

Chemical reactions

3

Your life depends on chemical reactions. Useful materials such as cloth, paper, ink, ceramics, metals and polymers are all products of chemical reactions. Chemical reactions occur in the cooking and digestion of your food, and they must occur in all the cells of your body to sustain life. Medicines help cure illness by affecting chemical reactions in your body.



How do light sticks produce light?

Key outcomes

Specify the characteristics, chemical reactions and usefulness to society of groups of similar substances.

Represent chemical change using chemical symbols and formulae.

Describe the production and uses of substances with unusual and specialised properties.

Think about these

They are not battery operated, so how do light sticks produce light?

Spectacles that turn into sunglasses — how do they do it?

You may have juggled balls, but have you ever balanced atoms?

When a candle burns, it disappears — or does it?

Your family car probably has one. How does a catalytic converter work?

What do a burning candle and a motorcycle have in common with an MP3 player?

In which part of your body do you find catalytic catalase?

The gold rush is a colourful part of Australia's history. Why wasn't there a 'copper rush' or an 'iron rush'?

Your Quest

Evidence of chemical reactions



Reflecting on a burning candle

You will need:

safety glasses
candle
jar lid
matches
heatproof mat



- Place a jar lid on a heatproof mat.
 - Light a candle and allow a drop of wax to drip onto the jar lid. Place the candle on the drop of wax and fix it to the jar lid.
 - Observe the burning candle and answer the following questions.
1. Describe three physical changes that take place while the candle burns.
 2. Make a list of as much evidence as you can that a chemical reaction has taken place.

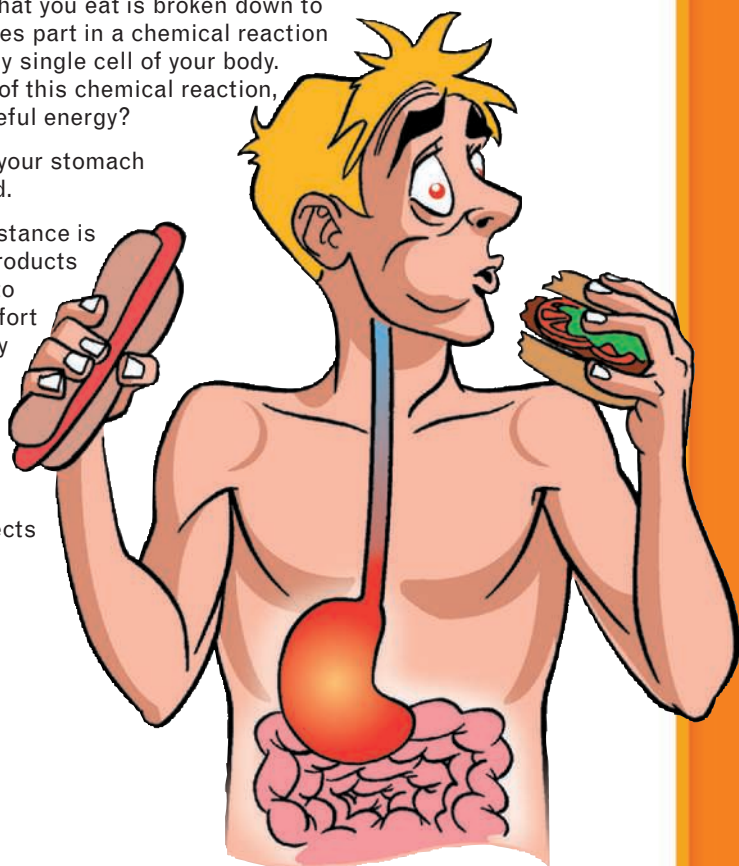
CAUTION: Do not touch the candle or flame and do not smell the vapour directly. You can fan the vapour towards your nose with your hand.

The chemistry of eating

THINK

Preparing, eating and digesting food all involve chemical reactions, many of which you already know about. Answer the following questions to find out what you already know about these important chemical reactions.

1. All of the food that we eat — including meat — begins with the growth of plants.
 - (a) What is the name of the chemical reaction that produces the glucose that plants produce?
 - (b) Which form of energy is necessary to allow this chemical reaction to take place?
2. The baking of bread makes use of a chemical reaction involving yeast and sugar. The same type of reaction is used in brewing to produce alcohol.
 - (a) What is the name of this chemical reaction?
 - (b) One of the products of this chemical reaction causes bread to rise while it is being baked. What is the name of this product? (*Clue: It's a gas.*)
3. The chemical digestion of food occurs when chemicals in your body react with the food.
 - (a) What name is given to the chemicals that speed up these chemical reactions?
 - (b) Much of the food that you eat is broken down to glucose, which takes part in a chemical reaction that occurs in every single cell of your body. What is the name of this chemical reaction, which releases useful energy?
4. Overeating can make your stomach produce too much acid.
 - (a) Which type of substance is contained in the products that can be taken to reduce the discomfort and pain caused by the extra acid?
 - (b) What is the name of the chemical reaction that provides you with relief from the effects of the extra acid?



Rearrange those atoms!

Have you ever felt the fizz on your tongue from a sherbet lolly? That fizz is the result of a chemical reaction. The exhaust fumes from a motorcycle are produced by another chemical reaction. In each of these reactions, bonds between atoms in the original chemicals, the **reactants**, are broken. The atoms are rearranged and new bonds are formed. In this way new chemicals, the **products**, are produced.

In chemical reactions, atoms are not created or destroyed. Consider the example of petrol burning in a motorcycle engine. Octane and oxygen react, producing carbon dioxide and water and releasing energy. This can be represented as the word equation:



The elements present in the reactants and products are listed in the table below.

Reactants	Elements present	Products	Elements present
octane	carbon hydrogen	carbon dioxide	carbon oxygen
oxygen	oxygen	water	hydrogen oxygen

The carbon, hydrogen and oxygen atoms that were present in the reactants are also in the products. They are simply rearranged during the reaction. This seems straightforward to us now, but it was not so readily apparent in the early days of chemistry when little was known about atoms and the way they combine.

A burning question

In the eighteenth century, Antoine-Laurent Lavoisier provided the evidence on which these ideas are based. He showed that although a candle seems to disappear as it burns, there is as much mass present after it has completely burnt as there was before. The apparent loss of mass was caused by gases moving into the atmosphere. Lavoisier's ideas led to the development of the **Law of Conservation of Mass**, which states that matter can be neither created nor destroyed during a chemical reaction.

Lavoisier also provided evidence for the **Law of Constant Proportions**, which states that a compound, no matter how it is formed, always contains the same relative amounts of each element. For example, carbon dioxide (CO₂) always contains the same relative amounts of carbon and oxygen (about 27 per cent of the mass is made up of carbon). It does not matter whether the carbon dioxide forms from the reaction of sherbet in your mouth, or from the reaction in

the engine of a motorcycle, this proportion is fixed because every molecule of CO₂ is formed when one carbon atom bonds with two oxygen atoms. This law helped to shape our understanding of the way atoms bond together.

Is it a chemical reaction?

The 'disappearance' of a substance is not reliable evidence that a chemical reaction has taken place. The only reliable evidence is the formation of a new product. For example, when magnesium is placed in hydrochloric acid, the magnesium 'disappears' and the new products magnesium chloride and hydrogen gas are formed. A chemical reaction has taken place.

When ice melts it also 'disappears' as water is formed. However, no new substance has formed. Atoms have not been rearranged. Water has simply changed state from solid to liquid.



The 'disappearance' of a substance, such as ice, may indicate a change of state, rather than a chemical change.

Starting the ball rolling

Simply placing two chemicals together does not always mean they will react. For example, hydrogen and oxygen react violently, yet a mixture of these two gases can be stored indefinitely if kept cool in a secure container. Energy must be supplied to start the reaction. Sometimes only a small amount of energy is needed to start (or initiate) the reaction. Heat transferred from the surroundings may be enough. Or energy may also be supplied by an electric current, a beam of light, or a Bunsen burner flame. This energy is needed to begin the process of breaking the bonds in the reactants, which allows the atoms to rearrange and form new bonds in the products.

Energy to go

Some chemical reactions produce energy. When fuels like octane are burnt, energy is released. This energy comes from the rearrangement of atoms.

experiment

> CONSERVE THAT MASS!

You will need:

safety glasses	250 mL conical flask
4 Alka-Seltzer tablets	1 balloon
matches	an electronic balance
100 mL measuring cylinder	water

CAUTION: Wear safety glasses.

- Place the conical flask on the balance and pour in approximately 100 mL of water.
 - Place two tablets alongside the conical flask and record the total mass.
 - Remove the flask from the balance and drop the tablets into the water. When the reaction is complete, weigh the flask and record the mass.
 - Rinse out the flask thoroughly and again add approximately 100 mL of water.
 - Place two tablets and a balloon alongside the conical flask and record the total mass.
 - Remove the flask from the balance and drop the tablets into the water. Quickly place the balloon on the flask.
 - When the reaction is complete, weigh the flask and record the mass. **Do not remove the balloon.**
 - After you have recorded the mass, remove the balloon. Light a match and test the gas. Record your observations.
- Describe what happened during the reaction.
 - Which gas do you think filled the balloon?
 - Comment on your results of the total mass before and after each reaction. Explain your answer.
 - Why do you think it took a long time for the Law of Conservation of Mass to be developed?

There is less energy 'stored' in the new bonds that form in the products. You have probably noticed reactions of this type in the laboratory when a test tube in which a reaction is occurring becomes warm. Chemical reactions which give out energy are called **exothermic** reactions.

Chemical reactions in which energy is absorbed from the surroundings are called **endothermic** reactions. There is more energy 'stored' in the new bonds that form in the products. One example of an endothermic reaction can be found in the instant 'icepacks' in first aid kits. They contain two packs of chemicals. When the packs are broken the chemicals react, absorbing energy from the surrounding injured area, cooling it just as a real icepack would.

The energy to power this motorcycle comes from a chemical reaction.



activities

REMEMBER

- What is the name for chemicals that react in a chemical reaction?
- What is the name for chemicals which result from a chemical reaction?
- State the Law of Conservation of Mass and explain in your own words what it means.
- Energy is required to start a reaction. List three possible sources of this energy.
- What are endothermic and exothermic reactions? Give an example of each.

THINK

- When a piece of sodium metal is added to a trough of cold water, a rapid and energetic reaction occurs.
 - Where does the energy to initiate the reaction come from?
 - Is energy absorbed or released in this reaction?

INVESTIGATE

- Find out more about Antoine-Laurent Lavoisier, his work and why he lost his head during the French Revolution.

A game of balance



The symbols of the elements in the periodic table are the chemists' 'alphabet'. Just as we can create millions of words from the 26 letters of the English alphabet, formulae for millions of chemicals can be written using the approximately 116 symbols of the elements (see chapter 2). These formulae can be used to write chemical **equations** that show how the atoms in the reactants are rearranged to form the products in a chemical reaction. The same formulae are used worldwide so they can be understood in every language.

Chemical mind-benders

Writing equations involves some simple mathematics and a knowledge of chemical formulae. Chemical equations are set out in the same way as word equations, with the reactants to the left of the arrow and products to the right of the arrow. However, they are different from word equations in three ways:

- formulae are used to represent the chemicals involved
- the physical states of the chemicals are often included
- numbers are written in front of the formulae in order to balance the numbers of atoms on each side of the equation.

