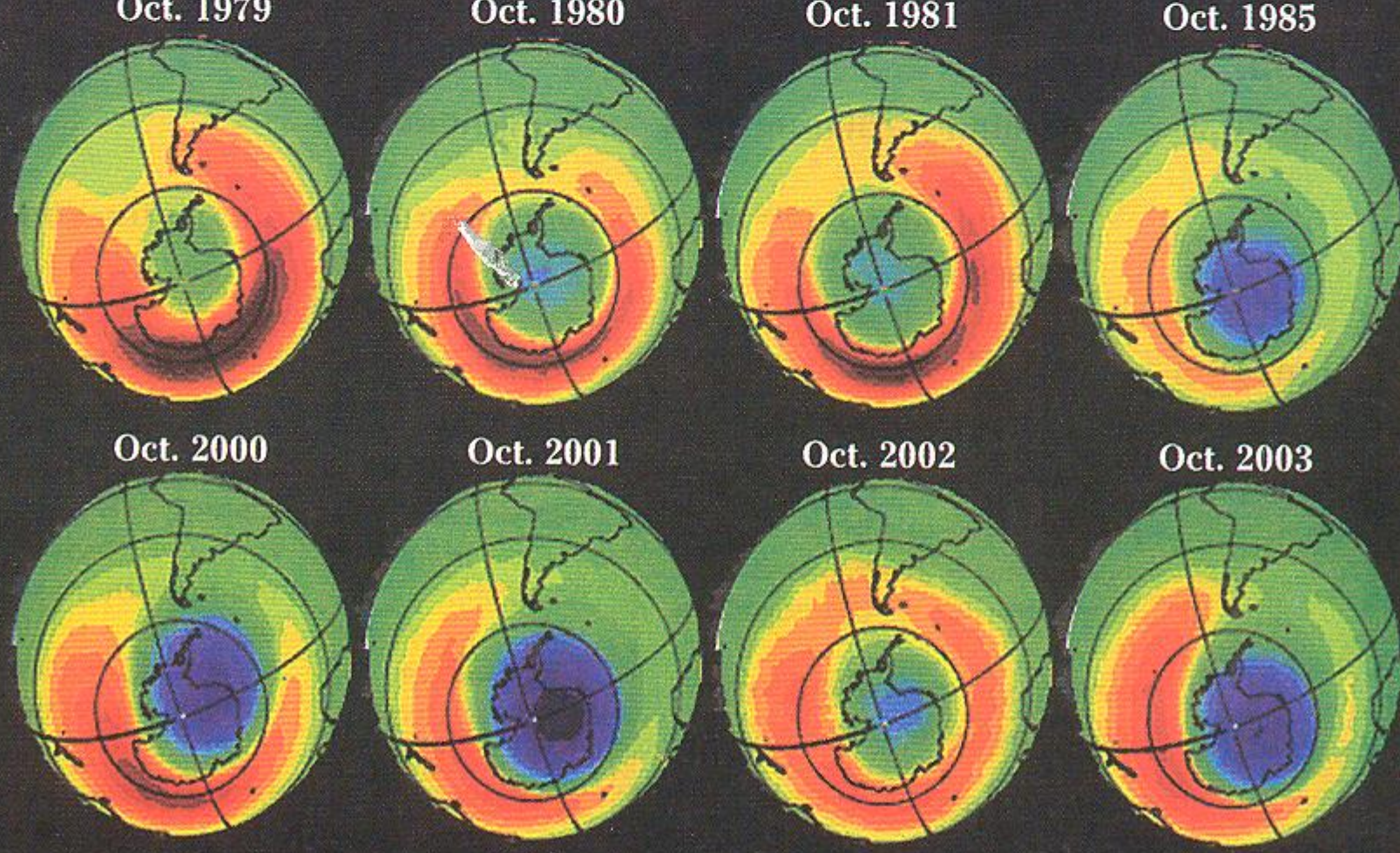
Chapter 8

Writing Equations



Each circle shows the ozone layer around the Earth. Note how the amount of ozone has decreased from 1979 to 2003.

