed.
4 Heating a solution makes the particles move faster, allowing them to collide with each other more easily. Reactions can only occur when the reactants are in physical contact. Therefore, heating the reactants will increase the rate of a reaction.

7.3 What are the risks of using chemicals?

1 'Chemical free' implies that no artificially produced chemicals are used.
2 Low concentrations of sodium chloride are an important part of a person's diet (to help with the conduction of electrical impulses along a nerve); however, high concentrations can affect the water balance of an organism. Other examples include the metals mercury and lead, and many vitamins (vitamin C is an essential nutrient at low levels, but high levels can cause diarrhoea, nausea, vomiting, heartburn and kidney stones).
3 Some toxic chemicals include lead, mercury, chlorine gas and arsenic. Chemicals that become more toxic after reacting include the common household cleaners bleach and ammonia. When mixed, these two chemicals can form toxic and potentially explosive liquid hydrazine. Although the latter tends not to explode in its impure form, the toxic chemical can boil, spraying the hot toxic liquid around. A toxic gas can also be produced.

<<DISCOVERING IDEAS>>

Producing iron

Answers

1 • Household uses of iron include as cast iron pots. Cast iron is a carbon–iron alloy that has a relatively low melting point (900°C), which enables it to be cast into any shape. It is also reasonably resistant to corrosion and is able to conduct heat well, which facilitates the cooking process.

• Infrastructure uses of iron include the use of steel (an alloy of iron) to make girders and other support structures. Other metals can be added to iron to improve its properties; for example, nickel and manganese will increase tensile strength, chromium will increase melting temperature and hardness, vanadium will reduce the effects of metal fatigue and the addition of chromium will result in the formation of the hard oxide on the surface seen in stainless steel.

• Transport uses of iron include the production of cars (see infrastructure above). Early trains used cast iron (see households above).

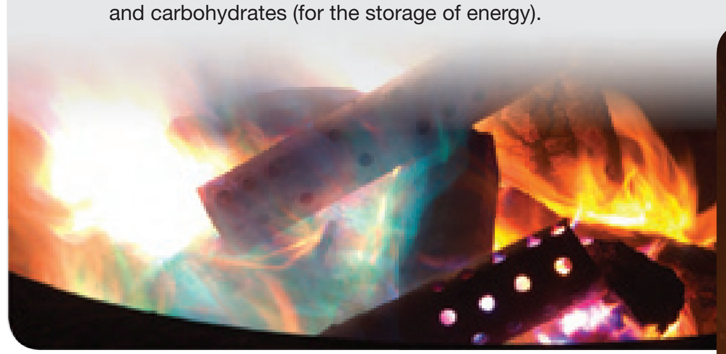
• Iron is used in sporting equipment. For example, different golf clubs (traditionally called 'irons') are used to make a variety of shots. The clubs are often made out of stainless steel (although the use of carbon fibre is increasing) and each club is usually made out of a single shaft of steel that has been cast from a mould. Clubs made out of steel are resistant to corrosion and have a high degree of tensile strength, important for the golf swing.

2 The thermite process is the process by which aluminium is used to remove the oxygen from the iron oxide. This reaction is highly exothermic and therefore caution is advocated before it is demonstrated in the classroom. As with many such experiments, there are many YouTube clips available that can be used instead.

7.1

How do we use the products of chemical reactions?

We use chemical reactions all the time and all chemical reactions result in the formation of products. Sometimes the chemical reactions are used because they give off energy, such as the combustion of fuels, including oil and gas, but it is often the products of the reactions that are the most important. Examples of how humans have learned to use the power of chemistry include the production of metals from metal ores and the manufacture of fertilisers from acids and bases. In nature, organisms have evolved to use chemical reactions to combine the elements carbon, oxygen, hydrogen and nitrogen into products such as proteins (for growth) and carbohydrates (for the storage of energy).



→ Fig 7.4 Iron ore exports are vital to the Australian economy.

<<DISCOVERING IDEAS>>

Producing iron

Iron is one of the resources that Australia is extremely rich in. Exports of iron ore bring millions of dollars into the Australian economy, with China and other Asian countries relying on iron from Australia to support the development of their industries and infrastructure. One of the major forms of iron ore is haematite, or iron(III) oxide to give it its chemical name.

1 Research four uses of iron: one household, one related to infrastructure, one related to transport and one related to sport or recreation. For each use, explain why the properties of iron make it suitable for use in that particular way.

2 Iron can be produced from haematite by reduction reactions. One such reaction is called the 'thermite process'. Your teacher may demonstrate this for you.

The reaction can be described using the following equation:

$$Fe_2O_3 + 2\,Al \rightarrow Al_2O_3 + 2\,Fe$$

Describe the role of the aluminium in the process.

3 Why do you think the iron(III) oxide is described as being reduced in the thermite reaction?

4 The thermite process is not used to produce iron on an industrial scale. Rather, carbon monoxide is used to reduce the iron in blast furnaces within iron and steelworks. Carbon dioxide is produced as a by-product in the process. Copy and complete the following equation for the reaction.

$$Fe_2O_3 + 2\,CO \rightarrow \_\_\_\_\_\_\_\_$$

(Hint: Make sure that you have applied the law of conservation of mass when writing the final equation.)

→ Fig 7.5 Molten iron produced from a blast furnace.

Types of chemical reactions

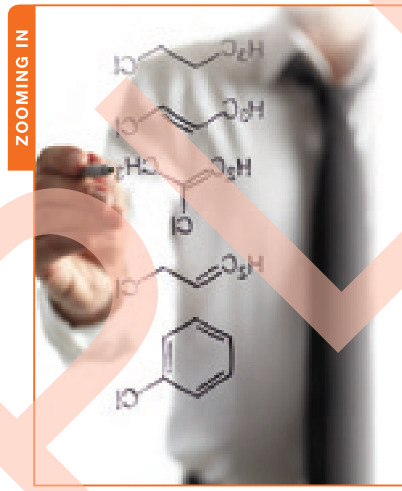
Almost every substance that you will use today was made in a chemical reaction. The role of chemists is to understand chemical reactions and the products they form. Classifying reactions into different types helps predict the products produced by reactions and helps us understand what reactants are required to produce particular products. To assist in classifying reactions, we can sort compounds into types, such as acids, bases, salts, hydrocarbons and polymers.

Classifying compounds into groups makes them easier to name and identify. Because all the compounds in the same group have similar properties, we can predict most of the properties of an unknown substance if we know to which group it belongs.

Similarly, the chemical reactions that are used to make compounds can also be classified. Reactions can be classified as combustion, decomposition or hydrolysis (reaction with water) reactions, among others.

Some of the main reaction types are summarised below.

ZOOMING IN



Synthesis

Synthesis is the building up of compounds by combining simpler substances, normally elements.

Metal + non-metal

metal + non-metal → salt (an ionic compound)

Example:

sodium + chlorine → sodium chloride

$2\,Na + Cl_2 \rightarrow 2\,NaCl$

Non-metal + non-metal

non-metal + non-metal → compound (a covalent compound)

Example:

carbon + oxygen → carbon dioxide

$C + O_2 \rightarrow CO_2$

3 'Reduction' is a type of reaction in which oxygen is removed (or electrons added) from a reactant (the oxidising agent). In this case the iron oxide is reduced when oxygen is removed, forming the element iron.

4 $Fe_2O_3 + 2\,CO \rightarrow 2\,CO_2 + 2\,Fe$

Types of chemical reactions

Many of the reactions covered in this chapter can be written in a general form.

Synthesis

$A + B \rightarrow AB$

Decomposition

$AB \rightarrow A + B$

Combustion

fuel + $O_2 \rightarrow H_2O + CO_2$ + energy

metal + $O_2 \rightarrow$ metal oxide + energy

Acids and metals

acid + metal → salt + H_2

acid + metal oxide → metal salt + H_2O

acid + metal hydroxide → salt + H_2O

acid + metal carbonate → salt + $H_2O + CO_2$

Precipitation

soluble + soluble → insoluble + soluble

Activity

Chemical equation bingo

Students can make up bingo cards with four to six products from the various chemical equations listed above (e.g. CO_2, H_2O, HCl, Mg, O_2, H_2, MgO, $CuSO_4$, NaCl, energy, CH_4, $C_6H_{12}O_6$). The reactants of an equation can then be read out. If the student has a product of the equation on their bingo card it can be crossed off ('the product of a combustion reaction'). When students have crossed off all the chemicals on their list, they should shout 'BINGO!'.

obook

ID07.03 Video link: Chemical reactions

EXPERIMENT 7.1

Direct synthesis with a 'pop'

Practical hints

- Warn the students that the reaction will make a noise. This may avoid a fright and an accident.
- Use long matches instead of lighting a splint.

Safety

1 M hydrochloric acid is corrosive. Wear safety glasses and lab coats. Avoid contact with the skin.

Clean up

Pour acid solution and metal through a plastic sieve and collect the metal or allow the magnesium to dissolve completely. Pour the solutions down the sink, followed by water.

Expected results

- A loud 'pop' sound will be heard when a lit match is placed in the hydrogen gas that has been collected.
- Water vapour will collect in the neck of the test tube during the reaction.

Discussion

1 Water can be seen to condense on the inside of the test tube that 'popped'.
2 $2\ H_2 + O_2 \rightarrow 2\ H_2O$
3 Many chemical reactions require energy (in the form of heat) to break the initial bonds within the molecule. In this case the lit match was needed to break the bonds of the hydrogen gas.
4 Heat and light were produced. Therefore, this reaction is exothermic.

Direct synthesis with a 'pop'

EXPERIMENT 7.1

Aim

To produce water by direct synthesis.

Materials

Two test tubes
Test tube rack
Rubber stopper
Wooden splint
Matches
Magnesium ribbon
Dilute hydrochloric acid (1 M)

Safety

Wear safety glasses and protective clothing. Avoid contact with the hydrochloric acid.

Method

For this reaction you require a test tube containing hydrogen gas. The easiest way to produce this is to place three 1-cm length pieces of magnesium ribbon into 10 mL dilute hydrochloric acid in a test tube. Place the other test tube (make sure it is dry) over the top of the first test tube so that any hydrogen gas produced enters the second test tube.

After 15 seconds, place a rubber stopper over the end of the second test tube to trap the hydrogen gas: you now have a test tube of hydrogen gas.

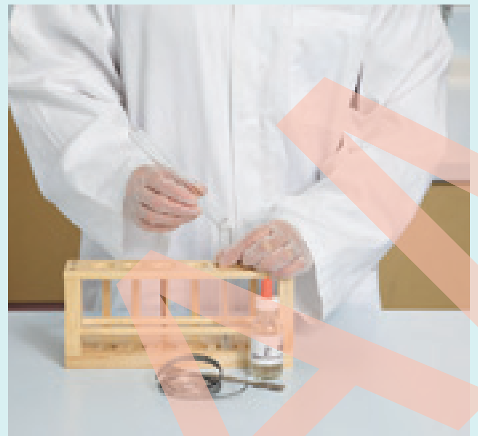
1 Place the sealed test tube containing your gas into a test tube rack.
2 Light the wooden splint. Remove the rubber stopper and carefully hold the burning splint close to the top of the test tube.
3 Observe the reaction that occurs and examine the inside of the test tube closely.

Results

Record your observations in an appropriate format.

Discussion

1 What evidence was there that water was formed in the reaction?
2 Write a chemical equation for the reaction that occurred, ensuring that no atoms are created or destroyed in the process.
3 Why do you think that heat was required to start the reaction?
4 Apart from synthesis, what other ways could this reaction be classified? (Hint: Think about the energy involved in this reaction.)



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Decomposition reactions

ZOOMING IN

Decomposition reactions are the breakdown of compounds into simpler substances, either elements or more simple compounds.

- Thermal decomposition—this uses heat to provide energy for the reaction. For example:

copper (II) carbonate → copper (II) oxide + carbon dioxide
$CuCO_3 \rightarrow CuO + CO_2$

- Electrolytic decomposition or electrolysis—this uses electricity to provide energy for the reaction. For example:

aluminium oxide → aluminium + oxygen
$2\ Al_2O_3 \rightarrow 4\ Al + 3\ O_2$

Decomposing a carbonate

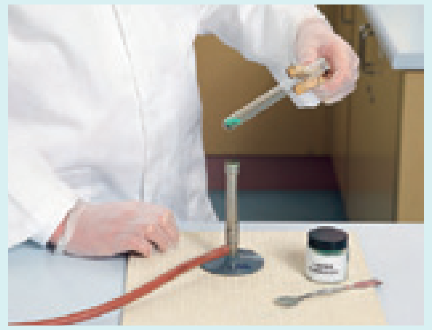
EXPERIMENT 7.2

Aim

To use heat to decompose copper(II) carbonate to produce copper oxide and carbon dioxide.

Materials

One Pyrex (high-strength) test tube
Test tube holder
Bunsen burner
Matches
Spatula
Copper(II) carbonate
Copper(II) oxide
Calcium carbonate powder



Safety

Wear safety glasses throughout this experiment. Make sure that the open end of the test tube is facing in a safe direction while heating.

Method

1 Describe the appearance of copper(II) carbonate and copper(II) oxide.
2 Place one spatula of copper(II) carbonate into the test tube.
3 Hold the test tube at an angle of approximately 45° and gently heat the bottom of the test tube by moving it carefully in and out of a Bunsen burner flame.
4 Carefully observe the changes that occur.

Results

Record your observations in an appropriate format.

Discussion

1 What evidence is there that copper(II) oxide was formed in the reaction?
2 What evidence is there that a gas was given off in the reaction?
3 Write a chemical equation for the reaction that occurred, including state symbols.
4 Apart from decomposition, what other ways could this reaction be classified?

Further investigation

How could you redesign this experiment to provide evidence that it is carbon dioxide gas that is produced in the reaction? Write an experimental method, including labelled diagrams, and list any additional equipment you will need. Show your design to your teacher and, if it is safe, try your design using copper (II) carbonate and then repeat using calcium carbonate.

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ZOOMING IN

Decomposition reactions

Whilst many students will accept that decomposition reactions are a type of reaction, more advanced students will ask why the reactions do not occur all the time. Decomposition reactions can be broken into three main types.

- In catalytic decomposition reactions, the reactant will readily break apart and the rate can be increased with the use of a catalyst.
- An electrolytic decomposition requires the use of an electrical current to provide the energy to initiate the reaction.
- In thermal decomposition, direct heat or radiation is used to initiate the reaction.

Irrespective of the initiating factor for the decomposition reaction, energy is always exchanged as a result.

EXPERIMENT 7.2

Decomposing a carbonate

Safety

- Safety glasses and lab coats or aprons must be worn.
- Safety procedures for Bunsen burner use must be observed. Tie hair back and remove or tuck away any loose clothing.
- Write a risk assessment, including safety advice from the Material Safety Data Sheets (MSDS) for copper carbonate.

Class clean up

Copper carbonate is NOT to go down the sink. Collect it in a waste beaker and pass it onto the lab tech for disposal.

Lab tech notes

- Collect the waste copper carbonate and store it in a waste container for future waste collection.
- Try to give the students spatulas that will actually go into the test tube or, alternatively, ask that they use small powder funnels to get the copper carbonate into the test tube. The powder tends to go everywhere if the students haven't got the right equipment.

Discussion

1 Copper carbonate is a green-coloured powder. When it is heated, it becomes a black powder that is similar in appearance to copper oxide.
2 Sometimes, a gas can be seen to be given off.
3 $CuCO_3\ (s) \rightarrow CuO\ (s) + CO_2\ (g)$
4 This is an endothermic reaction.

Further investigation

There are two ways students can test for carbon dioxide:

1 Bubbling carbon dioxide through limewater will make the latter milky. Limewater is calcium hydroxide. When carbon dioxide is added, insoluble calcium carbonate is formed.
2 Placing a lit splint into the test tube with carbon dioxide will make the splint go out.

EXPERIMENT 7.3

Electrolysis

Electrolysis is another example of a decomposition reaction. In this case, copper sulfate decomposes to form its ions. The resulting sulfate ion reacts with the positive carbon electrode, forming carbon dioxide, and the copper ions gain an electron to form copper metal over the surface of the negative electrode (the copper ions are repelled by the positive electrode and are attracted to the negative electrode). Once this reaction has been observed, students can reverse the electrodes to see the copper disappear from the electrode.

Safety

You are working with electricity and a liquid. Do not allow your power source to get wet. Do not let the carbon rods touch when they are connected to electricity and in the beaker of copper sulfate.

Class clean up

Do not pour copper sulfate down the sink. It is harmful to the aquatic environment. Collect the copper sulfate solutions in a beaker for the lab tech to dispose of.

Lab tech notes

Collect the copper sulfate solution. Put in its own waste container for reuse or for collection by a disposal company.

Discussion

1 A shiny copper layer formed over one of the carbon electrodes indicates that copper was created from the copper sulfate.
2 Water dissolves the ionic compound, allowing the ions to conduct electricity. The electrical circuit provides the energy to drive the electrolysis reaction. Copper forms over the electrode that has attracted the positive copper ions.
3 Only a small amount of copper can be produced in this set up because once copper covers the electrode, it prevents the reaction from occurring further. For usable amounts of copper to be produced, the copper would need to be removed from the electrode regularly to enable the reaction to proceed.

EXPERIMENT 7.3

Electrolysis

Background

Copper sulfate ($CuSO_4$) is an ionic substance containing copper(II) ions (Cu^{2+}) and sulfate (SO_4^{2-}) ions combined in an ionic network.

Aim

To use electricity to produce copper metal from copper(II) sulfate.

Materials

100 mL beaker
Stirring rod
Spatula
Copper(II) sulfate
DC power supply
Three leads
One 6 V globe and globe holder
Wires with alligator clips

Safety

Wear safety glasses throughout this experiment.
Do not let the carbon rods touch when they are in the beaker.

Method

1 Add one spatula of the copper(II) sulfate to the beaker and half fill it with water.
2 Stir until the crystals are all dissolved.
3 Set the power supply to a maximum of 6 volts and connect the circuit as shown in Figure 7.6.
4 Touch the carbon rods together to check the circuit works and then place the carbon rods in the beaker with a 1 cm gap between them.
5 Hold the rods in place for 30 seconds and observe any changes that occur.
6 Turn the power supply off.

Results

Record your observations in an appropriate format.

Discussion

1 What evidence was there that copper was formed in the reaction?
2 Considering the structure of the copper sulfate, describe:
- the role of the water in the process
- the role of the electric circuit
- the reason that the copper was only found on one of the carbon electrodes.
3 Do you think that a usable amount of copper could be produced this way? If not, what changes would need to be made to the set-up to produce more copper?

→ Fig 7.6

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→ Fig 7.7 (a) A lime kiln being used to produce quicklime. (b) A modern furnace used to decompose limestone.

Products from chemical reactions

QUICKLIME

Quicklime, or calcium oxide (CaO), is an important industrial product. It is used in agriculture as a fertiliser and to neutralise acidic soils. It is also key component in building materials, such as mortar. The ability of quicklime to absorb other chemicals enables it to be used in the preparation and purification of a range of chemicals. When added to water, quicklime produces calcium hydroxide ($Ca(OH)_2$), which is known as slaked lime. This compound is a base and is a key component in whitewash, as well as being used in the treatment of drinking water.

Calcium oxide is produced by the thermal decomposition of calcium carbonate ($CaCO_3$). The most common and cheapest naturally occurring form of calcium carbonate is limestone. Calcium oxide has been produced from limestone for many centuries using lime kilns. These stone structures were fuelled by coal, with blocks of limestone having to be broken up, often by hand, and added to the kiln, where the temperatures could reach close to 1000°C.

Nowadays limestone is roasted in more modern furnaces, often fuelled by gas, where the temperature can be regulated by controlling the flow of gas and air into the furnace.

ALUMINIUM

Aluminium is used extensively in modern life in food packaging, buildings, casings for computers and in electric cabling. Aluminium is produced by electrolytic decomposition. The raw material for this process is bauxite, an ore of aluminium mined extensively in Australia. The bauxite provides aluminium oxide (Al_2O_3), an ionic solid. This solid is heated to high temperature and then separated into aluminium and oxygen using electrolysis. Very high temperatures are required for this process because the pure aluminium oxide needs to be in a liquid form for electrolysis to work. For this reason, aluminium remains a relatively expensive metal, despite the fact that bauxite, and other aluminium-containing compounds, are very common in the Earth's crust.

Fig 7.8 Aluminium is produced by electrolysis in a smelter.

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Products from chemical reactions

Quicklime

Because quicklime is inexpensive and easy to make, and it has many uses in industry, including:

- as a dehydrating agent—it reacts with the water to produce calcium hydroxide
- to remove carbon dioxide fumes
- as a flux to remove impurities such as silica, sulfur and phosphorus from scrap metal
- to neutralise acidic soil—when mixed with water, quicklime creates calcium hydroxide (an alkali)
- to clear contaminants from water pipes.

Contrary to widespread belief, quicklime cannot be used to dispose of a corpse. Many people believe packing a body with quicklime will encourage decomposition. In fact, the quicklime acts as a preservative, absorbing water from the body (or surrounding soil), causing partial desiccation and preventing putrefaction. As a result, the body can mummify.

Aluminium

The production of aluminium can be broken into a series of steps that students can cut and paste in to a flow chart.

1 The bauxite must be crushed into a fine powder and mixed with sodium hydroxide to form a slurry.
2 High pressure and temperatures are used to encourage the aluminium to react with the sodium hydroxide to form sodium aluminate solution. Many other impurities will not dissolve in the caustic soda.
3 The impurities are allowed to settle and are then filtered out.
4 The still-warm sodium aluminate solution is pumped into large tanks and seed crystals of alumina are added. Alumina crystals form around the seed crystals as the solution cools. The increased weight causes the crystals to sink to the bottom, where they can be filtered off.
5 The resulting precipitate is rinsed and dried, eventually producing a fine white powder.
6 The alumina powder is dissolved in cryolite and an electric current is passed through the mixture. The resulting electrolysis produces metallic aluminium.

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ID07.04 Weblink: Electrolysis

Answers

What do you know about types of chemical reactions?