There are a few rules to observe in this game of balancing equations. They are described below with a worked example of the explosive reaction between hydrogen gas and oxygen gas. Make sure you read through the rules very carefully before you play the game.

Game Rules																			
Game rule 1. Know your products The products of a reaction must be known from observation. We cannot always observe a reaction in the classroom laboratory, so we depend on reliable sources (such as chemists) to tell us the products of reactions. For our example, it is well known that the product of the reaction between hydrogen gas and oxygen gas is water vapour (gas). Game rule 2. Know your formulae You need to know the formulae of all the reactants and products. For example: • formula of hydrogen gas H_2 • formula of oxygen gas O_2 • formula of water vapour H_2O. Remember! Because each substance has only one correct chemical formula, these formulae cannot be changed by altering the subscript numbers at any stage of the game. Game rule 3. Write down the formulae They must be written according to the word equation, with reactants on the left-hand side of the arrow and products on the right-hand side. $\text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}$	Game rule 4. Balance the numbers of atoms First, make a list of the elements present in the formulae under the heading 'Element', as shown below. Then count up how many atoms are represented by the formula of each element under the headings 'Reactants' and 'Products'. <table border="1"> <thead> <tr> <th>Element</th> <th>Reactants</th> <th>Products</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>2</td> <td>2</td> </tr> <tr> <td>O</td> <td>2</td> <td>1</td> </tr> </tbody> </table> You can see that there are not enough oxygen atoms on the product side of the equation. The only way this can be adjusted is by writing numbers in front of the chemical formulae. When we write a number in front of a formula, it multiplies all the atoms in that formula. Let's increase the number of oxygen atoms on the product side by placing a '2' in front of the formula for water: $\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}.$ Recounting the atoms we find: <table border="1"> <thead> <tr> <th>Element</th> <th>Reactants</th> <th>Products</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>2</td> <td>4</td> </tr> <tr> <td>O</td> <td>2</td> <td>2</td> </tr> </tbody> </table> The oxygen atoms are now balanced, but the hydrogen atoms are not. Let's try writing a '2' in front of hydrogen's formula on the reactant side to increase the number of hydrogen atoms. $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$	Element	Reactants	Products	H	2	2	O	2	1	Element	Reactants	Products	H	2	4	O	2	2
Element	Reactants	Products																	
H	2	2																	
O	2	1																	
Element	Reactants	Products																	
H	2	4																	
O	2	2																	

Recounting the atoms again we find:

Element	Reactants	Products
H	4	4
O	2	2

The numbers of each of the elements are the same on both sides of the equation. The equation is balanced!

Game rule 5. Include the states

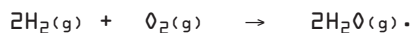
To indicate the physical state of each chemical involved in the reaction, the following symbols are used:

- solid (s)
- liquid (l)
- gas (g).

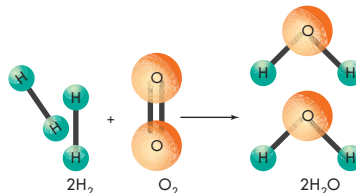
The symbol (aq) is used to represent an **aqueous solution** of a substance.

An aqueous solution is obtained when a substance is dissolved in water.

Write the correct symbol representing the physical state of each reactant and product:



Formulae correct! Number of atoms balanced! States correct! Formula equation complete! Game over!



The reaction between hydrogen and oxygen

Play

Quit

Status



Play the game

- Write a word equation and an equation using formulae for each of the six reactions listed. See the tables below for the correct formulae.
1. Carbon monoxide gas and oxygen gas react to form carbon dioxide gas.
 2. Sodium hydroxide solution and hydrochloric acid solution react to form sodium chloride solution and water.

The formulae of some common ionic compounds

Compound	Formula
sodium hydroxide	NaOH
sodium chloride	NaCl
magnesium chloride	MgCl ₂
copper hydroxide	Cu(OH) ₂
sodium sulfate	Na ₂ SO ₄
copper sulfate	CuSO ₄
sodium hydrogen carbonate	NaHCO ₃
mercury(II) oxide	HgO
sodium citrate	C ₆ H ₅ O ₇ Na ₃

3. Mercury metal and oxygen gas react to form solid mercury(II) oxide.
4. Magnesium metal and hydrochloric acid solution react to form hydrogen gas and magnesium chloride solution.
5. Sodium metal and water react to form hydrogen gas and sodium hydroxide solution.
6. Copper sulfate solution and sodium hydroxide solution react to form solid copper hydroxide and sodium sulfate solution.

The formulae of some common covalent substances

Compound	Formula
water	H ₂ O
citric acid	C ₆ H ₈ O ₇
carbon dioxide	CO ₂
oxygen	O ₂
hydrochloric acid	HCl
carbon monoxide	CO
hydrogen	H ₂



REMEMBER

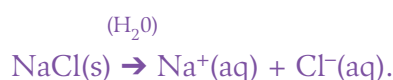
- 1 Describe three differences between word equations and equations in which formulae are used.
- 2 How are the states (solid, liquid and gas) indicated in a chemical equation?
- 3 What is an aqueous solution and how is it represented in a chemical equation?

THINK

- 4 Which symbols would you use in a chemical equation to represent the metals iron, mercury, zinc and aluminium?
- 5 Try writing a balanced equation using formulae for the reaction that occurs when you eat a sherbet lolly. These sweets commonly contain citric acid and sodium hydrogen carbonate. In the mouth, these chemicals dissolve in your saliva and then react together to form sodium citrate solution, carbon dioxide gas and water.
- 6 Explain why it is necessary to balance chemical equations.

Finding the solution

When table salt (sodium chloride) is dissolved in water to form an aqueous solution, it seems to 'disappear'. The ions in the salt no longer bond together as a large array of positive and negative ions like they do as a solid. The sodium ions and the chloride ions separate when they dissolve in water. Because the separated ions are so small, we cannot see them. However, when we evaporate water from the solution we find that sodium chloride crystals are left behind. The dissolving of sodium chloride in water can be represented by the equation:



Ions in aqueous solutions are therefore separate entities and are able to react independently.

experiment

> WILL IT PRECIPITATE?

You will need:

5 semi-micro test tubes and test-tube rack

a white tile

a black tile

safety glasses

dropping bottles of the following solutions: copper sulfate, sodium chloride, silver nitrate, cobalt chloride, sodium hydroxide and potassium iodide

CAUTION: Wear safety glasses.

- Place 10 drops of copper sulfate solution in each test tube.
 - Add 10 drops of sodium chloride to the first test tube, 10 drops of silver nitrate to the second, and so on until each tube contains copper sulfate solution and **one** other solution. Hold a black or white tile behind the test tube if necessary to detect the presence of a precipitate.
 - If there is a reaction, record your observations in a table.
 - Tip the residues into a waste bottle. Wash out the test tubes thoroughly and this time place 10 drops of sodium chloride in each of the test tubes. Again add one of the other solutions to each of the test tubes (but not copper sulfate as this combination has already been tested). Record your observations in your table.
 - Repeat until all possible pairs of solutions have been tested.
- Write word equations for each of the pairs that reacted to form a precipitate.
 - Use formulae to write equations for each of the pairs that reacted to form a precipitate.
 - You could have predicted which pairs of solutions would form a precipitate using the box of solubility rules on the opposite page. Check to see if the rules match your results.

Suddenly it appeared!

When colourless lead nitrate solution and colourless potassium iodide solution are added together, a brilliant yellow solid is formed. Where does this solid come from? When two solutions containing dissolved ions are mixed together, these ions are able to come into contact with each other. Oppositely charged ions attract. In some cases, the attraction is strong enough to form ionic bonds and hence a new ionic compound. Some of these compounds are insoluble (unable to dissolve in water) and so a solid forms. This solid is called a **precipitate**. Chemical reactions in which precipitates form are called **precipitation reactions**.

Ionic compounds dissolve in water to varying degrees. Some are said to be soluble, others slightly soluble and others insoluble. The box on the right outlines some handy rules for predicting if a compound is soluble or not.

The formation of the brilliant yellow precipitate, lead iodide, from the colourless solutions lead nitrate and potassium iodide



SOLUBLE OR NOT?

1. All compounds containing either the Na^+ , NH_4^+ , K^+ , or NO_3^- ion will dissolve in water. Compounds containing these ions never form precipitates.

Example: This rule tells us that NaCl , NH_4Cl , K_2SO_4 and AgNO_3 are all soluble in water and therefore do not form precipitates.

2. Compounds containing the Cl^- , Br^- and I^- ions are soluble, except when they contain the Ag^+ , Pb^{2+} or Hg^{2+} ions.

Example: This rule tells us that FeCl_3 , ZnBr_2 and AlI_3 are soluble, but that AgCl , HgBr_2 and PbI_2 are not soluble.

3. Compounds containing the SO_4^{2-} ion are soluble, except for BaSO_4 , PbSO_4 and CaSO_4 .

Example: This rule tells us that ZnSO_4 will dissolve, but BaSO_4 will form a precipitate.

4. Compounds containing CO_3^{2-} and PO_4^{3-} are insoluble except when they contain the ions Na^+ , NH_4^+ or K^+ .

Example: This rule tells us that BaCO_3 will form an insoluble precipitate, but Na_2CO_3 will not.

5. Compounds containing OH^- are insoluble, unless they contain the ions Na^+ , NH_4^+ or K^+ .

Example: This rule tells us that Zn(OH)_2 will form a precipitate, but NaOH will not.

6. Some compounds are slightly soluble. These include Ca(OH)_2 , PbCl_2 , PbBr_2 , CaSO_4 and Ag_2SO_4 .

Changing partners

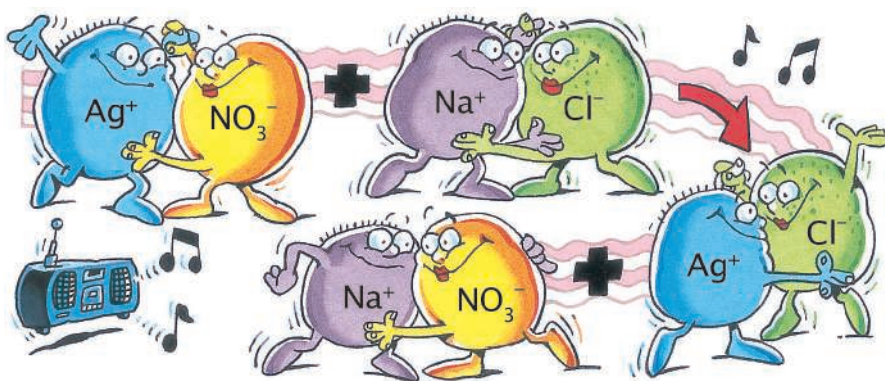
Another example of a precipitation reaction is the one between silver nitrate solution and sodium chloride solution. When these two clear, colourless solutions are added together, the contents of the test tube become cloudy, indicating that a precipitate has formed. If the tube is allowed to stand for a while, the solid settles to the bottom and we can see that a clear solution is also present. The products of the reaction are insoluble solid silver chloride (the precipitate) and sodium nitrate (not visible because it is soluble in water). This reaction can be represented by the equations:

silver nitrate + sodium chloride $\rightarrow$ silver chloride + sodium nitrate



The box on the left indicates that silver nitrate, sodium chloride and sodium nitrate all dissolve in water. Therefore, they have the symbol '(aq)'. Silver chloride does not dissolve in water so it has the symbol '(s)' to indicate that it is solid. The precipitation of silver chloride can be used as evidence of the presence of silver ions in an unknown solution.