A chemical called ozone exists in our stratosphere. It forms a protective layer around the Earth. It absorbs harmful radiation from the Sun, reducing our risk of getting skin cancer.

Unfortunately, the ozone layer around the Earth is disappearing. Scientists performed experiments and discovered that some chemicals that we release into the atmosphere react with ozone and break it down. These reactions, as well as other chemical reactions, can be represented as chemical equations.

Chemical equations can be used to represent how the ozone layer is disappearing. They are also important in many other situations, as you will see in the next two chapters. In this chapter, you will learn how to write chemical equations correctly.

Chapter Outline

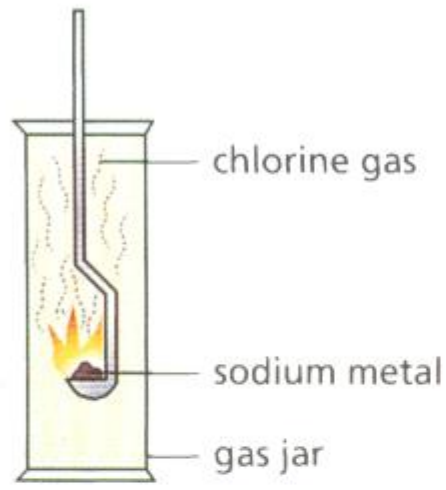


Fig. 8.1 Sodium and chlorine react to form sodium chloride.

8.1 Chemical Equations

What is a chemical equation?

In chemistry, an equation represents what occurs in a chemical reaction. We can write an equation by using words or chemical formulae. The most important thing to remember is that an equation must represent a reaction known to take place. The **word equation** (equation in words) for the reaction between sodium and chlorine is written below.

Word equation

sodium + chlorine ⟶ sodium chloride

We can also *make use of chemical formulae to write* the **chemical equation**.

Chemical equation

$Na + Cl_2 \longrightarrow NaCl$

- $Na + Cl_2$: We write the reacting substances or **reactants** on the left-hand side of the equation. In this case, sodium (Na) and chlorine (Cl_2) are the reactants.
- ⟶: The arrow means 'react to form'. The reaction proceeds from left to right.
- $NaCl$: We write the substances formed or **products** on the right-hand side of the equation. Here, sodium chloride ($NaCl$) is the only product.

Notice that on the left-hand side of the equation, there are two chlorine atoms but on the right-hand side of the equation, there is only one chlorine atom. This means that the equation is *not* balanced. An equation is balanced when there is an *equal number of atoms of each element on both sides of the equation*. In the next section, you will learn how to write a **balanced chemical equation**.

Chem-Aid

(s) represents a solid.
(*l*) represents a liquid.
(g) represents a gas.
(aq) represents an aqueous solution, i.e. dissolved in water.

Did you know that common salt is actually sodium chloride?

Writing Balanced Equations

An equation is usually written using chemical formulae, unless you are instructed to write a word equation. There are four steps in writing a balanced chemical equation:

Step	
1	Write down the formulae of the reactants and products.
2	Check the number of atoms of each element on both sides of the equation. If the equation is not balanced, proceed to step 3.
3	Balance the equation by placing numbers in front of the formulae of the substances in the equation. The number '1' is *not* written.
4	Include the state symbols in the equation.

Example 1

Making use of these four steps, we can write the balanced chemical equation for the reaction between sodium and chlorine.

Solution:

Step		
1	Write down the formulae of the reactants and products.	Na + Cl_2 ⟶ NaCl sodium chlorine sodium chloride
2	Check the number of atoms of each element on both sides of the equation.	There are two chlorine atoms on the left-hand side but only one chlorine atom on the right-hand side. This means that the equation is not balanced.
3	Balance the equation. To balance the number of chlorine atoms, we need to put a '2' in front of the 'NaCl'. The equation is still not balanced because there are two sodium atoms on the right-hand side and one sodium atom on the left-hand side. To balance the equation, we need to put a '2' in front of 'Na'.	Na + Cl_2 ⟶ 2NaCl 2Na + Cl_2 ⟶ 2NaCl
4	Add the state symbols.	2Na(s) + Cl_2(g) ⟶ 2NaCl(s)

The balanced equation reads as 'Two atoms of sodium react with one molecule of chlorine to form two formula units of sodium chloride'.