1 Decomposition reactions occur when a single substance is broken down into several products.
2 A by-product is a substance that is produced in the process of making something else.
3 Calcium oxide is produced in a decomposition reaction. Ammonia is produced in a synthesis reaction.
4 a Energy is required in a decomposition reaction to break the bonds of the reactant to form new products.
  b Energy is required in direct synthesis reactions to form new bonds between the reactants, forming the product.

ZOOMING IN

Combustion and respiration

Combustion reactions

These reactions always use oxygen to produce energy (in the form of heat and light). There are two main types of combustion reactions covered: the rusting of metal and the burning of fuels.

A discussion of burning fuel provides an excellent opportunity to introduce rates of reaction. A campfire can be used as an example. The rate at which a fire burns (indicated by how hot it is) can be increased by:

- adding more wood or blowing on the fire (increasing the concentration of reactants)
- chopping the wood into smaller pieces (increasing the surface area of the reactants)
- starting the fire on a hot day (increasing the temperature).

These general principles can be revisited in the next section of this chapter.

AMMONIA

Ammonia (NH_3) is a very important chemical produced by direct combination of its elements, nitrogen and hydrogen. It is used in a large number of fertilisers, as well as in a range of household cleaning products. You will learn more about how the method used to produce ammonia was developed at the end of this chapter. The modern method used to produce ammonia is called the Haber process, which relies on the reaction shown below:

$$3\,H_2(g) + N_2(g) \rightarrow 2\,NH_3(g)$$

Nitrogen is not a very reactive element, so specific conditions are required for this reaction to occur. It involves heating the two gases so that the reaction will happen quickly enough.

What do you know about types of chemical reactions?

1 Why do decomposition reactions always produce more than one product?
2 What is meant by a by-product?
3 Describe, in terms of the types of chemical reactions, major differences between the reaction used to produce ammonia and the reaction used to produce calcium oxide.
4 Why is energy required in:
  a decomposition reactions
  b direct synthesis reactions?

Other chemical reactions

A wide variety of products can be produced by a range of other chemical reactions. Below are some reactions that you will have come across before. Look at the types of products produced by these reactions. Are there any patterns you can identify? Can you give examples of where these reactions are used to produce specific products for a specific use? Do these reactions occur naturally or are they used by humans to produce things specifically for our use?

ZOOMING IN

Combustion and respiration

Combustion is the fast reaction with oxygen. The reaction releases light and heat energy, which we may see as a flame. Combustion is a type of reaction called oxidation. Other oxidation reactions are corrosion and respiration.

Combustion

metal + oxygen → metal oxide

Example:

magnesium + oxygen → magnesium oxide

$2\,Mg(s) + O_2(g) \rightarrow 2\,MgO(s)$

Respiration

sugar + oxygen → carbon dioxide + water

Example:

glucose + oxygen → carbon dioxide + water

$C_6H_{12}O_6(aq) + 6\,O_2(g) \rightarrow 6\,CO_2(g) + 6\,H_2O(l)$

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Reactions of acids

Acids are substances that dissolve in water to form hydrogen ions. The hydrogen ions are reactive and give the acids their special properties. Acids react with many groups of compounds.

ZOOMING IN

Acid and metal reactions

Acids and metals

acid + metal → salt + hydrogen

Example:

sulfuric acid + zinc → zinc sulfate + hydrogen

$H_2SO_4(aq) + Zn(s) \rightarrow ZnSO_4(aq) + H_2(g)$

Note: Only the more reactive metals will form a salt and hydrogen when reacting with acids. Copper, silver and gold are unreactive metals.

Acids and metal oxides

acid + metal oxide → salt + water

Example:

nitric acid + magnesium oxide → magnesium nitrate + water

$2\,HNO_3(aq) + MgO(s) \rightarrow Mg(NO_3)_2(aq) + H_2O(l)$

Acids and metal hydroxides

acid + metal hydroxide → salt + water

Example:

sulfuric acid + sodium hydroxide → sodium sulfate + water

$H_2SO_4(aq) + 2\,NaOH(aq) \rightarrow Na_2SO_4(aq) + 2\,H_2O(l)$

Acids and metal carbonates

acid + metal carbonate → salt + water + carbon dioxide

Example:

nitric acid + calcium carbonate → calcium nitrate + water + carbon dioxide

$2\,HNO_3(aq) + CaCO_3(s) \rightarrow Ca(NO_3)_2(aq) + H_2O(l) + CO_2(g)$

→ Fig 7.9 Zinc metal reacting in acid.

Polymers and plastics

Plastics are a major part of our lives. They form the wrap we put around our sandwiches and the containers we store our food and other products in. Recycled plastics are used to make wheelie bins. Plastics are made up of giant molecules called **polymers**. These polymers have been synthesised by chemists. There are also many naturally occurring polymers, including proteins, DNA and cellulose.

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ZOOMING IN

Acid and metal reactions

Many of these reactions have already been experienced by students.

A class can be broken into groups to demonstrate an example of each reaction to the rest of the class.

Students should write up a method for each experiment, including the list of equipment they need, the concentrations of the chemicals and the safety hazards to be aware of (they may use previous experiments as a guide). Each group should present their experiment, together with a balanced equation and a generalised equation for the reaction.

Possible reactions students could use are detailed below.

Acids and metals

- Adding magnesium ribbon to 1 M HCl will produce hydrogen and magnesium chloride.
- The 'pop test' from earlier in this chapter will demonstrate the production of hydrogen.

Acids and metal oxides

- a rusty nail and a drop of 1 M HCl (in the presence of universal indicator)

Acids and metal hydroxides

- 1 M HCl and 1 M NaOH (in the presence of universal indicator)

Acids and metal carbonates

- making sherbet ($\frac{1}{2}$ teaspoon citric acid, $\frac{1}{4}$ teaspoon bicarbonate soda, icing sugar and jelly crystals)

  OR
- vinegar and bicarbonate soda
- students can test for the presence of carbon dioxide using a lit splint

obook
ID07.05 Weblink: Reactions of acids

Formation of polymers

The concept of polymers consisting of a chain of smaller units (called monomers) is an important part of senior chemistry and biology.

EXPERIMENT 7.4 (TEACHER DEMONSTRATION)

Making nylon fibre

Practical hints

Ask the lab tech to prepare your two solutions and the alcohol solution, so all you need to do is combine them and make the nylon.

Safety

- Prepare a risk assessment, thoroughly understanding all safety aspects of the chemicals you are using. Refer to the MSDS for the chemicals being used.
- All aspects of this practical demonstration have to be performed in a fume cupboard. Do not breathe in the vapours.
- Protective clothing is essential. Gloves, safety glasses and a lab coat must be worn.

Clean up

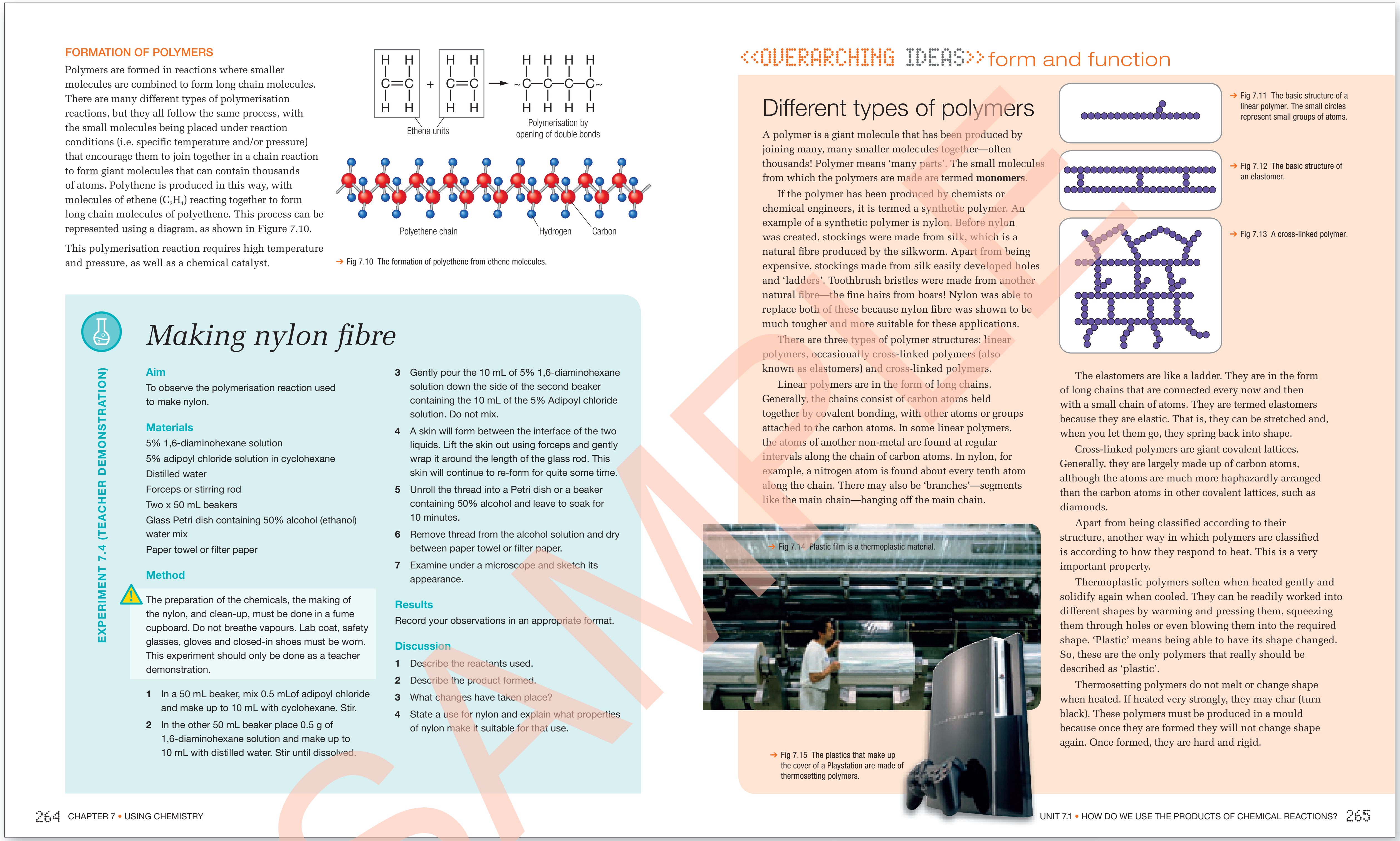
Leave used chemicals in the fume cupboard, with the cupboard turned on, until the lab tech can dispose of them or seal them in a container so no vapours can escape.

Lab tech notes

- Please read the MSDS for all the chemicals used and write a risk assessment for yourself.
- Make up the chemicals prior to class so the teacher only needs to combine the adipoyl chloride solution and the 1,6-diaminohexane solutions to make the nylon.
- The nylon liquid chemical mix must be collected and stored in its own individual container for waste pick up.

Discussion

1. Anhydrous sodium carbonate and diaminohexane are clear, odourless solutions.
2. The product (nylon) formed is a white 'lump' that can be drawn into a long thread.



FORMATION OF POLYMERS

Polymers are formed in reactions where smaller molecules are combined to form long chain molecules. There are many different types of polymerisation reactions, but they all follow the same process, with the small molecules being placed under reaction conditions (i.e. specific temperature and/or pressure) that encourage them to join together in a chain reaction to form giant molecules that can contain thousands of atoms. Polythene is produced in this way, with molecules of ethene (C_2H_4) reacting together to form long chain molecules of polyethene. This process can be represented using a diagram, as shown in Figure 7.10.

This polymerisation reaction requires high temperature and pressure, as well as a chemical catalyst.

Fig 7.10 The formation of polyethene from ethene molecules.

Making nylon fibre

EXPERIMENT 7.4 (TEACHER DEMONSTRATION)

Aim

To observe the polymerisation reaction used to make nylon.

Materials

5% 1,6-diaminohexane solution
5% adipoyl chloride solution in cyclohexane
Distilled water
Forceps or stirring rod
Two x 50 mL beakers
Glass Petri dish containing 50% alcohol (ethanol) water mix
Paper towel or filter paper

Method

The preparation of the chemicals, the making of the nylon, and clean-up, must be done in a fume cupboard. Do not breathe vapours. Lab coat, safety glasses, gloves and closed-in shoes must be worn. This experiment should only be done as a teacher demonstration.

1 In a 50 mL beaker, mix 0.5 mLof adipoyl chloride and make up to 10 mL with cyclohexane. Stir.
2 In the other 50 mL beaker place 0.5 g of 1,6-diaminohexane solution and make up to 10 mL with distilled water. Stir until dissolved.
3 Gently pour the 10 mL of 5% 1,6-diaminohexane solution down the side of the second beaker containing the 10 mL of the 5% Adipoyl chloride solution. Do not mix.
4 A skin will form between the interface of the two liquids. Lift the skin out using forceps and gently wrap it around the length of the glass rod. This skin will continue to re-form for quite some time.
5 Unroll the thread into a Petri dish or a beaker containing 50% alcohol and leave to soak for 10 minutes.
6 Remove thread from the alcohol solution and dry between paper towel or filter paper.
7 Examine under a microscope and sketch its appearance.

Results

Record your observations in an appropriate format.

Discussion

1 Describe the reactants used.
2 Describe the product formed.
3 What changes have taken place?
4 State a use for nylon and explain what properties of nylon make it suitable for that use.

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<<OVERARCHING IDEAS>> form and function

Different types of polymers

A polymer is a giant molecule that has been produced by joining many, many smaller molecules together—often thousands! Polymer means 'many parts'. The small molecules from which the polymers are made are termed **monomers**.

If the polymer has been produced by chemists or chemical engineers, it is termed a synthetic polymer. An example of a synthetic polymer is nylon. Before nylon was created, stockings were made from silk, which is a natural fibre produced by the silkworm. Apart from being expensive, stockings made from silk easily developed holes and 'ladders'. Toothbrush bristles were made from another natural fibre—the fine hairs from boars! Nylon was able to replace both of these because nylon fibre was shown to be much tougher and more suitable for these applications.

There are three types of polymer structures: linear polymers, occasionally cross-linked polymers (also known as elastomers) and cross-linked polymers.

Linear polymers are in the form of long chains. Generally, the chains consist of carbon atoms held together by covalent bonding, with other atoms or groups attached to the carbon atoms. In some linear polymers, the atoms of another non-metal are found at regular intervals along the chain of carbon atoms. In nylon, for example, a nitrogen atom is found about every tenth atom along the chain. There may also be 'branches'—segments like the main chain—hanging off the main chain.

Fig 7.11 The basic structure of a linear polymer. The small circles represent small groups of atoms.

Fig 7.12 The basic structure of an elastomer.

Fig 7.13 A cross-linked polymer.

The elastomers are like a ladder. They are in the form of long chains that are connected every now and then with a small chain of atoms. They are termed elastomers because they are elastic. That is, they can be stretched and, when you let them go, they spring back into shape.

Cross-linked polymers are giant covalent lattices. Generally, they are largely made up of carbon atoms, although the atoms are much more haphazardly arranged than the carbon atoms in other covalent lattices, such as diamonds.

Apart from being classified according to their structure, another way in which polymers are classified is according to how they respond to heat. This is a very important property.

Thermoplastic polymers soften when heated gently and solidify again when cooled. They can be readily worked into different shapes by warming and pressing them, squeezing them through holes or even blowing them into the required shape. 'Plastic' means being able to have its shape changed. So, these are the only polymers that really should be described as 'plastic'.

Thermosetting polymers do not melt or change shape when heated. If heated very strongly, they may char (turn black). These polymers must be produced in a mould because once they are formed they will not change shape again. Once formed, they are hard and rigid.

Fig 7.14 Plastic film is a thermoplastic material.

Fig 7.15 The plastics that make up the cover of a Playstation are made of thermosetting polymers.

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3. At the interface between the two liquids, the individual units of the reactants bond to form a polymer chain. As the chain is lifted out of the beaker, more units combine to form a longer polymer.
4. Nylon is used to make toothbrushes, stockings, clothing, hairbrushes etc. Many of these products require strength, as well as flexibility.

OVERARCHING IDEAS

Different types of polymers

There are several different ways of demonstrating polymers.

- Paper chains can be used to represent linear polymers that form a long chain. Every tenth link in the chain can be a different colour, representing the nitrogen atom in nylon. Branches can hang off this link.
- The cross-linked polymer can be made using a series of rubber bands. The bands can be folded over a paperclip with the two end loops hanging off together. A second rubber band can be passed through the loops of the first band and folded over. The third band passes through the loops of the second and so on. This will create a chain of loops that will be elastic. The ends of the chain can be tied off with a small strip of elastic. This elastic can also be used to link several such chains together, representing the elastic lattice nature of these polymers.
- The paper chain can also be called a 'thermosetting polymer', which does not change shape when heated but can char.
- The elastic bands can also represent thermoplastic polymers (or elastomers) because they spring back into shape when stretched.

It is often important for students to link the theory to everyday items. Ask students to bring in an item they think is made of nylon and ask them to explain the properties of their item in terms of the properties of nylon. This creates relevance in the study of chemistry and provides an opportunity to discuss possible careers in chemistry.

obook
ID07.06 Video link: Different types of polymers

EXPERIMENT 7.5

Testing polymers

Practical hint

Some examples of polymers include anything plastic, styrofoam cups, blocks of wood (cellulose), rubber, silly putty, nylon, silicone, Bakelite, PVC, polystyrene, polyethylene and polypropylene.

Discussion

1 Results will vary depending on the plastics tested.
2 This question relates the plastic properties of the samples in question 1 to the term thermoplastic.
3 Placing nylon in a flame can cause the sample to melt, forming droplets that will stick to the skin and cause significant burns. Therefore, hot water was used.
4 A fair test would require samples to be the same size, thickness and weight, and the water to be exactly the same temperature for each test (not cooling down over time).

Answers

What do you know about other chemical reactions?

1 Linear polymers are long chains of polymers that may have branches hanging off them. Cross-linked polymers are giant covalent lattices in which the monomers are linked in several directions.
2 a thermoplastic
b thermosetting
c thermosetting
d thermoplastic
e thermosetting
3 A thermosetting plastic is most likely to be a cross-linked polymer because it is less able to be stretched out of shape as a result of the extensive cross-linking. Any attempt to melt this plastic may cause decomposition before the melting temperature is reached.

EXPERIMENT 7.5

Testing polymers

Aim
To classify polymers based on their properties.

Materials
Samples of different polymers
Forceps
Beaker of very hot water
Large white ceramic tile

Be very careful not to be burnt by the water or steam.

Method
1 Drop each of the polymer samples individually into the beaker of hot water using the forceps.
2 After 1 minute, remove the sample and place it on the tile.
3 Examine it carefully as you handle it.

Results
Record your observations for each polymer you tested. Did it become softer and more pliable after being dropped in the beaker of hot water?

Discussion
1 When a polymer softens on heating and can be made to change shape, it is said to be in a plastic state. The softening temperature is the temperature at which this occurs. Did any of the polymers you tested become plastic?
2 From your results, identify which of the polymers is thermoplastic.
3 Suggest why this property was not tested by placing the samples in a flame.
4 For a fair comparison, what should have been true of all the samples tested? On the basis of this, did you conduct a fair test? Discuss.

What do you know about other chemical reactions?
1 What are the differences between a linear polymer and a cross-linked polymer?
2 For each of the following applications, state whether it would be better to make the object from a thermosetting polymer or a thermoplastic polymer:
a food wrap
b a light switch
c a disposable cup for soft drinks
d a wash bottle for a science laboratory
e the handles of barbecue tongs
3 Which would you expect to be a thermosetting plastic: a linear polymer or a cross-linked one? State your reasoning.

How do we use polymers today?

Many different polymers are used today. More and more designer polymers are being developed and modified to suit particular applications. Before the Second World War and the invention of nylon, tents were made of canvas. Canvas is a strong, durable, natural fabric. However, it can tear and leak, which is the last thing you need in stormy weather. Moreover, canvas is heavy to carry. Today, many tents are made from nylon, which is used to produce a lightweight, tear-resistant fabric. Bigger tents are made of cotton polyester. The bases of the tents are made of polyurethane, another useful, waterproof polymer.

The downside of using synthetic polymers for tents and other outdoor applications is that, over time, many deteriorate as a result of the action of ultraviolet (UV) radiation from the Sun. Substances known as UV stabilisers can be added to the polymer material to help slow this process down.

Fig 7.16 Tents are made of nylon, which makes them lightweight.

These days, most people have at least one piece of clothing made of Polarfleece, but do you really know why it is so warm and yet lightweight? Polarfleece is a synthetic wool made from PET, or PETE (polyethylene terephthalate). PET is a thermoplastic polymer and, for Polarfleece, is sourced from recycled plastic bottles that have been processed into a clothing fabric. PET gives Polarfleece its soft, warm, durable and fast-drying properties, which make it perfect for camping and other outdoor activities.

Fig 7.17 Polarfleece has many uses when camping in the great outdoors.

ZOOMING IN

Bubble wrap buildings

The 2008 Olympics famously used a number of different polymers, mainly at the swimming pool. The new Speedo LZR racing suit is one example of a high-technology synthetic polymer, as is the building in which the swimming pool was housed! The outer structure of the Water Cube was composed of a super strong plastic material known as EFTE (or ethylene tetrafluoroethylene). This polymer is made from carbon, hydrogen and fluorine atoms.

Fig 7.18 Beijing's Water Cube.

The designers of the Water Cube received a huge rap (pardon the pun!) for using a material that is not only cheap, but also lightweight, flexible and strong. The building was made up of 3000 bubbles that let the light in and retained heat like a greenhouse. Therefore, the building heats up naturally, minimising energy use. If designers continue to build 'bubble wrap' buildings, imagine what cities would look like in 100 years time!

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How do we use polymers today?

The dramatic increase in the use of polymers has presented a unique problem for waste systems: plastic takes time to decompose and its nature means that it can occupy a lot of landfill space.

Because many of the raw products come from the limited resource petroleum, recycling of these products has become a high priority. Only three polymers in current use can be recycled; one of these is polyethylene terephthalate (PETE). This polymer can be produced from the monomers ethylene glycol and dimethyl terephthalate. One of the most common uses of PETE is in soft drink bottles.

The plastic is first broken into small flakes and compressed into bales before being treated and reformed. Unlike many recyclable products, PETE can only be recycled once. As a result, the objects made from recycled polymers are chosen for their long shelf life (polar fleece, cafeteria trays, plastic toys and carpeting). Your students may be wearing a recycled soft drink bottle!