The equations above show that the ions in the reactants have changed 'partners'. The silver ion is paired with the chloride ion on the product side of the reaction and the sodium ion is paired with the nitrate ion. The opposite is the case on the reactant side of the equation. A positive ion can pair up only with a negative ion because oppositely charged ions are attracted to each other. When writing the formula of any new compound, the positive ion is always written first.



Ions sometimes change 'partners' when a chemical reaction takes place.

activities

REMEMBER

- 1 What is a precipitate?

THINK

- 2 Write an equation for the reaction that occurs when the salt copper sulfate dissolves in water.
- 3 Which two of the following compounds will be soluble in water?

(a) NaNO_3
(b) KI

(c) PbI_2
(d) Zn(OH)_2

- 4 Which of the following compounds will be insoluble in water?

(a) CuCO_3
(b) AgI

(c) NaCl
(d) Mg(OH)_2

- 5 Write down the possible combinations of ions when the following solutions are mixed together:

(a) sodium chloride and copper sulfate

(b) sodium hydroxide and copper sulfate

(c) lead nitrate and sodium hydroxide

(d) potassium iodide and sodium carbonate.

- 6 For each of the reactions listed in 'Think' question 5, name the precipitate that would form. If you believe that no precipitate would form, write 'no precipitate'.

A world of reactions

In a world where countless chemical reactions take place, it is helpful to classify the reactions. They can be classified according to whether they release or absorb energy and can also be grouped together according to the nature of the reactants, the nature of the products, the way in which charged particles in atoms rearrange themselves, or even the number of reactants. Because there are different ways of classifying chemical reactions, any one reaction can fall into several different groups.

Corroding away

Corrosion reactions are those in which a metal is 'eaten away' by substances in the air or water. If you look at a sheet of **galvanised** iron, you will notice that it does not have a shiny metallic surface. Galvanised iron has been coated with a layer of zinc metal. The zinc prevents the iron underneath from reacting with the oxygen and water in the air and rusting. Instead, zinc reacts with oxygen and a dull layer of zinc oxide forms on the surface. The equation for this reaction is:



The rusting of this shed is an example of corrosion.

Displaced metals

In the classroom laboratory, waste solutions containing silver ions are never poured down the sink. They are collected and sent to commercial laboratories where the valuable silver is recovered from the solutions. Silver metal can be recovered from silver nitrate solution simply by adding a piece of copper wire. This happens according to the equation:



Reactions of this type, where an element displaces another element from a compound, are called **displacement reactions**. In this example, copper has displaced the silver from the silver nitrate solution.

experiment

> SILVER CRYSTALS

You will need:

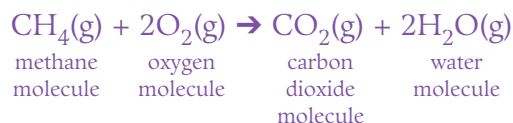
test tube and test-tube rack
silver nitrate solution
100 mL conical flask
15–20 cm of copper wire
filter funnel
filter paper
watchglass
wash bottle
hand lens

CAUTION: Silver nitrate will stain skin and clothing. Use with care.

- Fill three-quarters of the test tube with silver nitrate solution.
- Note the colour of the solution and record it in your workbook.
- Twist the copper wire into a spiral and place it in the test tube, making a hook over the lip of the test tube so the wire can be lifted out.
- Place the test tube in the test-tube rack and leave them in a dark cupboard overnight.
- Observe the silver crystals with a hand lens and note the colour of the solution.
- Remove the copper wire, shaking the silver into the test tube.
- Place the filter paper in the funnel and place the end of the funnel in the conical flask. Filter the contents of the test tube using the wash bottle to ensure complete transfer of all of the silver.
- Rinse the crystals a few times with a small amount of water.
- Place the filter paper and crystals on a watchglass to dry. Observe with a hand lens.

Combustion — a burning question

Combustion reactions are those in which a substance reacts with oxygen and heat is released. Examples of combustion reactions include the burning of petrol in a motorcycle engine, wax vapour in a candle flame and natural gas in a kitchen stove. In each of these cases **hydrocarbons** (compounds containing only the elements carbon and hydrogen) combine with oxygen in the air to form carbon dioxide gas and water vapour. This is shown in the following equation for the burning of methane (natural gas) in a gas jet.



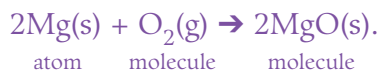
Breaking down

In **decomposition reactions** one single compound breaks down into two or more simpler chemicals. An example of this is the decomposition of zinc carbonate. This is represented by the equation:



Getting together

Often two elements combine in chemical reactions to form a compound. Such reactions are called **combination reactions**. The reaction of magnesium with oxygen is a spectacular example. Magnesium burns in air producing a brilliant flash of white light. The equation for this combination reaction is:



Notice that this combination reaction is also a combustion reaction. It is also an exothermic reaction because it transfers energy to the surroundings. (Endothermic reactions are chemical reactions that absorb energy from the surroundings.)

Transferring electrons

In many chemical reactions, electrons are either completely or partially moved from one atom, ion or molecule to another. This process is known as **electron transfer**. Chemical reactions which involve electron transfer are called **redox reactions**. Redox reactions are extremely important in industry and in our everyday lives.

A redox reaction is really two reactions occurring simultaneously. In the electron transfer process, one reactant loses electrons and another gains electrons. Loss of electrons is known as **oxidation**. Gain of electrons is called **reduction**. Oxidation and reduction always occur together, thus the two words are combined to form the word redox, which is used to describe reactions where electrons are transferred.

The mnemonic **OIL RIG** may help you to remember these processes: **oxidation is loss, reduction is gain.**

Each of the corrosion, displacement, combustion and combination reactions described on pages 68 and 69 are examples of redox reactions. Oxidation and reduction can be clearly seen in the reaction that occurs when zinc corrodes (see page 70).

experiment

> DECOMPOSING POWDER

You will need:

laboratory coat and safety glasses

zinc carbonate powder

spatula

Bunsen burner, heatproof mat and matches

large pyrex test tube and
test-tube rack

test-tube holder

an electronic balance

marking pen

stereo microscope

Petri dish

CAUTION:

Wear safety glasses and laboratory coat.

- Place two spatulas of zinc carbonate powder in the test tube. Weigh the test tube and record the mass.
- Mark the level of the powder in the test tube with the marking pen.
- Heat the test tube gently in a blue Bunsen burner flame for 5 to 10 minutes.

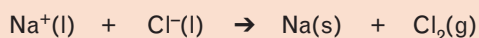
CAUTION:

Make sure the test tube is not pointing at anyone.

- While heating the test tube, hold a lit match at the mouth of the tube. Record your observations.
 - Allow the test tube to cool down. Note any change in the level of powder and then reweigh the test tube. Record the mass.
 - Place small amounts of zinc carbonate and the powder from the test tube in the Petri dish. Examine them using a stereo microscope. Record your observations.
1. Which gas was given off during the reaction?
 2. Explain any change that occurred in the mass.
 3. Write word and formula equations for the reaction.

In the early days of chemistry, oxidation was defined as the combination of a chemical with oxygen or as the removal of hydrogen from a compound. Reduction was defined as the opposite of oxidation; that is, the removal of oxygen or the combination of hydrogen with a chemical. Today we know that oxygen and hydrogen may not be involved at all in a redox reaction. An example is when sodium metal and chlorine gas are produced by passing an electric current through molten sodium chloride.

sodium + chloride → sodium + chlorine
ions ions metal gas



In this redox reaction, sodium is reduced and chlorine is oxidised.

Oxidation is now defined as the transfer of electrons from a reactant. In the above redox reaction, chlorine is oxidised and sodium is reduced.

atoms ($\text{Cu}(\text{s})$) lose electrons, forming copper ions ($\text{Cu}^{2+}(\text{aq})$) which dissolve into a solution. The formation of copper ions changes the colour of the solution from colourless to blue. The copper atoms are oxidised. The nitrate ion is not involved in the electron transfer.

Combustion of methane

The chemical equation for the burning of methane in a gas jet is:



In this redox reaction, electron transfer is not complete. The reactants are molecules and the products are also molecules. In each molecule, electrons are shared by the atoms. However, the oxygen atoms in the products attract the electrons more strongly than the carbon and hydrogen atoms. Therefore, the shared electrons spend more time close to the oxygen atoms. The electrons have been partially transferred to the oxygen atom. Thus, oxygen is reduced and the carbon in methane is oxidised.

Combination of magnesium and oxygen

The chemical equation describing the combination of magnesium and oxygen as a result of burning is:



In this reaction, electrons are transferred from the atoms in the magnesium metal to the oxygen atoms in the oxygen molecule. This forms positive metal ions and negative oxide ions. These ions are attracted to each other due to their opposite charges and form the white, ionic, solid magnesium oxide. Magnesium, which loses electrons, is oxidised, and oxygen is reduced.

Corrosion of zinc

The chemical equation for the corrosion of zinc is:



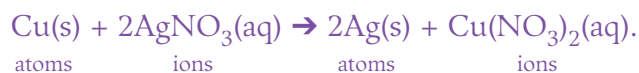
In the corrosion of zinc, a transfer of electrons from the zinc atoms to the oxygen molecules occurs, causing the formation of positive zinc ions and negative oxide ions. These oppositely charged ions attract and bond together to form the ionic compound zinc oxide.



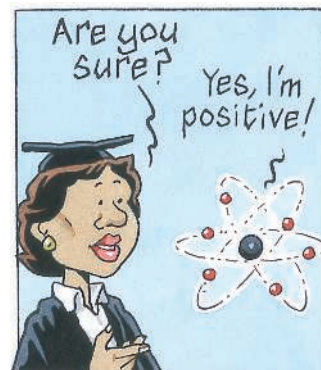
In this reaction, zinc atoms lose electrons, thus zinc is oxidised. Oxygen molecules gain electrons, thus oxygen is reduced. Remember that oxidation and reduction always occur together.

Displacement of silver

The chemical equation for the displacement of the silver ion from silver nitrate by copper is:



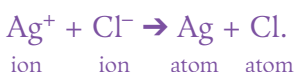
In this reaction, electrons are transferred from the copper atoms to the silver ions. Silver ions (Ag^+) in the solution gain electrons to form atoms of solid silver. Thus, silver ions are reduced. Copper



Light and shade

People who wear glasses often don't want to bother with swapping over to sunglasses when they go outside. **Photochromic** glasses solve the problem by darkening as the wearer moves from indoors into bright sunshine. They lighten again when the wearer moves back into an area of low light. Plastic photochromic glasses use organic material which darkens the lenses when exposed to ultraviolet light.