Example 2

Methane gas (CH_4) is often used as fuel for Bunsen burners in laboratories. Methane burns in oxygen to form carbon dioxide and water vapour. Write an equation for this reaction.

Chem-Aid

When balancing equations, never change the formula of a substance.

Solution:

Step			
1	Write down the formulae of the reactants and products.	CH_4 + O_2 ⟶ CO_2 + H_2O methane oxygen carbon dioxide water vapour	
2	Check the number of atoms of each element on both sides of the equation.	**reactants**	**products**
		1 carbon atom	1 carbon atom
		4 hydrogen atoms	2 hydrogen atoms
		2 oxygen atoms	3 oxygen atoms
3	Balance the equation.	CH_4 + $2O_2$ ⟶ CO_2 + $2H_2O$	
4	Add the state symbols. Note that the state symbol for H_2O is 'g' because water vapour (a gas) is formed.	CH_4(g) + $2O_2$(g) ⟶ CO_2(g) + $2H_2O$(g)	

What does the balanced equation read as?

Test Yourself 8.1

Question

Copper(II) oxide reacts with ammonia to give copper, water and nitrogen. What must the values of *x*, *y* and *z* be in order to balance this equation?

$3CuO(s) + 2NH_3(g) \longrightarrow xCu(s) + yH_2O(l) + zN_2(g)$

8.2 | Ionic Equations

Many substances, especially ionic compounds, are soluble in water. An **ionic equation** is a simplified chemical equation that shows the reactions of such substances in water.

How do we write ionic equations?

When aqueous sodium chloride is added to aqueous silver nitrate, a white precipitate of silver chloride is formed. This reaction can be represented by the chemical equation below.

Word equation sodium chloride + silver nitrate ⟶ silver chloride + sodium nitrate

Chemical equation $NaCl(aq) + AgNO_3(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$

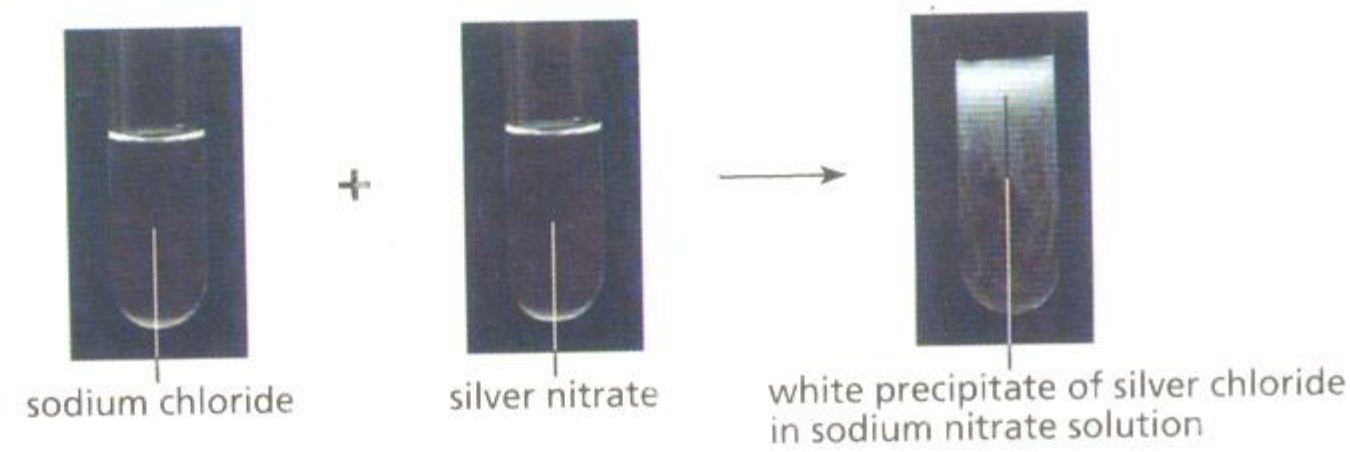


Fig. 8.2 This reaction produced silver chloride precipitate.

