4

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.

CHEMICAL REACTIONS AND ENERGY 4.1

Different types of matter can react. The atoms within the matter rearrange and form new substances. These reactions either require energy, or release energy.

Students:

» identify that chemical reactions transfer energy and can be classified as either exothermic or endothermic

» construct simple electrochemical cells to describe energy transfer (additional content)

THE RATE OF REACTIONS 4.2

The speed or rate of a reaction is a measure of how quickly a product is made. Changing the conditions of the reaction can alter the rate of a reaction. Knowledge of rates of reactions and how to speed them up or slow them down can be used to control and improve chemical reactions.

Students:

» compare combustion and respiration as exothermic reactions of different rates

» describe the effects of changes in temperature, surface area and catalysts on the rate of chemical reactions

CHEMISTRY AND INDUSTRY 4.3

Understanding of different chemicals, how they react, the rates of reaction and the products they make is vital for industry. New materials can be made, old ones improved and the methods of production made more efficient, cheaper, safer or cleaner.

Students:

» analyse how the development of new materials can be influenced by social, ethical and environmental considerations

» describe examples where advances in science and technology generate new career opportunities

» investigate the process involved in the production of synthetic fibres (additional content)

» balance chemical equations (additional content)

4.1 CHEMICAL REACTIONS AND ENERGY

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 often, it is 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).

ENERGY CHANGES IN CHEMICAL REACTIONS

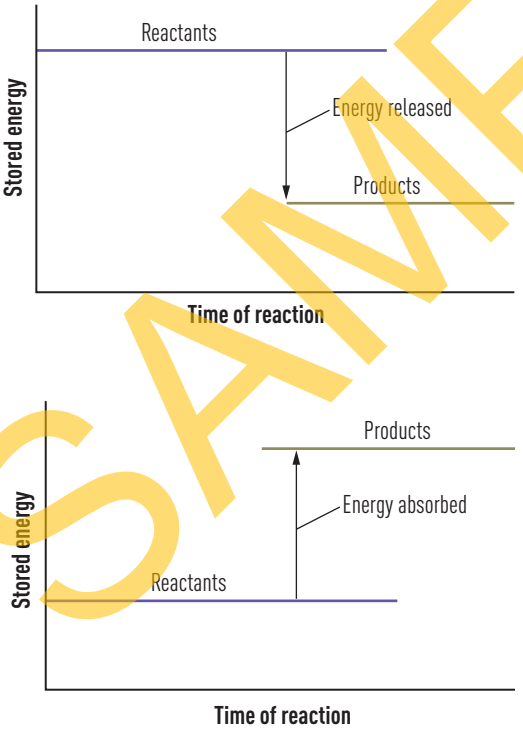

Figure 4.1 (a) In an exothermic reaction, energy is released and the products have less stored energy than the reactants (b) In an endothermic reaction, energy is absorbed and the products have more stored energy than the reactants.

You may have noticed that a test tube or beaker sometimes feels warmer after a chemical reaction. All chemicals contain a certain amount of stored energy. Reactions that release energy are called **exothermic** reactions (exo = 'to give out', thermic = 'heat'). The energy released is usually heat energy but can also be light or electrical energy. An exothermic reaction can be as fast as a match burning or as slow as the rusting of iron.

Reactions that absorb energy are called **endothermic** reactions. For example, for photosynthesis to happen, plants need energy from the Sun to produce glucose and oxygen from carbon dioxide and water.

In an exothermic reaction, the products have less stored energy than the reactants at the start of the reaction (see Figure 4.1a). This energy is released from the chemicals and goes into the surroundings, usually causing the temperature to rise.

In an endothermic reaction, energy is taken from the surroundings and the products have more energy than the reactants (see Figure 4.1b). Because energy is being removed from the surroundings, endothermic reactions will often cause the temperature of the surroundings to drop.

ACTIVITY 4.1.1: COMMON ENERGY TRANSFERS

1 In pairs or small groups, brainstorm as many different chemical reactions as you can.
2 Classify your reactions as natural (happen spontaneously in nature) or industrial (deliberately used by people to produce something useful).
3 Then classify your list of reactions as being either endothermic (uses up energy) or exothermic (produces excess energy).
4 Combine your group's lists with another group or the rest of the class.
   - Did you come up with more natural or more industrial reactions?
   - Did you come up with more endothermic or exothermic reactions?
   - Discuss whether natural reactions are more likely to be endothermic or exothermic reactions. Suggest why this may have been the case.
   - Discuss whether industrial reactions are more likely to be endothermic or exothermic reactions. Suggest why this may have been the case.

Figure 4.2 Do you think digestion is an endothermic or exothermic reaction?

Energy changes and particles

Compounds contain atoms held together by **chemical bonds**. Chemical reactions involve the breaking and making of these chemical bonds.

Reactions and processes that involve the breaking of strong chemical bonds tend to be endothermic. The energy absorbed by the chemicals is required to break the bonds.

Reactions that involve the formation of strong chemical bonds tend to be exothermic. The strongly bonded products have less energy than the reactants, and that difference in energy is released, often in the form of heat.

Some types of cold packs used for injuries (see Figure 4.3) work with the help of an endothermic reaction. They usually contain ammonium nitrate. When the inner bag is broken, the ammonium nitrate dissolves in the water, absorbing heat as it does so. Thus, the bag feels cold.

Figure 4.3 Instant ice packs use endothermic reactions to absorb energy in the form of heat from the surroundings, and feel cold.

EXPERIMENT 4.1.1: ENERGY CHANGES

This experiment may be carried out using a temperature probe and datalogging equipment instead of a thermometer.

WARNING

> Check the safety data sheets to see how to handle the chemicals in this experiment safely.
> Wear your lab coat, safety goggles and plastic gloves.

Aim

To investigate and compare an exothermic with an endothermic process.

Materials

- Sealed bottle containing potassium nitrate (KNO_3)
- Sealed bottle containing calcium chloride ($CaCl_2$)
- Measuring cylinder
- Water
- Stirring rod
- Thermometer (or temperature probe)
- 2 polystyrene cups
- 2 spatulas
- Stopwatch
- Wash bottle
- Residue bottle

Method

1. Prepare an appropriate table to record the times and temperatures.
2. Measure 50 mL of water into a polystyrene cup.
3. Measure the temperature of the water and record it.
4. Place three heaped spatulas full of calcium chloride into the water and immediately commence stirring and timing.
5. Record the temperature every 15 seconds for 3 minutes.
6. Dispose of the solution into the container provided and carefully rinse the thermometer with the wash bottle, ensuring the rinse water is also added to the residue bottle. Dispose of the cup as directed by your teacher.
7. Repeat steps 2–6 using potassium nitrate.

Results

Record your data in an appropriate table.

Draw a graph of temperature against time and plot your results from the two chemicals on the same graph. Make sure that you label both axes and use the correct units.

Discussion

1. Which reaction was endothermic and which was exothermic? How did you reach this conclusion?
2. In which reaction did the products have less energy than the reactants?
3. In which reaction did the products have more energy than the reactants?
4. Use the graphs to describe how quickly the temperature rose or fell.
5. Did the temperature reach a steady value after some time? Discuss why you think this is the case.
6. Suggest how the method used in this experiment could be changed to improve the accuracy of the results.

Conclusion

Write a paragraph that uses your experimental evidence to compare endothermic and exothermic reactions.

Activation energy

A chemical reaction occurs when the particles of the reactants collide in the correct ratio. However, not every collision results in a reaction. The particles must collide with enough energy to cause the bonds to break and form to allow the atoms to rearrange. This energy is called the **activation energy** (E_a) and is required even if there is an overall net release of energy (exothermic reactions). You can think of the activation energy as like giving the reactants a little push to get the reaction going.

Like all forms of energy, activation energy is measured in joules (J). Activation energy is commonly in the form of heat, but can be in many different forms like electrical or kinetic energy. In the case of photosynthesis, the activation energy is provided by sunlight.

The activation energy of a reaction and the net change in energy between reactants and products (ΔH) can be shown as a line graph. Figure 4.4 shows the changes in energy during endothermic and exothermic reactions.

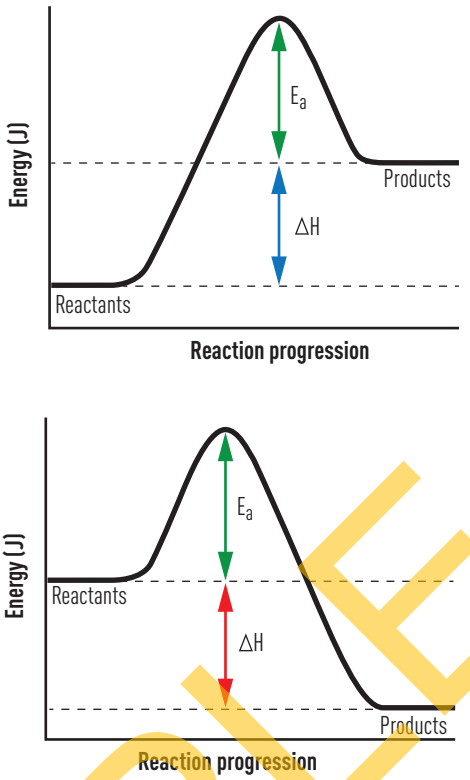

Figure 4.4 Change in energy during an (a) endothermic and (b) exothermic reaction.

QUESTIONS 4.1.1: ENERGY CHANGES IN CHEMICAL REACTIONS

Remember

1 Give three examples of exothermic chemical reactions.

2 In your own words define the term 'activation energy'.

3 The following statements are false. Rewrite them to make them true.

- **a** The energy released in exothermic reactions is always heat.
- **b** Chemical reactions that form chemical bonds tend to be endothermic reactions.

