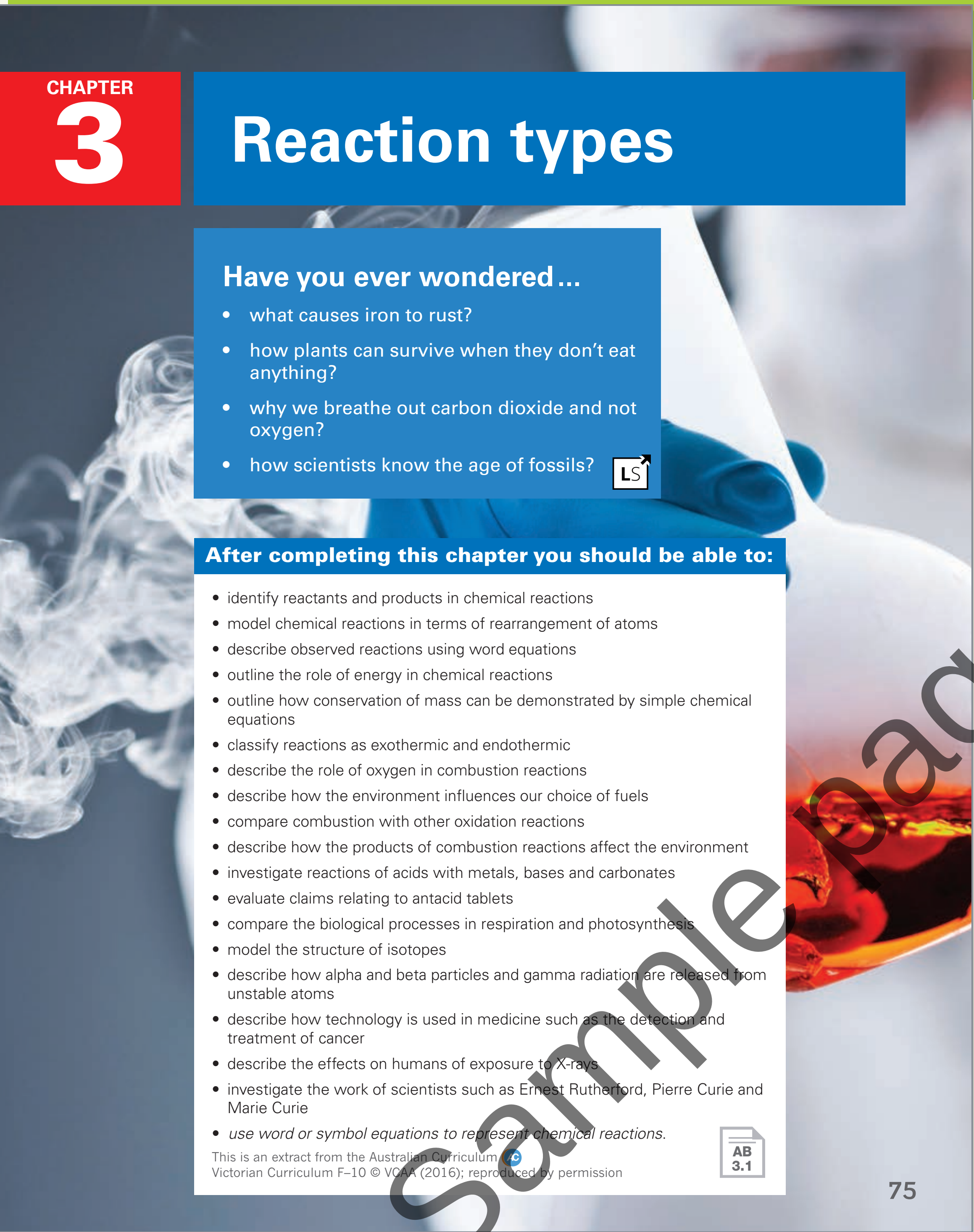

CHAPTER 3

Reaction types

Have you ever wondered...