Sodium chloride, silver nitrate and sodium nitrate are soluble in water. They exist as ions in solution. If we write the chemical equation in terms of ions, we get

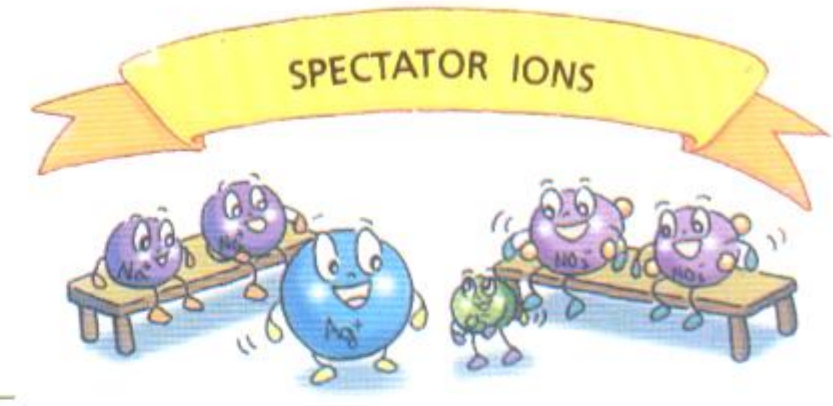
$Na^+(aq) + Cl^-(aq) + Ag^+(aq) + NO_3^-(aq) \longrightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$

The ions marked in red (Na^+ ions and NO_3^- ions) have *not* taken part in any chemical reactions. They are still ions in solution at the end of the reaction. Such ions are called **spectator ions**.

Since only silver ions and chloride ions have reacted, the equation for the reaction can therefore be simplified as shown below.

Ionic equation $Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$

The above equation is called an **ionic equation**. An **ionic equation** *shows the ions taking part in a reaction and the products formed. It leaves out the spectator ions that do not react.*



How do we write an ionic equation?

The steps in writing an ionic equation are:

Step	
1	Write the balanced chemical equation of the reaction. Include the state symbols.
2	Identify ionic compounds that are soluble in water (you may refer to page 196 to check solubility of compounds). These compounds become ions in water. Rewrite the chemical equation in terms of ions.
3	Cancel out the spectator ions.
4	Write the ionic equation.

Example 1

When hydrochloric acid reacts with sodium hydroxide solution, the products formed are sodium chloride and water. Write the ionic equation for this reaction.

Chem-Aid

Some covalent compounds form ions in water, e.g. hydrochloric acid (HCl).

Solution:

Step		
1	Write the balanced chemical equation.	$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$
2	Rewrite the equation in terms of ions for substances that are soluble in water.	$H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \longrightarrow Na^+(aq) + Cl^-(aq) + H_2O(l)$
3	Cancel out the spectator ions.	$H^+(aq) + \cancel{Cl^-(aq)} + \cancel{Na^+(aq)} + OH^-(aq) \longrightarrow \cancel{Na^+(aq)} + \cancel{Cl^-(aq)} + H_2O(l)$
4	Write the ionic equation.	$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$

Example 2

When zinc is added to copper(II) sulphate solution, copper and zinc sulphate are formed. Write the ionic equation for this reaction.

Link

Sodium hydroxide (NaOH) is an alkali. Find out more about alkalis and acids in chapter 11.

Solution:

Step		
1	Write the balanced chemical equation.	$Zn(s) + CuSO_4(aq) \longrightarrow Cu(s) + ZnSO_4(aq)$
2	Rewrite the equation in terms of ions for substances that are soluble in water.	$Zn(s) + Cu^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow Cu(s) + Zn^{2+}(aq) + SO_4^{2-}(aq)$
3	Cancel out the spectator ions.	$Zn(s) + Cu^{2+}(aq) + \cancel{SO_4^{2-}(aq)} \longrightarrow Cu(s) + Zn^{2+}(aq) + \cancel{SO_4^{2-}(aq)}$
4	Write the ionic equation.	$Zn(s) + Cu^{2+}(aq) \longrightarrow Cu(s) + Zn^{2+}(aq)$

Example 3

A solution of sodium carbonate reacts with sulphuric acid to form sodium sulphate, carbon dioxide and water. Write the ionic equation for this reaction.