Recycled plastics are recognisable by their symbol of a triangle made of arrows. Plastic is recyclable if it has a 1 (PETE), 2 (high-density polyethelene) or 3 (PVC) in the triangle.

Because there are many types of plastics used, the effectiveness of recycling these products can be improved by:

- removing and discarding all lids or caps
- rinsing all containers
- crushing the bottles to save space.

Application of knowledge

This is an ideal opportunity for students to apply their knowledge of polymers to their own school. Making posters encouraging recycling, investigating school cafeterias and the use of recycling bins are all ways to encourage the students to become involved and make science relevant.

ZOOMING IN

Bubble wrap buildings

Ethylene tetrafluoroethylene is a 250 micrometre-thick lightweight polymer. Stretching it thin and then folding it creates small air bubbles within the material that lets light pass through whilst trapping and storing heat. This provides insulation much like that of a 'doona' that is also fire resistant, shatter-proof and can be easily cleaned. The light weight of the panels means the support framework is also lighter and hence easier to construct than traditional glass panels. The overall effect is much like that of a greenhouse with 90% of the heat being trapped and recycled into heating the pools inside. One of the disadvantages of this material is that it transmits sound at a greater level than glass. This can make it very noisy when it rains as the air pockets in the ethylene tetrafluoroethylene can act as mini drums, magnifying the sound.

Precipitation reactions

- (aq) indicates an aqueous solution—this means the compound has been dissolved in water (it is soluble)
- (s) means that the substance is in a solid state
- (l) means that the substance is in a liquid state
- (g) means that the substance is in a gaseous state

There are many uses of precipitation reactions:

- making pigments—some paints such as Prussian blue are created through a chemical reaction between ferric chloride and potassium ferrocyanide that causes an insoluble pigment to be formed; this pigment is then dried and can be used
- testing for the presence of contaminants in water—many commercially produced tests use the principle of adding a compound to water that will react with possible contaminants, causing them to precipitate (giving a positive result for contamination)
- identifying blood types—if the wrong blood type is transfused into a person, their blood will clot. Precipitation reactions are used to identify the blood type of a person before transfusion.
- softening hard water—water containing calcium ions and magnesium ions is said to be 'hard'. This interferes with the use of soap when cleaning. Sodium carbonate can be used to cause the metal ions to precipitate. The solids can then be filtered out, making the water more appropriate for use.
- metal purification—many commercial companies use precipitation to separate metals from their naturally occurring ores

Precipitation reactions

Precipitation reactions are used to produce solid products from solutions of ionic substances. Precipitation reactions are used in the removal of impurities during water treatment and to produce pigments, which are often mixed with oil or water to produce paints.

A solution of an ionic substance consists of ions separated in a solvent. For example, a solution of lead(II) nitrate ($Pb(NO_3)_2$) consists of lead (Pb^{2+}) ions and nitrate ions (NO^{3-}) together with many water molecules. When two solutions are mixed, a solid substance may form. This is because a positive ion from one solution combines with a negative ion from the other solution to form an insoluble compound. This insoluble compound is known as a **precipitate.**

When a solution of lead(II) nitrate is added to potassium iodide—both colourless solutions—a bright yellow precipitate of lead iodide (PbI_2) is formed. The reaction can be written as shown here.

lead(II) nitrate + potassium iodide → lead(II) iodide + potassium nitrate

$$Pb(NO_3)_2(aq) + 2\,KI(aq) \rightarrow PbI_2(s) + 2\,KNO_3(aq)$$

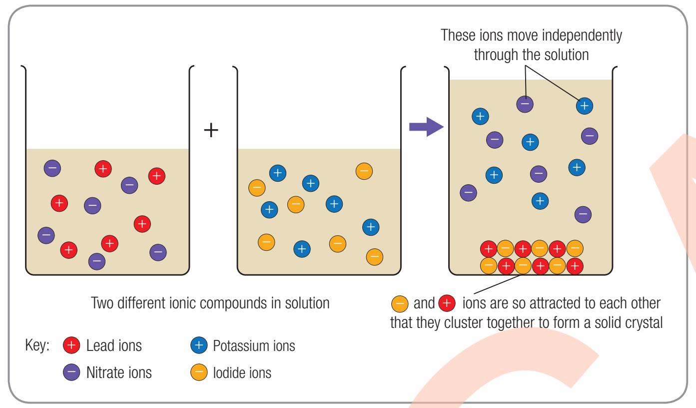
The lead ions and the iodide ions have combined together to form a precipitate of the insoluble lead(II) iodide, which forms as a solid in the solution. But what has happened to the potassium and nitrate ions? These are still dissolved in solution. They are not taking part in the reaction. This is why they are called spectator ions. Because of this, it is actually possible to write this equation in a different way that shows only those ions that are changing in the reaction.

→ Fig 7.19 Pigments are insoluble compounds.

$$Pb_2^{+} + 2\,I^{-} \rightarrow PbI_2(s)$$

Lead compounds were used in a number of pigments until the 1970s, when it was discovered that the lead in these pigments could damage the nervous system.

→ Fig 7.20 At the particle level, when a solution of lead(II) nitrate ($Pb(NO_3)_2$) is added to potassium iodide (KI), the ion partners are swapped.



→ Fig 7.21 A precipitation reaction forming yellow lead(II) iodide.

Using precipitation reactions

Precipitation reactions are important for chemical analysis. The data shown in Table 7.1 can be used to decide whether a precipitate will form. For example, PbI_2 is insoluble, as you have just learnt. So, if any soluble lead(II) compound is mixed with any soluble iodide, this precipitate will form. Similarly, Table 7.1 tells us that $Cu(OH)_2$ is insoluble. This means that if any soluble hydroxide, such as NaOH, is mixed with any soluble copper(II) compound, such as $CuSO_4$, a precipitate of $Cu(OH)_2$ will form.

Chemists sometimes use precipitation reactions to find out which chemicals are present in a substance or how much is present. Common table salt (NaCl) is essential in our diet because the sodium is needed to maintain the correct concentration of body fluids, assist in the transmission of nerve impulses and to help cells absorb nutrients.

Chemical analysis can determine the amount of salt in foods by using a precipitation reaction with silver nitrate. The salt reacts with the silver nitrate to form a precipitate of silver chloride. The mass of sodium chloride can be calculated using the mass of silver chloride that has been precipitated:

$$NaCl(aq) + AgNO_3(aq) \rightarrow NaNO_3(aq) + AgCl(s)$$

→ Table 7.1 Solubility of some common ionic compounds in water

Soluble	Insoluble	Slightly soluble
Group 1 elements		
All ammonium salts		
All nitrate salts		
Most chlorides, bromides and iodides	AgCl, AgI, AgBr, $PbCl_2$, PbI_2, $PbBr_2$	
	Most carbonate and phosphate compounds	
Group 1 hydroxides, $Ba(OH)_2$, and $Sr(OH)_2$	Most hydroxides and sulfates	$Ca(OH)_2$, Ag_2SO_4, $CaSO_4$

What do you know about how we use polymers today?

1. Draw a diagram to show which particles are present in a beaker containing a sodium chloride solution.
2. What symbol is used to show the state of an insoluble compound?
3. What precipitate would form if solutions of lead(II) nitrate and sodium sulfate were mixed?
4. Complete the following word equations below and then write balanced chemical equations for each reaction.
   a. zinc nitrate + potassium hydroxide →
   b. calcium nitrate + sodium carbonate →

Writing chemical equations

Explosions occur when a large amount of gas and a vast amount of energy is produced very suddenly in a chemical reaction that takes place within a sealed container or closed environment. The gas particles gain an enormous amount of kinetic energy from the reaction and so are propelled violently outwards, resulting in a huge blast of gases that causes all the damage.

An example of an explosive substance is nitroglycerine, which is the active constituent of dynamite. In chemical equations, such as for the explosion of nitroglycerine, the substances before the arrow are those substances we start with and they are termed the reactants. The substances after the arrow are the substances formed in the reaction, known as the products. The symbols (s), (l), (g) and (aq) indicate the state of the substance. The numbers in front of the chemical formulas show us the relative numbers of molecules involved.

Rules of solubility

Many students have difficulty understanding the rules of solubility. Many students need to be encouraged to approach this in a systematic manner.

NO_3^-	All nitrates are soluble
Cl^-	All chlorides are soluble, except AgCl, Hg_2Cl_2 and $PbCl_2$
SO_4^{2-}	Most sulfates are soluble, except $BaSO_4$, $PbSO_4$ and $SrSO_4$
CO_3^{2-}	All carbonates are insoluble, except NH_4^+ and those of the group 1 elements
OH^-	All hydroxides are insoluble, except those of the group 1 elements, $Ba(OH)_2$ and $Sr(OH)_2$; $Ca(OH)_2$ is slightly insoluble
S^{2-}	All sulfates are insoluble except those of the group 1 and 2 elements and NH_4^+

Answers

What do you know about how we use polymers today?

1. Students' diagrams should show water molecules with sodium ions and chloride ions present.
2. An insoluble or solid compound is indicated by (s).
3. Lead sulfate ($PbSO_4$) is insoluble in water (refer to Table 7.1).
4. a. zinc nitrate + potassium hydroxide → zinc hydroxide + potassium nitrate
   $Zn(NO_3)_2\ (aq) + KOH\ (aq) \rightarrow Zn(OH)_2\ (s) + 2\ KNO_3\ (aq)$
   b. calcium nitrate + sodium carbonate → calcium carbonate + sodium nitrate
   $Ca(NO_3)_2\ (aq) + Na_2CO_3\ (aq) \rightarrow Ca(CO_3)\ (s) + 2\ NaNO_3\ (aq)$

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ID07.07 Weblink: Writing chemical equations

EXPERIMENT 7.6

Precipitation reactions

Practical hints

- laminating the table on which the reactions take place works really well, saves set-up time for the students and can be repeatedly reused for future classes
- ensure only one drop is used per chemical

Safety

- Wear safety glasses, lab coats and gloves and ensure hair is tied back.
- Prepare a risk assessment for each chemical used from its MSDS. Note that silver nitrate stains. It appears clear for a start but, once in contact with benches, clothes, skin etc., it stains black and is difficult to remove. Read the MSDS for hazard alerts and the appropriate action for spills.

Clean up

- Place folded paper towel at one of the edges of the laminated table and carefully pour the drops into it. Place the paper towel in a disposable bag and discard it into the bin.
- Rinse the laminated table under water and dry. Store for next time.

Lab tech notes

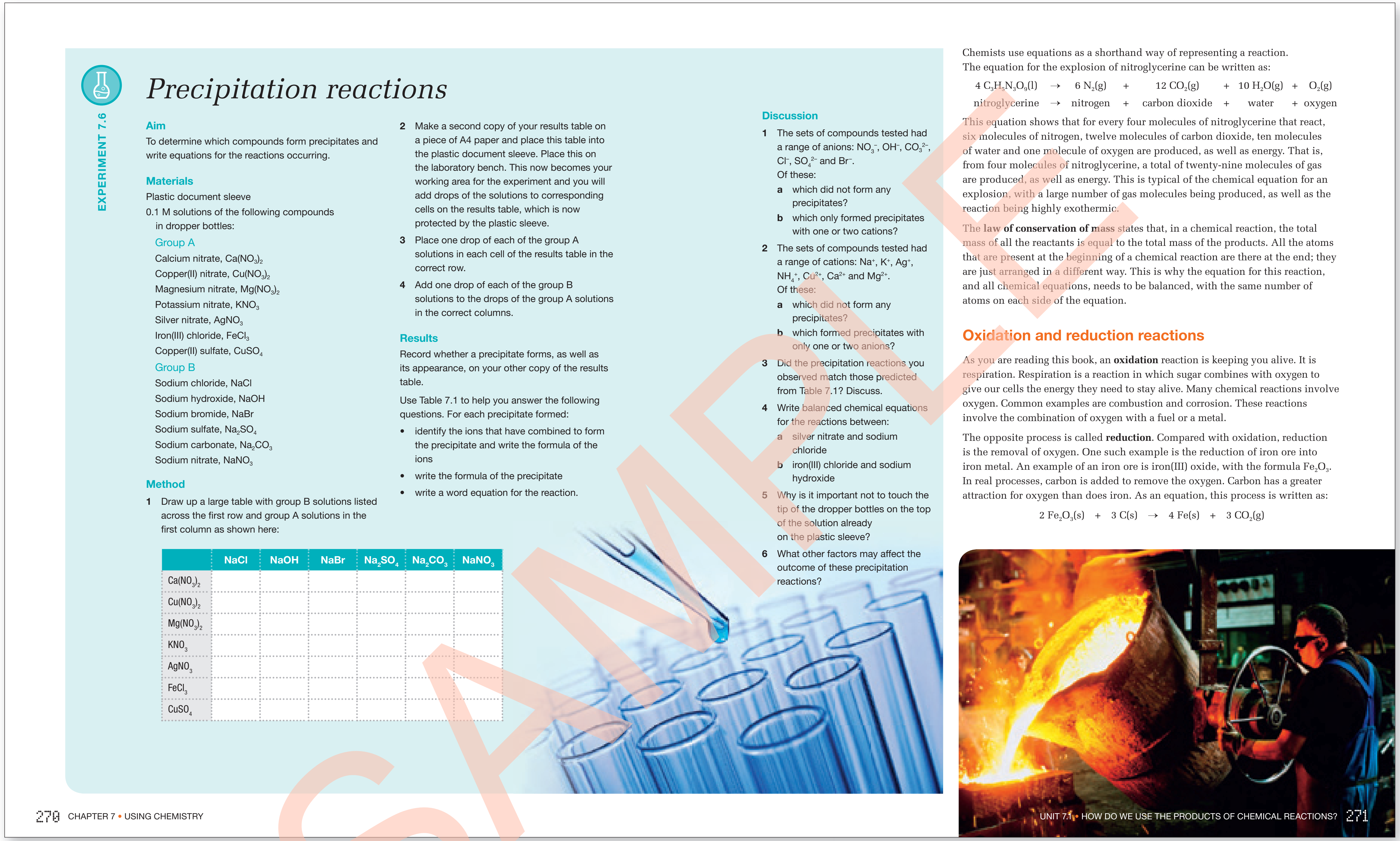
- Prepare the tables for the students. Make sure the tables are big enough for the drops. Laminate. Each group will require two tables, one for the experiment and the other for writing up their results.
- Make up dropper bottles of the 0.1 M solutions.

Results

The expected results of these reactions are:

	NaCl	NaOH	NaBr	Na_2SO_4	Na_2CO_3	$NaNO_3$
$Ca(NO_3)_2$	–	$Ca(OH)_2$	–	–	$CaCO_3$	–
$Cu(NO_3)_2$	–	$Cu(OH)_2$	–	–	$CuCO_3$	–
$Mg(NO_3)_2$	–	$Mg(OH)_2$	–	–	$MgCO_3$	–
KNO_3	–	–	–	–	–	–
$AgNO_3$	AgCl	Ag(OH)	AgBr	–	Ag_2CO_3	–
$FeCl_3$	–	$Fe(OH)_3$	–	–	$Fe_2(CO_3)_3$	–
$CuSO_4$	–	$Cu(OH)_2$	–	–	$CuCO_3$	–

Note: the solubility of some of these solutions (e.g. $Ca(OH)_2$ and $Mg(OH)_2$) is dependent on their concentration, because small amounts will dissolve in water.



Precipitation reactions

EXPERIMENT 7.6

Aim

To determine which compounds form precipitates and write equations for the reactions occurring.

Materials

Plastic document sleeve

0.1 M solutions of the following compounds in dropper bottles:

Group A

Calcium nitrate, $Ca(NO_3)_2$
Copper(II) nitrate, $Cu(NO_3)_2$
Magnesium nitrate, $Mg(NO_3)_2$
Potassium nitrate, KNO_3
Silver nitrate, $AgNO_3$
Iron(III) chloride, $FeCl_3$
Copper(II) sulfate, $CuSO_4$

Group B

Sodium chloride, NaCl
Sodium hydroxide, NaOH
Sodium bromide, NaBr
Sodium sulfate, Na_2SO_4
Sodium carbonate, Na_2CO_3
Sodium nitrate, $NaNO_3$

Method

1 Draw up a large table with group B solutions listed across the first row and group A solutions in the first column as shown here:

	NaCl	NaOH	NaBr	Na_2SO_4	Na_2CO_3	$NaNO_3$
$Ca(NO_3)_2$						
$Cu(NO_3)_2$						
$Mg(NO_3)_2$						
KNO_3						
$AgNO_3$						
$FeCl_3$						
$CuSO_4$						

2 Make a second copy of your results table on a piece of A4 paper and place this table into the plastic document sleeve. Place this on the laboratory bench. This now becomes your working area for the experiment and you will add drops of the solutions to corresponding cells on the results table, which is now protected by the plastic sleeve.

3 Place one drop of each of the group A solutions in each cell of the results table in the correct row.

4 Add one drop of each of the group B solutions to the drops of the group A solutions in the correct columns.

Results

Record whether a precipitate forms, as well as its appearance, on your other copy of the results table.

Use Table 7.1 to help you answer the following questions. For each precipitate formed:

- identify the ions that have combined to form the precipitate and write the formula of the ions
- write the formula of the precipitate
- write a word equation for the reaction.

Discussion

1 The sets of compounds tested had a range of anions: NO_3^-, OH^-, CO_3^{2-}, Cl^-, SO_4^{2-} and Br^-.
Of these:
a which did not form any precipitates?
b which only formed precipitates with one or two cations?

2 The sets of compounds tested had a range of cations: Na^+, K^+, Ag^+, NH_4^+, Cu^{2+}, Ca^{2+} and Mg^{2+}.
Of these:
a which did not form any precipitates?
b which formed precipitates with only one or two anions?

3 Did the precipitation reactions you observed match those predicted from Table 7.1? Discuss.

4 Write balanced chemical equations for the reactions between:
a silver nitrate and sodium chloride
b iron(III) chloride and sodium hydroxide

5 Why is it important not to touch the tip of the dropper bottles on the top of the solution already on the plastic sleeve?

6 What other factors may affect the outcome of these precipitation reactions?

Chemists use equations as a shorthand way of representing a reaction. The equation for the explosion of nitroglycerine can be written as:

$$4\,C_3H_5N_3O_9(l) \rightarrow 6\,N_2(g) + 12\,CO_2(g) + 10\,H_2O(g) + O_2(g)$$

nitroglycerine → nitrogen + carbon dioxide + water + oxygen

This equation shows that for every four molecules of nitroglycerine that react, six molecules of nitrogen, twelve molecules of carbon dioxide, ten molecules of water and one molecule of oxygen are produced, as well as energy. That is, from four molecules of nitroglycerine, a total of twenty-nine molecules of gas are produced, as well as energy. This is typical of the chemical equation for an explosion, with a large number of gas molecules being produced, as well as the reaction being highly exothermic.

The **law of conservation of mass** states that, in a chemical reaction, the total mass of all the reactants is equal to the total mass of the products. All the atoms that are present at the beginning of a chemical reaction are there at the end; they are just arranged in a different way. This is why the equation for this reaction, and all chemical equations, needs to be balanced, with the same number of atoms on each side of the equation.

Oxidation and reduction reactions

As you are reading this book, an **oxidation** reaction is keeping you alive. It is respiration. Respiration is a reaction in which sugar combines with oxygen to give our cells the energy they need to stay alive. Many chemical reactions involve oxygen. Common examples are combustion and corrosion. These reactions involve the combination of oxygen with a fuel or a metal.

The opposite process is called **reduction**. Compared with oxidation, reduction is the removal of oxygen. One such example is the reduction of iron ore into iron metal. An example of an iron ore is iron(III) oxide, with the formula Fe_2O_3. In real processes, carbon is added to remove the oxygen. Carbon has a greater attraction for oxygen than does iron. As an equation, this process is written as:

$$2\,Fe_2O_3(s) + 3\,C(s) \rightarrow 4\,Fe(s) + 3\,CO_2(g)$$

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Discussion

1 a All nitrates and sulfates were soluble.
b Chloride ions and bromide ions formed a precipitate with silver cations only.

2 a Potassium did not form any precipitates. (Depending on their concentration, magnesium and calcium may not have formed any precipitates.)
b Calcium, copper, magnesium and iron only formed some precipitates.

3 Students' results will vary.

4 $AgNO_3\,(aq) + NaCl\,(aq) \rightarrow AgCl\,(s) + NaCO_3\,(aq)$
$FeCl_3\,(aq) + 3\,NaOH\,(aq) \rightarrow Fe(OH)_3\,(s) + NaCl\,(aq)$

5 Touching the end of the droppers on the plastic sleeve may contaminate the solution in the dropper. A precipitate will form that may affect the dropper or the results of the experiment.

6 Some solutions may have a partial solubility. The concentrations of the solutions may affect the results. Many senior chemistry students need to memorise the rules of solubility when they go on to further study. This can be encouraged early on using a range of memory tools.

Oxidation and reduction reactions

It is important to provide many examples of these reactions so that students can label the various reactants and oxidants.

- $4\,Fe$ (reductant) $+ 3\,O_2$ (oxidant) $\rightarrow 2\,Fe_2O_3$
- CO_2 (oxidant) $+ H_2$ (reductant) $\rightarrow CO + H_2O$

Rusting is a good example to use. Rusting is the oxidation of the metal, forming the metal oxide. This can be prevented by placing a barrier between the oxygen and the metal. This can be done on a car, for example, using wax or a polyurethane coating. Other metal objects can be protected with a coat of paint, whereas fruit, like apples, can be protected with a squeeze of lemon juice. Of course, if the coating isn't complete, the oxygen will penetrate any holes. This is the reason painted bikes can still rust.

Answers

What do you know about writing chemical equations?

1 Oxidation is when an element or compound combines with oxygen. Cellular respiration is an example of this.
Reduction is when a compound loses oxygen. The purification of iron from iron oxide is an example of this.
2 Oxidants supply the oxygen for an oxidation reaction (they are reduced). The iron oxide is an example of this.
Reductants receive the oxygen for an oxidation reaction (they are oxidised). The carbon in the iron purification process is an example of a reductant.
3 Iron oxide is the oxidant, carbon is the reductant.
4 Being underwater restricts access to oxygen; therefore, oxygen needs to be supplied through an oxidant for the oxidation of the fuel.