Glass photochromic glasses work due to the presence of silver chloride (AgCl) crystals in the glass. When a wearer is in the sunshine, ultraviolet light is absorbed by the silver chloride crystals and a redox reaction occurs. Electrons are transferred from the chloride ion to the silver ion according to the equation:



Silver particles then form in the glass, darkening the lens so that visible light is absorbed and reflected.

The fading of the dark glass is more complicated. The chlorine atoms are very reactive. To stop them reacting with the silver atoms and reversing the process too quickly, singly charged copper ions are dissolved in the molten glass during the manufacturing process. These ions react with the chlorine atoms to form chloride ions and doubly charged copper ions in the reaction:



When the glasses are no longer in the sunlight, the doubly charged copper ions accept an electron from the silver atom. The silver ion re-forms and the dark lens becomes light again:



Reactions with a zap!

The chemical reactions that produce electrical energy in electric cells (more commonly known as batteries) are redox reactions. In electric cells, electrons are transferred from one reactant to another through the wires that make up the electric circuit. This is very useful because the moving electrons can provide the energy to operate our appliances. Thus, chemical energy from the redox reaction is converted to electrical energy. The reactants in the cells are not in direct contact with each other. In an ordinary carbon battery or dry cell, the reactants are separated by a paste that allows the movement of electric charge. The electrons flow from one reactant at the negative electrode, through the electric circuit to the other reactant at the positive electrode. Chemical products are formed at both electrodes.

activities

REMEMBER

- 1 Construct a table like the one below and use it to summarise each of the groups of reactions discussed on pages 68–9. List one example of a reaction for each group.

Reaction type	Description	Example

- 2 What do all redox reactions have in common?
- 3 What is oxidation?
- 4 What is reduction?
- 5 Where does the word redox come from?
- 6 Consider the reaction:
- $$2\text{Zn(s)} + \text{O}_2\text{(g)} \rightarrow 2\text{ZnO(s)}$$
- (a) From which reactant are the electrons being transferred?
- (b) Which reactant are they transferred to?
- 7 Give an example of a redox reaction where electron transfer is not complete.

THINK

Refer to the tables on pages 53 and 54 of chapter 2 and the tables on page 65 of this chapter to answer 'Think' question 8.

- 8 Write a balanced equation using formulae for the following reactions:
- (a) copper metal + zinc sulfate solution $\rightarrow$ zinc metal + copper sulfate solution
- (b) sodium metal + oxygen gas $\rightarrow$ solid sodium oxide
- (c) carbon monoxide gas + oxygen gas $\rightarrow$ carbon dioxide gas
- (d) hydrogen peroxide (H_2O_2) solution decomposes to form hydrogen gas and oxygen gas.
- 9 State the type of each of the reactions in 'Think' question 8.
- 10 Explain how it can be said that the reaction between magnesium and oxygen is four reactions in one: a combustion reaction, a combination reaction, a redox reaction and an exothermic reaction.

Health: Chemicals can be a health hazard

Many of the chemicals used in industry, medicine, schools, universities and homes can be hazardous to your health. The hazards come about because these chemicals can react with parts of your body — inside or out. Apart from the dangers to your own health, chemicals can, as a result of their properties or their reactions with common substances such as water and air, cause great damage to property and the environment.

Laws exist, at both national and state level, to ensure that people using harmful chemicals are informed about how to handle and use them safely. For this purpose, harmful chemicals are placed within one or both of the groups known as **dangerous goods** or **hazardous substances**.

Dangerous goods

Chemicals in the dangerous goods group are those that could be dangerous to people, property or the environment. Most dangerous goods are grouped into one of nine classes, according to the greatest immediate risk they present. Some of the classes are divided into subclasses. Dangerous goods must be identified with the appropriate dangerous goods sign on their labels. The table on the opposite page lists the classes and subclasses, along with their respective label signs.

Outside these 9 classes, there are two other groups of dangerous goods.

1. Goods too dangerous to be transported (GTDTBT).
2. Combustible liquids (C1), which includes liquids that are not as easily ignited as flammable liquids, but which will ignite at temperatures below their boiling point.



COMBUSTIBLE LIQUID

Hazardous substances

Chemicals in the hazardous substances group are those that have an effect on human health. The effect may be immediate, such as poisoning and burning, or long term, such as liver disease or cancer. Hazardous substances can enter the body in a number of ways. They can be inhaled, absorbed through the skin, ingested (swallowed) or injected.

Hazardous substances are identified on their labels by a 'signal word' providing a warning about the substance, or the word 'Hazardous' printed in red. 'Signal words' include 'dangerous poison', 'poison', 'warning' and 'caution'. Labels of hazardous substances also include:

- information about the risks of the substance
- directions for use
- safety information
- first aid instructions and emergency procedures.

If the substance is also in the dangerous goods group, the label will also include the appropriate diamond sign showing its class.



A hazardous substance label

Classes and subclasses of dangerous goods

Class	Description	Sign
Class 1	Explosive substances or articles used to produce explosions	
Class 2.1	Flammable gases: gases that ignite in air if in contact with a source of ignition such as a spark or flame	
Class 2.2	Non-flammable, non-toxic gases: these gases may cause suffocation	
Class 2.3	Toxic gases: gases likely to cause death, serious illness or injury if inhaled	
Class 3	Flammable liquids: liquids with vapours that can ignite on contact with air at temperatures below 60.5°C	
Class 4.1	Flammable solids: solids that are easily ignited by a source of ignition such as a spark or flame	
Class 4.2	Substances liable to spontaneous combustion: solids that can ignite without an external source of ignition	
Class 4.3	Substances that emit flammable or toxic gases on contact with water	
Class 5.1	Oxidising agents: substances that may contribute to the combustion of other substances, increasing the risk of fire	
Class 5.2	Organic peroxides: substances that undergo exothermic decomposition reactions	
Class 6.1	Toxic substances: chemicals likely to cause death, serious illness or injury if swallowed, inhaled or brought into contact with skin	
Class 6.2	Infectious substances: substances containing micro-organisms likely to cause diseases in humans or animals	
Class 7	Radioactive material	
Class 8	Corrosive substances: substances that corrode metals or cause injury by reacting on contact with living tissue	
Class 9	Miscellaneous dangerous goods and articles: dangerous substances and objects that do not belong to the other classes	

Keeping you informed

All employers are required by law to make sure that their employees are fully informed about the chemicals in the workplace that are classified as dangerous goods and/or hazardous substances. A list of such chemicals stored or used in the workplace must be kept, along with a copy of the chemical's **MSDS** (material safety data sheet). Chemical suppliers are required to provide an MSDS for each of the hazardous substances or dangerous goods that they supply. In turn, employers are required to make the MSDS accessible to employees that are exposed to the chemicals.

An MSDS is likely to consist of several A4 pages and many can be downloaded directly from the Internet. The information on an MSDS should include:

- the ingredients of the product
- the date of issue — an up-to-date MSDS should be no more than 5 years old
- information about health hazards and first aid instructions
- precautions that need to be taken when using the product
- information about storage and safe handling of the product.
- information about whether the chemical is classified as a hazardous substance or dangerous good
- a list of protective measures to be taken. These might include the use of a fume hood and/or the wearing of safety glasses or other protective items.
- first aid information.

Most of the information used in a risk assessment is obtained from the MSDS for each of the chemicals used. The date on the MSDS used for each chemical must be stated to ensure that the risk assessment is up to date.

Part of a risk assessment sheet is shown on the right. Risk assessment sheets in schools are usually completed and signed by a qualified science teacher or laboratory technician. Your science teacher is required to carefully read the risk assessment sheet before allowing an experiment involving chemicals to commence.

Assessing risk

A **risk assessment** identifies the potential hazards of an experiment and gives protective measures to minimise the risk. Before any experiment involving chemicals is conducted in your school laboratory, a risk assessment is carried out. The form of a risk assessment varies from school to school, but will always contain:

- a summary of the experiment
- a list of the risks and safety precautions for each chemical

activities

REMEMBER

- 1 What do chemicals listed as dangerous goods have in common?
- 2 If a chemical in the dangerous goods group is explosive, toxic and corrosive, how is the decision about which class it is placed in made?
- 3 What do chemicals listed as hazardous substances have in common?
- 4 List four 'signal words' used on the labels of hazardous substances.
- 5 What is an MSDS and what should it include?
- 6 From where do employers obtain an MSDS for hazardous substances and dangerous goods?

- 7 Whose responsibility is it to make sure that people have access to an MSDS for each of the hazardous chemicals and dangerous goods that they store or use?

THINK

- 8 What characteristics do chemicals listed as both dangerous goods and hazardous substances have in common?
- 9 Explain the difference between flammable liquids (Dangerous goods, Class 3) and combustible liquids (Dangerous goods, C1).
- 10 Explain the difference between the purposes of an MSDS and a risk assessment sheet.
- 11 Why should every chemical used in a laboratory (including water) be considered to be a health hazard?

INVESTIGATE

- 12 Many chemical suppliers provide access to MSDSs online. Use the Internet to search for an MSDS on hydrochloric acid and use it to answer the following questions.
 - (a) List some alternative names for hydrochloric acid.
 - (b) What are the health hazards of hydrochloric acid?
 - (c) Describe the first aid treatment recommended if hydrochloric acid:
 - (i) is ingested (swallowed)
 - (ii) is inhaled
 - (iii) makes contact with an eye
 - (iv) makes contact with the skin.
 - (d) What recommendations are made for the storage of hydrochloric acid?

RISK ASSESSMENT SHEET

ACTIVITY	Investigating reactivity		
REFERENCE	Science Quest 4		
CHAPTER 3	Chemical reactions	PAGE	76

SUMMARY OF EXPERIMENT

REACTIVITY OF METALS

- 1 Placing pieces of magnesium, copper, zinc, aluminium and iron in test tubes
- 2 Adding 1M hydrochloric acid to the test tubes and observing the reaction.

PROTECTIVE MEASURES

GLASSES	GLOVES	DUST MASK	LAB COAT	FUME HOOD
X			X	X

SAFETY INFORMATION

REACTANT	HS	DG	CLASS	MSDS	UN	HAZCHEM
Hydrochloric acid 1M	N	Y	8			
		• Do not breathe gas/fumes/vapour/spray. • Wear suitable protective clothing. • Avoid contact with skin.				

FIRST AID

SWALLOWED	Contact doctor or poisons centre. Give glass of water.					
EYE	Wash with running water for 15 minutes. Medical attention					
SKIN	Remove contaminated clothing. Wash with soap and water.					
INHALED	Fresh air. Rest. Keep warm.					
REACTANT	HS	DG	CLASS	MSDS	UN	HAZCHEM
Magnesium	N	Y	4.1		1869	4(Y)
• Flammable		• Wear suitable clothing and eye protection. • Do not breathe dust. • Never add water to this product. • Keep locked up. • Avoid contact with skin.				

FIRST AID

SWALLOWED	Rinse mouth with water.					
EYE	Wash with running water.					
SKIN	Wash with soap and water. For burns: Immerse in cold running water. Bandage lightly. Medical attention					
INHALED	Blow nose. Rinse mouth with water.					
REACTANT	HS	DG	CLASS	MSDS	UN	HAZCHEM

Part of a risk assessment sheet for the experiment 'Investigating reactivity' on page 76

How reactive?