Solution:

Step		
1	Write the balanced chemical equation.	$Na_2CO_3(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + CO_2(g) + H_2O(l)$
2	Rewrite the equation in terms of ions for substances that are soluble in water.	$2Na^+(aq) + CO_3^{2-}(aq) + 2H^+(aq) + SO_4^{2-}(aq) \longrightarrow 2Na^+(aq) + SO_4^{2-}(aq) + CO_2(g) + H_2O(l)$
3	Cancel out the spectator ions.	~~$2Na^+(aq)$~~ $+ CO_3^{2-}(aq) + 2H^+(aq) +$ ~~$SO_4^{2-}(aq)$~~ $\longrightarrow$ ~~$2Na^+(aq)$~~ $+$ ~~$SO_4^{2-}(aq)$~~ $+ CO_2(g) + H_2O(l)$
4	Write the ionic equation.	$CO_3^{2-}(aq) + 2H^+(aq) \longrightarrow CO_2(g) + H_2O(l)$

Key ideas

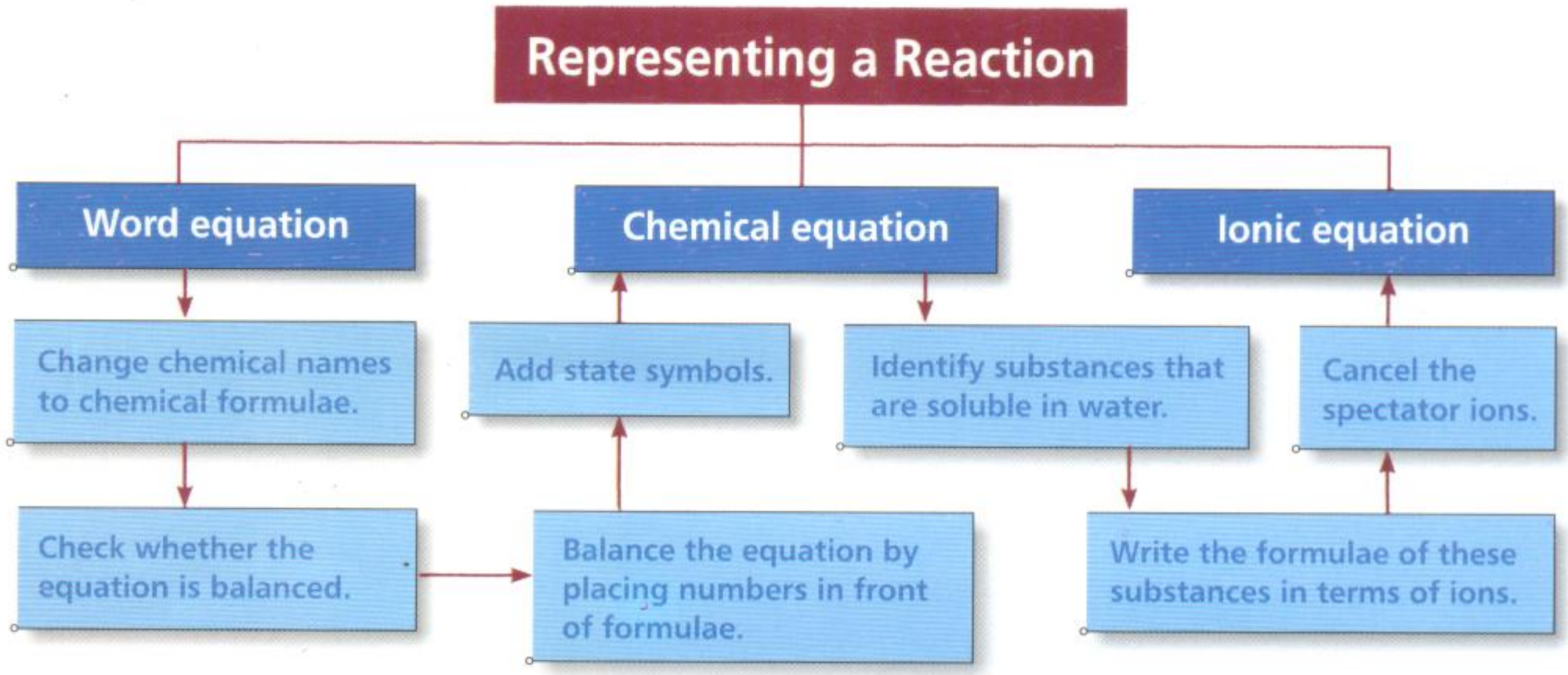
1. A chemical equation is used to represent a chemical reaction.
2. A chemical equation is balanced when there is an equal number of atoms of each element on both sides of the equation.
3. An ionic equation shows the reaction between ions.