This reduction reaction occurs in the making of iron and steel from iron ore. Carbon, in the form of coke, is added to a blast furnace. Molten iron forms and is drained off to form ingots of iron, or further purified and alloyed to become steel.

Some chemical jars have a diamond-shaped warning label on the side, with the words 'OXIDISING AGENT' or 'OXIDANT'. These substances can supply oxygen, or take the place of oxygen, in an oxidation reaction. In gunpowder, the oxidant is potassium nitrate, $KNO_3(s)$, which provides the oxygen for the combustion process to occur. This is why gunpowder burns without air. Similar oxidants are potassium chlorate ($KClO_3$), potassium perchlorate ($KClO_4$) and potassium permanganate ($KMnO_4$). Other oxidants are chlorine (Cl_2) and hydrogen peroxide (H_2O_2).

The opposite of an oxidant is a reductant (reducing agent). Reductants remove oxygen, or take it, from other substances; they combine with the oxygen atoms they have taken. Common reductants are carbon and carbon monoxide. Both of these reductants take oxygen to form carbon dioxide.

$$C(s) + \text{oxygen} \rightarrow CO(g)$$
$$CO(g) + \text{oxygen} \rightarrow CO_2(g)$$

Carbon is the most common reductant in the processing of metals. Carbon is readily available, and cheap, in coal. When coal is heated in the absence of air, the volatile components are released. The solid left behind is called 'coke', which is nearly pure carbon. Coke is porous and ideal for use as a reductant in many chemical processes.

What do you know about writing chemical equations?

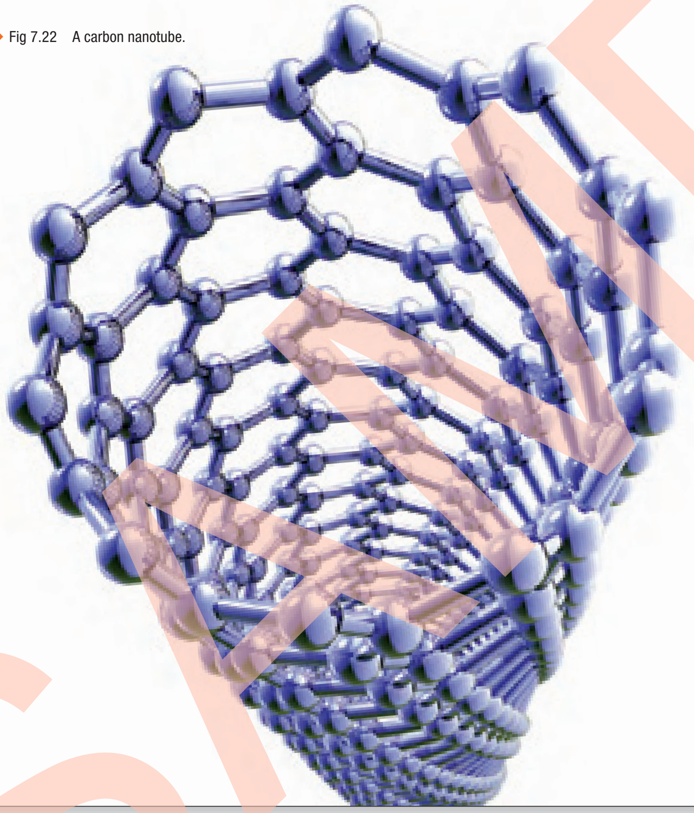
1 What are oxidation and reduction? Give an example of each process.
2 What are oxidants and reductants? Give an example of each.
3 What is the oxidant and reductant in the smelting of iron ore to form iron?
4 Torpedoes (underwater missiles) contain a solid fuel and a solid oxidant. What is the advantage of this?

Nanotechnology

Nanotechnology operates at the scale of the nanometre, which is approximately one-ten thousandth of the width of a human hair. This is the level of atoms or molecules. Nanotechnology allows artificial manipulation of atomic or molecular processes or objects. For example, computers the size of blood cells with tiny wireless transmitters could report on the health of a person without that person requiring surgery. Nanomachines (or nanobots) are tiny machines that are being developed at the molecular level. Scientists hope to develop nanobots as small as viruses or bacteria to perform tasks on a nanometre scale.

A **carbon nanotube** is an allotrope of carbon with very different properties to its other allotropes, such as graphite and diamond. Carbon nanotubes are the focus of intensive research for many applications in the future.

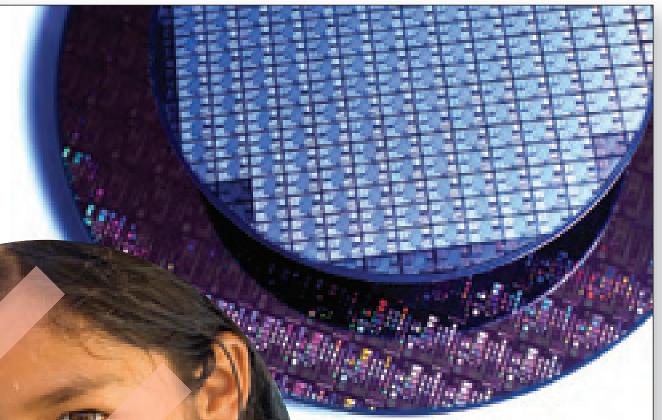
Carbon nanotubes are extremely hard, have very high tensile strength and are very efficient conductors of heat and electricity. That is, carbon nanotubes exhibit many properties usually found in metals. However, in contrast with most metals, carbon nanotubes are extremely light and flexible.



→ Fig 7.22 A carbon nanotube.

Carbon nanotubes might be used:

- in medicine, where their high electrical conductivity may make them suitable to bypass faulty nerve cell wiring in damaged brains
- to create clothing with unique properties, such as protection against bullets and other missiles
- in computing and television, where they are being used to develop flat, folding, futuristic television screens with greater image resolution than the human eye can detect
- for renewable energy devices, such as solar panels, due to their efficient absorption of heat, and in wind turbines for making blades lighter and stronger.



How are carbon nanotubes made?

The emergence of nanotechnology as a key scientific force has resulted from relatively recent and rapid developments in the capacity of scientists to:

- put (nano-sized) quantities of matter where it is wanted
- use controlled amounts of nano-sized materials for a practical purpose
- detect and monitor the location and configuration of nanoscale materials.

There are two manufacturing approaches to making nano-sized materials:

1 The top-down method involves using mass materials and breaking them down by physical or other means into nanoscale components.
2 The bottom-up method, also referred to as molecular manufacturing, is a more complicated process because it relies on the construction of templates on which nanomolecules will form under the appropriate chemical and physical conditions.

A good example of the top-down method can be found in the sunscreen industry, where materials to block UV light, such as titanium oxide and zinc oxide, can be transformed by a grinding process from their white, opaque mass forms into invisible, nano-sized particles. These are known as nanopowders.

A good example of the bottom-up method is the production of carbon nanotubes. A layer of metal catalyst particles is exposed to high heat and a carbon-containing gas. The nanotubes form at the interface between the gas and the metal catalyst.

What do you know about nanotechnology?

1 What two main manufacturing processes are used to make nanomaterials?
2 Which one of these two would be described as a chemical process? Explain your reasoning.
3 All powders are made up from small particles. How is a nanopowder different from a normal powder?
4 What is a carbon nanotube? Describe its structure.
5 The production of carbon nanotubes involves the use of a catalyst. What do you understand by the term 'catalyst'?

Nanotechnology

Carbon nanotubes

Introducing the concept of nano measurements can be difficult for some students. Using a common ruler with centimetres and millimetres can help. Ask the students to place their fingers either side of a millimetre. Ask them to imagine a nanometre is one millionth of a millimetre. The hydrogen atom is approximately 0.12 nanometres wide. This means approximately eight hydrogen atoms can fit in one nanometre. Nanotechnology involves understanding the properties of atoms well enough to be able to manipulate the way they are arranged.

For example, one of the first arrangements to be discovered is the buckminsterfullerene molecule (C60). This molecule has 60 carbon atoms arranged in a soccer ball shape. The molecule can be used to deliver drugs by placing small amounts of other molecules inside the 'ball'.

Carbon nanotubes (which look like a tube of chicken wire with carbon atoms at the joins) behave more like individual molecules than the graphite sheets (the usual arrangement of carbon atoms). They come in a variety of diameters and lengths.

Answers

What do you know about nanotechnology?

1 The top-down method involves breaking apart large materials to form the smaller nanoparticles. The bottom-up method involves chemically building the nanotubes.
2 The bottom-up method involves using chemical and physical processes to construct the nanotubes from small templates.
3 The particles in nanopowder are much smaller than normal powder.
4 A carbon nanotube is a small tube of carbon atoms (4 nanometres) arranged like chicken wire with the carbon atoms at the links in the wire.
5 Catalysts increase the rate of a reaction without taking part (or being used up).

obook
ID07.08 Video link: Carbon nanotubes

BIG IDEAS

7.1 How do we use the products of chemical reactions?

Remember and think

1 Decomposition reactions usually involve a single reactant breaking apart into several products. Direct synthesis reactions involve several reactants chemically bonding to form a single product.

2 acids + bases → water + salt
acids + carbonates → water + salt + carbon dioxide
acids + metals → salt + hydrogen

3 acids + carbonates and some combustion reactions (respiration)

4 Oxidants, such as carbon dioxide, provide oxygen for oxidation reactions.

Apply

5 Polypropylene is a thermoplastic that softens when heated. These 'plastics' have a linear structure that allows them to be melted and moulded into set shapes.

6 Soluble sodium nitrate will be formed along with two precipitates, namely ammonium sulfate and lead chloride.
- ammonium nitrate + sodium sulfate → sodium nitrate + ammonium sulfate (s)
- lead (II) nitrate + sodium chloride → lead chloride (s) + sodium nitrate

7 a The bauxite would be reduced (have oxygen removed) to form aluminium.
b $2\ Al_2O_3 \rightarrow 4\ Al + 3\ O_2$

8 Students' results will vary. Possible examples include the treatment of exhaust fumes from burning petrochemicals and enzymes in the digestion of food.

Analyse and evaluate

9 The melting of a polymer refers to the polymer structure changing from a crystalline structure to a solid, shapeless phase. Thermoset polymers will decompose at high temperatures before they melt. The formation of polymers involves the joining together of the monomer units into a long chain. As a result, small molecules (water) can be given off.

10 $CuO + H_2 \rightarrow Cu + H_2O$. In this example the copper oxide is reduced to copper and the hydrogen is oxidised to form water.

<<BIG IDEAS>> Interaction and change

7.1 How do we use the products of chemical reactions?

Remember and understand

1 Describe the differences between decomposition reactions and direct synthesis reactions.

2 What types of products are formed when acids react with metals, carbonates or bases?

3 Describe two different types of reactions that both produce carbon dioxide.

4 Using an example, describe what is meant by the term 'oxidant'.

Apply

5 Polypropylene is a plastic that can be easily melted and formed into a range of products. Describe the likely structure of polypropylene and explain how its structure allows the plastic to be moulded into a range of shapes.

6 A student mixed the following solutions together in a beaker: ammonium nitrate, sodium chloride, lead(II) nitrate, sodium sulfate. Describe what would be seen in the beaker. Explain your answer using a chemical equation.

7 Sodium metal was used to produce aluminium from purified bauxite (Al_2O_3).
a What type of reaction would be occurring?
b Write a chemical equation for the process, ensuring that the law of conservation of mass is applied to the equation.

8 Describe two examples of the use of catalysts in the production of chemical products.

Analyse and evaluate

9 Describe, in terms of molecules, the key differences between the formation and melting of a polymer.

10 A student read in a science textbook that when an oxidation reaction happens, a reduction reaction always occurs. Use an example to demonstrate this fact.

Critical and creative thinking

11 How do you think advances in technology will have helped scientists improve their methods for producing chemical products?

<<CONNECTING IDEAS>> Interaction and change

12 When the plastic polyethene is produced, molecules of ethene, which is a gas at room temperature, interact and produce the long chain molecule polyethene. A chain reaction occurs, which enables the chain to build up.
a What conditions are used in this reaction to ensure that the interactions result in a new product?
b Explain how a gas is able to be changed into a solid product in this reaction.
c Suggest why the ethene gas must be very pure for this reaction to succeed.
d Do you think this type of chemical change can be described as direct synthesis? Explain your reasoning.

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7.2 How can we control the speed of chemical reactions?

How fast a chemical reaction happens can be a life and death issue. The rapid combustion reactions occurring in a bushfire can easily get out of control as the fire spreads, turning wood to ash and producing vast amounts of heat energy as the fire proceeds. Our bodies rely on chemical reactions that convert the glucose in our blood to glycogen. If this process is too slow, as is the case in some types of diabetes, high levels of blood sugar ensue, a condition called hyperglycaemia. This has the potential to result in heart or other diseases. Controlling chemical reactions is vital in our environment, in our lives and in our bodies.

<<DISCOVERING IDEAS>>

Fast or slow?

We are surrounded by chemical reactions. Some are fast, like the gas burning in a barbecue, and some are slow, like the corrosion on the outside of the barbecue. Sometimes we want reactions to occur quickly, but sometimes a fast reaction may not be required or may, in fact, be dangerous.

For each of the following situations, describe whether you think a fast or slow chemical reaction is preferred. Discuss your thoughts with others. For each situation, write down ways that we are able to control the rate of the reaction, either to slow down or speed up the production of products.
- the rusting of an iron bridge
- the reaction in the baking of bread that produces carbon dioxide (which makes the bread rise)
- the oxidation of alcohol in wine to form vinegar
- the combustion of a fuel in a rocket engine
- the chemical processes involved in the action of a pain-killing drug

For one of the situations for which you chose to speed up the reaction, think about what is happening to the particles (atoms or molecules) during the reaction. Explain how your chosen method to speed up the reaction would enable the particles to interact and change more quickly.

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Critical and creative thinking

11 Understanding catalysts has allowed commercial quantities of substances to be produced. Nanotechnology is allowing the more effective use of small quantities of drugs.

<<CONNECTING IDEAS>>

12 a Ethene gas needs high temperatures and pressure to enable the polymer to be made. Alternatively, catalysts can be used.
b Ethene gas can be converted into a white solid at high temperatures and pressures.
c Any impurities in the gas are removed before production because the high pressure and temperature can cause exothermic reactions or weaken the polymer that is made.
d Direct synthesis is the building up of larger molecules using smaller molecules. This process describes the formation of a polymer.

<<DISCOVERING IDEAS>>

Fast or slow?

This is an ideal topic for a jigsaw activity. A class can be broken into groups, with each group to research one of these methods.

Each student should write down what their group discovers. When finished, one student from each group reports back to a second group to describe their research.

Together, the second group should discuss how the movement of particles can explain the first group's findings.

The rusting of an iron bridge can be prevented by a coat of paint, which provides a barrier against the oxygen needed for the oxidation process. Alternatively, key parts of a bridge (such as bolts) can be galvanised before they are used. This provides a protective coating of zinc over the bolt, preventing damage.

Bread is made with yeast. Yeast undergoes respiration, producing carbon dioxide. If the yeast in 'rising bread' is kept warm, it will respire faster, producing more carbon dioxide for the bread to rise faster.

To speed up the oxidation of alcohol to make vinegar, the mixture can be heated and extra oxygen mixed through.

To increase the combustion of fuel in a rocket engine, extra oxygen can be added.

The activity of a pain-killing drug can be increased by having a stronger concentration of the drug.

Reactions can be increased by
- increasing the concentration of the reactants (more particles to collide and react)
- increasing the temperature of the reactants (particles move faster and collide more often)
- adding a catalyst (helps the particles to meet)
- decreasing the size of the reactant particles (greater surface area for a reaction to occur)
- stirring the mixture (helps the particles meet).

Why are reaction rates important?

There are many reasons why industry needs to speed up or slow down a chemical reaction; however, there are also many everyday examples:

- In a hurry to get to school? Crush the multivitamin so that it dissolves faster.
- Really bad headache? Crush the aspirin or Panadol tablet so that it dissolves or is absorbed faster.
- Bath salts will dissolve faster in a hot bath than in a warm bath.
- A fire will light quicker and be hotter if it has easy access to oxygen.
- Closing a door behind you when escaping from a fire will make the fire burn slower.
- Painting over a scratch on a bike will prevent the bike from rusting.
- Chewing food will speed up the rate at which it is digested.
- High-octane fuel has a higher concentration of burnable fuel. Thus, the combustion reactions in an engine will be more effective.

DESIGN YOUR OWN …

Effect of the size of pieces on reaction rate

As part of the *Australian Curriculum: Science*, students need to develop a series of scientific skills. All teachers should be aware of the requirements at each level. Some of the criteria covered by this experiment include:

- combine research using primary and secondary sources with students' own experimental investigation
- explain the choice of variables to be controlled, changed and measured in an investigation
- consider the potential hazards of chemicals or biological materials used in experimental investigations
- describe safety precautions required for investigations
- design and construct appropriate graphs to represent data and analyse graphs for trends and patterns
- distinguish between random and systematic errors and how these can affect investigation results

Why are reaction rates important?

A **reaction rate** is how fast a reaction proceeds. A fast reaction has a high reaction rate; a slow reaction has a low reaction rate.

The reaction rate is very important. Explosions must have a high reaction rate if they are to be useful. The rusting of iron has a slow reaction rate. Imagine what would happen to iron if it rusted at the same rate as an explosion. Chemists have a role to ensure that reactions occur quickly enough to be useful, but not too quick so as to be explosively dangerous.

In the chemical industry, controlling the rate of a reaction is vital. Reactions that are too slow are not economic, because equipment is tied up for a long time. Reactions that are too fast need to be controlled, or contained in strong reaction vessels. The containment vessels cost a lot of money to build and maintain. Chemists and chemical engineers have the role of making chemical reactions as cheap as possible. A large part of this is achieved by controlling the rate of the reaction.

What controls the rate of a reaction?

The factors that control the rate of a reaction in a factory are the same as the factors that control reactions in your school laboratory. You can therefore investigate each factor and then relate it to a chemical process in a factory.

DESIGN YOUR OWN …

Effect of the size of pieces on reaction rate

Aim

To discover how the size of pieces (chunky, fine, powder) affects the rate of a chemical reaction.

Materials

Pieces of calcium carbonate (limestone, chalk or marble)
Dilute hydrochloric acid (1.0 M)
Test tubes
Test tube rack
Stopwatches
Weighing scales
Measuring cylinders
Safety glasses
(Note: you may be able to access other equipment depending on your experimental plan.)

Method

1 Separate the samples of calcium carbonate according to size and/or use a hammer to crush some pieces to make smaller pieces or powder.
2 Gather up approximately half a teaspoon of each size.
3 Plan an experiment—on your own or in a group, as your teacher directs—that will determine the relationship between the size of the pieces and the rate of the reaction.

Notes

- The reaction that you are investigating is between calcium carbonate and hydrochloric acid. The equation for this reaction is:
  $CaCO_3(s) + 2\,HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$
- You will need to decide on the best way to measure the rate of this reaction. This may involve some preliminary trials to test whether your method will work.

Discussion

Using the guide on the opposite page to help you, write a conclusion for your experiment.

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SKILLS LAB

How to conduct an investigation

Below is a guide to finding answers to questions using an experiment and scientific method.

Generic guide	Specific notes for this experiment
Questioning and predicting	
What question do you want to answer?	How does the size of the pieces (with a different surface area) affect the rate of reaction?
Rewrite the question as a hypothesis that can be easily tested.	If there are small pieces, with a large surface area, then the reaction rate will be faster.
Planning and conducting	
Plan an experiment to test the hypothesis. • What will you do? • How will you set up the experiment? • What will you observe or measure? • Will this actually test the hypothesis? • What are the dependent and independent variables?	• Use limestone chips, $CaCO_3$, and select a range of sizes or crush some with a hammer. React with dilute hydrochloric acid, HCl. • Use a series of test tubes, each containing limestone chips of a different surface area. Add acid to each test tube. • Look for bubbles, or fizzing, of CO_2 gas. The more bubbles, the faster the reaction rate. • Use the same volume of acid, the same sized test tubes and the same mass of chips.
Safety assessment: • Is this experiment safe? • What personal protective equipment will you need? • What actions should you take to ensure your safety, as well as that of others?	• Safety glasses are essential every time you use acid. Make sure that they fit properly. • Enclosed shoes protect your feet from broken glass, drop injuries and spilt acid. • A plastic apron to protect your school uniform is a good idea.
What will be your control, or comparison, in this experiment? What variables should you control?	Consider: • the amount of $CaCO_3$ used • the volume of acid used • the concentration of acid used • the temperature of the acid and $CaCO_3$ chips • the size of the test tubes used
Processing and analysing data and information	
How will you record your results? Will the results be quantitative or qualitative?	Construct a table to show the results.
Is the hypothesis supported by these results? Will this be the same with other chemicals and other reactions?	You will have to answer this question when you have completed this experimental investigation.
What generalisations can you make from your hypothesis and the results of the experiment?	Can the conclusions from the reaction of acid and calcium carbonate be applied to other chemical reactions?
Evaluating	
What were the sources of error and how could you improve the quality of the evidence that was obtained from the experiment?	Was the way of measuring the rate of the reaction accurate? How could that be improved? Were the quantities of chemicals used measured accurately enough?

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- explain why suggested changes will improve the accuracy of investigations
- compare conclusions with earlier predictions and review scientific understanding where appropriate.

Practical hint

Have the various particle sizes of calcium carbonate prepared prior to class. Marble chips come in various sizes; sort them into small and large. Use a mortar and pestle to crush some chalk to use as the fine powder.

Safety

- Wear safety glasses and lab coats and have hair tied back.
- 1 M hydrochloric acid is corrosive. Wear safety glasses and lab coats. Avoid contact with the skin.
- If students choose to break up marble chips themselves, there is the added risk of broken chips becoming a missile. All students and teachers need to be wearing safety glasses at all times anyone is hammering in the area.

Expected results

The finer the calcium carbonate, the faster the reaction.

SKILLS LAB

How to conduct an investigation

- dependent variable—the variable that will be tested at the end of an experiment
- independent variable—the variable that the scientist has control over, that can be chosen and manipulated

For example, if the scientist is studying how stress affects heart rate, the independent variable is the stress and the dependent variable is heart rate.