Have you ever wondered why it is that gold can be found lying near the surface of the Earth and yet we need to mine iron ore and smelt it in large furnaces before we can obtain iron? The answer lies in the reactivity of the metals. Gold is a very unreactive element. It does not combine readily with other elements to form compounds. Iron, however, is much more reactive. When the Earth formed, the iron near the surface reacted with other elements to form compounds in the Earth's crust. These compounds are the iron ores. They include haematite (Fe_2O_3), magnetite (Fe_3O_4), siderite (FeCO_3), pyrite (FeS_2) and chalcopyrite (CuFeS_2). The mining industry is based on an understanding of the reactivity of metals.



Few metals are found as elements; most are found as compounds or ores.

The reactivity of metals can be investigated by observing the reactions of metals with acids. When a metal reacts with hydrochloric acid, it reacts according to the equation:



These reactions are redox reactions because electrons are transferred away from the metal atoms to the hydrogen in the acid, forming positive metal ions and hydrogen gas. The metal is said to have displaced the hydrogen from the acid. For this reason, these reactions are also displacement reactions.

experiment

> INVESTIGATING REACTIVITY

You will need:

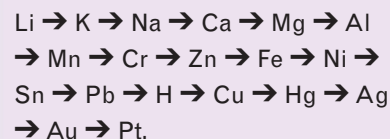
5 test tubes and a test-tube rack
safety glasses
1 cm × 4 cm piece of magnesium ribbon (or equivalent amount)
1 cm × 4 cm piece of zinc, copper, aluminium and iron
1M hydrochloric acid
measuring cylinder, small funnel, thermometer and steel wool

CAUTION: Wear safety glasses.

- Polish each of the metal pieces with the steel wool.
 - Pour 10 mL of acid into each test tube. Measure and record the temperature.
 - Add one metal to each of the test tubes. Look for the presence of bubbles on the surface of the metals. Arrange the test tubes in order of increasing bubble production and record your observations.
1. List the metals in order of increasing reactivity.
 2. Discuss the limitations of this experiment.

The activity series

The activity series places the elements in decreasing order of reactivity:



In order to react with acid and release hydrogen gas, the metal must be before hydrogen in the activity series.

experiment

> QUANTIFIED REACTIVITY

You will need:

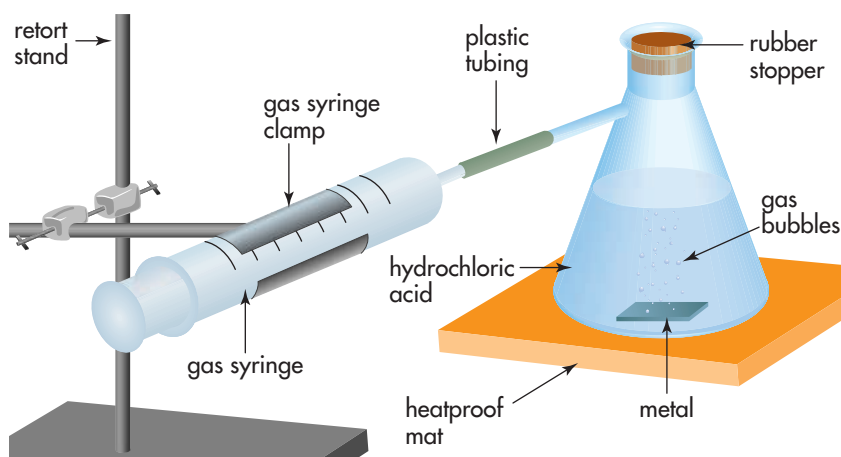
safety glasses, heatproof mat, steel wool and gas syringe
1 cm × 4 cm piece of zinc, copper, aluminium and iron
1 cm × 4 cm piece of magnesium ribbon (or equivalent amount)
1M hydrochloric acid
retort stand, boss head and gas syringe clamp
1 cm × 6 cm length of plastic tubing
250 mL side arm conical flask
rubber stopper to fit conical flask
stopwatch or clock with second hand
50 mL measuring cylinder
distilled water

CAUTION: Wear safety glasses.

- Polish each of the metal pieces with the steel wool.
- Mount the gas syringe in the clamp as shown in the diagram below. Your teacher will tell you if the syringe needs to be lubricated. Push the plunger fully in and attach the plastic tubing to the nozzle.
- Pour 50 mL of acid into the flask.
- Connect the other end of the plastic tubing to the conical flask.
- Place one of the pieces of metal in the conical flask and quickly seal with the rubber stopper.
- Have one student act as a timer and another as a recorder.

- As soon as the metal is dropped in, start timing.
- Using a suitable table, record the volume of the gas in the syringe every 30 seconds until gas is no longer produced, the syringe is full or 10 minutes has passed, whichever occurs first.
- Repeat the procedure with the other metals, taking care to rinse out the flask carefully each time with distilled water.
- In your workbook, plot the results for all of the metals on one set of axes. Put the volume of gas on the vertical axis and time on the horizontal axis.

- Use your graph to list the five metals in increasing order of reactivity and explain your reasoning.
- Write a word equation for the reaction of each of the metals with the acid. If no reaction occurred, write 'no reaction'.
- Write an equation using formulae for the reaction of each of the metals with the acid. If no reaction occurred, write 'no reaction'.
- To which general reaction type or types do reactions between metals and acids belong?
- Some of the variables in this investigation were not carefully controlled. List them and explain how this may have affected your results and conclusions.



sciFacts

Lithium, potassium, sodium and calcium are the most reactive metals. They will react with water to produce hydrogen gas. Magnesium through to lead will react with acid to form hydrogen gas, but copper, mercury and silver will not. Gold and platinum are even less reactive than copper and silver. Most of the elements at the top of the activity series were discovered much later than those at the bottom. Gold, silver, mercury and copper were all discovered over 2000 years ago. Potassium, sodium and calcium were not discovered until 1808. Why do you think this is so?

activities

REMEMBER

- Name the gas produced in the reaction of metals with hydrochloric acid.
- Why is iron usually found in the form of a compound in the Earth's crust?

CREATE

- When scientists attend conferences they often present the results of their investigations as a 'poster'. A poster can describe their work with photographs, drawings and concise written summaries. Present the findings of your investigation into the reactivity of metals as a poster to display in your classroom.

INVESTIGATE

- Design and carry out an experiment that investigates the reactivity of alloys, such as stainless steel and brass. Compare these results with those obtained for the metal elements.

Acids and bases

Chemical reactions involving **acids** and **bases** play an important role in our lives. They occur in the kitchen, in the laundry, in the garden, in swimming pools and even inside the body.

Acids

Acids are **corrosive** substances. That means that they react with solid substances, 'eating' them away. Acids have a sour taste — in fact, the word 'acid' comes from the Latin word *acidus* meaning sour. Some acids, like the sulfuric acid used in car batteries, are dangerously corrosive. The acids in ant stings and bee stings cause pain. Others, like the acids in fruits and vinegar, are safe — even pleasant — to taste.

Bases

Bases have a bitter taste and feel slippery or soapy to touch. Some bases are very corrosive, especially caustic soda. Caustic soda will break down fat, hair and vegetable matter. Other bases are used in shampoos, toothpaste, and cleaning agents like dishwashing liquid and cloudy ammonia. Bases that can be dissolved in water are called **alkalis**.

Common acids and bases

Acid	Uses
hydrochloric acid	- to clean the surface of iron during its manufacture - food processing - the manufacture of other chemicals - oil recovery
nitric acid	the manufacture of fertilisers, dyes, drugs and explosives
sulfuric acid	- the manufacture of fertilisers, plastics, paints, drugs, detergents and paper - petroleum refining and metallurgy
citric acid	- present in citrus fruits such as oranges and lemons - in the food industry and in the manufacture of some pharmaceuticals
carbonic acid	formed when carbon dioxide gas dissolves in water: present in fizzy drinks
acetic acid	- found in vinegar - in the production of other chemicals, including aspirin
Base	Uses
sodium hydroxide (caustic soda)	- in the manufacture of soap - as a cleaning agent
ammonia	in the manufacture of fertilisers and in cleaning agents
sodium bicarbonate	to make cakes rise when they cook

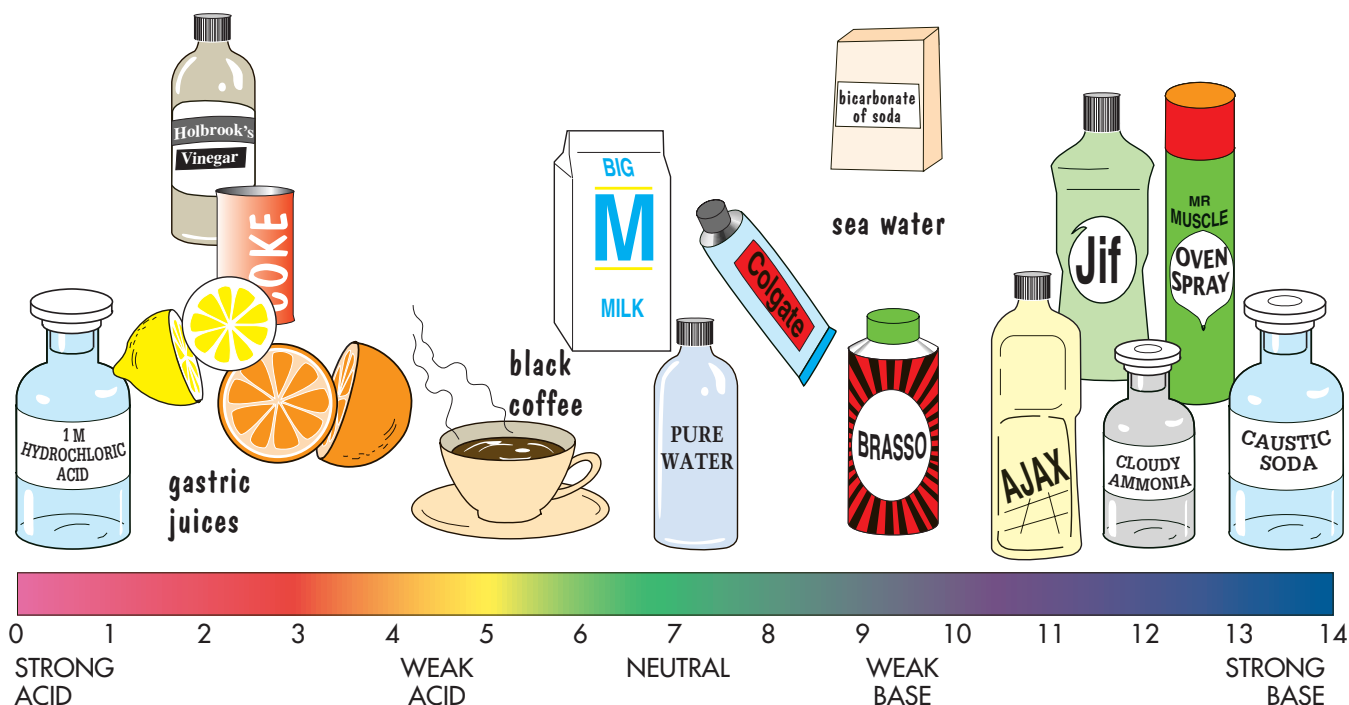
Describing acids and bases



You can describe how acidic or basic a substance is by using the numbers on the **pH scale**. The pH scale ranges from 0 to 14. Low pH numbers (less than pH 7) mean that substances are acidic. High pH numbers (more than pH 7) mean that substances are basic. If a substance has a pH of 7 it is said to be **neutral** — neither acidic nor basic. This is shown on the pH scale opposite. Acids and bases can be graded from strong to weak. For example, a strong acid has a very low pH (pH 0 or 1) and a strong base has a very high pH (pH 13 or 14).