4 Recall the difference between E_a and ΔH.

Apply

5 Complete the following sentences:

During an endothermic reaction, the temperature of the surroundings _____ . The energy of the products is _____ than the energy of the reactants. An example of an endothermic reaction is _____ .

6 Classify the following as exothermic or endothermic processes. Justify your answers.

- **a** A candle burning
- **b** Ice changing to water
- **c** A cake baking

7 Explain why a reaction that produces excess energy requires an energy input to start.

ENERGY TRANSFERS IN SYNTHESIS AND DECOMPOSITION

Most endothermic and exothermic reactions involve the breaking and making of chemical bonds, respectively.

Synthesis reactions

Figure 4.5 A generalised synthesis reaction.

Synthesis is the building up of compounds by combining simpler substances, normally elements. As new bonds are formed, excess energy is released, often in the form of heat. Synthesis reactions are generally exothermic.

Metals can join with non-metals to form ionic compounds or salts. Ionic bonds are usually weak and easily formed and therefore do not release much energy.

metal + non-metal → salt

Example:

sodium + chlorine → sodium chloride

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

Non-metals can bond with other non-metals to form covalent or molecular compounds. Covalent bonds are much stronger than ionic bonds and are harder to form, so tend to release much more energy.

non-metal + non-metal → covalent compound

Example:

carbon + oxygen → carbon dioxide

$$C + O_2 \rightarrow CO_2$$

Quicklime, or calcium oxide (CaO), is an important industrial product generated by a synthesis reaction. 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.

quicklime + water → calcium hydroxide

$$CaO + H_2O \rightarrow Ca(OH)_2$$

EXPERIMENT 4.1.2: POP SYNTHESIS

Aim

To synthesise water.

Materials

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

WARNING

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

Method

Preparing the hydrogen gas

1. 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.
2. Place another test tube (make sure it is dry) over the top of the first test tube so that any hydrogen gas produced is collected in the second test tube.
3. After 15 seconds, lift the second test tube up vertically and place a rubber stopper over the end to trap the hydrogen gas. You now have a test tube of hydrogen gas.

Synthesising water

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. You may like to record your experiment with photograph or a video.

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, i.e. write a balanced chemical equation.
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 – what evidence do you have that energy was absorbed or released?)

Conclusion

Write a short paragraph that uses scientific evidence to classify the reaction as a synthesis reaction and either an endothermic or exothermic reaction.

Figure 4.6 (a) Add dilute HCl to a magnesium strip and (b) quickly invert a second test tube over the first to catch the hydrogen gas formed.

Decomposition reactions

In Chapter 3 you learnt about decomposition reactions, where the chemical bonds in the reactants are broken down to produce two or more different products, usually simpler compounds or basic elements. Energy is required to break these bonds and so decomposition reactions need to absorb energy from their surroundings and are usually endothermic reactions. The stronger the chemical bonds, the harder they are to break and the more energy is absorbed.

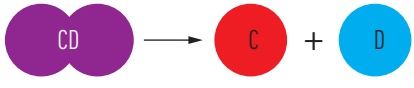

Figure 4.7 A generalised decomposition reaction.

Decomposition reactions typically use energy in the form of heat or electricity to break the bonds in the reactants.

Figure 4.8 (a) A lime kiln being used to produce quicklime. (b) A modern furnace used to decompose limestone.

Thermal decomposition

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

copper(II) carbonate → copper(II) oxide + carbon dioxide

$$CuCO_3 \rightarrow CuO + CO_2$$

You decomposed copper carbonate using the heat from a Bunsen burner in Experiment 3.2.5. Calcium oxide (CaO) is produced by the thermal decomposition of calcium carbonate ($CaCO_3$).

calcium carbonate → calcium oxide + carbon dioxide

$$CaCO_3 \rightarrow CaO + CO_2$$

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 controlling the flow of gas and air into the furnace regulates the temperature.

EXPERIMENT 4.1.3: THERMAL DECOMPOSITION OF A CARBONATE

Aim

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

Materials

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

WARNING

- 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.

Figure 4.9 Make sure to point the test tube away from you and other students while heating.

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?

Conclusion

Use your experimental evidence to describe thermal decomposition.

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 method using copper(II) carbonate and then repeat using calcium carbonate.

Electrolytic decomposition

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

aluminium oxide → aluminium + oxygen

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

Aluminium is used extensively in modern life in food packaging, buildings, casings for computers and in electric cabling. Aluminium is produced by electrolysis. The raw material for this process is bauxite, an ore of aluminium mined extensively in Australia. The bauxite provides the 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.

The combination of maintaining high temperatures and the use of electricity in production means that aluminium remains a relatively expensive metal, despite the fact that bauxite, and other aluminium-containing compounds, are very common in the Earth's crust.

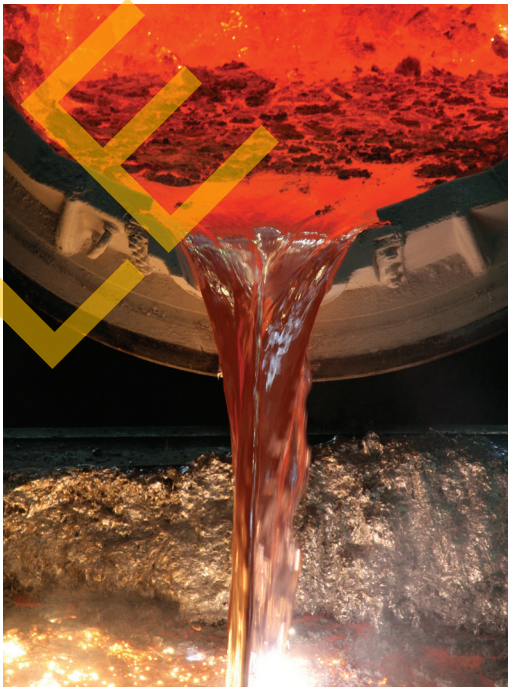

Figure 4.10 Aluminium is produced by electrolysis in a smelter.

EXPERIMENT 4.1.4: 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
- 3 leads
- One 6 V globe and globe holder
- 2 carbon (graphite) electrodes
- Wires with alligator clips

WARNING

> 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 4.11.

4 Touch the carbon electrodes together to check the circuit works and then place the carbon electrodes in the beaker with a 1 cm gap between them.

5 Hold the electrodes 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.

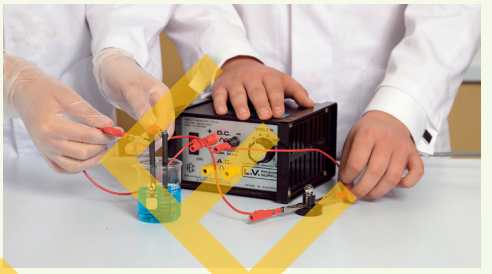

Figure 4.11 Use alligator clips to connect the electrodes to the power supply and the globe.

Discussion

1 What evidence was there that copper was formed in the reaction?

2 Considering the structure of 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?

Conclusion

Use your experimental evidence to describe electrolysis.

QUESTIONS 4.1.2: ENERGY TRANSFERS IN SYNTHESIS AND DECOMPOSITION

Remember

1 Describe the key characteristic(s) of a synthesis reaction.

2 Recall whether decomposition reactions make or break chemical bonds.

3 Recall whether synthesis reactions are usually endothermic or exothermic reactions.

Apply

4 Suggest a reason why decomposition reactions always produce at least two products.

5 Propose a meaning for the term 'by-product' and, using one of the reactions in this section, provide an example of a by-product.

Analyse

6 Why is energy required in:

a decomposition reactions?

b direct synthesis reactions?

ELECTROCHEMICAL TRANSFER OF ENERGY

An **electrochemical cell** is a device, which produces electricity from an exothermic chemical reaction, or uses electricity to drive an endothermic chemical reaction. Electrochemical cells that produce electricity are called voltaic or galvanic cells, and cells that use electricity are called electrolytic cells.

Both types of electrochemical cell are made up of two half-cells (see Figure 4.12). Each half-cell contains an **electrode**, which is usually made of metal, partially submerged in a liquid **electrolyte**. The electrolyte contains a dissolved ionic substance, which separates into its positive cations and negative anions. Half-cells may contain the same or different electrolytes. A porous membrane or 'salt-bridge' joins the two half-cells and allows the ions to pass between the cells.

Figure 4.12 This voltaic cell has a manganese electrode in a beaker of manganese sulphate on the left and a copper electrode in a beaker of copper sulphate on the right. A salt bridge of filter paper connects the two half-cells.

The reactions in voltaic cells occur spontaneously between the electrode and the electrolyte. At one electrode, positive metal cations are released from the electrode into the electrolyte. This causes the electrode to have a negative charge and it is now called the **anode**. At the other electrode, the metal cations bond to the electrode, forming a new layer of metal. The addition of cations causes the electrode to become a positively charged **cathode**.

The movement of the cations results in the movement of electrons in the opposite direction. This movement of electrons between the two half-cells is what causes the electric current. Electricity will continue to flow until one half-cell runs out of the substances needed for its reaction.

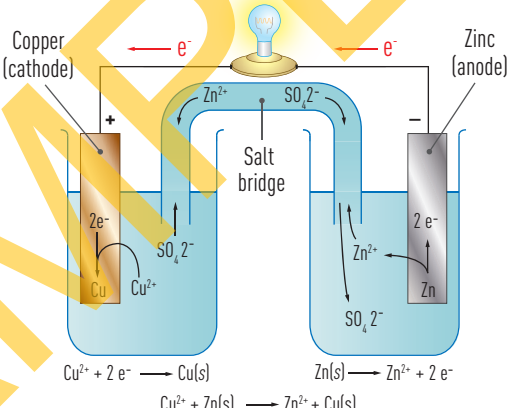

Figure 4.13 The movement of ions in a voltaic cell.