- what causes iron to rust?
- how plants can survive when they don't eat anything?
- why we breathe out carbon dioxide and not oxygen?
- how scientists know the age of fossils? LS

After completing this chapter you should be able to:

- identify reactants and products in chemical reactions
- model chemical reactions in terms of rearrangement of atoms
- describe observed reactions using word equations
- outline the role of energy in chemical reactions
- outline how conservation of mass can be demonstrated by simple chemical equations
- classify reactions as exothermic and endothermic
- describe the role of oxygen in combustion reactions
- describe how the environment influences our choice of fuels
- compare combustion with other oxidation reactions
- describe how the products of combustion reactions affect the environment
- investigate reactions of acids with metals, bases and carbonates
- evaluate claims relating to antacid tablets
- compare the biological processes in respiration and photosynthesis
- model the structure of isotopes
- describe how alpha and beta particles and gamma radiation are released from unstable atoms
- describe how technology is used in medicine such as the detection and treatment of cancer
- describe the effects on humans of exposure to X-rays
- investigate the work of scientists such as Ernest Rutherford, Pierre Curie and Marie Curie
- *use word or symbol equations to represent chemical reactions.*

AB 3.1

Chapter overview

In this chapter, students will learn that all matter is composed of atoms and has mass, will identify a range of compounds, and will investigate various types of chemical reactions.

Students will construct word equations and deduce that new substances are formed during chemical reactions by a rearrangement of atoms. Students will identify that radioactivity arises from the decay of nuclei in atoms, and evaluate the benefits and problems of radioactive substances.

The activities using word and/or symbol equations to represent chemical equations are included in this chapter from the Victorian Curriculum.

Pre-prep

The practical investigations in this chapter require chemical preparation, so check the requirements before each practical. Extra practical and inquiry activities are provided in this Teacher Companion. Photosynthesis investigations may need some preparation of plants and leaves. Some practical investigations can be performed simultaneously, or in the same lesson with similar equipment.

Students will learn most from this chapter if it is practical and demonstrated.

Chapter duration: 3 to 4 weeks

Pre-quiz

Formative assessment

1. Explain how you can tell that a chemical reaction has occurred.
   A change will have occurred.
2. Is water a chemical? Explain.
   Yes, it is made up of hydrogen and oxygen.
3. Explain whether salt is a chemical.
   Yes, it is a chemical. Salt is sodium chloride, symbol NaCl.
4. Define the difference between fission and fusion.
   Fission is when a large atom splits to create smaller atoms. Fusion is where two smaller atoms come together to make a larger atom.
5. Explain some of the risks of nuclear radiation.
   Student answers, for example: sickness, cancer, cell mutation.

PEARSON science 9 RESOURCES

Differentiation and literacy

Teacher support

There is a series of expert spreads at the beginning of this Teacher Companion that assist with the implementation of a number of teaching and learning strategies throughout.

'Differentiation in the science classroom' on pages xx–xxii supports and unpacks the approach taken to differentiation suggestions.

'The literacies of science' on page xix supports and unpacks the approach taken to literacy suggestions.

Weblinks

A selection of weblinks and descriptions to support the development and application of content and skills in this chapter are accessible via your eBook.

Activity Book

3.1 *Knowledge preview* enables insight into students' prior knowledge of key content and ideas.

Vocabulary preview

anodising
balanced equation
combustion
complete combustion
corrosion
endothermic reaction
exothermic reaction
glucose
hydrocarbons
incomplete combustion
law of conservation of mass
photosynthesis
products
reactants
rust
tarnish
verdigris
word equation

science 4 fun

Eating sherbet

Background

Sherbet creates a fizz in your mouth when you eat it. This is an endothermic reaction. Students have probably eaten sherbet, so they are likely to be familiar with the concept. This activity allows students to make sherbet.

Hints and suggestions

If you don't have time to make sherbet, you could just use a bought one or discuss previous experiences, although there are benefits in having students go through the process and see the ingredients.

Possible results and looking forward

Get students to discuss the feeling of the fizz in their mouths. What is happening here? Use this to discuss endothermic and exothermic reactions.

MODULE 3.1

Combustion and corrosion reactions

Chemical reactions happen continually around you. Two important types of chemical reactions are combustion and corrosion. Combustion happens when anything burns or explodes. Corrosion happens when a metal such as copper or an alloy such as steel changes into something else. Similar substances tend to undergo similar chemical reactions. These similarities allow you to predict what might happen if two chemicals are mixed. The similarities become more obvious when chemical reactions are expressed as chemical equations.

science 4 fun

Eating sherbet

YES

An endothermic reaction absorbs energy from its surroundings. What does an endothermic reaction feel like?