- controlled variables—the things that should be controlled in the experiment
  - the amount of $CaCO_3$ should be weighed so that the same amount can be added to each test tube
  - measure 2 mL of 1 M HCl into each test tube
  - all solutions should be at room temperature
  - the same equipment should be used for all measurements
  - the same sized test tubes should be used for each experiment

It is important to emphasise the need to take measurements in all experiments because any other observations may be subjective. This can be shown using the following demonstration.

You will need three containers large enough to place two hands in (ice cream containers work well).

Fill the first container with cold water (with ice), the second container with warm water and the third container with hot water (it must be safe to place a hand in).

A student should place one hand in the hot water and the other hand in the cold water and leave for 2 minutes.

After 2 minutes, the student should remove both hands and place both in the warm water (one hand will feel warm and the other will feel cold despite the water being the same temperature).

After completing this demonstration students can consider how to take a measurement of the acid and carbonate reaction. (Measure the amount of time it takes for the $CaCO_3$ to dissolve completely.)

obook
ID07.09 Weblink: Rates of reaction

EXPERIMENT 7.7

Effect of temperature on reaction rate

One example of a reaction that must be kept at a constant temperature is that within a nuclear reactor. The coolant fluid in nuclear reactors is designed to keep the fuel rods cool so that they do not react too quickly and melt from the heat produced. If the coolant fluid is lost (as happened at Three Mile Island and Fukushima), the rods will heat up so much that the uranium will melt through the floor of the plants and react with the ground water, releasing large explosions of hydrogen, producing radioactive steam and debris.

Practical hints

- Three possible variations of temperature could include room temperature, ice water and boiling or very hot water. The test tube could be placed in a 250-mL beaker with a thermometer.
- Suggest using 5 mL of 0.005 M oxalic acid and 5 mL of 0.001 M potassium permanganate in a test tube: put one chemical in the test tube and allow its temperature to reach equilibrium with the temperature of its surroundings before adding the second chemical.

Safety

Potassium permanganate is classified as toxic. Do not put it down the sink. 0.005 M oxalic acid is classified as a weak acid. Safety glasses, lab coats and gloves should be worn.

Lab tech notes

- 0.005 M oxalic acid has a pH of 2.71 and 0.001 M potassium permanganate has a pH of 5.7. Both chemicals are acidified.
- Oxalic acid is a solid with a MW of 126.07. Thus, 126.7 g oxalic acid to 1 litre will give a solution of 1 M oxalic acid, whereas 0.32 g oxalic acid to 500 mL will give a solution of 0.005 M oxalic acid.
- Potassium permanganate is a solid with a MW of 158.03. Thus, 158.03 g potassium permanganate to 1 litre will give a 1 M solution and 0.08 g potassium permanganate to 500 mL will give a 0.001 M solution.

Expected results

The higher the temperature, the faster the reaction.

Investigating other factors that may affect reaction rates

There are other factors that affect the rate of a reaction. Table 7.2 lists some of the other factors that can affect reaction rate, along with a hypothesis that could be written for each of the variables. In the table there are suggestions for chemical reactions that are suitable for testing the hypothesis.

Table 7.2 suggests some aspects of the rates of chemical reactions that can be investigated. Your teacher may guide you with these or other investigations. In all cases, the guide to performing a scientific investigation on page 277 will help you design your experiments and to use your results effectively.

The next section includes some more specific experiments that can be performed to investigate the rates of chemical reactions.

→Table 7.2 Factors that can affect reaction rates

Variable	Hypothesis	Suggestions for chemicals and reactions suitable to test the hypothesis
Surface area	If there are small grains, with a large surface area, then the reaction rate will be faster	Calcium carbonate and dilute hydrochloric acid
Concentration	The more dilute a solution, the slower the reaction rate	Use powdered $CaCO_3$ and different concentrations of hydrochloric acid or use magnesium ribbon and different concentrations of hydrochloric acid (in both cases, the volume of gas produced can be measured)
Heat or temperature	Reactants with more heat (at a higher temperature) react faster than reactants with less heat (at a lower temperature) or if reactants have a higher temperature, they will react quicker	Use a solution of potassium permanganate mixed with a solution of oxalic acid (the purple permanganate solution becomes colourless when the reaction is complete); the solutions can be warmed before mixing to investigate the effects of changes in temperature
Mixing or stirring	Reactants that are mixed by stirring will react faster than reactants that are not mixed	Use a solution of potassium permanganate mixed with a solution of oxalic acid—the amount of stirring of the reaction mixture can be varied
Adding a catalyst	1 Adding a catalyst increases the reaction rate compared with not using a catalyst 2 A catalyst can be recovered and used again	Dilute hydrogen peroxide (H_2O_2) solution decomposes slowly and can be used to investigate the effect of the catalyst manganese dioxide

EXPERIMENT 7.7

Effect of temperature on reaction rate

Aim

To investigate the effect of temperature on reaction rate.

Materials

0.001 M potassium permanganate solution
0.005 M oxalic acid solution
Test tubes
Stopwatch
250 mL beaker
10 mL measuring cylinders
Safety glasses
Kettle or access to hot water
Thermometer

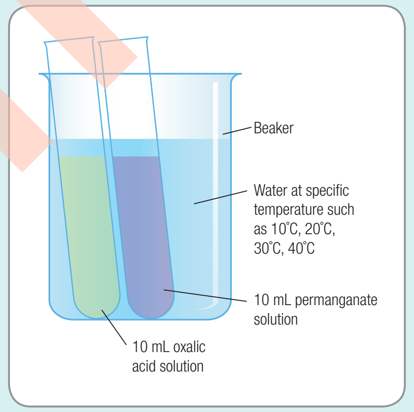
Avoid contact with the potassium permanganate solution and oxalic acid solution. Wear protective gloves, lab coats and safety glasses.

Method

1 Construct a hypothesis for your experiment.
2 This experiment can be performed using a water bath to warm or cool specific amounts of the two solutions to the required temperature before they are mixed. Leave the test tube containing the reaction mixture in the water bath while the reaction time is measured. (The reaction is finished when the purple colour of the potassium permanganate disappears.)
3 Consider what different temperatures will be used, how the temperature will be measured, what volumes of solutions should be used and how the results will be best presented.

Conclusion

Write a conclusion for your experiment that includes a discussion of your hypothesis based on the data from the experiment and an evaluation of the methods used to produce these data.



→Fig 7.23 A water bath can be used to control the temperature of solutions.

EXPERIMENT 7.8

Using a catalyst

Aim

To investigate the effect of adding a catalyst to a reaction. The reaction used in this experiment is the decomposition of hydrogen peroxide:

$$2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g)$$

Materials

Hydrogen peroxide solution (H_2O_2) (10 volume)
Manganese dioxide powder (MnO_2)
Test tubes

Safety glasses and protective clothing must be worn at all times. Avoid contact with the hydrogen peroxide.

Method

1 Place 5 mL hydrogen peroxide solution into two separate test tubes.
2 Allow one of the tubes to stand; add a small amount of the manganese dioxide to the other test tube using a spatula.
3 Observe and describe the changes that occur in the two test tubes.

Results

Record your observations in an appropriate format.

Discussion

1 Was there any evidence of any reaction in the test tube in which manganese dioxide was not added?
2 Would you say that the manganese dioxide acted as a catalyst in this reaction? Justify your answer.

Further investigation

For each of the two scenarios below, write a hypothesis and design an experiment to test your hypothesis. You may need to use some additional equipment. Once you have checked with your teacher, you may be able to complete your investigation. Don't forget to write a report of your findings.

1 Is the manganese dioxide used up in the reaction?
2 Does the amount of the catalyst used affect the rate of the reaction?

EXPERIMENT 7.8

Using a catalyst

Practical hint

The approximate amount of manganese dioxide required is the amount that fits on the tip of a small spatula.

Safety

Wear safety glasses, lab coat and gloves. Hydrogen peroxide can burn the skin and damage the eyes.

Lab tech notes

A 10-volume hydrogen peroxide solution is equivalent to 3% hydrogen peroxide. A 3% hydrogen peroxide solution can be purchased from the supermarket or diluted from a concentrate.

Expected results

The test tube with no manganese dioxide has no reaction. The test tube with manganese dioxide and hydrogen peroxide fizzes and bubbles rapidly.

Discussion

1 There should be no reaction visible. It is important to emphasise to students that although they saw no reaction occurring, this does not mean there was no reaction at all. It was just too slow to observe.
2 When manganese dioxide was present, the reaction occurred much faster even though the manganese dioxide did not appear to be used in the reaction. These are the characteristics of a catalyst.

Further investigation

1 Manganese does not get used up in the experiment. This can be tested by weighing the manganese dioxide before the experiment, drying it after use in the experiment and then reweighing it.
2 The amount of catalyst available affects the rate of a reaction. This can be shown by measuring the amount of oxygen being released using a ruler to determine the distance the oxygen bubbles move up the side of the test tube.

EXPERIMENT 7.9

Effect of concentration on reaction rate

Practical hints

- Ask your lab tech to gather similar sized marble chips prior to class. Avoid the chips being crushed and powdery.
- Each group will need a digital balance.
- Ensure students know how to handle and use an electronic balance before they start. In addition, ensure they know that the balance must be kept dry.
- When the graphs are drawn, the students can use the same graph but it could be suggested that each line showing each concentration could be drawn using a different coloured pen.

Safety

Avoid contact with the acid solutions because they are corrosive. Wear lab coats, gloves and safety glasses at all times.

Class clean up

Collect conical flasks with acid and marble chips still in them. With all safety clothing still on, pour the marble chips and HCl solutions through a sieve into a single sink. Rinse the conical flasks and marble chips thoroughly with cold tap water. Place the marble chips on a paper towel to dry for re-use. Flush the sink with cold water.

Expected results

- The more concentrated the solution of hydrochloric acid, the faster the reaction.
- A table of possible results showing the effect of concentration on reaction rate and mass loss, in grams, over time is given below.

HCl (M)	30 s	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min
0.5M HCl	0.08 g	0.11 g	0.11 g	0.11 g	0.11 g	0.11 g	0.12 g	0.12 g	0.12 g
1.0M HCl	0.18 g	0.28 g	0.30 g	0.31 g	0.31 g	0.31 g	0.31 g	0.31 g	0.31 g
2.0M HCl	0.36 g	0.55 g	0.63 g	0.64 g	0.64 g	0.65 g	0.65 g	0.65 g	0.65 g

EXPERIMENT 7.9

Effect of concentration on reaction rate

Aim

To investigate the effect of concentrations of solutions on reaction rate.

Materials

20 mL x 0.5 M HCl (hydrochloric acid)
20 mL x1.0 M HCl
20 mL x 2.0 M HCl
30 g small marble chips of similar size
3 x 100 mL conical flasks
Electronic balance
Stopwatch
25 mL measuring cylinder

Avoid contact with the acid solutions because they are corrosive. Wear lab coats, gloves and safety glasses. Wash off with water immediately if contact is made.

Method

1 Construct a hypothesis for your experiment.
2 Prepare a table for your results as shown in Table 7.3.
3 Place a conical flask on the digital balance and tare the balance so it reads zero. Weigh approximately 10 g of marble chips to the flask.
4 Using a measuring cylinder add 20 mL of 0.5 M hydrochloric acid to the conical flask still sitting on the digital balance. Immediately tare the balance once so that it returns to zero briefly, and start the stopwatch. The numbers on the balance will move into negative readings from zero, as gas is given off.
5 Record in your results table the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.
6 Repeat the experiment as described above using 1.0 M HCl and then 2.0 M HCl.
7 Plot a graph of the mass loss by minutes as shown in your table. All three acid concentrations can be plotted on the same graph for comparison.

Conclusion

Write a conclusion for your experiment that includes a discussion of your hypothesis based on the data from the experiment and an evaluation of the method used to produce these data.

Table 7.3 Effect of concentration on reaction rate

HCl concentration (M)	30 s	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min
0.5									
1.0									
2.0									

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What do you know about why reaction rates are important?

1 What are the steps of the scientific method?
2 Why is it important to follow the steps of the scientific method?
3 What is a 'hypothesis'? Why is one important in an investigation?
4 What is a 'variable'?
5 What are the controlled variables in the experiment investigating the effects of particle size on reaction rate?
6 What are the independent and dependent variables in the experiment investigating the effects of temperature on reaction rate?

Reaction rates and particles

Party time!

Imagine this scenario. It's Sunday morning. You have a science assignment due on Monday morning but your friends have asked you to an important party on Sunday afternoon.

You decide to do your assignment, but it takes longer than you thought. So you rush to the shower and get dressed. But your hair is wet. There is not enough time to allow it to dry. How can you dry your hair quickly?

- blow air over it—moving air carries away water vapour, bringing in dry air to carry away more vapour
- heat the air—heat energy is needed to evaporate water, so the water will evaporate faster if the air is heated
- spread out or fluff up your hair—this gives a larger surface area for the water to evaporate from so that more water can evaporate at the same time.

Each of these methods will help you dry your hair quickly, so you will not be late for the party. Drying hair is a physical change. But the methods used to dry hair are similar to the methods chemists use to speed up the rate of chemical reactions.

How can you speed up the rate of a chemical reaction?

A chemical reaction proceeds when the reactants interact. The reactants combine to form the products. The more reactants that can interact in a certain amount of time, the faster the products will form and the reaction will be faster. A faster reaction has a higher reaction rate.

The theory that explains how reactions occur is called **collision theory**. It states that the particles of the reactants, such as atoms, ions or molecules, must collide so they can react. In explaining how to make a reaction occur faster, it is best to think of how to make more collisions.

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Answers

What do you know about why reaction rates are important?

1 The steps of scientific method are:
- ask a question
- write a hypothesis
- plan the experiment, including the variables (independent, dependent and controlled)
- determine any safety considerations
- complete the experiment
- record the results
- evaluate the results.

2 An experiment cannot be complete without an indication of what is being tested. Planning the experiment allows for fair testing of just one variable and the control of all other factors that may affect the result. Safety must always be considered. Results must be recorded accurately in a logical manner so that they can be evaluated to determine whether the original hypothesis was valid.

3 A hypothesis is an educated guess; a proposition, or set of propositions, set forth as an explanation for an observation

4 A variable is something that is changed during the experiment (independent), may change as a result of the experiment (dependent) or can be controlled during the experiment (controlled).

5 Controlled variables include the amount of $CaCO_3$, the amount of HCl, the temperature of the reactants and the equipment used.

6 The independent variable is the size of the $CaCO_3$ particles and the dependent variable is how fast the reaction occurred (or how many bubbles were produced).

How can you speed up the rate of a chemical reaction?

If not already done, it is important to revise the particle model for students to understand the collision theory. Everything around us is made up of moving particles. In solids, the particles are vibrating; in liquids, they are rolling over each other; and in gases, there is little attraction between them so they bounce around in the available space. This then extends to temperature. Hot particles move faster than slow particles.

How can you speed up the rate of a chemical reaction?

Increase the surface area

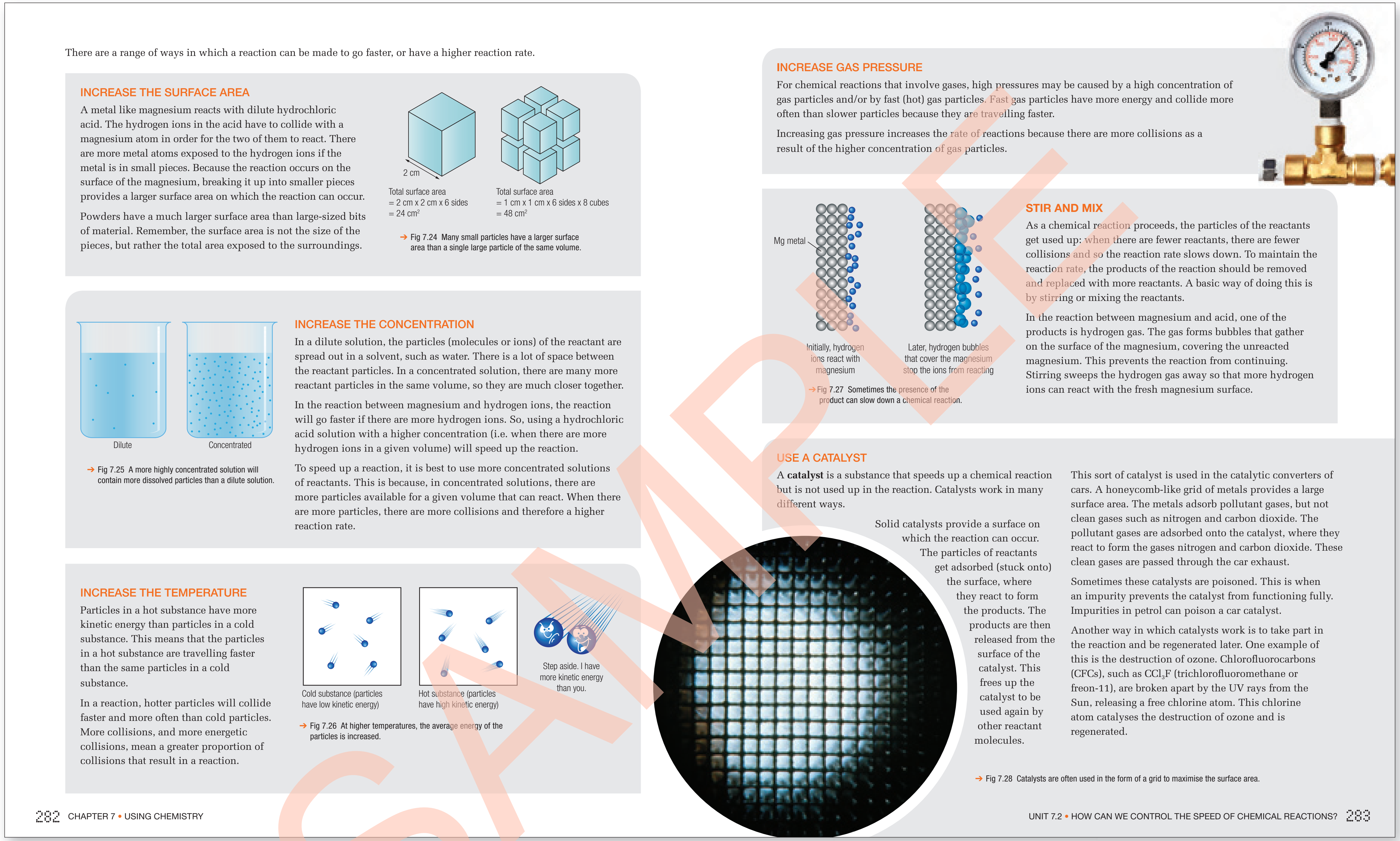
The concept of surface area can be easily demonstrated using small building blocks (like Lego). The blocks should be a mix of single cubes, double cubes or larger. Draw a template of a single square. This can then be duplicated until a grid is formed (like graph paper).

The students can then compare how many squares it takes to cover four single blocks compared with the four blocks jointed together. Students should realise the volume (and hence the mass) is constant; however, the number of squares reflects the surface available for the reaction to occur.

Increasing the concentration and/or temperature

This can be demonstrated by students moving around a set area. Measure and mark a square 3 m × 3 m on the ground. This is the set volume. Place two students (molecules) in the square and ask them to move around randomly. (Every time they bump into each other, a reaction will occur.) Then increase the concentration by placing four students (molecules) in the square. The number of collisions will increase, representing the increase in the rate of the reaction.

An increase in temperature can be represented by the students moving at a faster pace as they move around the square.



There are a range of ways in which a reaction can be made to go faster, or have a higher reaction rate.

INCREASE THE SURFACE AREA

A metal like magnesium reacts with dilute hydrochloric acid. The hydrogen ions in the acid have to collide with a magnesium atom in order for the two of them to react. There are more metal atoms exposed to the hydrogen ions if the metal is in small pieces. Because the reaction occurs on the surface of the magnesium, breaking it up into smaller pieces provides a larger surface area on which the reaction can occur.

Powders have a much larger surface area than large-sized bits of material. Remember, the surface area is not the size of the pieces, but rather the total area exposed to the surroundings.

Fig 7.24 Many small particles have a larger surface area than a single large particle of the same volume.

INCREASE THE CONCENTRATION

Fig 7.25 A more highly concentrated solution will contain more dissolved particles than a dilute solution.

In a dilute solution, the particles (molecules or ions) of the reactant are spread out in a solvent, such as water. There is a lot of space between the reactant particles. In a concentrated solution, there are many more reactant particles in the same volume, so they are much closer together.

In the reaction between magnesium and hydrogen ions, the reaction will go faster if there are more hydrogen ions. So, using a hydrochloric acid solution with a higher concentration (i.e. when there are more hydrogen ions in a given volume) will speed up the reaction.

To speed up a reaction, it is best to use more concentrated solutions of reactants. This is because, in concentrated solutions, there are more particles available for a given volume that can react. When there are more particles, there are more collisions and therefore a higher reaction rate.

INCREASE THE TEMPERATURE

Particles in a hot substance have more kinetic energy than particles in a cold substance. This means that the particles in a hot substance are travelling faster than the same particles in a cold substance.

In a reaction, hotter particles will collide faster and more often than cold particles. More collisions, and more energetic collisions, mean a greater proportion of collisions that result in a reaction.

Fig 7.26 At higher temperatures, the average energy of the particles is increased.

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INCREASE GAS PRESSURE

For chemical reactions that involve gases, high pressures may be caused by a high concentration of gas particles and/or by fast (hot) gas particles. Fast gas particles have more energy and collide more often than slower particles because they are travelling faster.

Increasing gas pressure increases the rate of reactions because there are more collisions as a result of the higher concentration of gas particles.

Fig 7.27 Sometimes the presence of the product can slow down a chemical reaction.

STIR AND MIX

As a chemical reaction proceeds, the particles of the reactants get used up: when there are fewer reactants, there are fewer collisions and so the reaction rate slows down. To maintain the reaction rate, the products of the reaction should be removed and replaced with more reactants. A basic way of doing this is by stirring or mixing the reactants.