In Oxford Insight Science 8, you constructed an electrochemical battery using lemons. In the following experiment you are to investigate how energy is transferred in an electrochemical cell.

EXPERIMENT 4.1.5: ELECTROCHEMICAL FRUIT CELLS

Aim

To construct a simple electrochemical cell to describe the transfer of energy.

Materials

- Copper metal (foil or uninsulated wire)
- Galvanised nail (untarnished)
- 1 large fresh lemon per group
- Alligator clip leads (short)
- LED (or small light globe)
- Multimeter (optional)

Figure 4.14 Adding appropriate electrodes and connecting wires to a lemon can produce an electrical current.

Method

1. Roll the lemon and squeeze gently to soften the skin and make sure it is juicy on the inside.
2. Slit the lemons and insert a strip of copper foil. Mark the electrode with a positive sign.
3. At the opposite end insert the galvanised nail, making sure that the nail is not touching the copper. Mark the electrode with a negative sign.
4. Connect an alligator clip to the copper foil and another clip to the nail.
5. Connect the copper lead to the long arm of the LED and the zinc lead (from the galvanised nail) to the short arm of the LED. The LED will not work if connected incorrectly.
6. Darken the room and look carefully at the LED. It should have a faint glow.

Discussion

1. Identify the anode and the cathode in this cell.
2. What role does the lemon play in this cell?
3. Describe the movement of the electrons through this circuit.
4. Explain the link between the transfer of electrons and the transfer of energy.
5. Suggest a method of confirming which electrode was the anode and cathode.
6. Suggest a method of increasing the amount of electrical energy being released.

Conclusion

Write a statement that uses your experimental results to explain the aim.

QUESTIONS 4.1.3: ELECTROCHEMICAL TRANSFER OF ENERGY

Remember

1. Recall the type of electrochemical cell in which endothermic reactions take place.
2. Draw and label a generalised voltaic electrochemical cell.
   - **a** Include the following terms: electrode, electrolyte, salt bridge, connecting wire, globe, anode and cathode.
   - **b** Draw and label an arrow to indicate the direction of electron movement.
   - **c** Draw and label an arrow to indicate the direction of cation movement.
3. Recall the charges on the anode and cathode in voltaic cells.

Apply

4. Propose how electrochemical cells could be used to determine whether a reaction was endothermic or exothermic.
5. Evaluate whether the following food items could be used to make an electrochemical cell. For each item, explain why they would or would not be suitable.
   - **a** Tomato
   - **b** Banana
   - **c** Potato
   - **d** Sponge cake

CHEMICAL REACTIONS AND ENERGY

4.1 CHECKPOINT

Remember and understand

1 The following statements are false. Rewrite them to make them true.
   - **a** The anode of a voltaic cell is positively charged and attracts electrons. [1 mark]
   - **b** The electrolyte of an electrochemical cell is made up of dissolved molecular compounds. [1 mark]
   - **c** Energy, in the form of electricity, is produced by the exothermic reactions in an electrolytic electrochemical cell. [1 mark]

2 In exothermic reactions, the products contain less stored energy than the reactants. Explain what happens to the energy during the reaction. [1 mark]

3 Recall the purpose of the salt bridge in an electrochemical cell. [1 mark]

4 Photosynthesis is an endothermic reaction. Recall the type of energy input. [1 mark]

Apply

5 A burning candle requires a flame (lit match) to start the reaction. Identify whether this is an example of an endothermic or exothermic reaction. Justify your answer. [2 marks]

6 Relate endothermic and exothermic processes to the making and breaking of chemical bonds. [2 marks]

7 All endothermic and exothermic reactions eventually stop absorbing and producing heat. Explain why this is the case. [2 marks]

Analyse and evaluate

8 Explain why exothermic reactions have an activation energy even though they have a net release of energy. [2 marks]

9 Describe how chemical reactions transfer energy. [3 marks]

10 Compare and contrast electrolysis with an electrolytic electrochemical cell. [3 marks]

Research

11 Choose one of the following electrochemical cells to research. Construct an annotated poster of your chosen cell, clearly outlining the structure and chemical processes of the cell. Indicate its common uses. Make sure to include a bibliography of your sources. [5 marks]
   - **a** Mercury cells
   - **b** Rechargeable batteries
   - **c** Alkaline batteries
   - **d** Nickel-cadmium cells
   - **e** Zinc-carbon cells
   - **f** Dry-cell batteries

Making connections

12 Imagine all the chemical reactions that take place when baking bread in an oven fuelled by LPG gas. Describe in around 100 words, as many chemical changes that would occur in this process, including the production of heat in the oven as well as the changes in the bread. Identify each reaction as being either endothermic or exothermic. You may need to carry out some additional research to fully answer this question. [5 marks]

Figure 4.15 Which reactions in the process of baking bread are endothermic, and which are exothermic?

TOTAL MARKS [/30]

4.2 THE RATE OF REACTIONS

How fast a chemical reaction happens can be a life or 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 disease or other serious medical conditions. Controlling the rate of chemical reactions is vital in industry, our environment and in our bodies.

THE IMPORTANCE OF REACTION RATE

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 so quick 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.

Figure 4.16 Some slow reactions include (a) the rusting of iron and (b) the baking of muffins. Fast reactions include (c) fuel combustion in rocket launches and (d) controlled explosions.

ACTIVITY 4.2.1: 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.

1 For each of the following situations, describe whether you think a fast or slow chemical reaction is preferred. Discuss your thoughts with others.
   - **a** The rusting of an iron bridge.
   - **b** The reaction in the baking of bread that produces carbon dioxide (which makes the bread rise).
   - **c** The oxidation of alcohol in wine to form vinegar.
   - **d** The combustion of a fuel in a rocket engine.
   - **e** The chemical processes involved in the action of a pain-killing drug.

2 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.

3 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.

Rates of exothermic reactions

Exothermic reactions release energy, usually in the form of heat, light and sound. This energy causes increased temperatures, sparks and flames, and the sounds of crackling or explosions.

The amount of energy released and the rate or speed at which it is released varies between the different forms of exothermic reactions.

Figure 4.17 Combustion is a fast reaction that releases energy in the form of heat, light and sound.

Combustion

Combustion reactions require a fuel to react with the oxygen. Fuels can be solids, liquids or gases. Solid fuels include coal, wood and metals; liquid fuels include petrol and diesel; gaseous fuels include methane, propane (LPG) and hydrogen.

fuel + oxygen → oxide

Example:

magnesium + oxygen → magnesium oxide + energy (heat, light and sound)

$$2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)} + \text{energy}$$

All combustion reactions require ignition. Ignition is the activation energy of the reaction. Ignition is often in the form of friction (e.g. striking a match) or electrical energy (e.g. an electrical spark or lightning strike).

Combustion is considered to be a fast reaction, quickly releasing energy as the oxides, or oxygen-based compounds, are formed. Very fast combustion reactions result in explosions.

Respiration

Respiration is an exothermic reaction that releases energy from glucose to be used by the cell for its many different functions. There is so much energy in glucose that if it was all released at once, the heat produced would be enough to cook the cell. So respiration releases the energy in stages and at a rate that allows the energy to be converted into ATP molecules (the body's energy molecules). The rate at which the energy is released during respiration is slower and much more controlled than the energy released during a combustion reaction.

sugar + oxygen → carbon dioxide + water + energy

Example:

glucose + oxygen → carbon dioxide + water + energy

$C_6H_{12}O_{6(aq)} + 6O_{2(g)} \rightarrow 6CO_{2(g)} + 6H_2O_{(l)} + ATP$

Figure 4.18 All combustion reactions require ignition.

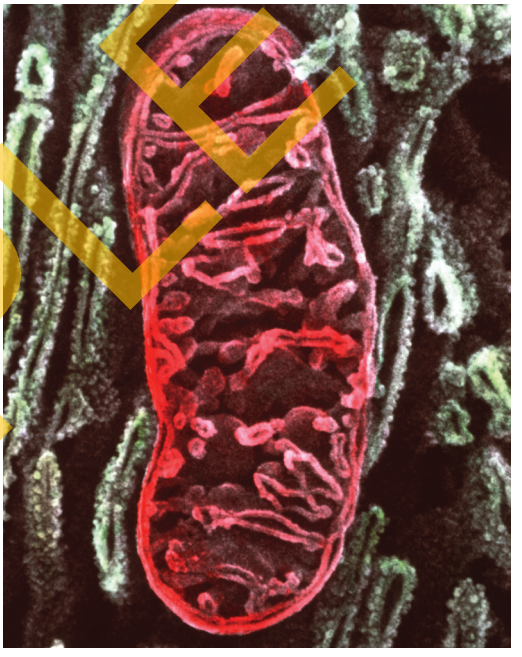

Figure 4.19 Mitochondria are the site of cellular respiration.

QUESTIONS 4.2.1: THE IMPORTANCE OF REACTION RATE

Remember

1 Recall the specific name for the activation energy of a combustion reaction.

2 List three reactions that need to proceed at a fast rate and three that need to proceed at a slow rate.

Apply

3 Identify whether respiration or combustion has the fastest rate of reaction. Justify your decision.

4 Provide two explanations why all the energy from glucose is not released at once.

Analyse

5 Propose two advantages and two disadvantages of increasing the speed of reactions in industry.

6 Zinc is more reactive than iron, which is more reactive than tin. Assuming that all other conditions were the same, suggest which metal would corrode the slowest.

COLLISION THEORY

For a chemical reaction to occur, the atoms or ions or molecules must collide together, in the right orientation and with enough energy for that reaction to occur. This concept is known as **collision theory**. The energy required for the reactants to interact is the activation energy.