Test Yourself 8.2

Questions

1. Which of the following equations are balanced?
   a) $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$
   b) $2Al(s) + Fe_2O_3(s) \longrightarrow 2Fe(s) + Al_2O_3(s)$
   c) $4NO_2(g) + H_2O(l) + 2O_2(g) \longrightarrow 4HNO_3(l)$
2. Identify the spectator ions in the following reactions.
   a) $Na_2SO_4(aq) + Ba(NO_3)_2(aq) \longrightarrow BaSO_4(s) + 2NaNO_3(aq)$
   b) $CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

Concept Map



Exercise 8

Foundation

1. Phosphorus(V) chloride dissolves in water to form phosphoric acid, H_3PO_4 and hydrochloric acid. What is the value of x, y and z in the balanced equation for this reaction?

$PCl_5(s) + xH_2O(l) \longrightarrow yH_3PO_4(aq) + zHCl(aq)$

	x	y	z
A	2	1	4
B	2	2	5
C	4	2	4
D	4	1	5

2. Sodium reacts with water to produce sodium hydroxide and hydrogen gas. Which of the following shows the correct chemical equation?

A $Na(s) + H_2O(l) \longrightarrow NaOH(aq) + \frac{1}{2}H_2(g)$
B $Na(s) + H_2O(l) \longrightarrow NaOH(aq) + H_2(g)$
C $2Na(s) + 2H_2O(l) \longrightarrow 2NaOH(aq) + H_2(g)$
D $2Na(s) + H_2O(l) \longrightarrow Na_2OH(aq) + H_2(g)$

3. Write balanced chemical equations for each of the following reactions. State symbols are not required.
   a) calcium + chlorine $\longrightarrow$ calcium chloride
   b) hydrogen + nitrogen $\longrightarrow$ ammonia
   c) ethane (C_2H_6) + oxygen $\longrightarrow$ carbon dioxide + water vapour

4. Balance the following equations and include the state symbols. You may check the solubility of the substances on page 196.
   a) $Fe + Cl_2 \longrightarrow FeCl_3$
   b) $H_2SO_4 + Al(OH)_3 \longrightarrow Al_2(SO_4)_3 + H_2O$
   c) $Pb^{2+}(aq) + Cl^- \longrightarrow PbCl_2$
   d) $H^+(aq) + CO_3^{2-} \longrightarrow H_2O + CO_2$

Challenge

1. Potassium hydroxide (KOH) and sulphuric acid (H_2SO_4) react to produce potassium sulphate (K_2SO_4) and water. Which of the following shows the ionic equation for the reaction?

A $H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$
B $H^+(aq) + OH^-(aq) \longrightarrow \frac{1}{2}H_2O(l)$
C $2K^+(aq) + SO_4^{2-}(aq) \longrightarrow K_2SO_4(s)$
D $K^+(aq) + SO_4^{2-}(aq) + H^+(aq) \longrightarrow KHSO_4(s)$

2. When aqueous sodium phosphate, Na_3PO_4, was added to aqueous calcium chloride, $CaCl_2$, calcium phosphate was precipitated.
   a) Write the formula for the ionic compound, calcium phosphate, formed.
   b) i) Write the chemical equation for the reaction between calcium chloride and sodium phosphate.
      ii) Write the ionic equation for the reaction in (b)(i).