In the reaction between magnesium and acid, one of the products is hydrogen gas. The gas forms bubbles that gather on the surface of the magnesium, covering the unreacted magnesium. This prevents the reaction from continuing. Stirring sweeps the hydrogen gas away so that more hydrogen ions can react with the fresh magnesium surface.

USE A CATALYST

A **catalyst** is a substance that speeds up a chemical reaction but is not used up in the reaction. Catalysts work in many different ways.

Solid catalysts provide a surface on which the reaction can occur. The particles of reactants get adsorbed (stuck onto) the surface, where they react to form the products. The products are then released from the surface of the catalyst. This frees up the catalyst to be used again by other reactant molecules.

This sort of catalyst is used in the catalytic converters of cars. A honeycomb-like grid of metals provides a large surface area. The metals adsorb pollutant gases, but not clean gases such as nitrogen and carbon dioxide. The pollutant gases are adsorbed onto the catalyst, where they react to form the gases nitrogen and carbon dioxide. These clean gases are passed through the car exhaust.

Sometimes these catalysts are poisoned. This is when an impurity prevents the catalyst from functioning fully. Impurities in petrol can poison a car catalyst.

Another way in which catalysts work is to take part in the reaction and be regenerated later. One example of this is the destruction of ozone. Chlorofluorocarbons (CFCs), such as CCl_3F (trichlorofluoromethane or freon-11), are broken apart by the UV rays from the Sun, releasing a free chlorine atom. This chlorine atom catalyses the destruction of ozone and is regenerated.

Fig 7.28 Catalysts are often used in the form of a grid to maximise the surface area.

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Stir and mix; use a catalyst

This activity is dependent on the atmosphere of the class. Teachers should use their judgement to determine whether this activity is appropriate.

Stirring and mixing can be demonstrated using the activity from the previous page. The 3 m × 3 m square is measured out on the ground and two or four students are placed in the square and told to move around to represent molecules moving in a set volume. To demonstrate mixing, when the students move to the outer reaches of the square, other students placed around the square can gently push them towards the centre of the square. This should increase the number of collisions between the two (or four) students (molecules), demonstrating an increase in the rate of the reaction.

The effectiveness of a catalyst can be demonstrated by placing a responsible student (or teacher) in the square to pull the moving molecules towards each other. The catalyst should not chase the students; however, when a student is within range they should hold onto them until a second student is in range and then cause them to bump gently into each other. The catalyst should then release all molecules and start again. This is to demonstrate that a catalyst must be in contact with the molecules before being activated.

Developing an understanding of the movement of molecules is difficult for many students because they must imagine the movements and reactions of things too small to see. Kinaesthetic activities, such as those described above, can assist in developing the students' understanding of such concepts.

obook

ID07.11 Video demonstration: Elephant's toothpaste
ID07.12 Interactive activity: Types of chemical reactions
ID07.13 Weblink: Rates of reactions virtual experiment

Enzymes as catalysts

It is important to use the correct terminology when discussing these concepts. It is incorrect to say 'catalysts do not take part in the reaction'. Catalysts, such as enzymes, must be in contact with the reactants in order to speed up the rate of the reaction. Therefore, they do not take part in the reaction. They do not, however, get used up in the reaction.

Answers

What do you know about reaction rates and particles?

1 Increase the surface area of the reactants, increase the concentration of the reactants, increase the temperature of the reactants, increase the gas pressure, stir or mix the reactants, use a catalyst.
2 Increasing the surface area of the reactants increases the amount of surface available for the reactants to collide.
3 A dilute solution has fewer molecules available in the same volume. This means there are fewer chances for the reactants to collide, as well as fewer reactants available to react.
4 When a reaction is stirred, it encourages the reactants to move faster, increasing their chances of colliding with each other.
5 A catalyst is a substance that speeds up a chemical reaction but is not used up in the reaction.
6 Catalysts can provide a contact surface for the reactants to undergo a chemical reaction or they can take part in the reaction and be regenerated at the end of the reaction.
7 An enzyme is a catalyst that is made and used in a cell. Enzymes are catalysts that speed up chemical reactions in living cells. Biology is the study of living things, therefore an enzyme is a biological catalyst.

The collision theory

The earlier demonstration of increasing rates of reactions does not take into account the three-dimensional shape of molecules. Students will often consider molecules and compounds as two-dimensional. This can be corrected using commercially available three-dimensional chemical models or, alternatively, Play Dough.

In this way, one chlorine atom from the original CFC can destroy up to ten thousand ozone molecules. The reactions occurring can be shown as follows:

$$CCl_3F + UV \rightarrow CCl_2F + Cl$$

Then ozone is destroyed:

$$Cl + O_3 \rightarrow ClO + O_2$$

The ClO is destroyed by O atoms, making more Cl:

$$ClO + O \rightarrow Cl + O_2$$

The Cl atoms are then free to destroy more ozone.

Fig 7.29 Chlorofluorocarbons (CFCs) were used to pressurise the gas used in aerosol cans before it was proven that the CFCs damaged the ozone layer.

Enzymes as catalysts

An enzyme is a catalyst made and used in living cells. Enzymes play an important part in all cellular processes. All the reactions that occur inside a cell are helped along by these catalysts. There are numerous enzymes in our bodies to help speed up reaction rates. For example, enzymes in the digestive system help break down food. Enzymes only work with specific reactants and so will only catalyse certain reactions.

Enzymes are also responsible for the ripening of fruit. When an apple is cut and left exposed to the air, it turns brown. But when vitamin C is sprinkled on the cut surface of the apple, it does not turn brown. The browning process is a result of enzymes in the fruit. As the fruit is exposed to air, enzymes in the fruit cells react with oxygen and digest the fruit cells. This process is known as oxidation. It is shown by changes in the colour (brown) and taste (bitter) of the fruit. Vitamin C is an antioxidant. It stops this reaction from taking place because it reacts with the enzymes, preventing them from digesting the fruit cells. So, the fruit does not brown.

What you know about reaction rates and particles?

1 What are the six ways of speeding chemical reactions in a solution in a beaker?
2 Why does a greater surface area increase the rate of reactions?
3 Why does a more dilute solution decrease the rate of reactions?
4 Why does a reaction occur faster when the reactants are stirred together?
5 What is a catalyst?
6 Explain the two ways in which catalysts can work.
7 Why is an enzyme often called a 'biological catalyst'?

The collision theory

For a chemical reaction to occur, the atoms or ions or molecules must collide together with enough energy for that reaction to occur. This idea is known as collision theory.

One reaction that has been studied is the decomposition reaction of hydrogen iodide. The reaction, in symbols, is:

$$2\,HI(g) \rightarrow H_2(g) + I_2(g)$$

Hydrogen iodide is a gas and its molecules travel quickly. Each hydrogen iodide molecule must collide with another hydrogen iodide molecule in order to react.

Some collisions do not result in a reaction. In these collisions, the hydrogen iodide molecules bounce apart with no reaction, as shown in Figure 7.30.

In the collision shown in Figure 7.31, there is a reaction. A weak chemical bond forms between the iodide ions and the hydrogen ions. This intermediate substance is unstable and only exists for a short period of time, before it breaks apart.

Only some collisions result in a reaction. The molecules must collide in the correct orientation for a reaction to occur.

Reversible reactions

Many reactions can occur in reverse and these sorts of reactions are called **reversible reactions**. For example, the decomposition of hydrogen iodide can occur in reverse. This would then be called the synthesis of hydrogen iodide.

Effect of temperature

Reactions occur faster, with a higher reaction rate, when the temperature is higher. This is because the particles in a hot gas have more kinetic energy, and move faster, than the particles in a cold gas. Faster moving particles will collide more often because they travel further in the same time as a cold particle. In addition, hot gas particles that collide have more energy. Think of a collision between two cars—if both cars are moving at 30 km/h, there are not many injuries to the occupants; however, if both cars are moving at 100 km/h, severe injuries may occur.

Slow moving gas molecules will be pushed apart by the repulsion of the electrons that orbit the atoms: they never come close enough to form new chemical bonds. Fast moving molecules can 'push through' the repulsion and their electrons can orbit around a different atom. The faster the molecules, the higher the proportion of molecules with sufficient energy to change into products.

What do you know about the collision theory?

1 Is it true that every time the molecules of reactants collide they form molecules of the products? Explain.
2 How does temperature affect the rate of a chemical reaction?
3 What is a reversible reaction?
4 What is the collision theory?
5 How does the collision theory explain the dramatic increases in the rate of a reaction as the reactants are heated?

An unsuccessful collision
An unsuccessful collision

Fig 7.30 Not all collisions result in a chemical reaction.

A successful collision

Fig 7.31 When the collisions between particles have enough energy, and the particles are aligned correctly, a reaction may occur.

H_2I_2 is unstable and short lived.
It is called an intermediate complex.

Fig 7.32 An intermediate stage during the reaction. The products of this reaction move apart. (This is due, in part, to electrical repulsion.)

Fig 7.33 The final products are formed.

Making H_2O

- Make a large oxygen molecule out of one colour of Play Dough and two smaller hydrogen molecules out of another colour.
- Use toothpicks to illustrate pairs of electrons on the outer surface of the oxygen. Oxygen has six electrons in its outer shell, so you will need three toothpicks.
- Students should be aware that oxygen needs a share of two more electrons to be stable.
- Break one of the toothpicks in half to represent the two electrons oxygen is prepared to share with the hydrogen molecules.
- Arrange the toothpicks in the Play Dough oxygen so that they are as far apart from each other as possible. Ensure that students use all three dimensions of the atom.
- Half a toothpick can be inserted into each of the hydrogen atoms to represent the electron that each atom is prepared to share.
- The molecule of water can now be put together with the half toothpick on the hydrogen atom joining together with the half toothpick on the oxygen atom. When the atom is constructed, the water molecule should resemble the V-shaped molecule that is known.

Reversible reactions

The idea of reversible reactions is an important concept to introduce to students at this level because it leads into equilibrium, which is often a part of senior chemistry studies.

Reversible reactions occur in closed systems where the amount of reactants is limited and the products are not removed.

Many reactions start with a large number of reactants and little product. As the reactions progress, the amount of reactants decreases and the number of products increases. Some products undergo spontaneous breakdown so that the reactants reform. This is reversal. As the reaction continues, the amount of product being formed will eventually be equal to the amount being reversed. This is the concept of chemical equilibrium. A simple analogy is walking the wrong way on an escalator. You walk forwards at the same speed as the escalator is moving backwards. Both you and the escalator are moving, but you are not going anywhere.

Answers

What do you know about the collision theory?

1 Reactants will not react every time they collide because they need to meet at the correct angle for the reaction to occur.
2 Increasing temperature increases the rate of a reaction.
3 A reversible reaction is one that can occur in reverse (both directions).
4 Collision theory states that for a chemical reaction to occur, the atoms or molecules must collide together with enough energy for a reaction to occur.
5 When a reaction is heated, the molecules are given more energy. This extra kinetic energy will make the molecules travel further in the same time, making it more likely that the molecules will collide. The extra energy will also overcome any repulsion forces that may exist between the two reactants. All this will increase the rate of a reaction.

BIG IDEAS

7.2 How can we control the speed of chemical reactions?

Remember and think

1 The particles need to meet before a chemical reaction can take place.

2 surface area, temperature, mixing, concentration of reactants, gas pressure, catalysts

3 The rate of a reaction can be measured by the decrease in the reactants or the increase in products.

4 Exothermic reactions can be dangerous if they occur too quickly.

Apply

5 Cooling food slows any chemical reactions that may occur, including the chemical breakdown of the food. Cooling also slows the chemical reactions in any bacteria, preventing them from dividing or producing toxins.

6 Coal dust has small particles with a large surface area for a reaction to occur. This will increase the rate of a reaction. As a result, coal dust is more explosive than large chunks of coal.

7 a concentrations of reactants; the size of the magnesium metal; the amount the reaction is mixed; the presence of any catalysts

b All of the variables in part (a) can increase the rate of a reaction, thus making it difficult to determine whether temperature affects reaction rate.

Analyse and evaluate

8 The movement of the particles in matter helps scientists explain why the rates of reactions increase. Factors that increase the movement of the particles will increase the rate of a reaction.

9 The presence of nitrogen dioxide increases the rate of the reaction and, because it is reformed at the end of the reaction, the amount does not decrease as a result of the reaction. Therefore, nitrogen dioxide is a catalyst in this reaction.

Critical and creative thinking

10 Enzymes are three-dimensional molecules that have specific areas that bind to the reactants so that the reaction can occur. High temperatures

<<BIG IDEAS>> Interaction and change

7.2 How can we control the speed of chemical reactions?

Remember and understand

1 In terms of particles, what is required for a chemical reaction to take place?

2 List four factors that will affect the rate of a chemical reaction.

3 Describe two ways that the rate of chemical reactions can be measured.

4 Describe one situation where it could be dangerous if a reaction occurs too quickly.

Apply

5 Why is food stored in a refrigerator?

6 In many industrial environments, the presence of a fine dust is regarded as an explosion hazard. Why is coal dust more likely to explode than chunks of coal?

7 A student wanted to investigate the effect of temperature on the reaction between hydrochloric acid and magnesium metal.

a List four variables that should be kept constant in this investigation.

b For two of these variables, explain how the experimental error would be increased if they were not controlled properly.

Analyse and evaluate

8 How does the particle model of matter help us understand the rate of reactions?

9 The reaction $2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)$ is very slow at room temperature. The reaction occurs in two steps, which are shown below. The reaction occurs more quickly in the presence of nitrogen dioxide gas.

- Step 1 $2\ SO_2(g) + 2\ NO_2(g) \rightarrow 2\ SO_3(g) + 2\ NO(g)$
- Step 2 $2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$

Explain two reasons why the nitrogen dioxide is regarded as a catalyst.

Critical and creative thinking

10 A student was investigating the reaction that occurs when starch is broken down into glucose in the presence of the enzyme amylase. The student found that initially, as the temperature increased the rate of the reaction also increased but, once the reaction mixture was above 60°C, the reaction became very slow. Suggest an explanation for these observations.

11 Indigestion tablets often contain carbonates, which take part in neutralisation reactions in our stomach to reduce excess acidity. The general reaction can be described as:

- acid + carbonate → salt + water + carbon dioxide
- Describe problems that might result if the reaction occurred:
  a too quickly
  b too slowly.

<<CONNECTING IDEAS>> Interaction and change

12 Some catalysts work by providing a surface on which reactions can occur. These surface catalysts work by allowing the reacting particles to interact together on the surface of the catalyst.

a Why would attracting particles onto a surface of another chemical encourage a chemical change to occur?

b Why would a substance that actually bonded chemically to the reacting particles not make a good catalyst?

c Give an example of the use of a surface catalyst, describing in detail the chemical reaction.

d Use your knowledge of collision theory to explain why most catalysts are used in the form of a powder or fine mesh.

286 CHAPTER 7 • USING CHEMISTRY

7.3 What are the risks of using chemicals?

Chemicals may have a public relations problem. We often see products advertised as 'chemical free' or 'organic'. It is easy to tap into people's fear of chemicals because the word 'chemical' is often associated with substances that are seen to do harm to the environment. Acids, pesticides, chlorofluorocarbons (CFCs), industrial waste and food additives are all chemicals, but chemistry is not just about these types of materials, and even these are safe to use if their quantities are controlled and their use is monitored. A better understanding of chemistry allows us to predict, manage and reduce the risks of using chemicals in our environment.

<<DISCOVERING IDEAS>>

Oxygen—a toxic chemical?

We all know that the presence of oxygen on Earth is essential for our survival. But can oxygen be toxic? Can it be considered a harmful substance? In what situations is the presence of oxygen dangerous?

Hyperbaric chambers are often used by sports stars to speed up recovery from injury. It is believed that breathing in an atmosphere of pure oxygen improves wound healing and stimulates the growth of new blood vessels. However, the discovery that oxygen was toxic came through the experiences of early scuba divers, who were breathing pure oxygen for long periods of time at higher than normal pressure. Considering more long-term effects, it is thought that oxygen in our bodies causes the formation of reactive particles called 'free radicals'. These free radicals cause the tissues and organs in our bodies to age.

Fig 7.35 Football players have often used oxygen treatments to speed up their recovery from injury.

Fig 7.34 Some harmful effects have resulted from scuba divers breathing pure oxygen.

1 Do you think that oxygen should be described as a 'toxic' substance?

2 Why do you think that some people ensure that their diet contains a certain amount of antioxidants?

3 Do you know of any specific examples where oxygen treatment has been used by sports men or women to recover from injury before an important match?

4 Why do you think that breathing oxygen at high pressure might increase the chance of ill effects?

UNIT 7.3 • WHAT ARE THE RISKS OF USING CHEMICALS? 287

can cause the shape of the molecule to break apart, making it difficult for the reactants to bind and react. As a result of the loss of the catalyst, the rate of the reaction will slow.

11 a A high rate of reaction will cause large amounts of carbon dioxide to be produced. This will extend the stomach and make the person burp.

b If the reaction occurs too slowly the stomach acid will not be neutralised, causing the indigestion to last longer.

<<CONNECTING IDEAS>>

12 a Attracting the reactants to the same surface will allow them to meet and react.

b If a substance bonded chemically to a reactant, it may prevent other molecules or atoms binding or colliding with the reactant, thus preventing the reaction from occurring.

c Students' results will vary. A possible answer could be the production of carbohydrates. An enzyme provides a surface for the smaller sugars to meet, allowing them to interact, forming a larger carbohydrate molecule such as glycogen.

d Catalysts work most effectively when they can provide a large surface area for the reactants to interact. The larger surface area of small powder particles or a fine mesh will increase the rate of a reaction to a greater degree than large clumps of enzymes.

<<DISCOVERING IDEAS>>

Oxygen—a toxic chemical?

Breathing pure oxygen at high pressure (as the scuba divers did) can cause nausea, dizziness, muscle twitches, blurred vision and seizures or convulsions.

Breathing pure oxygen at normal pressure can cause fluid accumulation in the lungs, slowing down the gas flow across the air sacs (alveoli), causing chest pain and possible collapse of the lungs.

Two astronauts were able to breathe 100% oxygen at low pressure for 2 weeks without any harmful effects.

1 Toxic means containing or being a poisonous material, especially when capable of causing death or serious debilitation. In 1954, it was discovered by Dr Patz that supplying pure oxygen to premature infants can damage the retina of the eyes, causing blindness. Because this is a permanent serious debilitation, the oxygen can be said to be toxic.

2 Antioxidants can remove oxygen free radicals from cells. Oxygen free radicals have been implicated in the development of several diseases, including cancer and heart disease. For this reason many people add antioxidant foods, like fruits and vegetables, to their diet.

3 Hyperbaric oxygen treatment has been used to improve wound management, such as muscle–tendon damage or ligament damage (i.e. sprains or strains).

4 Cells normally clean up oxygen free radicals as soon as they occur so that they cannot do much damage. High-pressure oxygen causes the oxygen free radicals to be formed at a much higher rate so that they can accumulate in a cell and cause more damage.

Chemicals and pollutants

Carbon pollution

A carbon footprint has traditionally been considered to be the total set of greenhouse gas emissions caused by a person or a group of people. The difficulty of estimating all the gases produced by a person in a set period has resulted in a more simplified definition. Instead, a carbon footprint is now defined as the total amount of carbon dioxide and methane emitted by a person or group of people within a set time. Activities that can affect our carbon footprint include:

- transport
- manufactured goods, such as clothing
- roads and buildings
- land clearance
- fuels for heating
- the production and consumption of food.

There have been many discussions regarding the importance of a person's carbon footprint and their eventual impact on the environment. Before students can enter a discussion of a carbon economy, they must first understand how extensive the use of carbon in everyday life can be. This can be determined using a carbon footprint calculator, which can be easily found on the Internet.

Once the students have established their carbon footprint, they can debate ways of decreasing the population's reliance on carbon fuels or how to maximise the use of such fuels. This should establish an understanding of the need for the study of chemistry.

Carbon monoxide

Carbon monoxide is an odourless and tasteless gas that is found naturally in the air (around 2 parts per million). This amount is not harmful to humans. Natural sources of carbon monoxide include volcanoes, bushfires, exhaust fumes and tobacco smoke.

Chemicals and pollutants

The chemicals we use contribute to the lifestyle we enjoy. But there may be a trade-off. Sometimes unwanted substances enter the environment and cause pollution.

Pollutants are chemical substances that are in the wrong place or are present in the wrong amounts. Carbon dioxide is not normally a pollutant, but too much in the atmosphere is one factor contributing to climate change.

Chemists are constantly developing new products and processes. New products are often more environmentally friendly than the products they replace. New processes reverse many of the negative environmental effects. Consider the methods used to prevent pollution from cars and the plans to implement carbon capture at coal-burning power stations.

Our carbon economy

The chemical fuels that our society relies upon are based on carbon. Our ancestors burnt wood, which is mainly the carbon compound cellulose. Later generations burnt coal, which is close to pure carbon. Coal is made by the dehydration and compaction of buried plant remains. Our generation uses coal to produce electricity and petroleum as a liquid fuel for transport.

All these fuels contain molecules made of carbon. Cellulose is a polymer of $C_5H_{10}O_5$ units arranged end-to-end, coal is 95% pure carbon (depending on the type) and petroleum is a mixture of hydrocarbons. Petrol is mostly octane (C_8H_{18}), diesel is a mixture with the average formula $C_{12}H_{23}$, natural gas is CH_4 and liquefied petroleum gas (LPG) is propane (C_3H_8).

Petrol, diesel, natural gas and LPG are fossil fuels. They are obtained from the Earth and were formed from the fossilised remains of plants and animals. The energy in them was captured by photosynthesis millions of years ago. This carbon has been locked away out of the atmosphere for millions of years. Even renewable fuels, such as biodiesel and ethanol, contain carbon atoms. The carbon atoms in renewable fuels were captured by photosynthesis in the last growing season.

It is fair to say that our society runs on carbon. It is in every important fuel. Carbon is the mainstream of our economy. This is why is it called a carbon economy.

Carbon pollution

Burning carbon fuels provides energy at a relatively low cost, but there is a price to the environment.