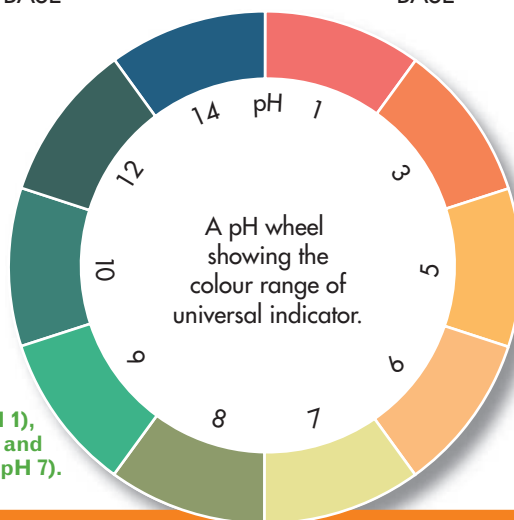


Some common acids and bases are found around the home.



The pH values of some common substances

The pH of a substance can be measured using a pH meter or a special indicator called universal indicator. Universal indicator is a mixture of indicators that changes colour as the strength of an acid or base changes. The colour range of universal indicator is shown on the right.



The colour range of universal indicator. It is pink in strong acid (pH 1), blue in strong base (pH 14) and green in neutral solutions (pH 7).

activities

REMEMBER

- How are acids and bases different from each other?
- What do some acids and bases have in common when they come into contact with solid substances?
- What is the difference between a base and an alkali?
- Which type of substance has a pH value:
 - less than 7?
 - more than 7?
 - equal to 7?

USING DATA

- A pH meter is used to measure the pH of 5 different substances and the results are as shown in the table below.

Substance	A	B	C	D	E
pH value	6.0	12	3.0	7.0	8.0

- Which substance is most likely to be:
 - orange juice?
 - milk?
- Which substance could be:
 - a weak base?
 - pure water?
 - vinegar?
 - a strong base?
- Which two of the substances would you expect to be the most corrosive?

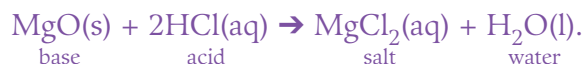
THINK

- A burning feeling in your stomach is often due to the juices in your stomach becoming too acidic. The treatment for this 'indigestion' problem is to take an antacid tablet. Antacid tablets contain a base, which neutralises the excess acid and relieves the pain. When you take an antacid tablet, would you expect the pH value in your stomach to increase or decrease?

Producing salts

Tea, coffee, shampoo and baking powder are all examples of household chemicals designed to be used when dissolved in water. Because water is a good **solvent**, it is able to dissolve many other substances. Chemicals which are dissolved are called **solutes**. A **solution** is a mixture of a solute and the solvent in which it is dissolved. Many reactions involving acids and bases occur in water. These reactions are said to occur in solution.

One very important reaction involving acids and bases is **neutralisation**. Neutralisation is the name given to the chemical reaction in which an acid and a base react with each other to produce water. The other substance produced in a neutralisation reaction is called a **salt**. Your stomach contains hydrochloric acid, which helps to break up food for digestion. Too much acid, however, can be a problem. If your stomach produces too much acid, you may need to take an antacid such as 'milk of magnesia'. This medicine has the solid base magnesium oxide (MgO) suspended in it. This base reacts with the hydrochloric acid in your stomach according to the equation:



The products are the salt, magnesium chloride, and water. The salt contains the positive metal ion from the base and the negative non-metal ion from the acid.

The base sodium hydrogen carbonate, commonly known as 'bi-carb', is a component of baking powder. It has the formula NaHCO_3 and contains the hydrogen carbonate ion HCO_3^- . When bases containing this ion react with acids, the gas carbon dioxide is produced as well as salt and water. When hydrochloric acid and bi-carb are mixed together, the following reaction takes place:



The products are sodium chloride, carbon dioxide and water. In both of the above reactions, the salts formed were metal chlorides, because they contained the chloride ion (Cl^-) from the hydrochloric acid. Neutralisation reactions between many different acids and bases are possible; therefore, it is possible to produce many different salts. The names of all these salts are related to the bases and acids from which they are formed. Some of these are summarised in the table below.

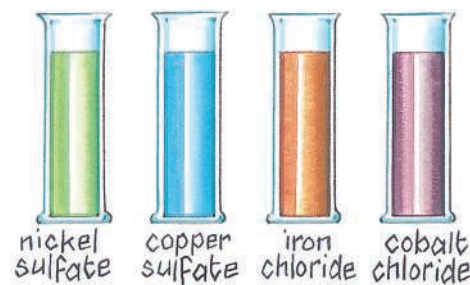
Base	Acid	Negative ion present in salt	Salt
sodium hydroxide	sulfuric acid	sulfate SO_4^{2-}	sodium sulfate
magnesium oxide	hydrochloric acid	chloride Cl^-	magnesium chloride
sodium oxide	acetic acid	acetate CH_3COO^-	sodium acetate
copper(II) oxide	nitric acid	nitrate NO_3^-	copper(II) nitrate



Many chemicals react when they are in solution.

sciFacts

Many salts are brightly coloured and many are highly poisonous and not at all suitable for sprinkling on your fish and chips! Salts containing copper ions are usually blue, those containing nickel are pale green, those containing iron can be green or orange and cobalt salts are pink.



Not all salts can be sprinkled on your fish and chips!

experiment

> PASS THE SALT!

You will need:

safety glasses and laboratory coat
50 mL burette
retort stand, boss head and clamp
tripod and gauze mat
Bunsen burner, heatproof mat and matches
20 mL pipette
100 mL conical flask
pipette bulb
white tile
dropping bottle of phenolphthalein indicator
wire shaped into a loop with a handle
small funnel
1M hydrochloric acid solution
1M sodium hydroxide solution
evaporating dish
silver nitrate solution in a dropping bottle
sample of sodium chloride
test tube

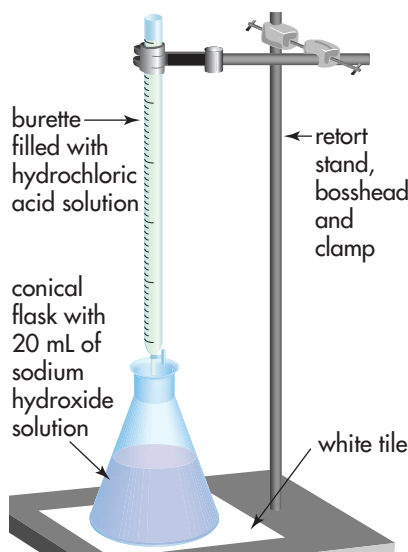
CAUTION: Wear safety glasses and a laboratory coat.

- Rinse the burette with the hydrochloric acid solution and then, using the funnel, fill the burette with the hydrochloric acid solution.
- Rinse the pipette with sodium hydroxide solution using the pipette bulb.

CAUTION: Never pipette using your mouth.

- Set up the equipment as shown in the diagram on the right. Use the pipette and bulb to transfer 20 mL of the sodium hydroxide solution into the conical flask.
- Add a few drops of phenolphthalein indicator to the sodium hydroxide.
- Add the acid from the burette carefully until the pink colour of the indicator disappears. The colour change indicates that the neutralisation reaction is complete.
- Pour the contents of the flask into an evaporating dish. Heat the dish with the Bunsen burner and gently evaporate the water. Be careful — spattering may occur.

- When the water has nearly evaporated, turn off the Bunsen burner and allow the dish to cool and the remaining water to evaporate without further heating.
 - Test the white crystals for the presence of sodium ions by placing a few crystals on a wire loop and heating in a Bunsen burner flame. Compare this flame colour with a known sample of sodium chloride. Record your observations.
 - Test for the presence of chloride ions by dissolving a few crystals in half a test tube of water and adding a few drops of silver nitrate. A white cloudiness indicates that chloride ions are present. Record your observations.
- Comment on the information that the flame and silver nitrate tests provided. What conclusion can you draw?
 - Write a word equation for the neutralisation reaction.
 - Write a balanced equation, using formulae, for the neutralisation reaction.
 - Design a test to show that water was the other product of the reaction.



activities

REMEMBER

- Explain the meaning of the words 'solute', 'solvent' and 'solution'.
- What does the expression 'reaction in solution' mean?
- What is a salt?
- What are the products of the reaction between an acid and a base that contains the hydrogen carbonate ion?

THINK

Use the table on page 80 and the table below to answer the following questions.

- Using formulae, write equations for the following reactions:
 - solid sodium hydrogen carbonate and sulfuric acid react to form a sodium sulfate solution, carbon dioxide and water
 - solid potassium hydroxide and hydrochloric acid react to form a solution of potassium chloride and water
 - solid copper oxide reacts with sulfuric acid to form a solution of copper sulfate and water.
- Name the salts that would form from the reaction between:
 - magnesium hydroxide and hydrochloric acid
 - potassium hydroxide and acetic acid
 - sodium carbonate and sulfuric acid.

Common laboratory bases

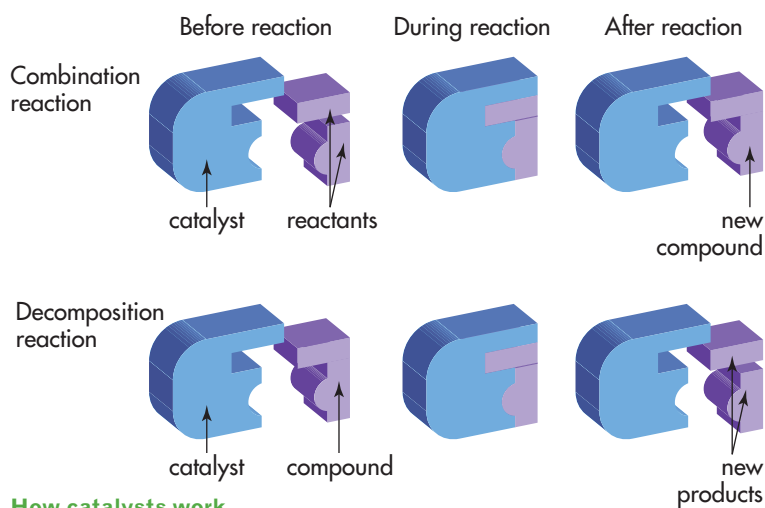
Base	Formula
sodium hydroxide	NaOH
copper hydroxide	Cu(OH) ₂
magnesium oxide	MgO
potassium hydroxide	KOH
magnesium hydroxide	Mg(OH) ₂
sodium carbonate	Na ₂ CO ₃
sodium bicarbonate	NaHCO ₃

The need for speed

The speed at which chemical reactions occur varies. Some reactions occur within a fraction of a second, while others may take days or even years. The speed, or **rate**, of a reaction can be very important. We may need to know how long food will take to cook, or how long it will take for a medicine such as an antacid to make us feel better. Controlling the rate at which reactions occur is therefore of great interest to scientists. Increasing the temperature, the surface area of solid reactants, the concentration of the reactants or, in some cases, the exposure to light can increase the rate of chemical reactions. Another way to increase the rate of a reaction is to use a **catalyst**.