For example, hydrogen iodide (HI) decomposes according to the following chemical reaction.

$$2HI_{(g)} \rightarrow H_{2(g)} + I_{2(g)}$$

Hydrogen iodide is a gas and its molecules travel quickly. Each hydrogen iodide molecule must collide with another hydrogen iodide molecule in the correct orientation and with enough energy to provide the activation energy for the reaction to proceed.

Many collisions do not result in a reaction. In these collisions, the hydrogen iodide molecules bounce apart with no reaction, as shown in Figure 4.20.

In the collision shown in Figure 4.21, there is a reaction. A weak chemical bond forms between the iodide ions and the hydrogen ions. This intermediate complex is unstable and only exists for a short period of time, before it breaks apart to form the final products.

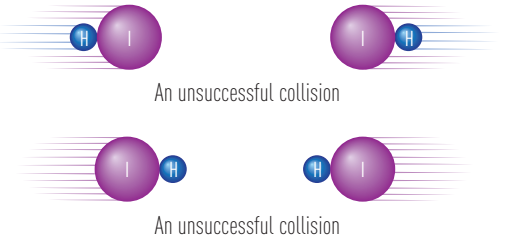

Figure 4.20 If the particles are not in the correct position when they collide, or if they don't collide with enough energy, they will not react.

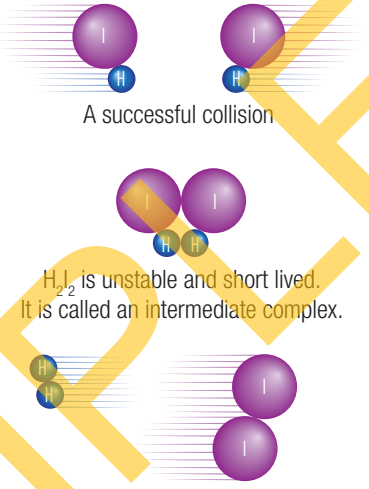

Figure 4.21 (a) When the particles are aligned correctly and collide with enough energy, a reaction will occur. (b) The intermediate complex H_2I_2 is unstable and short lived. (c) It breaks down into the final products, which separate partly due to electrostatic repulsion.

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.

Decomposition of hydrogen iodine:

$$2HI_{(g)} \rightarrow H_{2(g)} + I_{2(g)}$$

Synthesis of hydrogen iodine:

$$H_{2(g)} + I_{2(g)} \rightarrow 2HI_{(g)}$$

A reversible reaction can be written with a double-headed arrow, showing that the reaction can proceed in both directions.

$$2HI_{(g)} \leftrightarrow H_{2(g)} + I_{2(g)}$$

In the case of photosynthesis, while the reactants of respiration are the products of photosynthesis (in the overall reaction), and vice versa, they cannot be written as a reversible reaction. Both respiration and photosynthesis are actually a series of smaller reactions that involve very different intermediate products and enzymes. They are in fact very different processes and neither is reversible.

Collision theory and rates of reaction

The collision theory tells us that reactant particles only react when they collide in the correct ratio, correct orientation and with energy equal to or greater than the activation energy. Increasing the rate of successful collisions increases the overall rate of the reaction.

The factors that control the rate of a reaction in industry 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 industry. Table 4.1 lists a number of variables that could affect reaction rate along with a brief description of the change to the particles. The table also suggests some reactions that could be used to test a hypothesis about each variable.

Table 4.1 Factors that can affect reaction rate

Variable	Particles	Suggested chemicals and reactions suitable to test the hypothesis
Surface area	The larger the surface area the more particles available for collisions.	Calcium carbonate and dilute hydrochloric acid
Concentration	The more particles in a solution, the more likely collisions will occur.	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	The higher the temperature, the more energy the particles have, so they move around more and are more likely to collide.	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	Mixing or stirring increases movement of the particles, making them more likely to collide.	Use a solution of potassium permanganate mixed with a solution of oxalic acid – the amount of stirring of the reaction mixture can be varied.
Presence of a catalyst	A catalyst is a 'helper' molecule that brings the reactant particles together in the correct orientation, but is not actually a part of the reaction itself and can be reused over and over. While a catalyst itself does not increase the rate of reaction, it lowers the activation energy, which means the reaction will take place at a lower temperature.	Dilute hydrogen peroxide (H_2O_2) solution decomposes slowly and can be used to investigate the effect of the catalyst manganese dioxide.

STUDENT DESIGN TASK

Investigating the effect of surface area on reaction rate

Before you start

- The reaction that you are investigating is between calcium carbonate and hydrochloric acid. The equation for this reaction is:

$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$$

- 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.

Questioning and predicting

Write an appropriate aim and hypothesis for your experiment.

Planning and conducting

- Use the guide in the Science Skills to plan an appropriate method for your experiment.
- Consider the dependent, independent and controlled variables.
- Consider safety equipment and perform a risk assessment for your method.
- Carry out your experiment as you have outlined in your method.

Suggested materials

- Pieces of calcium carbonate (limestone, chalk or marble)
- Dilute hydrochloric acid (1.0 M)
- Test tubes
- Test-tube rack
- Stopwatch
- Electronic balance
- Measuring cylinder
- Safety glasses
- Hammer or mortar and pestle

(Note: you may be able to access other equipment depending on your experimental plan.)

Processing, analysing and problem solving

- Construct an appropriate table to collate your results. You may like to present your data as a graph to make it easier to identify trends.
- Identify the links between the size of the pieces of calcium carbonate and surface area.
- Determine whether or not your hypothesis was supported. Use evidence to support your claims, or suggest alternative explanations for your results.
- Identify what your results can tell you about other similar reactions.
- Suggest ways to improve your original method if you felt it was flawed. If your experiment was successful, suggest a new experiment to extend the depth of your investigation.

Communicating

Present your investigation as a formal scientific report, or in another format as negotiated with your teacher.

Figure 4.22 Which form of calcium carbon has the highest surface area? Which will react the fastest?

EXPERIMENT 4.2.1: EFFECT OF CONCENTRATION ON REACTION RATE

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

Hypothesis
Read the method of this experiment and write an appropriate hypothesis as an 'If ... then ...' statement.

Materials
- 20 mL of 0.5 M HCl (hydrochloric acid)
- 20 mL of 1.0 M HCl
- 20 mL of 2.0 M HCl
- 30 g small marble chips of similar size
- 3 × 100 mL conical flasks
- Electronic balance
- Stopwatch
- 25 mL measuring cylinder

WARNING
- 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. Prepare a table for your results as shown below.
2. 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.
3. 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 released.
4. Record in your results table the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.
5. Repeat the experiment as described above using 1.0 M HCl and then 2.0 M HCl.
6. 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.

Figure 4.23 Marble reacts with hydrochloric acid: calcium carbonate + hydrochloric acid → calcium chloride + water + carbon dioxide

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

Results

Discussion
Write a couple of paragraphs about the key findings of your experiment, any trends in the data, and an evaluation of the method used to produce these data. Suggest solutions to these issues or propose a new experiment to extend the investigation.

Conclusion
Write a conclusion for your experiment that includes a statement about the validity of your hypothesis based on the data from the experiment.

EXPERIMENT 4.2.2: EFFECT OF TEMPERATURE ON REACTION RATE

Aim
To investigate the effect of temperature on reaction rate.

Hypothesis
Read the method of this experiment and write an appropriate hypothesis as an 'If ... then ...' statement.

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

WARNING

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

Method
1 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.)

2 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.

3 In your report only write the steps of the method that you and your group planned. Make sure to include any appropriate units.

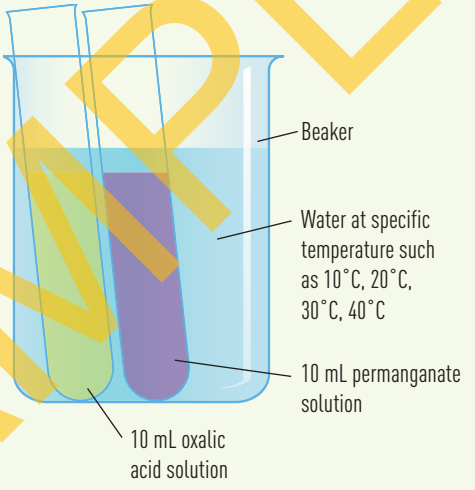

Figure 4.24 A water bath can be used to control the temperature of solutions.

Results
Design an appropriate table to collect and collate your data. You may like to draw a graph of your results to display any trends more clearly.

Discussion
Write a couple of paragraphs about the key findings of your experiment, any trends in the data and an evaluation of the method used to produce these data. Suggest solutions to these issues or propose a new experiment to extend the investigation.

Conclusion
Write a conclusion for your experiment that includes a statement about the validity of your hypothesis based on the data from the experiment.

EXPERIMENT 4.2.3: EFFECT OF A CATALYST ON REACTION RATE

Aim

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

$$2H_2O_{2(aq)} \rightarrow 2H_2O_{(l)} + O_{2(g)}$$

Hypothesis

Read the method of this experiment and write an appropriate hypothesis as an 'If ... then ...' statement.

Materials

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

WARNING

> 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.

Figure 4.25 The gas product can be tested with a glowing splint. CO_2 will extinguish the splint, H_2 will cause a 'pop' and in O_2 the splint will relight.

Results

Record your observations in an appropriate format.

Discussion

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

Conclusion

Write a conclusion for your experiment that includes a statement about the validity of your hypothesis based on the data from the experiment.

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?