Burning carbon fuels in excess oxygen produces carbon dioxide and water. When there is less oxygen available, carbon monoxide and soot (carbon) form. With even less oxygen, unburnt hydrocarbon is released, with water. As an example, the following equations show three possible reactions for the combustion of propane (C_3H_8). Note that as less oxygen is available, the product of the reaction will change.

$$C_3H_8 + 5\,O_2 \rightarrow 3\,CO_2 + 4\,H_2O$$
$$C_3H_8 + 3\tfrac{1}{2}\,O_2 \rightarrow 3\,CO + 4\,H_2O$$
$$C_3H_8 + 2\,O_2 \rightarrow 3\,C + 4\,H_2O$$

Carbon monoxide (CO) is a poison that binds tightly onto the haemoglobin in red blood cells, much tighter than oxygen. Victims of carbon monoxide poisoning die because of a lack of oxygen to the brain and other body tissues. Small particles of soot cause breathing problems, especially in people with asthma. It is important that all users of fossil fuels burn them cleanly. In addition to releasing less pollution, burning fossil fuels cleanly provides more energy.

Fig 7.36 Carbon is the chemical basis for oil that we extract from the Earth.

Other pollutants from burning fuels

Carbon fuels are not pure. Wood contains water and plant oils, whereas coal contains dust, nitrogen, sulfur and tar. Oil refineries now process petroleum to remove the sulfur from it, but this has not always been the case.

When a fuel is burnt, the impurities in it, such as sulfur, are also burnt.

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

At high temperatures in an engine or furnace, nitrogen in the air can react with oxygen.

$$N_2(g) + O_2(g) \rightarrow 2\,NO(g)$$

The gases sulfur dioxide (SO_2), sulfur trioxide (SO_3; made from SO_2 in the atmosphere) and nitric oxide (NO) dissolve in water and form acid. Even small amounts of acid can raise the acidity enough to destroy the ecosystems in forests, lakes and rivers. In cities, **acid rain** dissolves the limestone and marble on buildings and statues.

Fig 7.38 Acid rain is caused by non-metal oxides, such as SO_2 and NO.

Fig 7.37 In rockets, liquid hydrogen and liquid oxygen react to provide the thrust for the launch.

Pollution control in cars

Modern cars produce much less pollution than older cars. The pollutants are reduced by computer-controlled combustion in the engine and are removed in the exhaust system by a catalytic converter. As the exhaust gases pass through the converter, they react on the surface of the metals to form harmless gases. The metals that act as catalysts are platinum, palladium and rhodium. These metals are expensive.

The overall reaction that occurs in the catalytic converter is:

$$2\,CO(g) + 2\,NO(g) \rightarrow 2\,CO_2(g) + N_2(g)$$

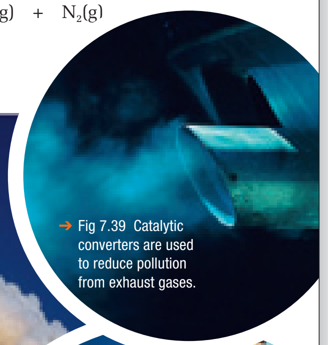


Fig 7.39 Catalytic converters are used to reduce pollution from exhaust gases.

Fig 7.40 Heavy traffic increases pollution levels.

What do you know about chemicals and pollutants?

1. Why are carbon fuels so important to our society?
2. Why is the sulfur removed from the petrol used in cars?
3. What is a catalytic converter? Why are they used?
4. What is the difference between renewable and non-renewable fuels?
5. Why does the amount of oxygen available affect the products formed in the combustion process?

Pollution control in cars

A catalytic converter has a reduction catalyst and an oxidation catalyst. Both have a ceramic structure coated in a metal catalyst (usually platinum, rhodium and/or palladium). The reduction catalyst (platinum and rhodium) converts the NO or NO_2 molecules into N_2 and O_2 gas. The oxidation catalyst (platinum and palladium) oxidises the unburned hydrocarbons and carbon monoxide, converting them to carbon dioxide.

Answers

What do you know about chemicals and pollutants?

1. Carbon fuel is used for travelling, heating, cooking and the manufacture of goods.
2. Sulfur is removed from fuels so that it will not oxidise and contribute to the formation of acid rain.
3. A catalytic converter is a device that changes harmful pollutants (carbon monoxide, hydrocarbons and nitrogen oxides) into less harmful gases before they leave the car's exhaust.
4. Renewable fuels are not depleted by use. Non-renewable fuels can take millions of years to be recreated.
5. Combustion requires oxygen for the chemical reaction to occur. If there is no oxygen, then other types of reactions will occur, producing new (and potentially more dangerous) products.

obook
ID07.13 Weblink: Putting a price on carbon
ID07.14 Weblink: Carbon footprint calculator

Acid pollution

The most common acid found in the environment is carbonic acid. A very weak acid it is formed when carbon dioxide is dissolved in the water according to the reaction:

$CO_2 + H_2O \rightarrow H_2CO_3$

Although this acid plays an important role in controlling breathing in humans, it can cause a pH of 5.5 by the time rain falls to the ground. This may seem strong enough to do some damage; however, it is the acids formed by sulfur and nitrogen gases in pollution that cause much greater damage to exposed metal surfaces, limestone and plant life.

EXPERIMENT 7.10

Reactions of acids and a carbonate

Practical hint

Occasionally the delivery tube will create an air lock and stop the gas from being transferred. To avoid this, raise the flask slightly higher than the test tube and tilt slightly. Once it starts bubbling through, the gas will continue to flow until the reactants are fully reacted.

Safety

- Wear lab coats and safety glasses while working on this experiment.
- 1 M hydrochloric acid is corrosive; 1 M ethanoic acid is a weak acid. Avoid contact with the skin.

Class clean up

Collect test tubes with acid and marble chips still in them. With all safety clothing still on, pour the marble chips and acid solutions through a sieve into a single sink. Rinse the conical flasks and marble chips thoroughly with cold tap water. Place the marble chips on a paper towel to dry for re-use. Flush the sink with cold water.

Expected results

- Both 1 M ethanoic acid and 1 M hydrochloric acid produce gas that turns limewater milky in colour.
- 1 M ethanoic acid is slower to react in the flask and slower to turn the limewater milky in colour than 1 M hydrochloric acid.

Acid pollution

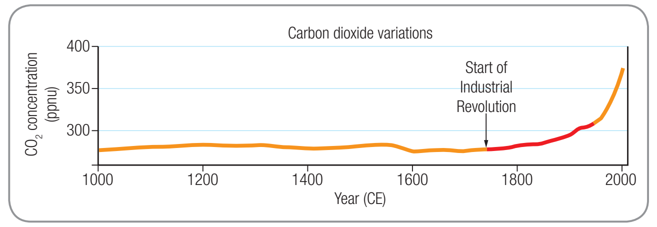
Many people think that acids are only found in bottles in the laboratory, but acids are also found in the environment. Some acids in the environment are made by people. Anything made by people is said to be anthropogenic.

Carbon dioxide

Carbon dioxide is a natural product, but is a pollutant when there is too much of it. The levels of carbon dioxide in the atmosphere are increasing all the time. Some of this carbon dioxide dissolves in the oceans, where it can change the acidity of the sea water.

Carbon dioxide is an essential part of the environment. Plants use it for photosynthesis and animals produce it in respiration. It also helps form bones and shells in many animals. Large quantities of carbon are present in the oceans and in the carbonate rocks called limestone and dolomite.

Fig 7.41 Carbon dioxide levels in our atmosphere have been increasing dramatically in recent years.



Reactions of acids and a carbonate

EXPERIMENT 7.10

Aim

To investigate and compare the reactions of calcium carbonate with a strong acid (hydrochloric acid) and a weak acid (ethanoic acid).

Materials

- 1 M hydrochloric acid, HCl
- 1 M ethanoic acid (acetic acid), CH_3COOH
- Limewater (calcium hydroxide), $Ca(OH)_2$
- Marble chips (calcium carbonate), $CaCO_3$
- Test tubes
- Test tube rack
- Spatula
- Two 100 mL conical flasks
- One-holed rubber stopper with bent glass delivery tube

Wear safety glasses and lab coats, and avoid skin contact with the acids.

Method

1 Draw up a table to record each test and the results for each acid.
2 Using a clean spatula, transfer four to five marble chips to one of the conical flasks. Add approximately 2 cm of limewater to a test tube. Now add enough 1 M hydrochloric acid to cover the marble chips and place the stopper delivery tube in the mouth of the flask so that any gas produced will bubble into the limewater in the test tube.
3 Record your observations of any changes that occur in both the flask and the test tube.
4 Repeat step 2 with 1 M ethanoic acid, using a fresh conical flask and a fresh tube of limewater. Compare the rate of this reaction with that of the hydrochloric acid.

Discussion

1 What can be concluded about the strength of ethanoic acid compared with that of hydrochloric acid? Discuss.
2 The limewater test is the standard test for carbon dioxide gas. It goes milky because the carbon dioxide reacts with the limewater to produce a precipitate of calcium carbonate. The equation for the reaction is:

$$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$$

3 Did your tests confirm that carbon dioxide gas was produced? Was there a difference in the rate of its production? If so, suggest why.
4 Write balanced equations for the reactions of the two acids with calcium carbonate.

Oxides of nitrogen and sulfur

Natural rainwater is slightly acidic due to the carbonic acid dissolved in it. However, acid rain is more acidic because of oxides of non-metals that have dissolved in it.

Small amounts of sulfur in fuels and nitrogen in the air combine with oxygen to form oxides of sulfur and nitrogen. Because there is a variety of oxides formed, each with a different formula, these compounds have been given the formulas SO_x and NO_x, where 'x' stands for a small number, such as 1, 2 or 3.

These oxides can react with water in the atmosphere to form acids, which contribute to the formation of acid rain.

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq) \text{ (sulfurous acid)}$$
$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq) \text{ (sulfuric acid)}$$
$$2\,NO_2(g) + H_2O(l) \rightarrow HNO_2(aq) + HNO_3(aq) \text{ (nitrous acid and nitric acid)}$$

These are a selection of some of the reactions that occur. Acid rain is really a mixture of many acids. The water could be rain, snow, cloud or dew, but it is all called acid rain. Even small amounts of acid can raise the acidity enough to disturb the ecological balance.

Natural rainfall has a pH of between 5.8 and 4.8, depending on the amount of carbon dioxide dissolved in it. The urban average is pH 4.5. The most acidic rain recorded worldwide had a pH of 2.3.

The effects of acid rain include:

- increased corrosion of masonry and metals
- changes to availability of ions in the soil
- damage to new growth on trees
- effects on marine life, such as shell formation.

What do you know about acid pollution?

1 What is the difference between natural and anthropogenic carbon dioxide?
2 What is the name of the acids formed from carbon, sulfur and nitrogen?
3 What is the pH of natural rain? What is the pH of acid rain? Why is there such a difference?
4 What are the effects of acid rain?
5 What can be done to reduce the incidence of acid rain in the environment?

<<OVERARCHING IDEAS>>

Stability and change

Reactions in the ozone layer

The ozone layer is part of the stratosphere. It is the region in the stratosphere from 10 to 50 km high, with the greatest concentration at an altitude of 30 km. Ozone in this region absorbs the UV light that would otherwise cause many more skin cancers and eye problems.

Chlorofluorocarbons (CFCs) are the main destroyers of ozone. The CFCs were developed as refrigerants for use in refrigerators. The CFCs are non-flammable, non-toxic, cheap to manufacture, easy to store and chemically stable and were used in aerosol cans, fire extinguishers and asthma puffers, as well as in foam insulation for furniture, bedding, coffee cups and hamburger containers.

The depletion of ozone in the upper atmosphere was first noted in 1974. It was worst over Antarctica during the spring, but occurred over the rest of the world as well. Teams of scientists studied the depletion in the ozone layer.

The reactions that take place are shown below.

When exposed to ultraviolet (hν) radiation, as they are in the upper atmosphere, the CFC molecules lose a chlorine atom.

$$CCl_2F_2 + h\nu \rightarrow CClF_2 + Cl$$

If the chlorine atom collides with an ozone molecule, it may then react with it.

$$Cl + O_3 \rightarrow ClO + O_2$$

Answers

What do you know about acid pollution?

1 Anthropogenic carbon dioxide is caused by humans. Natural carbon dioxide is caused by all other means.
2 Carbon forms carbonic acid. Sulfur forms sulfuric acid. Nitrogen forms nitric acid and nitrous acid.
3 The pH of natural rain is 5.5. The pH of acid rain is 4.3–5.0.
4 Acid rain reacts with exposed metal surfaces, producing hydrogen and metal salts. It also reacts with limestone and marble buildings, causing the surfaces to crumble away.
5 Reducing pollution (particularly that containing sulfur and nitrogen) will raise the pH of rain.

OVERARCHING IDEAS

Reactions in the ozone layer

Understanding the chemistry of what is going on in the world around them can be important for the general scientific literacy of students. There are often many such topics in the news and students at this level will need to have a deep enough understanding to vote on government policies in a few years time. Topics such as this are significant; for example, the Montreal Protocol was signed before any in the class were born, yet it is having an impact on their lives today.

This is also an ideal opportunity for students to debate current newsworthy topics that will affect their or their children's futures.

Discussion

1 Ethanoic acid is weaker than hydrochloric acid because it did not react as strongly with the marble chips.
3 The limewater became milky, indicating that carbon dioxide was produced. The rate at which the limewater became milky was slower in the reaction with ethanoic acid than that with hydrochloric acid.
4 $2\,HCl\,(aq) + CaCO_3\,(s) \rightarrow CO_2\,(g) + CaCl_2\,(aq) + H_2O\,(l)$
$2\,CH_3COOH\,(aq) + CaCO_3\,(s) \rightarrow Ca(CH_3COO)_2\,(aq) + H_2O\,(l) + CO_2\,(g)$

Oxides of nitrogen and sulfur

Most plants (both natural and crops) can be damaged by acid rain. Acid rain can stunt plant growth by destroying nutrients in the soil; in addition, the protective waxy coating of the leaves can be damaged, making the plants vulnerable to disease. Microorganisms that are necessary for restoring the nitrogen balance in the soil can also be killed. This rain can wash into local waterways, affecting the survival of wildlife. A pH of 5.0 can cause fish eggs to degrade and prevent the young from developing. Adult fish and frogs can tolerate acidic water with a pH of 4.0; however, their food supplies will be affected and they may struggle to survive. Nitrogen that is released into the soil by the rain will wash into the waterways, encouraging algal growth. Bacteria will feed on the algae, using up large amounts of the oxygen available in the water during the process, thus reducing the oxygen available for other animals.

OVERARCHING IDEAS

Reactions in the ozone layer

1. The concentration of ozone varies throughout the year, with a significant depletion in levels during late winter and spring in both the Arctic (January–April) and Antarctic (August–October).
2. It is important that the ozone layer stays intact because it absorbs most of the harmful ultraviolet light from the sun while letting other wavelengths of light through. A hole in the ozone layer can damage eyes, immune systems, cause skin cancer and decrease phytoplankton in the ocean.
3. The increased use and disposal of CFCs by humans caused a change in the amount of ozone over time.
4. The chlorine atom in CFCs can be detached when exposed to ultraviolet light. It collides with the ozone molecules, causing them to break apart into oxygen and releasing the chlorine atom to start the reaction once more.
5. Many nations signed the Montreal Protocol in 1987, agreeing to reduce their emissions of CFCs to a half by 2000. It is thought that global ozone levels will recover by 2050.

→ Fig 7.42 Ozone offers some protection from some harmful ultraviolet radiation.

The ClO groups of atoms will react with oxygen atoms that are present in this region of the atmosphere, formed by the breakdown of oxygen molecules.

$$ClO + O \rightarrow Cl + O_2$$

This reaction releases the same chlorine atom to destroy another ozone molecule. The chlorine atoms act as catalysts—they help the reaction but do not get used up themselves.

Ozone, essential for our protection, is destroyed. The chlorine atoms, which caused the destruction, still exist. Every chlorine atom can destroy ten thousand ozone molecules. The only way to break the cycle is to remove the CFCs from the atmosphere.

The Montreal Protocol (an agreement made in the Canadian city of Montreal) in 1987 phased out the use of CFCs. Replacement chemicals that were 'ozone friendly' were developed and used as replacements for the ozone-depleting substances.

1 Is the concentration of ozone in the atmosphere constant throughout each year?

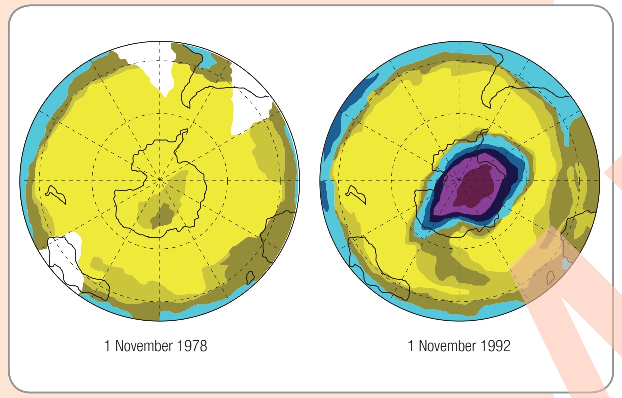
2 Why is it important that, over time, the amount of ozone in the atmosphere is stable?

3 What has caused a change in the amount of ozone in the atmosphere over time?

4 Which part of the CFC molecule destroys ozone? How does this atom become detached?

5 What is the name of the international agreement to ban the use of CFCs and find replacements?

→ Fig 7.43 Ozone levels reduce over the southern hemisphere every year. The darker colours show where the 'hole' in the ozone layer has grown.



Green chemistry and sustainability

Being 'green' means doing something positive for the environment. Scientists with special knowledge in ecology, biochemistry, zoology and botany study the environment and how it responds to changes. It is these scientists who detect changes caused by natural events, as well as by human-made actions. They monitor the environment for changes that may have been caused by the actions of society.

There are some chemicals that have a negative impact on the environment and living things. When these substances are identified, scientists take action to reduce their use and to prevent them from entering the environment. Sometimes some substances are banned from use altogether.

New chemical products and processes are described as being 'green' if they have less impact on the environment than the product or process they replace. The study and development of new substances that have a low impact on the environment is called 'green chemistry'.

Some examples of the development of 'green' alternatives are described below.

- Pesticides and herbicides have been used to kill the living things that eat our food crops and the plants that compete with these crops for sunlight and nutrients. Some of these products killed all living things, not just the target species. Most were non-degradable (did not break down) and remained in the environment long after they were no longer needed. These substances are now banned and have been replaced with biodegradable poisons. In many cases chemical poisons have been replaced with new farming practices, such as crop rotations and pest-resistant crop varieties.
- CFCs were developed as refrigerants and quickly found other uses in aerosol cans and fire extinguishers. It was later discovered that their use caused severe environmental damage—destruction of the ozone layer. The CFCs were banned and new substances were developed to replace them.
- Heavy metals include lead, mercury and cadmium. Heavy metals had many uses, especially in dyes, and were used in chemical processes, especially as catalysts. But these metals accumulated in the bodies of living things, including people. The most dramatic example is that of Minamata disease, caused when people in Minamata, Japan, in 1956, were poisoned by mercury after eating contaminated seafood. The use of these metals in situations where they could enter the environment has been largely stopped. They have been replaced by different catalysts and even different production processes.
- Acrylic paints have replaced solvent-based enamel paints and lacquers. The solvent used in the old paints was a hydrocarbon, such as turpentine, and it evaporated as the paint dried. These solvent-based paints have been replaced with acrylic paints, which are water based and set by polymerisation of the paint, not by evaporation of a solvent. The hydrocarbon solvents in enamel paint were toxic to aquatic life in waterways and the fumes from the paint caused 'painter's disease' in the workers who inhaled them.
- Green chemistry is sometimes called 'sustainable chemistry'. It is about reducing the impact of chemicals on the environment—chemists produce substances in processes that have less impact on the environment than the substances they replace.

→ Fig 7.44 Many chemical products considered safe for use in the past have been replaced by more environmentally friendly substances.

Green chemistry and sustainability

DDT (dichlorodiphenyltrichloroethane)

The insecticidal properties of DDT were first discovered by Paul Hermann Müller, who was awarded the Nobel Prize in Physiology or Medicine for his discovery in 1948. After the Second World War, the use of DDT increased until it became a common household insect repellent. It wasn't until 1962 that scientists became aware of the long-term effects of this chemical, which is very slow to degrade, with a half-life of 2–15 years. The use of DDT continued in Australia, with a 1972 report suggesting that the usefulness of DDT far outweighed its disadvantages. The use of DDT wasn't officially banned in Australia until 1987 following the Stockholm Convention on Persistent Organic Pollutants.

Painter's disease

A person suffering from painter's disease can have significant neurological deficits, including acute narcosis (falling asleep without warning), blue–yellow colour deficits, coarse tremor, impaired vibration sensation in the legs and cognitive impairment (learning problems).

Research activity

The use of chemicals previously thought to be safe is constantly being revised by government scientists. Students can research some of these chemicals, including those listed below, to discover their original uses and the reasons behind the review of their use.

- thalidomide
- asbestos
- benzene
- chlorobenzidine

obook

ID07.15 Weblink: Ozone hole size tracker
ID07.16 Weblink: Green chemistry

Answers

What do you know about green chemistry and sustainability?

1 There are many different types of tests that are used to determine how safe a chemical product is. The company that produces the product is responsible for determining its safety and must submit its results to the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) at the Department of Health and Ageing for review. The types of assessments considered are:
- toxicity
- environmental
- occupational health and safety
- public health.

An example of the types of tests that are completed for explosives include:
- a shock test to determine sensitivity to intense mechanical stimulus
- a thermal test to determine whether the energy produced in the reaction is enough to cause spontaneous detonation
- explosive capacity in a large fire.

2 Lead, mercury and cadmium were all used as pigments or preservatives. Lead was used in common white paint until 1989. All are heavy metals that can build up in the body over time and are considered toxic to humans.

3 The company that produces the chemical and sells it in commercial quantities is responsible for conducting the tests to determine the chemical's safety. The results of those tests must be submitted to the relevant government authorities. If those tests are not sufficient, or there are some errors or misleading information in the testing, then the company is responsible, as in the recent thalidomide court cases.


What do you know about green chemistry and sustainability?

1 How do scientists determine how safe a product is?
2 The 'old masters', the painters of 1600s–1800s, used pigments made of compounds of lead, mercury and cadmium. Why are these paints no longer available to today's painters?
3 If you discovered an important new chemical today, could you be responsible for any consequences that occurred 30 years in the future? Could the people who are affected in 30 years time blame you?