Catalysed reactions

Catalysts are chemicals that help speed up chemical reactions. They are not changed by the reaction. There is always as much catalyst present at the end of a reaction as there was at the start. Catalysts work by helping bonds to break more easily; therefore, the reactants need less energy to react and the reaction is faster. A catalyst can be recovered and used again and again. Catalysts are extremely important in industry as they help maximise the production of chemicals in a given time, thus saving the manufacturer time and money. They are also important in our daily lives. Cars have catalytic converters, contact lenses are cleaned using a catalysed chemical reaction and catalysts are in the food you eat every day. There are also thousands of catalysts in your body without which you could not live. These biological catalysts are called **enzymes**.

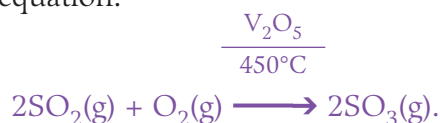


How catalysts work

Catalysts in industry

Industry makes use of many catalysts:

- Iron and iron oxide are used to catalyse the production of ammonia gas. Ammonia is used to make fertilisers and explosives.
- Vanadium oxide (V_2O_5) is used in the production of sulfuric acid. One important reaction in this process, between sulfur dioxide gas and oxygen, has a very slow rate at room temperature. However, it proceeds rapidly at 450°C in the presence of a vanadium oxide catalyst according to the equation:



Note that the catalyst is written above the arrow and not on the side of the reactants. It is not changed as the reaction takes place.

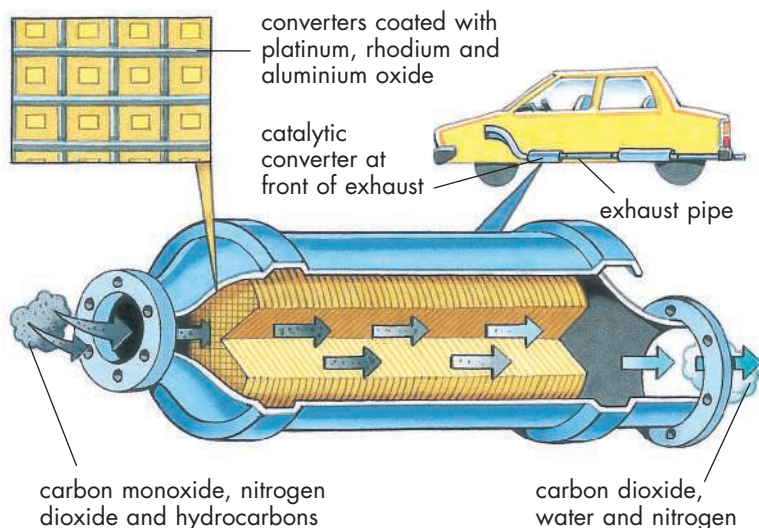
- Crystalline substances made of aluminium, silicon and oxygen called **zeolites** are used to 'crack' (break up) the large molecules in crude oil to form the smaller molecules, such as octane, found in petrol.

Everyday catalysts

In the confined space of the internal combustion engine, the fuel does not completely react with oxygen. As a result, carbon monoxide (CO), a highly poisonous gas, is produced. Nitrogen oxides are other harmful gases produced by car engines. In order to reduce the amount of pollution from these gases, cars are fitted with catalytic converters as part of the exhaust system. These converters have a honeycombed surface which is coated with the metals platinum, rhodium and with aluminium oxide. At the catalyst surface, the nitrogen oxides are converted to less harmful gases and the carbon monoxide is reacted with more oxygen to form carbon dioxide according to the equation:



Catalysts can also help clean your contact lenses. One cleaning product makes use of a platinum catalyst. A solution of hydrogen peroxide (H_2O_2) is poured into a



Catalytic converters have a large surface area and are coated with a metal catalyst.



Catalysts are used to clean some contact lenses.

small dish that contains a platinum-coated disc. The platinum causes the peroxide to decompose according to the reaction:



Any microbes not tolerant to oxygen on the contact lenses are killed by the oxygen released.

Catalysts in living things

Almost every one of the chemical reactions that take place in your body is controlled by an enzyme. Enzymes are large protein molecules. The enzyme **amylase**, which is present in your saliva, is involved in the breakdown of starch into sugar. Enzymes are also used to make bread, cheese, vinegar and many other food products. Your liver contains an enzyme called **catalase**. Catalase speeds up the breakdown of hydrogen peroxide, a toxic waste product produced in your cells.

experiment

> A LIVER CATALYST

You will need:

heatproof mat
safety glasses
2 test tubes and test-tube rack
20% hydrogen peroxide solution
fresh liver
mortar and pestle
spatula

- Pour hydrogen peroxide to a depth of 3 cm into the test tubes. Label the test tubes '1' and '2'.
 - Grind a small piece of liver in the mortar and pestle. Add liver to test tube 1 only.
 - Record your observations.
1. What effect did the liver have on the breakdown of hydrogen peroxide?
 2. What evidence is there to suggest that a chemical reaction has taken place?
 3. Suggest a reason why the liver was ground up before placing it in the hydrogen peroxide solution.
 4. What is the function of test tube 2?

activities

REMEMBER

- 1 Explain what a catalyst does and give three examples.
- 2 Why are catalysts important to industry?
- 3 What are enzymes?

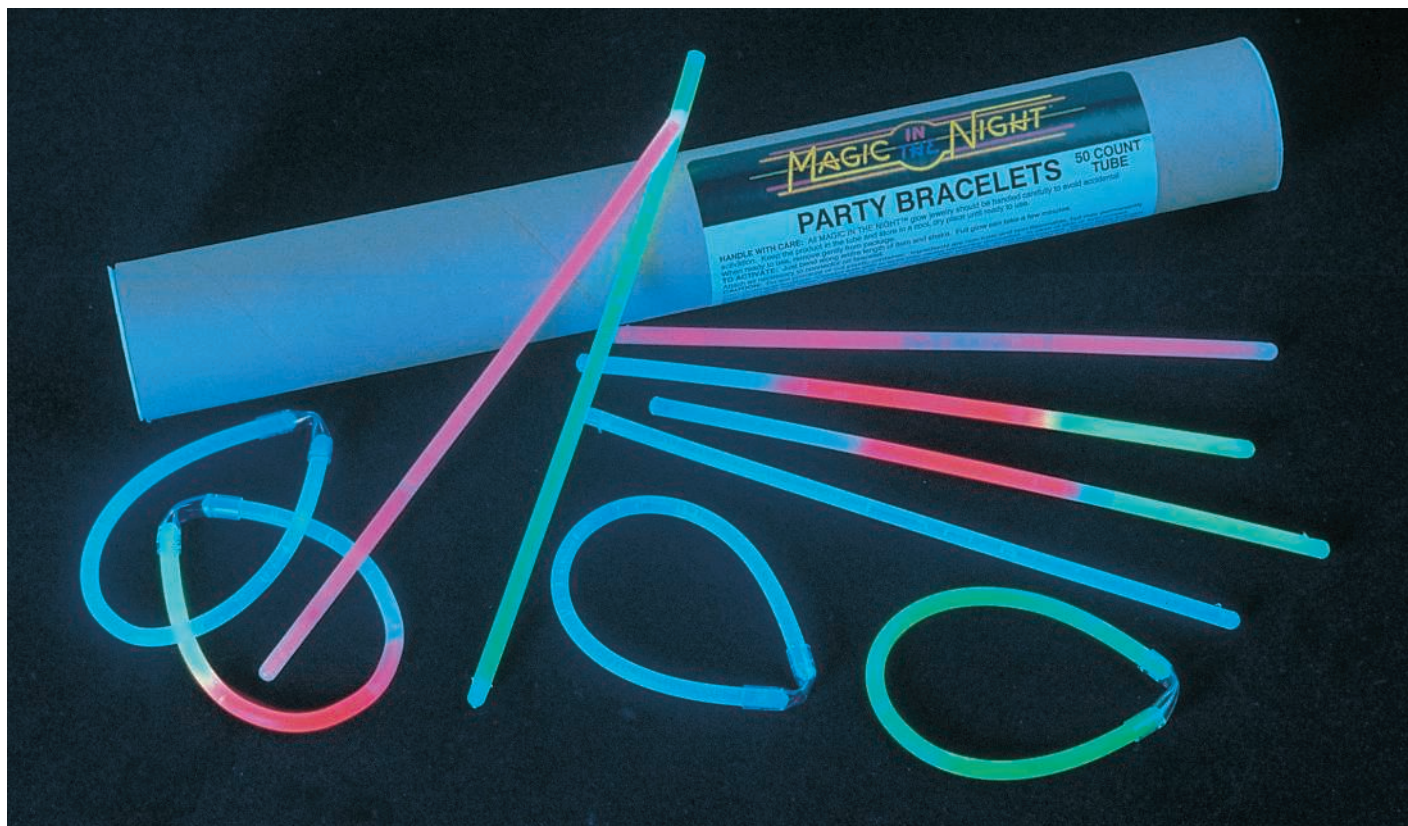
THINK

- 4 Why do catalytic converters have a honeycombed surface?
- 5 Bread contains the enzyme amylase. Give a reason why it is added.

INVESTIGATE

- 6 Find out why leaded petrol must not be used in cars fitted with catalytic converters.
- 7 Research the production of cheese. Find out the enzymes used to produce a range of cheeses. Present your findings as a poster or wall chart.
- 8 Several diseases are caused by the body's failure to produce a particular enzyme. Phenylketonuria (PKU) and galactosemia are two such diseases. Research one of these diseases and present a report of your findings.

A cool light



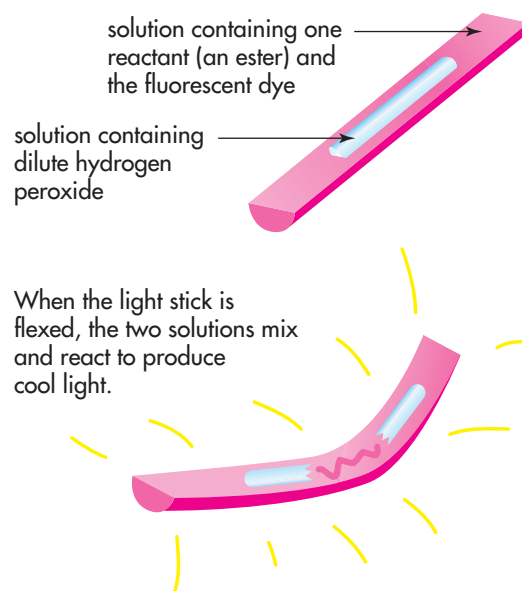
Light sticks can be used for safety and for fun.