QUESTIONS 4.2.2: COLLISION THEORY

Remember

1 Explain the main ideas of the collision theory in your own words.

2 Define the term 'reversible reaction'.

3 Explain why photosynthesis and respiration are not a pair of reversible reactions.

Apply

4 Using your knowledge of the collision theory, explain activation energy.

5 Describe how collision theory explains the rate of reactions.

6 Explain why it is important to follow the steps of the scientific method.

7 Identify the controlled variables in the experiment investigating the effect of concentration on reaction rate.

8 Identify the independent and dependent variables in the experiment investigating the effect of temperature on reaction rate.

Analyse

9 Evaluate the following statement: Every time reactant particles collide they react to form particles of the products.

FACTORS INFLUENCING THE RATE OF 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 collision theory 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.

You may have already investigated the effect of some of these factors in the previous section. In the next few pages you will discover why these factors affect reaction rate.

Increased surface area

A metal like magnesium reacts with dilute hydrochloric acid. A hydrogen ion in the acid has 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 pieces of material. Remember, the surface area is not the size of the pieces, but rather the total area exposed to the surroundings.

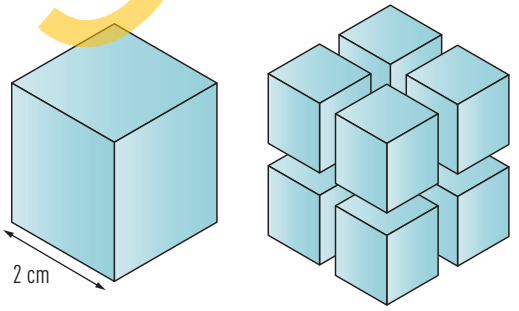

Figure 4.26 Many small particles have a larger surface area than a single large particle of the same volume.

Increased concentration

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.

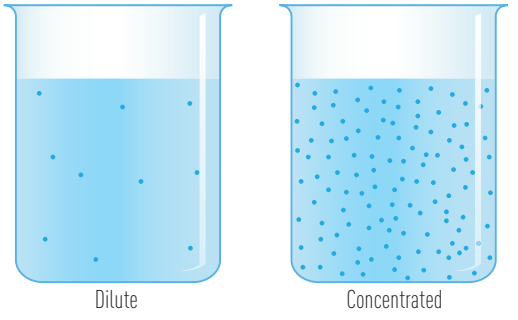

Figure 4.27 A more highly concentrated solution will contain more dissolved particles than a dilute solution.

Increased 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 more often and with more energy than cold particles. More collisions, and more energetic collisions (at or above the activation energy), mean a greater proportion of collisions that result in a reaction.

Slow moving 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, changing into products.

Increased pressure (gases)

For chemical reactions that involve gases, increasing pressure increases the rate of reactions. Gas pressures can be increased in two ways – by increasing concentration of particles in a fixed volume or by increasing the temperature of the gas. Increasing the number of particles in a volume means more particles are available to collide. Increasing the temperature of a gas provides the particles with additional kinetic energy, increasing the likelihood of energetic collisions.

Stirring and mixing

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.

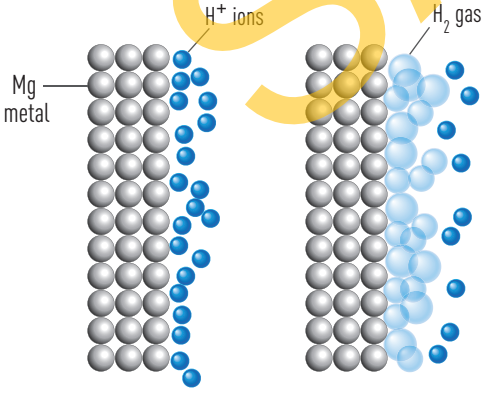

Figure 4.29 Sometimes the presence of the product can slow down a chemical reaction.

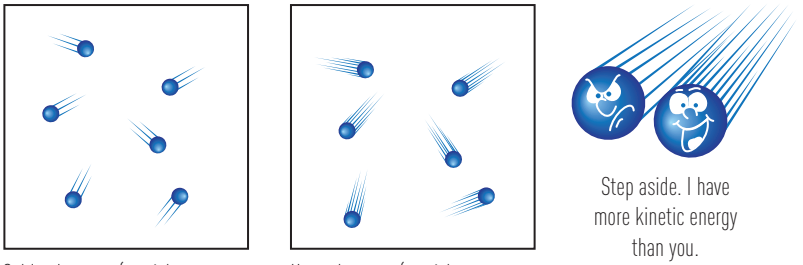

Figure 4.28 At higher temperatures, the average energy of the particles is increased, resulting in more movement and higher energy collisions.

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. The bubbles form a barrier that separates the magnesium from the hydrogen ions and prevents the reaction from continuing. Stirring sweeps the hydrogen gas away so that more hydrogen ions can react with the fresh magnesium surface.

Using a catalyst

A **catalyst** is any substance that speeds up a chemical reaction but is itself not used up in the reaction. In other words, a catalyst is a 'helper' particle that is not actually a part of the reaction.

Solid catalysts provide a surface on which the reaction can occur. The particles of reactants **adsorb** (stick 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.

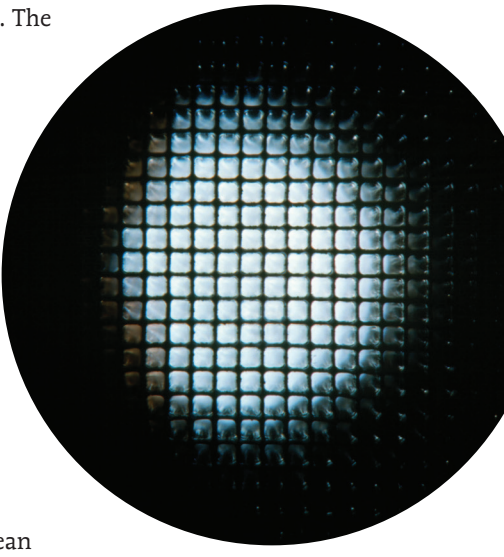

Figure 4.30 Solid catalysts are often used in the form of a grid to maximise the surface area.

An example of a catalyst acting as a 'helper' particle 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 can be reused over and over.

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.

1. UV radiation provides the energy for the decomposition of freon-11
2. The free chlorine atom forms an intermediate complex with an oxygen atom, catalysing the decomposition of ozone

   $Cl + O_3 \rightarrow ClO + O_2$

3. The ClO is destroyed by O atoms, releasing the Cl atom to destroy more ozone

   $ClO + O \rightarrow Cl + O_2$

Figure 4.31 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 are made from one or more protein molecules. Enzymes play an important part in all cellular processes. These catalysts increase the rate of the reactions that occur inside a cell. There are numerous different enzymes in our bodies, as each cellular reaction requires its own specific catalyst. For example, enzymes in the digestive system help break down food, while enzymes in mitochondria catalyse respiration. Enzymes only work with specific reactants and so will only catalyse certain reactions.

One model that explains the action of enzymes is the **lock-and-key model**. The enzyme molecule has a specific shape, or active site (the lock), into which only specific reactants (the keys) will fit. The enzyme brings the reactants close together in the correct orientation so that they can react to form the products. The products are slightly different in shape to the reactants and so no longer 'fit' in the active site. So the enzyme releases the products and becomes available to collect more reactants.

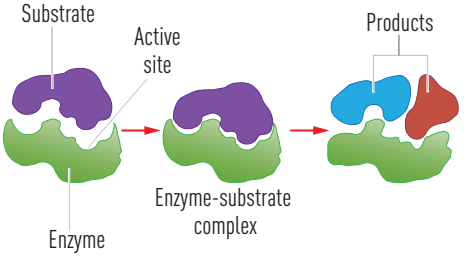

Figure 4.32 The lock-and-key model of enzyme activity.

QUESTIONS 4.2.3: FACTORS INFLUENCING THE RATE OF REACTIONS

Remember

1. Six factors affecting reaction rate have been explored in this unit. Identify the one thing they all have in common for increasing reaction rate.
2. Define the term 'catalyst'.
3. Identify why enzymes are considered to be 'biological catalysts'.

Apply

4. Explain why a greater surface area increases the rate of reaction.
5. Explain why a reaction may proceed more quickly when the reactants are stirred.
6. Describe the relationship between the concentration of reactants in solution and the rate of reaction.

7 Using your knowledge of collision theory, explain how decreasing the temperature of the reactants can reduce the rate of reaction.

8 Reactants A and B react to form product C. When catalyst X is added, the reaction rate appears to increase. Propose how you could test that X is really a catalyst and not a new reactant in a different reaction.

Analyse

9 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. Relate each of the methods listed below to methods of increasing reaction rate.

- 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

Figure 4.33 In what ways does blow-drying your hair increase the rate of drying?

4.2 CHECKPOINT

THE RATE OF REACTIONS

Remember and understand

1 In terms of particles, identify the key requirements for a chemical reaction to take place. [2 marks]

2 Identify whether respiration is an endothermic or exothermic reaction. Describe the evidence that supports your decision. [2 marks]

3 Recall at least four factors that influence the rate of reaction. [4 marks]

4 Describe a situation where it could be dangerous if a reaction occurs too quickly. [1 mark]

5 Describe a situation where it could be dangerous if a reaction occurs too slowly. [1 mark]

Figure 4.34 What is the purpose of refrigerating food?

Apply

6 Describe at least two ways in which the rate of a reaction could be measured. [2 marks]

7 Propose a reason why most food is kept refrigerated. [1 mark]

8 In many industrial environments, dust is regarded as an explosion hazard. Explain why a reactive dust is more likely to explode than blocks of the same material. [2 marks]

9 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. [4 marks]

b For two of these variables, explain how the experimental error would be increased if they were not controlled properly. [2 marks]

Analyse and evaluate

10 Propose how the particle model of matter helps us understand the rate of reactions. [3 marks]

11 The reaction $2SO_{2(g)} + O_{2(g)} \rightarrow 2SO_{3(g)}$ is very slow at room temperature. The reaction occurs more quickly in the presence of nitrogen dioxide gas. The reaction occurs in two steps, which are shown below.