Collect this ...

- ½ teaspoon of citric acid
- ¼ teaspoon of baking soda (bicarbonate of soda, $NaHCO_3$)
- 3 teaspoons of icing sugar
- clean mixing bowl, cup or mug
- teaspoon

SAFETY

You should never eat in the laboratory, so only eat sherbet that you have made at home.

Do this ...

1. Add all the ingredients to the small mixing bowl or mug.
2. Use the back of the teaspoon to crush any lumps and to mix everything together.
3. Keep it in a dry place until ready to eat!

Record this ...

1. Describe what happened in your mouth when you ate the sherbet.
2. Explain why you think this happened.

Chemical reactions

In a chemical reaction, new substances form and old ones disappear. **Reactants** are the old substances you started with before the chemical reaction. **Products** are the new substances formed by the chemical reaction.

A chemical equation is a convenient way of showing what happens to different substances in a chemical reaction. A chemical reaction is always written in the form:

reactants → products

A **word equation** is a simple description of what is happening in a reaction. It shows the names of all the chemicals that are reactants and all those that are products. An example of a word equation is:

nitrogen gas + hydrogen gas → ammonia

This word equation shows that nitrogen gas and hydrogen gas reacted to form ammonia. Another, more detailed way of showing what is happening in a reaction is to write a **balanced equation**. The balanced equation for the above reaction between nitrogen and hydrogen gases is:

$$N_2 + 3H_2 \rightarrow 2NH_3$$

76 PEARSON SCIENCE 9 2ND EDITION

Learning strategies

Literacy strategy

Common substances

MI: Bodily/Kinaesthetic, Verbal/Linguistic

Experiments often use chemicals that are unfamiliar to students. They come from special containers that students will not see anywhere else. Naturally, students do not connect these mysterious substances with everyday life. To address this problem, it is good to use common substances like baking soda, vinegar, sugar, salt and methylated spirits where possible. It can also be cheaper!

A balanced equation shows exactly what is happening in a reaction. The big numbers in front of each substance are called **coefficients**. These numbers show how much of each substance reacted and how much of each reactant was produced. For example, the balanced equation above shows that:

- every single molecule of nitrogen reacts with three molecules of hydrogen
- two molecules of ammonia were formed.

SkillBuilder

Writing word equations

To write a word equation, follow the steps below.

Identify the reactants and products.

As an example, consider the chemical reaction between copper and sulfur dioxide. This reaction forms copper sulfide and oxygen gas. You started with copper and sulfur dioxide, so these are the reactants. Copper sulfide and oxygen gas were produced. These are the products.

Write a word equation.

A word equation is a simple written description of what is happening in the reaction. The reactants are placed on the left side of the arrow and the products on the right.

reactants → products

copper + sulfur dioxide → copper sulfide + hydrogen gas

Energy in reactions

An **endothermic reaction** is a reaction that absorbs heat, taking it from the surroundings and making them feel colder.

In endothermic reactions, the products have more energy than the reactants. Endothermic reactions need energy to proceed and they get their energy from what is around them. An example is what happens in a chemical cold pack that you might use when you have an injury. Packets of ammonium nitrate and water are broken, allowing these substances to mix and react. As they react, they absorb energy from their surroundings, cooling the surroundings down. The sherbet in Figure 3.1.1 acts in a similar way.

While endothermic reactions absorb energy, **exothermic reactions** release energy. In exothermic reactions, the reactants have more energy than the products. During the reaction, energy is released into the surroundings, usually as heat and/or light.

Worked example

Writing word equations

Problem

A piece of aluminium was dropped into hydrochloric acid. The aluminium dissolved and reacted to form aluminium chloride. As it did so, hydrogen gas bubbled to the surface. Write a word equation for this reaction.

Solution

Thinking: Identify the reactants and products.

Working: Reactants = aluminium, hydrochloric acid

Products = aluminium chloride, hydrogen gas

Thinking: Write a word equation.

Working: reactants → products

aluminium + hydrochloric acid → aluminium chloride + hydrogen gas

Try yourself

Construct word equations for the following reactions.