ZOOMING IN

What can you do to control chemicals in the environment?

What can you, as one person, do to protect the environment and the planet?

By adapting the slogan REDUCE REUSE RECYCLE you can reduce your footprint on the environment. You can do this by:
- taking your own shopping bag and not using plastic
- composting grass clippings and food scraps and using this compost instead of chemical fertilisers.

1 What other materials can be recycled to reduce the risk of chemical pollution?
2 What are the properties of substances that would make them suitable for recycling?

By adapting the slogan ACT LOCAL, THINK GLOBAL you can act to reduce your footprint on the planet. You can do this by:
- buying trigger-action spray cans, not aerosols
- avoiding non-degradable products, such as some biocides
- leaving the car at home for short journeys, catching public transport or riding a bike
- using natural cleaning products and avoiding chlorine-based cleaners.

3 What other actions can you take to reduce your impact on the environment? Your actions will make a small difference, but when others join you, the effect is quite dramatic.

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Material Safety Data Sheets

A **Material Safety Data Sheet** (MSDS) is a small document that:
- describes the physical and chemical properties of a substance or a material
- provides advice on the safe handling and use of that material
- gives guidance in first aid.

The Safety Data Sheets are available from:
- manufacturers and importers of chemicals
- the point of sale, such as shops and retail outlets
- online.

There is an MSDS for every single chemical and mixture of chemicals sold in Australia, meaning that there are over 20 million MSDS that you could read!

On the label of each substance or material, you will find the MSDS information in a condensed form. There may be a diamond-shaped warning symbol. There is also information on the purity of the material and emergency first aid.

Many chemicals are transported by road or rail. There are warning labels on the side of tankers to guide emergency workers as to how to handle any emergencies.

Every time you use a chemical substance, at school or at home, ensure that you are familiar with any hazards it may pose. For example:
- Do you need to use it in a well ventilated area? Will it affect people with asthma?
- How do you clean up any spills?
- What should you do if you spill it on your skin?
- How do you store it safely until next time you need to use it?

Fig 7.45 Warning symbols used on Material Safety Data Sheets.

What do you know about Material Safety Data Sheets?

1 What information is contained in a Material Safety Data Sheet?
2 Why are graphics used on chemical warning labels?
3 What information is shown in the label in Figure 7.46?

Fig 7.46 Information signs on tankers carrying petrol and liquid ammonia. The large number is the United Nations number for this substance and the small number is a phone number for emergency information.

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ZOOMING IN

What can you do to control chemicals in the environment?

1 Other materials that can be recycled include plastics with the triangular arrows around the numbers 1–3. Clothing can also be recycled, as can many building products.

2 Any substance that can be broken down into smaller components can be reconstituted and reused. Other substances can have contaminants removed and can also be reused.

3 Students' answers will vary.

Material Safety Data Sheets

There are many new terms that can be found on MSDS sheets. A good activity for students is to prepare a glossary of these words. The glossary can be prepared as a class or individually.

Terms to review include:
- acidosis
- action level
- acute toxicity
- analgesia
- anoxia
- asphyxiation
- atrophy
- benign
- bradycardia
- carcinogenic
- catharsis
- caustic
- corrosive
- flammable
- flashpoint
- fatigue
- gastric
- hypotension
- immiscible

Answers

What do you know about Material Safety Data Sheets?

1 Material Safety Data Sheets must contain:
- the product name of the hazardous substance
- the chemical and generic names of certain ingredients
- the chemical and physical properties of the hazardous substance
- health hazard information
- precautions for safe use and handling
- the manufacturer's or importer's name, Australian address and phone number.

2 Graphics are used on chemical warning labels for quick guides for all users regardless of their level of education.

3 Information relating to dangerous substances (flammable liquids and toxic gases).

obook
ID07.17 Weblink: Chemicals in the environment

BIG IDEAS

7.3 What are the risks of using chemicals?

Remember and think

1 A fossil fuel is made of organic matter that lived millions of years ago. A biofuel is a result of photosynthesis.

2 Acid rain reacts with limestone, breaking the bonds in the $CaCO_3$ and forming carbon dioxide. This causes the limestone to be 'eaten away'.

3 The chlorine atoms in CFCs react with the ozone, causing a thinning of the layer above the Earth and holes to develop at the polar caps.

4 All chemicals used in a laboratory should have an MSDS so that all necessary safety precautions can be taken.

Apply

5 Most of the fuels used by our society are carbon based, such as coal, petroleum and natural gas.

6 When burned, fossil fuels produce SO_2 and NO gases. These gases react with the water in the air, forming H_2SO_4, HNO_3 and HNO_2.

7 Some possible student answers include:
- recycling
- reduce energy consumption
- compost food.

Analyse and evaluate

8 In high concentrations, carbon dioxide can undergo chemical reactions that can render the air, soil, water or other natural resources harmful or unsuitable for use.

9 Many bones and shells of marine creatures are made of calcium carbonate. This can react with acids in the ocean (H_2CO_3) according to the equation:

$H_2CO_3 + CaCO_3 \rightarrow Ca(HCO_3)_2$

Ethical behaviour

10 Students' results will vary.

Critical and creative thinking

11 Energy sources include coal, petroleum products, natural gas, solar power, wind power and biofuels. Cars, trucks and buses can use petroleum products, natural gas and biofuels.

<<BIG IDEAS>> Interaction and change

7.3 What are the risks of using chemicals?

Remember and understand

1 What is the key difference between a fossil fuel and a biofuel?

2 How does acid rain affect objects made from limestone?

3 What is the link between CFCs and the ozone layer?

4 Why should you always have an MSDS available when working in the laboratory?

Apply

5 Why do some people say that our society's energy demands are based on carbon?

6 How is acid rain formed from the burning of fossil fuels?

7 What are some examples of green chemistry that you could apply at home?

Analyse and evaluate

8 Why is carbon dioxide—a natural product—regarded as a pollutant?

9 What is the relationship between the acidification of the oceans and the ability of living things to form bone and shell? Include equations in your answer.

Ethical behaviour

10 In the 1920s, the compound tetra ethyl lead (TEL) was developed to prevent 'knocking' in car engines. ('Knocking' is where the spark plugs fire too early, resulting in loss of power and possible engine damage.) Adding TEL saved the cost of additional refining of petrol, which resulted in lower costs for consumers and motorists. However, some people raised concerns about the use of a lead compound that was being released from the exhaust of cars. If you had been part of the debate in the 1920s, what arguments would you use against the use of TEL?

Critical and creative thinking

11 List the energy sources available to our society. Which of these are suitable as fuel for cars, trucks and buses? Which of these are renewable? Which of these do not contribute to environmental change?

<<CONNECTING IDEAS>> Interaction and change

12 In our bloodstream, haemoglobin is responsible for the transport of oxygen from our lungs to the cells in our body, where respiration takes place. The oxygen molecules interact with the haemoglobin and combine to form oxyhaemoglobin. When the blood reaches the cells (having been pumped through the heart), the oxyhaemoglobin releases the oxygen. If carbon monoxide molecules are breathed into the lungs, they can attach themselves permanently to haemoglobin molecules, thus preventing the essential transfer of oxygen. Carbon monoxide poisoning is a very real danger and many Australians are killed by it each year.

a Use a diagram to represent the transfer of oxygen from the lungs to body cells.

b Explain why the chemical changes occurring between haemoglobin and oxygen need to be reversible.

c Do you think that the reaction between carbon monoxide and haemoglobin is reversible? Explain your answer.

d Suggest two ways that carbon monoxide poisoning can be prevented.

>>ZOOMING OUT<<

Research

Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

Rare metals

A range of rare metals is used in microelectronic devices. Many of these metals, such as tantalum and niobium, are sourced from Australia. Find out more about where these metals are found in Australia, in what form they occur naturally and what chemical processes are used to extract the pure metals.

Nanotechnology

Nanomaterials are now being used as catalysts for a range of chemical reactions, often to catalyse very specific reactions that produce valuable products. Research the products that are produced by using nanoparticles and how the use of these catalysts has improved the production method.

Minamata disease

Minamata disease is caused by people eating seafood contaminated with a compound containing mercury. The condition was called a 'disease' because when it was first described no one knew its cause. Research this disease and present your findings using the following headings:
- symptoms
- cause
- action taken
- lasting consequences (for the people affected, chemical industry and the world)

Ozone and CFCs

Although governments did act to limit the use of CFCs and hence reduce the damage to the ozone layer, it took time for many countries to recognise the risks and to act on the advice from scientists. Investigate how evidence for ozone depletion was discovered, how countries responded to the evidence and discuss implications for possible future action (or inaction) of governments based on scientific advice.

Reflect

Me

1 What do you think was the most important concept in this chapter?

2 What were the most difficult aspects of this topic? Why?

3 How has your understanding of chemical reactions improved?

4 What new science skills have you obtained from this chapter?

My world

5 Why is it important to know how chemical reactions can be used?

6 How has our increased knowledge of chemistry affected how we live?

My future

7 How do you think people will change how they use chemistry in the future?

8 Can chemistry contribute to the sustainable use of our resources?

Review

Key words

acid rain
carbon nanotube
catalyst
collision theory
combustion
decomposition
electrolysis
law of conservation of mass
Material Safety Data Sheet (MSDS)
monomer
nanotechnology
oxidation
ozone
pollutants
polymer
precipitate
precipitation
reaction rate
reduction
reversible reaction
synthesis

Renewable resources are solar power, wind power and biofuels. Solar power and wind power do not contribute to environmental change.

<<CONNECTING IDEAS>>

12 a Students' diagrams should show oxygen moving from the alveoli in the lungs into the red blood cells in the blood stream, then being transferred around the body until the oxygen moves into muscle and other cells.

b Chemical reactions between haemoglobin and oxygen must be reversible so the oxygen can leave the haemoglobin and move into the body's cells.

c The reaction between carbon monoxide is not reversible (except in the presence of extremely high oxygen concentrations) because the bond is much stronger than that between haemoglobin and oxygen.

d Carbon monoxide poisoning can be prevented by checking all heaters regularly and ensuring that any devices (such as barbecues and patio heaters) have a sufficient supply of oxygen when being used.

ZOOMING OUT

Research

Rare metals

Tantalum and niobium are often found together and are currently mined in Western Australia. The purification of these metals requires reacting the metals with acids. The individual metal salts can then be separated as potassium niobium oxyfluoride, which is highly soluble, and potassium tantalum, which is not.

Nanotechnology

Students' answers will vary according to the product they research.

Minamata disease

Minamata Bay is located in Japan. In 1908, a fertiliser factory was opened on the bay. A few years later it started producing other chemicals, releasing all of its waste water into Minamata Bay. By 1932, the factory had started producing acetaldehyde in a reaction that used mercury sulfate as a catalyst. As part of this reaction, methylmercury was produced and released into the bay. It wasn't until 1956 that a 5-year-old girl started having difficulty walking, speaking and eventually convulsions. Two days later her younger sister also started exhibiting the same symptoms. Within a week many more patients were discovered. At first the doctors didn't know what was causing the disease. Despite isolating the patients to prevent disease transmission, more and more patients were discovered. By the end of that year, forty patients had been found with the disease, fourteen of whom subsequently died. Eventually doctors found that the disease was the result of poisoning by a heavy metal. The source of the heavy metal was thought to be the fish and shellfish in the bay. In 1959, the cause was eventually found to be mercury (the levels of mercury was said to have been 2 kg per ton of bay sediment—high enough to be mined commercially). In an effort to avoid scrutiny, the chemical factory changed its outlet to the river instead of the bay, causing fish to die and spreading the disease to local villages downstream. Eventually all fishing was stopped in the bay and the chemical company was ordered to actively reduce the pollution in its waste water.

Ozone and CFCs

The depletion of ozone was discovered in 1985 by British scientists Joseph Farman, Brian Gardner and Jonathan Shanklin during a routine series of tests in the Antarctic. As a result, the Vienna Convention established a series of protocols for international cooperation for research into the ozone layer and, on this basis, the Montreal Protocol was created and signed by twenty-four countries. The Montreal Protocol called for a reduction in the use of CFCs, halons and other man-made ozone-depleting chemicals.

CONNECTING IDEAS

Clara Immerwahr

Clara came from a wealthy Jewish family. Her father, who had an interest in chemistry, encouraged her education by sending her to her grandmother's private school for girls and privately tutoring her during summer holidays.

She was often frustrated at the societal expectations of women at the time (particularly in the sciences). Clara completed her teachers training at the only college open for women at the time (a two year program in mathematics, science, economics, history, modern languages and Latin). This allowed her to work as a governess whilst she fought for the right to attend a university. She eventually won the right to attend lectures, as a visitor, until she passed the pre-doctoral qualifying exam in 1898 (the first female to do so). This allowed her to obtain her PhD in Chemistry at the University of Breslau in 1900 (for her study in the solubility of metal salts). At the time the local newspaper reported she vowed 'never in speech or writing to teach anything that is contrary to my beliefs. To pursue truth and advance the dignity of science to the heights to which it deserves.'

The highest academic position available to women at the time was as an assistant to Professor Abegg (pioneer of valence theory).

In 1901 Clara married Fritz Haber. She tried to maintain her interest in science by giving lectures to women's institutes on 'physics and chemistry in the home' but was frustrated to find that most people assumed her husband had written the lecture. She came into conflict with her husband over his support of the German 'fatherland' and in particular his interest in creating chemical weapons, something she called a 'perversion to the ideals of science'. Public rebukes and arguments with her husband for her stand, is thought to have led to her suicide in 1915.

Clara Immerwahr is now recognised annually through the Clara Immerwahr Award, conferred annually on young female scientists.

<<CONNECTING IDEAS>> Interaction and change

7

Clara Immerwahr

Clara Immerwahr was a Jewish–German chemist. She was the first woman to obtain a PhD at the University of Breslau in Germany. Despite this success, because of the social and cultural conventions of the time Clara was never able to fulfil her potential as a chemist and spent a lot of her time supporting her husband's work. When she was 44 years old, she pointed her husband's military pistol at her chest and fired a single bullet. Her 13-year-old son held her as she died.

Fig 7.47 Clara Immerwahr.

Fig 7.48 Fritz Haber.

Her husband was Fritz Haber. He was born into a Jewish family on 9 December 1868. Haber's extraordinary life was one full of science and tragedy. Fritz Haber's mother died giving birth to him. In his university studies, Haber was guided by Robert Bunsen, who invented the Bunsen burner, and August von Hofmann, also a very famous chemist. Between 1894 and 1911, Haber worked with Carl Bosch, a chemist and engineer, to develop what became known as the Haber–Bosch process. This process was able to produce ammonia (NH_3) on a vast scale. Ammonia is essential for the production of a number of synthetic fertilisers and, as the population of the world at the beginning of the 20th century was rapidly increasing, the demand for fertilisers to promote the growth of crops was also on the rise. Haber worked to determine the best conditions for the reaction of hydrogen and nitrogen to make the ammonia, whereas Bosch, as an engineer, was able to scale up Haber's laboratory methods into an industrial process. This work enabled the economically viable production of synthetic fertilisers, which resulted in the survival of millions of people.

Fig 7.49 Chlorine gas was first used as a weapon in World War I.

It was during this time, when he was 33 years of age, that Fritz Haber married Clara. Together, they had one son, Hermann, who would also grow up to be a chemist. In 1918, Fritz was awarded the Nobel Prize for Chemistry for this work, but before this happened his life and work took a tragic turn.

During World War I, Haber supported the German military effort. Not only were large amounts of the ammonia produced using his process being used to produce explosives, but Haber was also instrumental in designing ways to produce chlorine gas as a chemical weapon. Haber himself supervised some of the first uses of chlorine gas on the battlefields during the war. In 1915, one such attack killed 5000 French soldiers at Ypres, Belgium. It was Haber's celebration of this event that was the last straw for Clara, who had always opposed Fritz's use of science for the purposes of war. It was on this night that she took her own life. The next day Haber returned to his work with the military. He went on to help produce the poison gas Zyklon A, which was refined by the Nazis to produce Zyklon B, which was used to kill thousands of Jewish people in the gas chambers during the holocaust.

Clara's husband eventually died at 65 years of age, having been driven out of Germany due to his opposition to the actions and philosophies of the Nazi regime, especially in relation to the treatment of Jews. But he was also shunned by many in the scientific community for his work with chemical weapons.

Your task

1. Describe how the needs of society at the time influenced the work of Fritz Haber.
2. Describe how the values and conventions of society at the time influenced the work of Clara Immerwahr.
3. If Fritz Haber's mother had survived to watch her son grow up, what do you think her opinion of him would have been? Do you think he was a good scientist?

Your task answers

1. The rapid expansion of the human population at the start of the 20th century meant that more food needed to be produced in already over-used fields. Large amounts of nitrogen needed to be replaced which can be supplied by adding ammonia to the soil. As a result chemists like Fritz Haber were encouraged to produce fertilisers in large quantities.
2. In the 1890s in Germany, women were expected to be good housekeepers and wives. Although society was slowly changing to allow women to fit more roles, such as governesses or teachers, the expectation was once they were married they would support their husband and family. Many women scientists had their work accredited to their husbands. (It is interesting at this point to draw students' attention to countries where this societal expectation of women still occurs. In Egypt it is illegal for women to drive.)
3. Students responses to this question will vary. Extrapolations can be drawn to other areas in science. Was Einstein and the other designers of the atomic bomb responsible for what happened to Hiroshima and Nagasaki? Are fast car manufacturers responsible for road trauma? Is the creator of Facebook (Mark Zuckerberg) responsible for cyberbullying?

Activity

A mock trial can be held for Fritz Haber. Students can acts as lawyers, defenders, judge and jury. Clara Immerwahr and chemical warfare victims can testify for the prosecution. Other 'scientists' (such as Einstein) and people benefiting from the use of fertilisers can testify for the defence.

obook
ID07.18 Flashcard glossary
ID07.19 Student self-test

The Haber process

Equilibrium is a chemistry concept where a reaction can occur both ways (i.e. the reactions are reversible). As this implies, once the reactants form the products, the products can react to reform the reactants. When a reaction begins the rate of products being formed is greater than the rate of products reforming into reactants.

This changes as the reaction progresses until the rate of product being formed becomes equivalent to the rate of product reforming into reactants. Both reactions are still occurring but the net change in the number of products and reactants is zero.

An example of this is the reaction between nitrogen and hydrogen to form ammonia. At the beginning of the process, more nitrogen and hydrogen react to form ammonia than the amount of ammonia that decomposes to reform into nitrogen and hydrogen. As the reaction progresses, the amount of ammonia being formed slows and the amount breaking down into hydrogen and nitrogen increases until they become equivalent.

One of the basic principles of chemical equilibrium is that the removal of the product increases the direction of the reaction to the right (preventing equilibrium from being reached). Fritz Haber used this principle to prevent equilibrium being reached in the formation of ammonia. If the ammonia is removed from a gas mixture of nitrogen, hydrogen and ammonia by cooling the gas to –33° C (at this temperature the ammonia liquefies and can be drained from the condenser) and the remaining hydrogen and nitrogen gas is 'topped up', the cycle can be repeated. This process prevents equilibrium being reached and makes the process very efficient.

The Haber process

Ammonia is produced in the reaction of hydrogen gas and nitrogen gas. The reaction is a reversible process and can be represented as shown here:

$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

It is possible to speed up the reaction by heating it, increasing the pressure of the gases and by using a catalyst. Unfortunately, what scientists found was that if the temperature and pressure were increased too much, the reverse reaction (i.e. ammonia being converted back into nitrogen and hydrogen) also occurred and it was hard to collect enough ammonia. After years of painstaking trials, Haber was able to determine the exact conditions that would produce a fast enough reaction to produce ammonia without the ammonia turning back into the starting materials. These conditions consisted of temperatures between 300°C and 550°C, with a pressure of approximately 200 atm (200 times normal air pressure). An iron catalyst was found to speed up the reaction.

Fig 7.50 Huge quantities of ammonia are produced in Australia each year.

Australia produces large amounts of ammonia each year, with the largest ammonia plant in Australia situated on the Burrup Peninsula in Western Australia. The worldwide production of ammonia is huge, with more than 100 million tonnes of ammonia currently being produced each year. An amazing fact is that half of all the nitrogen-containing proteins in the average human body have been generated from nitrogen compounds made through the Haber process.

Your task

1 Look at the equation for the Haber process.
$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
  a What type of reaction is the forward reaction? Justify your answer.
  b What type of reaction is the reverse reaction? Justify your answer.
2 Conduct research to locate the Burrup Peninsula. What type of environmental concerns would need to be addressed at this site?
3 Chlorine was used as a chemical weapon in World War I. Describe two uses of chlorine in society today.
4 Use your knowledge of the collision theory to explain why, in the Haber process, increasing the pressure of the gases increases the rate of the reaction.
5 Using your knowledge of the collision theory, explain why, in the Haber process, the iron catalyst used is in the form of a powder or fine mesh.

Fig 7.51 Many of the fertilisers used nowadays have been manufactured from compounds containing ammonium salts.

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Your task answers

1 a Combination reaction: two reactants combine to form a product
  b Decomposition reaction: a single reactant forms two products
2 The Burrup Peninsula is found south of Broome and South Hedland. It is known for its ancient rock art. The main waste products of the Haber process are the warm water (used to cool the gases) and the iron catalyst. The release of iron into the waterways needs to be controlled, as well as reducing the risk of ammonia leaks. An expansion of the fertiliser plant to make ammonium nitrate is planned. The latter is a key ingredient in the manufacture of explosives needed by the mining industry.
3 Chlorine gas is used in swimming pools to disinfect the water. The chlorine reacts with the water to form hydrochloric acid. The resulting dilute acid destroys most microorganisms in the water. Chlorine is also used in the manufacture of commercial products such as bleach, bullet-proof vests, computer hardware, silicon chips and automotive parts.
4 Increasing the temperature of particles (such as the nitrogen and hydrogen gas) increases their kinetic energy, making them move faster. As a result they are more likely to collide with each other or the catalyst. This increases the rate of the reaction.
5 The reactants in a chemical reaction react on the surface of the catalyst. Using a fine powder or mesh as the catalyst increases the amount of surface area available for the reactants to bind, increasing the rate of a reaction.