Step 1:

$2SO_{2(g)} + 2NO_{2(g)} \rightarrow 2SO_{3(g)} + 2NO_{(g)}$

Step 2:

$2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)}$

Describe two reasons why the nitrogen dioxide is regarded as a catalyst. [2 marks]

Critical and creative thinking

12 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 [1 mark]

b too slowly. [1 mark]

Making connections

13 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 Propose a reason why attracting particles onto a surface of another chemical would encourage a chemical change to occur. [1 mark]

b Explain why a substance that actually bonded chemically to the reacting particles would not make a good catalyst. [1 mark]

c Give an example of the use of a surface catalyst, describing in detail the chemical reaction. You may have to do some research to answer this question. [3 marks]

d Use your knowledge of collision theory to explain why most catalysts are used in the form of a powder or fine mesh. [2 marks]

TOTAL MARKS [/35]

CHEMISTRY AND INDUSTRY

4.3

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. Many chemicals are vital in the production of materials that most of us use in our daily lives. A better understanding of chemistry allows us to predict, manage and reduce the risks of using chemicals in our environment as well as producing important resources.

INDUSTRIAL CHEMISTRY

A wide variety of products are produced by a range of chemical reactions. Many of the reactions occur naturally, but do not proceed quickly enough to make enough product to be useful. Chemists research new reactions and ways of increasing the rates of reactions to make all sorts of products, from metals, to plastics and fibres.

Industrial chemistry is involved in producing almost all substances that are not found in large quantities in nature.

Oxidation and reduction reactions

As you are reading this book, respiration is keeping you alive. Respiration is an **oxidation** reaction where oxygen combines with glucose to give our cells the energy they need to stay alive. Many chemical reactions involve bonding oxygen to other substances. Common oxidation reactions that you are likely familiar with 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 from compounds. One such example is the smelting of iron ore (iron(III) oxide – Fe_2O_3) into iron metal. Carbon is added to the iron(III) oxide to remove the oxygen. Carbon has a greater attraction for oxygen than does iron. As an equation, this process is written as:

$$2Fe_2O_{3(s)} + 3C_{(s)} \rightarrow 4Fe_{(s)} + 3CO_{2(g)}$$

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

Figure 4.35 The molten iron has been reduced by carbon.

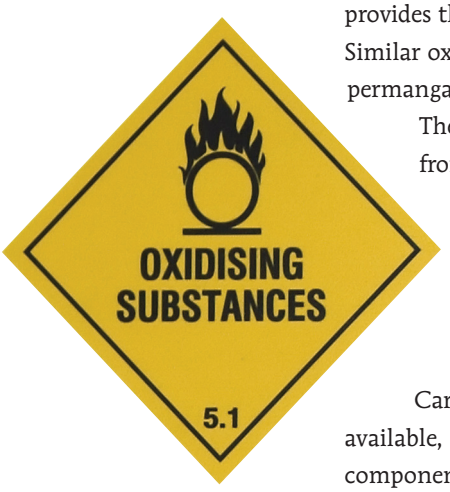

Figure 4.36 The warning label for oxidising agents.

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 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.

$C_{(s)}$ + oxygen-containing compound → $CO_{2(g)}$

$CO_{(g)}$ + oxygen-containing compound → $CO_{2(g)}$

Carbon is the most common reductant in the processing of metals. Carbon is readily available, and cheap, in the form of 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.

ACTIVITY 4.3.1: 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 iron(III) oxide, known as haematite.

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 a number of different 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:

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

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 or coke (C) 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.

$Fe_2O_3 + 2CO \rightarrow$ _____ + _____

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

Figure 4.37 Iron ore exports are vital for the Australian economy.

Figure 4.38 Hot iron being roll-pressed into a length of rail.

Plastics and polymers

Plastics are a major part of our lives. They form the wrap we put around our sandwiches and the containers in which we store our food and other products. 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.

Formation of polymers

Polymers are formed in **polymerisation** reactions where smaller molecules (**monomers**) are combined to form long chain molecules. There are many different types of polymerisation reactions, but they all follow the same process; the monomers are 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. Polyethene (also called polythene or polyethylene) is produced in this way, with molecules of ethene (C_2H_4) reacting together to form long chain polymer molecules. This process can be represented using a diagram, as shown in Figure 4.39.

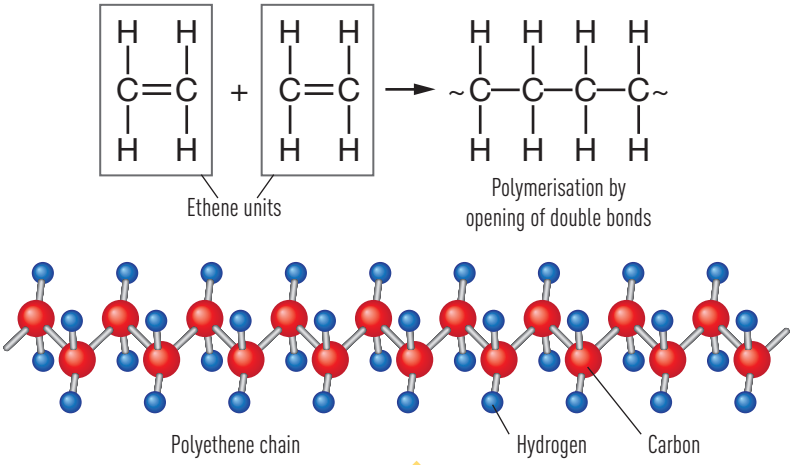

Figure 4.39 The formation of polyethene from ethene molecules.

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

Figure 4.40 Polyethene is a polymer that is commonly used to keep food fresh.

DEEPER UNDERSTANDING

Different types of polymers

A polymer is a giant molecule that has been produced by joining many, many smaller molecules or monomers together – often thousands! Polymer means 'many parts'.

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.

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.

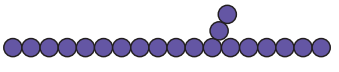

Figure 4.41 The basic structure of a linear polymer. The small circles represent the monomers.

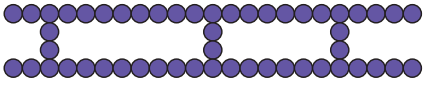

Figure 4.42 The basic structure of an elastomer.

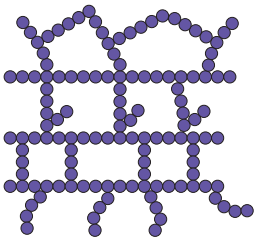

Figure 4.43 A cross-linked polymer.

Figure 4.45 The cover of a Playstation is made of thermosetting polymers.

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 'plastics'.

Figure 4.44 Plastic film is a thermoplastic polymer.

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.

EXPERIMENT 4.3.1: TESTING POLYMERS

Aim

To classify polymers based on their thermal properties.

Materials

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

WARNING

> 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? Did it spring back to its original shape as it cooled, or set hard in the new shape?

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 if any of the polymers are 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.

Conclusion

Use your data to write a statement that addresses the aim.

Figure 4.46 The properties of polymers determine their uses.

overmatter

EXPERIMENT 4.3.2: MAKING NYLON (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
- 2 × 50 mL beakers
- Glass Petri dish containing 50% alcohol (ethanol) water mix
- Paper towel or filter paper

WARNING

- 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.

Method

1. In a 50 mL beaker, mix 0.5 mL of 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.

Conclusion

Use your data to write a statement that addresses the aim.

Figure 4.47 Tents are made of nylon, which makes them lightweight.

Figure 4.48 Polar fleece has many uses when camping in the great outdoors.

Modern uses of polymers

Many different polymers are used today. More and more designer polymers are being developed and modified to suit particular applications. Before World War II 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 want 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.

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

QUESTIONS 4.3.1: INDUSTRIAL CHEMISTRY

Remember

1 Recall the differences between oxidation and reduction reactions. Give an example of each process.

2 Define the terms 'oxidant' and 'reductant'. Give an example of each.

Apply

3 Identify the oxidant and reductant in the smelting of haematite to produce iron.

4 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** Disposable drinking cup
- **d** Handles of barbeque tongs
- **e** A wash bottle for a science laboratory

Analyse

5 Deduce whether a thermosetting plastic is a linear or a cross-linked polymer. Justify your decision.

6 Polythene bags are commonly used throughout Australia, but some companies are now phasing them out or replacing them with other types of bag.

- **a** Propose reasons why polythene bags became common use.
- **b** Suggest some materials they may have replaced.
- **c** Research why Australia is trying to reduce the use of polythene bags.
- **d** Describe some measures that are being taken to reduce the use and production of polythene bags.

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 and cause harm. 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.

Pollution from fuels

Fuels are the substances we use to produce heat and/or electricity, and to run engines and motors. When choosing a fuel for a particular use, things such as cost, safety and efficiency are considered. Fuels can also be chosen according to the amount of pollution they release compared to the amount of energy they can produce.

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. Australia has huge supplies of brown coal and a good supply of natural gas.

All these fuels contain molecules made of carbon. Cellulose is a polymer of $C_5H_{10}O_5$ units arranged end-to-end, coal up to 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 hydrocarbons are released, along 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 products of the reaction will change.

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

$$2C_3H_8 + 7O_2 \rightarrow 6CO + 8H_2O$$

$$C_3H_8 + 2O_2 \rightarrow 3C + 4H_2O$$

Carbon monoxide (CO) is a poison that binds more tightly onto the haemoglobin in red blood cells 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.