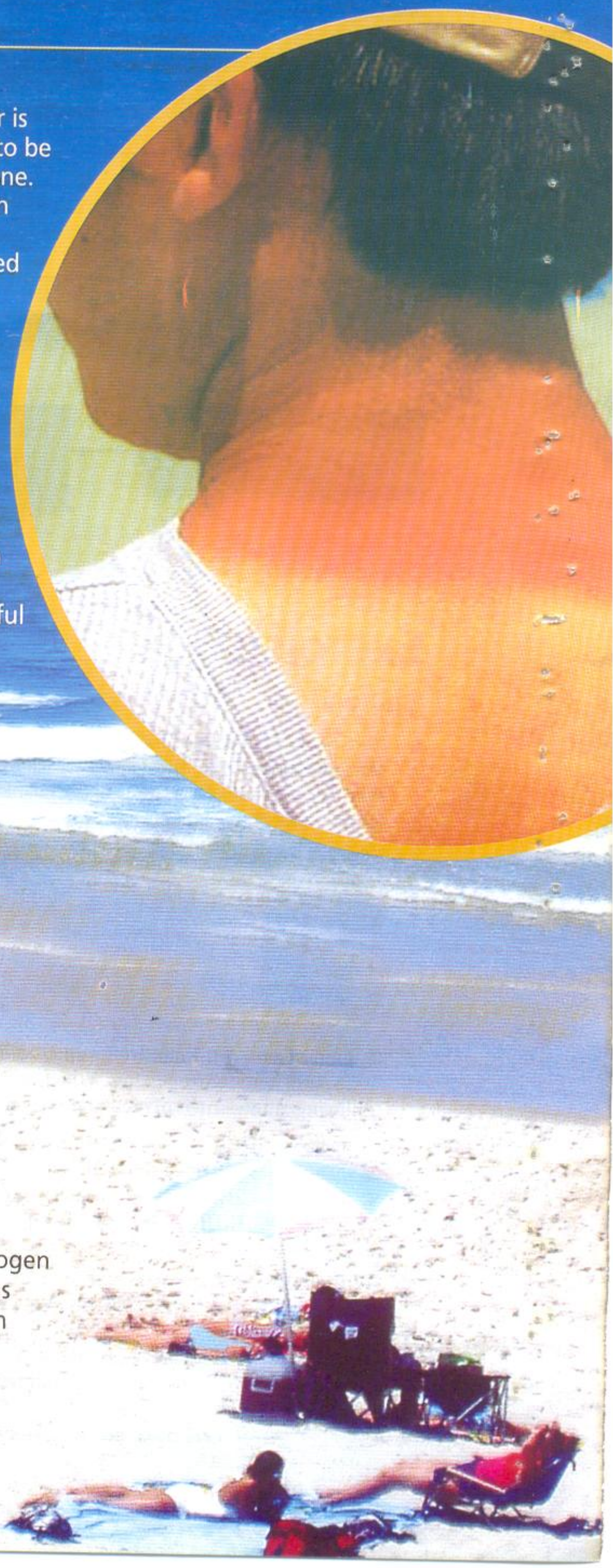
Chemistry Today

At the start of this chapter, we learnt that the ozone layer is disappearing. The main cause of the loss of ozone seems to be the reaction between chlorofluorocarbons (CFCs) and ozone. CFCs were found in aerosol cans. CFCs were released when aerosols were used or when air conditioners and freezers were not disposed of properly. Most countries have banned the use of CFCs, but the amount of CFCs already in the atmosphere will last for a long time.

CFCs rise into the atmosphere and release chlorine atoms. These chlorine atoms react with ozone (O_3) and produce oxygen. What is happening can be represented by a word equation:

ozone + chlorine atom
⟶ oxygen + compound of chlorine and oxygen

As a result, the amount of ozone to protect us from harmful radiation is decreasing.



CRITICAL THINKING

Another chemical that is destroying the ozone layer is nitrogen monoxide (NO) which reacts with ozone in the same way as CFCs. Write a word equation to show the reaction between nitrogen monoxide and ozone.