1 Sodium reacts with iron(II) chloride to form sodium chloride and iron.

2 When propanol is burnt in oxygen gas, carbon dioxide and water are formed.

3 Hydrogen peroxide splits to form water and oxygen gas.

AB 3.2

FIGURE 3.1.1 Sherbet leaves your tongue cold because an endothermic reaction absorbs heat from your mouth.

WORKED EXAMPLE ANSWERS

Writing word equations

1 Sodium + iron(II) chloride → sodium chloride + iron

2 propanol + oxygen gas → carbon dioxide + water

3 Hydrogen peroxide → water + oxygen gas

PEARSON science 9 RESOURCES

Activity Book

3.2 *Analysing a reaction* provides practice in interpretation of practical results.

Making connections

Exothermic reactions

MI: Verbal/Linguistic

Batteries or cells are explained in several chapters through the Pearson Science series. So are fuels. These are both examples of exothermic reactions. The energy released by these reactions is harnessed for particular purposes.

Inquiry activity

Cold packs

MI: Visual/Spatial, Verbal/Linguistic

Purpose: For students to conduct an endothermic reaction and to investigate a practical application for this reaction.

Class time: 15 minutes

Materials: Solid ammonium chloride (or ammonium nitrate), snap-lock bag, freezer bag with metal tie, thermometer

Hypothesis: How does an endothermic reaction work? Ask students to write a hypothesis about this before beginning the activity.

PROCEDURE

1 Add about 3 tablespoons of ammonium chloride to a freezer bag. Place a metal tie on the bag but just twist it once.

2 About half fill the snap-lock bag with water. Record the temperature of the water.

3 Place the freezer bag with ammonium chloride inside the snap-lock bag.

4 Seal the snap-lock bag.

5 Untie the metal tie on the ammonium chloride without opening the outer snap-lock bag.

6 Shake the contents of the snap-lock bag, to mix the water and ammonium chloride.

7 Wrap the thermometer in the bag for several minutes, then record the temperature change.

DISCUSSION

1 What temperature did the thermometer read?
The temperature should drop about 5 degrees below the original water temperature.

2 Explain whether this reaction is exothermic or endothermic.
Endothermic, as it is absorbing heat, making the surroundings colder.

3 What modifications could you make to increase the temperature change?
More solid, less water, better shaking.

Teacher demonstration

Combustion of iron

MI: Bodily/Kinaesthetic, Visual/Spatial

Purpose: To demonstrate a decomposition reaction and a combustion reaction.

Class time: 25 minutes

Materials: Gas jars, steel wool, tongs, Bunsen burner, potassium permanganate, test-tube with gas delivery tube

Hypothesis: What happens in a decomposition reaction? What happens in a combustion reaction? Ask students to suggest a hypothesis before you start.

PROCEDURE

1. Collect a gas jar sample of oxygen. Potassium permanganate can be heated in a test-tube to do this, and the gas collected by displacement of water.
2. Burn steel wool in a Bunsen flame. Observe any reaction.
3. Heat a new sample of steel wool in the Bunsen and plunge it quickly into the gas jar of oxygen.
4. Other materials can also be burnt in oxygen, e.g. sulfur on a deflagrating spoon, glowing splint.
5. Empty the contents of the test-tube that contained potassium permanganate into a gas jar filled with water. Observe.

DISCUSSION

1. What is the decomposition reaction taking place?
   Potassium permanganate is decomposing to oxygen and potassium manganate.
2. What evidence do you have that the potassium permanganate has been changed?
   The crystals 'jump' around when heated. The powder at the end causes a mixture of purple and green colour in water.
3. What combustion reaction is occurring?
   Iron and oxygen combining to iron oxide.
4. Write a word equation for this reaction.
   iron + oxygen → iron oxide
5. Why does the reaction flare up in the gas jar?
   The steel wool is burning in a high concentration of oxygen, unlike air, which is only 20% oxygen.

Combustion

Combustion reactions are examples of exothermic reactions. **Combustion** occurs whenever something reacts with oxygen gas (O_2), burning or exploding as it does so. A bushfire is a series of combustion reactions. The chemicals in living plants, dead twigs and leaves burn in oxygen, releasing huge amounts of heat and light energy as they react.

Combustion reactions belong to a type of reaction known as an oxidation reaction—in its simplest form, an oxidation reaction is when an element reacts with oxygen.