Figure 4.49 Methane is the main component of natural gas, which is used to fuel gas hot water systems and stoves.

Figure 4.50 Carbon is the chemical basis for oils and fuels that we extract from the Earth.

Figure 4.51 Acid rain is caused by non-metal oxides, such as SO_2 and NO.

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.

$$N_{2(g)} + O_{2(g)} \rightarrow 2NO_{(g)}$$

The gases sulfur dioxide (SO_2), sulfur trioxide (SO_3; made from SO_2 in the atmosphere) and nitrogen monoxide (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.

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. While the catalytic converters improve the efficiency of the vehicles and reduce pollution, these metals are very expensive.

The overall reaction that occurs in the catalytic converter is:

$$2CO_{(g)} + 2NO_{(g)} \rightarrow 2CO_{2(g)} + N_{2(g)}$$

Figure 4.52 Heavy traffic increases pollution levels.

Figure 4.53 Catalytic converters are used to reduce pollution from exhaust gases

ACTIVITY 4.3.2: 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.

Questions

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 competition?

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

Figure 4.54 Professional sport players have often used oxygen treatments to speed up their recovery from injury.

Figure 4.55 Some harmful effects have resulted from scuba divers breathing pure oxygen.

Alcohols and biofuels

In Australia, drivers can now purchase petrol that contains a certain percentage of **alcohol**. Alcohols are a family of compounds that contain carbon, hydrogen and oxygen. The two simplest members of this family are methanol, CH_3OH, and ethanol, C_2H_5OH (see Figure 4.56). Their formulas are written in this way to show how the atoms are bonded. In Australia, oil companies are allowed to include up to 10% ethanol in their petrol.

Methanol blends have been used in racing cars for many years. Ethanol blends have been used for vehicles for a long time in some other countries.

Why are these alcohols suitable for use in this way? One reason is that they meet the requirements of a fuel. The equation for the combustion of ethanol is:

ethanol + oxygen → carbon dioxide + water + ENERGY

$$C_2H_5OH_{(l)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 3H_2O_{(g)} + \text{ENERGY}$$

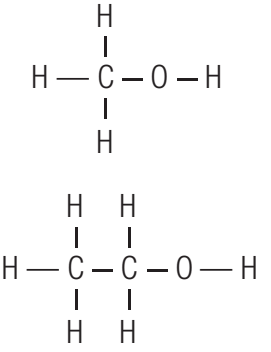

Figure 4.56 Chemical structures of methanol and ethanol.

Another reason is that alcohols burn more 'cleanly' than petrol. The greater the percentage of alcohol present, the lower the amount of pollutants produced. Some alcohols also greatly improve engine performance.

The main reason that ethanol is used is that it is regarded as a more sustainable fuel, because it can be produced by fermenting plant material, even wheat stubble. Its use will help decrease the rate at which we consume the hydrocarbon oils that are obtained from crude oil, a non-renewable resource.

Petrol is called a fossil fuel because the crude oil from which it comes was produced from ancient organisms, mainly plants, in a process that took millions of years. This process occurred with no oxygen. Alcohols such as ethanol are **biofuels** because they come from plant material that has only been recently grown and decayed. There is much debate about the long-term use of biofuels because the land required to grow plants can then not be used to grow food crops.

Biochemists are looking at ways to produce crops that have larger amounts of sugars. These sugars can then be fermented to produce ethanol. This could lead to higher yields of fuel ethanol and make it more likely that fossil fuels could be replaced by sustainable and affordable biofuels.

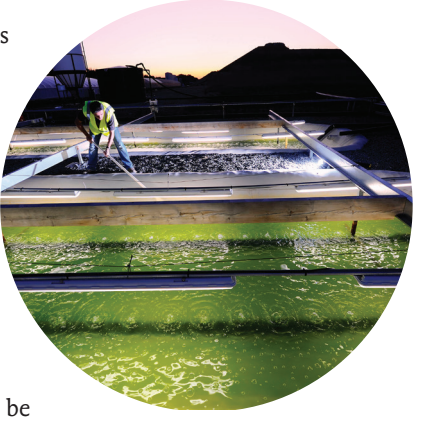

Figure 4.57 Microalgae are now being farmed to metabolise household wastes and produce methane as a fuel. The carbon dioxide produced in burning the fuel is then pumped back into the tanks to help promote photosynthesis.

LITERACY BUILDER

Biofuels deepen poverty and accelerate climate change: Oxfam report

www.oxfam.org.au, 25 June 2008

The biofuel policies of developed countries like the US and the EU have dragged more than 30 million extra people into poverty according to a report released by international aid agency Oxfam.

The report, 'Another Inconvenient Truth', finds that biofuel policies are not solving climate change or the fuel crisis but are instead contributing to food insecurity, hunger and inflation, which hit poor people hardest.

The report calculates that developed country biofuel policies have dragged people into poverty by causing a 30 per cent increase in global food prices.

The report follows news that food and drink companies including Unilever, Nestle, Cadbury and Heineken asked the European Commission to review its policy that encourages biofuel production, stating that they believed it would help drive agricultural commodity prices to further record highs.

Unlike many other developed countries, Australia has not set mandatory targets for biofuel production or use.

Figure 4.58 Large areas of Amazonian rainforest are being turned over to the production of soybeans for biofuel.

Oxfam Australia's biofuels and food crisis expert, Jeff Atkinson, said the report illustrated how catastrophic policies like mandatory targets had been, and urged the Australian Government not to adopt them.

'Biofuel policies are actually helping to accelerate climate change and deepen poverty and hunger. Rich countries' demands for more biofuels in their transport fuels are contributing to spiralling production and food inflation,' Mr Atkinson said.

Mandatory targets for biofuel use place a legal obligation on fuel companies to blend a certain volume or percentage of biofuels with the petrol and diesel they sell.

'The evidence about the damage of mandatory targets is overwhelming, and we strongly urge the Australian Government to ensure that these targets for biofuels are not adopted in Australia. Such targets would only serve to put pressure on agricultural land in developing countries,' Mr Atkinson said.

Mr Atkinson said the cultivation of biofuel products required mass land clearing that took over agricultural land and forced farming to expand into lands like forests and wetlands. This triggered the release of excessive and damaging carbon into the atmosphere, cancelling out the environmental benefits of biofuels.

He said in Indonesia, where peat land tropical rainforest was being cleared to make way for palm oil, which is used in biodiesel, it would take approximately 420 years of biofuel production to pay back the carbon debt accrued from this destruction of the rainforest's carbon stores.

Mr Atkinson said biofuels also would not address wealthy countries' need for fuel security.

'Even if the entire world's supply of grains and sugars were converted into ethanol tomorrow – in the process giving the world less to eat – we would only be able to replace 40 per cent of our petrol and diesel consumption,' Mr Atkinson said.

Questions

1. Biofuels in Australia are promoted as cheaper, cleaner, greener and locally made. Is this statement true? Are biofuels going to solve our fuel crisis?
2. Governments have put mandatory targets on biofuel production. What does this mean? What are the advantages and disadvantages of mandatory targets?
3. This report was published in 2008. Research the changes that have happened in the biofuels debate since then.

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 occur naturally in the environment while people make other acids. Any substance made by people is said to be anthropogenic.

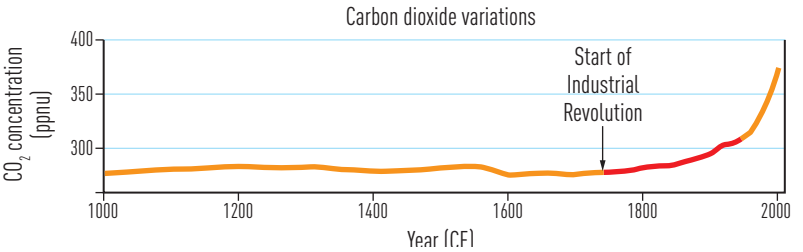

Figure 4.59 Carbon dioxide levels in our atmosphere have increased dramatically since the industrial revolution and continue to rise.

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 lower the pH of the sea water, causing it to become acidic.

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.

EXPERIMENT 4.3.3: EFFECTS OF ACID POLLUTION ON CARBONATES

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
- 2 × 100 mL conical flasks
- Single-holed rubber stopper with bent glass delivery tube

WARNING

> 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.

Results

Draw an appropriate table to record your results here.

Discussion

1. What can be concluded about the strength of ethanoic acid compared with that of hydrochloric acid? Discuss using your data as evidence.

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.

Conclusion

Use your data to write a statement that addresses the aim.

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 general of formulas SOx and NOx, where 'x' stands for a subscript 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.

$SO_{2(g)} + H_2O_{(l)} \rightarrow H_2SO_{3(aq)}$ (sulfurous acid)

$SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$ (sulfuric acid)

$2NO_{2(g)} + H_2O_{(l)} \rightarrow HNO_{2(aq)} + HNO_{3(aq)}$
(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 (stone work and concrete) and metals
- changes to availability of ions in the soil
- damage to new growth on trees
- effects on marine life, such as shell formation.

QUESTIONS 4.3.2: CHEMICALS AND POLLUTANTS

Remember

1 Recall why the sulfur is removed from the petrol used in vehicles.

2 Identify the difference between natural and anthropogenic carbon dioxide.

3 Identify what a catalytic converter is. Explain why they are used.

4 Identify two reasons why many people are now using ethanol blends in their cars.

5 Recall the pH of natural rain and acid rain. Explain why there is such a difference.

Apply

6 Petrol and ethanol came originally from living plant material. However, only ethanol is described as a biofuel. Explain why this is the case.

7 Propose some methods of reducing the incidence of acid rain in the environment.

8 Classify each of the following fuel compounds as a hydrocarbon, an alcohol or neither.

a C_4H_{10} **b** C_2H_4 **c** H_2 **d** C_3H_7OH

SAFE AND SUSTAINABLE USE OF CHEMICALS

Not all chemicals are dangerous, and those that are can be handled safely and used in industry. Knowledge and understanding of the properties of chemicals and their potential risks enables chemists to evaluate the risks and design appropriate methods of using those chemicals. Continual investigation and research into chemistry can lead to safer alternatives that may produce better quality products at greater quantities or faster rates as well as being better for the environment.

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 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**.

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. Below are some examples of why the development of 'green' alternatives are necessary.

- Pesticides and herbicides are poisons 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.

Figure 4.60 Many chemical products considered safe for use in the past have been replaced by more environmentally friendly substances.

ACTIVITY 4.3.3: 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.

By adapting the slogan 'THINK GLOBAL, ACT LOCAL' 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, and catching public transport or riding a bike instead
- using natural cleaning products and avoiding chlorine-based cleaners.

Figure 4.61 In what ways do 'green' shopping bags reduce harmful chemicals in the environment?

Figure 4.62 How can you reduce your carbon footprint? <

Figure 4.63 Riding a bike reduces traffic congestion and is a healthy way of keeping fit, as well as reducing the amount of carbon dioxide produced.

Questions

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?

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.

QUESTIONS 4.3.3: SAFE AND SUSTAINABLE USE OF CHEMICALS

Remember

1 What constitutes 'green' chemistry?

2 The 'old masters', the painters of 1600s–1800s, used pigments made of compounds of lead, mercury and cadmium. Explain why these paints are no longer available to today's painters.

Apply

3 Propose why graphics are used on chemical warning labels.

4 Why do you think 'unleaded' petrol was developed?

5 Propose why 'green chemistry' requires knowledge in ecology, biochemistry, zoology and botany as well as chemistry.

Ethical thinking

6 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?

CHEMISTRY AND INDUSTRY

4.3 CHECKPOINT

Remember and understand

1 Recall two different reactions that both release carbon dioxide as a product. [2 marks]

2 Using an example, describe what is meant by the term 'oxidant'. [2 marks]

3 Identify a key difference between a fossil fuel and a biofuel. [2 marks]

4 Describe the effect of acid rain on objects made of limestone (calcium carbonate). [1 mark]

5 Explain the advantages and disadvantages of using alcohol instead of petrol in cars. [2 marks]

6 Identify how many atoms of carbon, hydrogen and oxygen are present in a molecule of ethanol (CH_3CH_2OH). [3 marks]

Apply

7 Polypropylene is a plastic that is easily melted and formed into a range of different products. Describe the likely structure of polypropylene and explain how its structure allows the plastic to be moulded into different shapes. [2 marks]

8 Explain why some people say that our society's energy demands are based on carbon. [2 marks]

9 Describe how acid rain is formed from the burning of fossil fuels. [3 marks]

10 Propose some 'green chemistry' that could be applied at home. [2 marks]

Analyse and evaluate

11 Describe, in terms of molecules, the key differences between the formation and melting of a polymer. [2 marks]

12 Explain why carbon dioxide – a natural product – is regarded as a pollutant. [2 marks]

Ethical behaviour

13 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? [3 marks]

Critical and creative thinking

14 Propose how advances in technology have helped scientists improve their methods for producing chemical products. [3 marks]

15 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? [4 marks]

Making connections

16 Prepare a poster or digital presentation on the use of ethanol as a fuel. Outline the advantages and disadvantages of using ethanol in this way. Include relevant diagrams or images that support your arguments. [5 marks]

17 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.

Figure 4.65 Leaded petrol is no longer available.

TOTAL MARKS [/50]

4 CHAPTER REVIEW

1 Fill in the gaps, using the words in the Word Bank below:

A range of different types of chemical reactions can be sued to make specific _____. The reaction itself involves a transfer of _____ between the reactants and products. Reactions that have more energy in their products than _____, absorb energy and are called _____ reactions. Those that release energy are called _____ reactions.

Naturally occurring reactions exist with both fast, _____, and slow, _____, reaction rates. The _____ of reactions can be altered in a number of ways; _____ temperature increases reaction rate as does introducing a _____.

Knowledge of chemicals and their reactions enables the development of new and _____ products. The needs of _____ and the environment are balanced and generate new career paths like _____chemistry.

WORD BANK:

Combustion	Green	Reactants
Endothermic	Increasing	Respiration
Energy	Products	Society
Exothermic	Rates	Sustainable

Identify that chemical reactions transfer energy and can be classified as either exothermic or endothermic

2 Identify the following reactions as endothermic or exothermic. Provide reasons for your decisions.

a water + energy → hydrogen + oxygen [2 marks]

b methane + oxygen → carbon dioxide + water + energy [2 marks]

3 Explain why all reactions have an activation energy. [2 marks]

4 In terms of chemical bonds, explain how reactions transfer energy. [3 marks]

Construct simple electrochemical cells to describe energy transfer (additional content)

5 Describe the structure of a voltaic electrochemical cell using a lemon. [4 marks]

6 Explain the difference between electrolytic and voltaic electrochemical cells. [3 marks]

Compare combustion and respiration as exothermic reactions of different rates

7 Compare and contrast combustion and respiration.

a Identify combustion and respiration as either endothermic or exothermic reactions. [2 marks]

b Identify at least two other features that they have in common [2 marks]

c Identify at least two differences between the two reactions. [2 marks]

Describe the effects of changes in temperature, surface area and catalysts on the rate of chemical reactions

8 Explain what is meant by the 'rate of reaction'. [1 mark]

9 Give an example of a:

a slow reaction [1 mark]

b fast reaction. [1 mark]

10 Describe the relationship between the rate of reaction and:

a temperature [1 mark]

b surface area [1 mark]

c concentration [1 mark]

d the presence of a catalyst. [1 mark]

Analyse how the development of new materials can be influenced by social ethical and environmental considerations

11 Propose why industrial chemists and chemical engineers generally look for ways in increase reaction rates. [2 marks]

12 Identify two advantages and two disadvantages of making carpet from nylon. [4 marks]

13 Identify the advantages and disadvantages that might result if biofuels were to completely replace all fossil fuels. [4 marks]

Describe examples where advances in science and technology generates new career opportunities

14 Define the term 'green chemistry' and explain why this new branch of chemistry came into being. [2 marks]

15 Explain how the discovery of polymers provided new career opportunities. [3 marks]

Investigate the process involved in the production of synthetic fibres (additional content)

16 Define the terms 'polymer' and 'monomer'. [2 marks]

17 Describe the differences between linear polymers, cross-linked polymers and elastomers? [3 marks]

Balance chemical equations (additional content)

18 Write balanced chemical equations for the reactions listed in question 2. [4 marks]

19 Write a balanced chemical equation for the production of hydrogen gas from magnesium and hydrochloric acid (there is one other product). [2 marks]

TOTAL MARKS [/55]

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, what chemical processes are used to extract the pure metals and what we can do to conserve the use of these 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.

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.

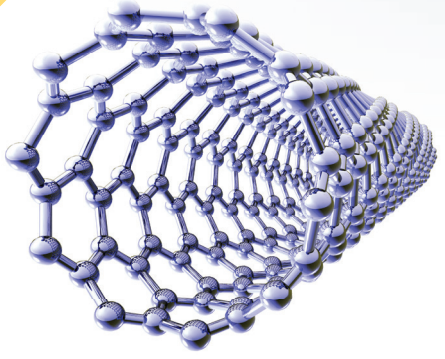

Figure 4.66 A carbon nanotube.

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?

Key words

activation energy
adsorb
alcohol
anode
biofuel
catalyst
cathode
chemical bonds
collision theory
electrochemical cell
electrode
electrolysis
electrolyte
endothermic
enzyme
exothermic
fossil fuels
green chemistry
lock-and-key model
monomers
oxidant
oxidation
pollutants
polymerisation
polymers
reaction rate
reductant
reduction
reversible
synthesis
thermal decomposition

4

MAKING CONNECTIONS

Interaction and change

Choose one of the following topics to complete.

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, the social and cultural conventions of the time meant 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.

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.

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.

Figure 4.67 Clara Immerwahr.

Figure 4.68 Fritz Haber.

Figure 4.69 Chlorine gas was first used as a weapon in World War I.

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? Justify your response.

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:

$$N_{2(g)} + 3H_{2(g)} \leftrightarrow 2NH_{3(g)}$$

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.

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.

Figure 4.70 Huge quantities of ammonia are produced in Australia each year.

Your task

1 Look at the equation for the Haber process.

$$N_{2(g)} + 3H_{2(g)} \leftrightarrow 2NH_{3(g)}$$

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 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 collision theory, explain why, in the Haber process, the iron catalyst used is in the form of a powder or fine mesh.

Figure 4.71 Many of the fertilisers used nowadays have been manufactured from compounds containing ammonium salts.

overmatter from page 188

9 For each substance in question 8, conduct some research to discover the name and a common use of the fuel.

Analyse

10 Propose reasons why carbon fuels are so important to our society.

11 Deduce why the amount of oxygen available affects the products formed in combustion of fuels.

overmatter from page 191

a Use a diagram to represent the transfer of oxygen from the lungs to body cells. [4 marks]

b Explain why the chemical changes occurring between haemoglobin and oxygen need to be reversible. [2 marks]

c Do you think that the reaction between carbon monoxide and haemoglobin is reversible? Explain your answer. [2 marks]

d Suggest two ways that carbon monoxide poisoning can be prevented. [2 marks]

overmatter from page 193

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 In what ways do you think people will change how they use chemistry in the future?

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