SciFile

That's shocking!

Explosions generate hot gases that suddenly expand at speeds of up to 8 kilometres per second! These expanding gases form blasts of wind called shockwaves, which can be as deadly as the explosion itself. A shockwave leaves a vacuum at the site of the explosion, and air flowing into this carries rubbish and debris.

Combustion of fossil fuels

Bunsen burners, gas stoves, water heaters and central heating furnaces produce a hot blue flame by burning methane or ethane gas in oxygen (Figure 3.1.2). The reactions are:

methane + oxygen gas → carbon dioxide + water

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

ethane + oxygen gas → carbon dioxide + water

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

FIGURE 3.1.2 A gas stove uses combustion to release its heat (and light).

Petrol is a mixture of highly combustible chemicals called **hydrocarbons**, the most important of which is octane. Octane combusts via the chemical equation:

octane + oxygen gas → carbon dioxide + water

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$

Incomplete combustion

The above combustion reactions all need an unlimited supply of oxygen fed into them. These reactions are known as **complete combustion**.

However, oxygen supply is sometimes restricted in some way. This might happen if there is not enough oxygen or the oxygen cannot mix properly with the fuel. This might happen if a fire was started indoors or the substance burning is so dense or tightly packed that oxygen cannot get into it. If the oxygen supply is restricted in some way, then other reactions occur instead. This is known as **incomplete combustion**. Incomplete combustion is still exothermic but does not release as much heat or light energy as complete combustion does.

The reactions below show what happens to methane if oxygen is restricted.

methane + oxygen gas → carbon monoxide + water

$$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$$

At the same time another reaction occurs.

methane + oxygen gas → carbon + water

$$CH_4 + O_2 \rightarrow C + 2H_2O$$

Incomplete combustion reactions are 'dirty' because they produce carbon, which is left behind as soot, charcoal or smoke, like that seen in Figure 3.1.3. They also produce the poisonous gas carbon monoxide. In contrast, complete combustion reactions are 'clean'.

FIGURE 3.1.3 Smoke and soot are an indication of incomplete combustion.

Numeracy strategy

Equations in this module

MI: Verbal/Linguistic

In this module, a range of equations are mentioned: combustion and corrosion reactions. Ask students to copy down each reaction equation, and help them to recognise each type of reaction.

Summarising

Appliances and items

MI: Verbal/Linguistic

Help students recognise the items in their household that perform combustion reactions. The text refers to a range of items (gas stoves, water heaters) that use combustion reactions. What other items or appliances would have these types of combustion reactions? Discuss what occurs in each that you have seen. Where else might you see a combustion reaction?

For example, a sheet of paper burns quickly without much smoke. This is because oxygen can easily get to all parts of the paper, allowing all parts to burn at once. However, crumple the paper into a tight ball and it will burn slowly and produce lots of smoke. This happens because only the outside gets enough oxygen to undergo complete combustion. The supply of oxygen to the inner layers of paper is very limited so much of the ball will undergo incomplete combustion. Hence it will burn slowly and produce lots of smoke.

A Bunsen burner can show both complete and incomplete combustion. If the flow of oxygen to it is good (open airhole), then combustion is complete and the flame is hot, clean and blue. If the air flow is restricted (closed airhole), then combustion is incomplete and a cooler, dirty yellow flame is produced.

SciFile

Suffocating fires

Fires consume oxygen, so there is less of it to breathe in the region of the fire. During World War II, the German city of Dresden was firebombed. Many of the 25 000 people killed in the attack are thought to have suffocated because of this lack of oxygen.

Pollution and climate change

Water vapour and carbon dioxide are released into the atmosphere whenever fossil fuels such as gas, petrol, oil, coal, diesel and aviation fuel are burnt. Carbon dioxide is a greenhouse gas that traps heat within the atmosphere. Over the past 150 years, we humans have burned huge quantities of fossil fuels to power our cars, ships and aircraft, and to heat their homes and generate electricity. For this reason, the amount of carbon dioxide in the atmosphere has increased to levels that most scientists agree are increasing the atmosphere's average temperature. If this view is correct, then the burning of fossil fuels could be affecting Earth's climate.

If the combustion of these fossil fuels is incomplete, then carbon monoxide and carbon are released.

Carbon adds relatively harmless but dirty soot to the atmosphere. Carbon monoxide gas has no smell, but it is so poisonous that even small amounts of it can kill. Petrol also contains additives that release other poisonous chemicals when burnt. These include oxides of nitrogen and sulfur, both of which can combine with moisture in the air to form smog and acid rain.

Other combustion reactions

A much slower and controlled combustion reaction occurs within the cells of your own body. **Aerobic respiration** combines the sugar **glucose** from the digestion of your food with the oxygen you breathe in. This reaction releases the energy that the cells of your body need. A waste product is carbon dioxide, which you breathe out (Figure 3.1.4).

$$\text{glucose + oxygen gas} \rightarrow \text{carbon dioxide + water}$$
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

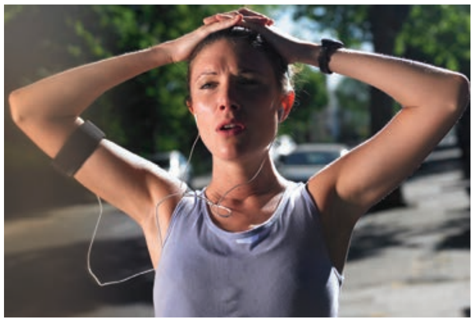

FIGURE 3.1.4 Respiration gives your body the energy it needs. The reaction needs glucose (from your food) and oxygen (breathed in). You breathe out its product, carbon dioxide.

Not all combustion reactions produce carbon dioxide and water vapour. When burnt, magnesium reacts to form magnesium oxide. No other products form.

$$\text{magnesium + oxygen gas} \rightarrow \text{magnesium oxide}$$
$$2Mg + O_2 \rightarrow 2MgO$$

You can see this reaction happening in Figure 3.1.5.

FIGURE 3.1.5 The light released by the combustion of magnesium is so bright that it can quickly damage your eyes.

Prac 1 p. 84 | Prac 2 p. 85 | Prac 3 p. 86

Making connections

Fire eats oxygen

PRODUCT DIFFERENTIATION

MI: Verbal/Linguistic, Visual/Spatial

Ask students to read the SciFile explaining how lack of oxygen can be as deadly as, or more deadly than, the fire itself. Students can create a poster, or an information report, explaining the reaction involved and why this occurs in the context of fire safety, and how, not only is the fire dangerous, but if you don't have access to oxygen you can't breathe. Explain how this relates to the masks that fire rescue workers wear.

Questioning

Smoke and soot

MI: Visual/Spatial, Verbal/Linguistic

Figure 3.1.5 describes how smoke and soot are indications of an incomplete combustion. Explain why this is so.

When there is not enough oxygen to complete the combustion reaction, carbon is produced. This creates the smoke and soot.

PEARSON science 9 RESOURCES

Practical investigations

Prac 1, page 84, shows that mass is conserved in a chemical reaction.

Prac 2, page 85, shows that combustion reactions obey the law of conservation of mass.

Prac 3, page 86, allows students to observe how combustion releases heat energy.

CHECKPOINT

Students can now answer Module 3.1 Review questions 3, 5, 9 and 11.

Extra support

Reactions are everywhere

MI: Visual/Spatial, Bodily/Kinaesthetic, Verbal/Linguistic, Logical/Mathematical

Help students recognise the application of science and chemicals in everyday situations. Ask them to walk around the classroom (or outside or for homework) and look at various objects/creatures (living or non-living, dead or alive) and ask what reactions they are a part of. Encourage them to identify a range of reactions represented in the text, such as respiration, photosynthesis, combustion or corrosion. Ask them to note five examples.

ICT

Tarnish

MI: Visual/Spatial, Verbal/Linguistic

Tarnish on silver is a corrosion reaction. Ask students to imagine they worked for a historical society and had to regularly clean silver. Ask them to look up the reactions that would occur in removing tarnish and how tarnish removal works. The society prefers to reverse the reaction rather than removing the silver so students should recommend how they could do this.

There are two ways of removing tarnish, one is to remove the silver sulfide (which also means some silver is lost) and the other is to reverse the chemical reaction which means you need to create a new reaction to do so. This reaction below will leave the silver by reversing the reaction.

$$3Ag_2S + 2Al \rightarrow 6Ag + Al_2S_3$$

From their research, students could write up an experiment about the removal of tarnish.

Home learning activity

CONTENT AND PROCESS DIFFERENTIATION

Balancing corrosion reactions

MI: Logical/Mathematical

Have students look up the corrosion reversal reactions based on the three corrosion reactions described (rust on iron, aluminium corrosion and tarnish on copper). Ask students to find appropriate reactions that can reverse these and then use their skills to balance these reactions. Students can use internet resources to investigate the corrosion reactions further. Provide internet resources and guiding questions for those students who need the structure to complete the task.

Corrosion reactions

Most metals corrode when exposed to water, air or other chemicals. **Corrosion** is a chemical reaction that forms other compounds from these metals.

For example, the iron/steel body of a car slowly reacts with water and oxygen in the air and will corrode until all that is left is a pile of rust.

In a similar way, copper corrodes by reacting with gases in the air to form green **verdigris**, a mixture of copper(II) hydroxide and copper(II) carbonate. The typical green colouring of verdigris is obvious in Figure 3.1.6. The chemical equation is:

copper + water + carbon dioxide + oxygen gas → copper(II) hydroxide + copper(II) carbonate

$$2Cu + H_2O + CO_2 + O_2 \rightarrow Cu(OH)_2 + CuCO_3$$

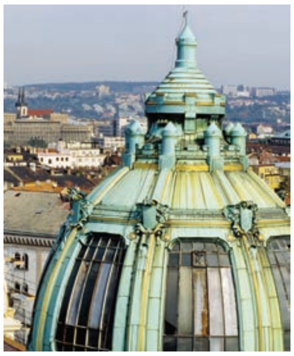

FIGURE 3.1.6 This copper roof has corroded to form a green coating called verdigris.

Pure silver reacts with sulfur to form a black coating called **tarnish** (silver sulfide). This sulfur comes from hydrogen sulfide in air pollution or from foods such as eggs, fish, onions and pea soup.

silver + hydrogen sulfide → silver sulfide + hydrogen gas

$$2Ag + H_2S \rightarrow Ag_2S + H_2$$

Pure sodium and potassium are such reactive metals that they react with just about anything. Their corrosion is very quick and often explosive because of the hydrogen gas that their reactions produce. Their chemical reactions with water are shown below.

sodium + water → sodium hydroxide + hydrogen gas

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

potassium + water → potassium hydroxide + hydrogen gas

$$2K + 2H_2O \rightarrow 2KOH + H_2$$

Rusting

Iron and its alloy, steel, are common and relatively cheap. This makes them the most used metals on Earth. Unfortunately, iron and most types of steel react with air and water to form **rust** (Figure 3.1.7). Rust is known chemically as hydrated iron(III) oxide (chemical formula $Fe_2O_3.H_2O$). Rust is flaky and easy to dislodge. This allows the rusting process to continue into the next layer, progressively making the iron or steel thinner and weaker.

FIGURE 3.1.7 Rust forms when iron is exposed to oxygen and water.

Although an extremely complex reaction, rusting can be summarised by the chemical equation:

iron + oxygen gas + water → hydrated iron(III) oxide

$$4Fe + 3O_2 + 2H_2O \rightarrow 2Fe_2O_3{\cdot}H_2O$$

This equation is often simplified to:

iron + oxygen gas → iron(III) oxide

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

In its simplest form, an oxidation reaction involves an element joining with oxygen in a chemical reaction. For this reason, rusting is considered to be an oxidation reaction.

Corrosion of aluminium

Aluminium is very reactive. The surface metal reacts almost immediately with oxygen in the air, forming a fine layer of dull, grey aluminium oxide (Al_2O_3).

aluminium + oxygen gas → aluminium oxide

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

Unlike rust, this layer does not flake but acts instead like a tightly bound layer of paint, protecting the aluminium from further corrosion. **Anodising** is a process that deliberately builds up a layer of aluminium oxide to protect the aluminium underneath (Figure 3.1.8).

FIGURE 3.1.8 These cups are made of anodised aluminium. Their surface is a layer of aluminium oxide that was deliberately built up on the surface of the metal and then coloured.

PEARSON science 9 RESOURCES

Untamed Science video

Building better bridges

Rob investigates a rusting bridge and visits a chemist who is developing methods to slow down the rusting process.

Access this video via your eBook.