Night golf can be played using golf balls that glow in the dark. Glow necklaces and light sticks are glowing plastic tubes that are popular in the evening at outdoor events and amusement parks. Light sticks can also be included in survival kits as a light source. Where does the light come from in these glowing devices? The answer lies in **chemiluminescence** — the production of light from a chemical reaction.

Light from a chemical reaction

A light stick consists of two distinct parts: an outer plastic tube and an inner glass vial. The outer plastic tube is sealed and contains a solution of a chemical called an ester and a fluorescent dye. The inner glass vial is thin and breakable. It contains a solution of hydrogen peroxide. When the light stick is bent, the inner glass vial breaks, causing the two solutions to mix. The chemical reaction (a redox reaction) between the two solutions produces the light.

The chemical reaction between the hydrogen peroxide solution and the ester solution releases energy which is transferred to the **fluorescent** dye molecules. The 'excited' dye molecules give off their excess energy as light without any noticeable heat. That is why the light is referred to as 'cool' light.



The combination of the ester, the hydrogen peroxide and the fluorescent dye produces a cool light.

Light from living things

Some living things can produce light in a process called **bioluminescence**. One of the most common examples of bioluminescence is seen in **fireflies**, insects of the family *Lampyridae*. The abdomens of fireflies glow during the mating season to attract potential mates. This type of light is also a form of cool light, produced by chemical reactions in the cells of the firefly. During these chemical reactions energy is transferred to luminescent molecules. Like the molecules of dye in the light stick, these luminescent molecules become excited and emit energy as light. In the firefly, the chemical reactions are controlled by special enzymes called **luciferases**. The luciferase enzymes are produced in the cells of the firefly's abdomen and allow the light-producing chemical reactions to occur.

There are many living things which use bioluminescence to light their dark surroundings, to attract their prey and to camouflage themselves. Organisms such as bacteria, protozoa, fungi, sponges, crustaceans, insects, fish, squid, jellyfish and simple plants have been found to be bioluminescent.

Mimicking bioluminescence

The production of cool light by fireflies has been used as a model for the development of chemiluminescent materials. Although the production of light by chemiluminescence has been possible for some time, commercial applications were often not developed because the reactions were relatively inefficient. The firefly is able to produce light very efficiently by the chemical reactions in the cells of its abdomen. However, in recent years chemical research has uncovered new chemiluminescent reactions and more efficient reactions have been developed. This has enabled the commercial production of chemiluminescent items and the use of chemiluminescence techniques in scientific research.

Using chemiluminescence and bioluminescence

The reactions which occur in chemiluminescence and bioluminescence have been adapted for use in scientific research, medicine, ecology, hygiene and food quality control. Bioluminescence is used when testing for tuberculosis to determine the most suitable antibiotic to be given to the patient. Scientists have used gene transfer technology to insert the firefly's gene for making luciferase enzymes into bacteria from the tuberculosis patient. These bioluminescent bacteria are then tested for their resistance to different antibiotics. The effectiveness of the antibiotics can be easily determined by the amount of bioluminescence remaining. Bioluminescent bacteria have also been used to test for mercury pollution in water. No doubt in the future many more uses will be found for chemiluminescence and bioluminescence.



Bioluminescent fungi during the day (left) and at night (right). Some scientists believe that bioluminescent fungi use their light to attract insects.

activities

THINK

- 1 In what ways are chemiluminescence and bioluminescence similar?
- 2 Draw a diagram to explain how light is produced in a chemiluminescent light stick.

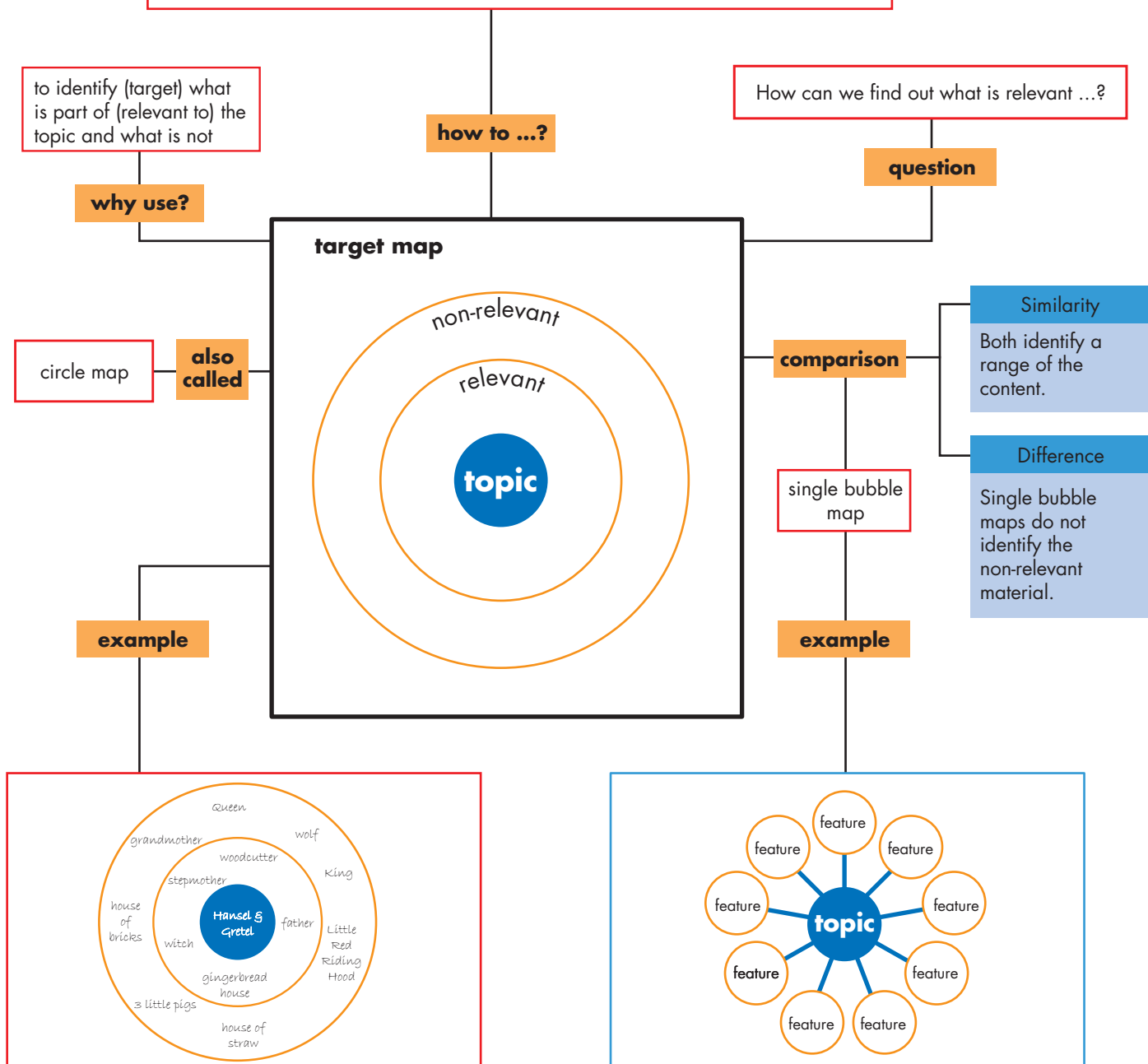
INVESTIGATE

- 3 Use the library and the Internet to find out how chemiluminescence and bioluminescence are used by scientists. Produce a web page of your findings, including hyperlinks to some of the web sites that you used for your investigation.
- 4 Bioluminescence can be used by organisms to light their dark surroundings, to attract a mate, to attract their prey and to camouflage themselves. Find examples of plants or animals that use bioluminescence for each of these reasons.

Thinking tools:

Target maps and single bubble maps

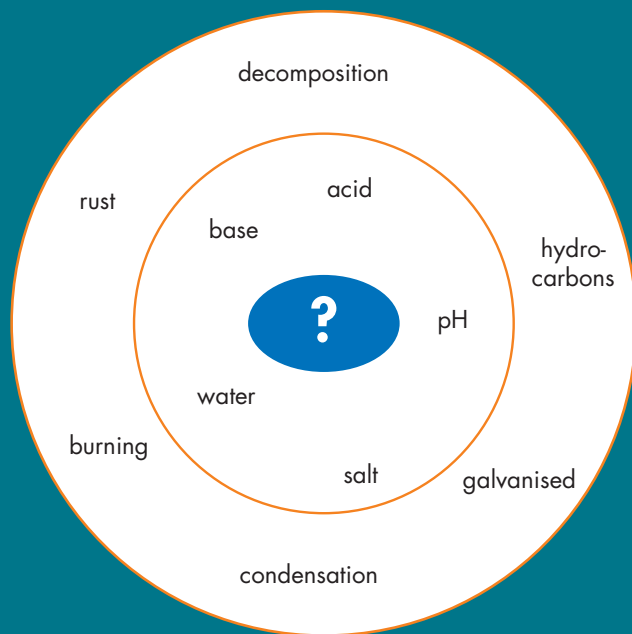
1. Draw three concentric circles on a sheet of paper.
2. Write the topic in the centre circle.
3. In the next circle, write words and phrases that are relevant to the topic.
4. In the outer circle, write words and phrases that are not relevant to the topic.



Adapted with permission from Hawker Brownlow Education © 2005 modellearning.com *Thinking Skills and EyeQ: Visual Tools for Raising Intelligence* by Ian Harris, Oliver Caviglioli and Bill Tindall

THINK AND CREATE

- 1 The target map below separates the content that is relevant to a particular group of chemical reactions. Which group of chemical reactions is represented?



- 2 Use the terms in the target map in question 1 and the box below to construct target maps that are relevant to:

- (a) endothermic reactions
- (b) combustion reactions
- (c) corrosion reactions.

precipitate	melting	reactants
oxygen	energy absorbed	products
evaporation	broken bonds	

- 3 (a) Work in a small group to write down as many ideas associated with chemical reactions as you can.

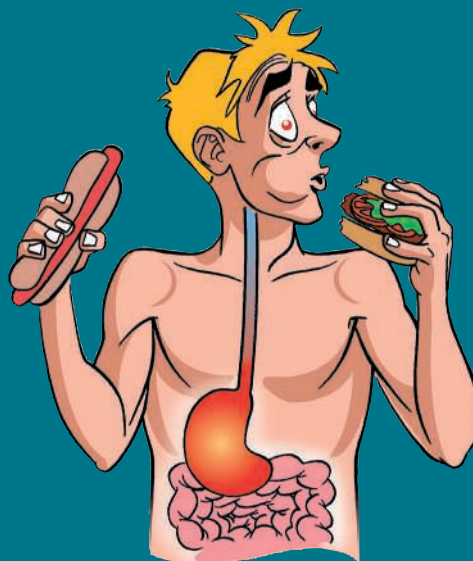


- (b) Once your group has completed a list, work on your own to create a single bubble map that represents what you believe to be the ten most important ideas related to chemical reactions.

- 4 Create single bubble maps to represent the important ideas associated with:

- (a) precipitation reactions
- (b) redox reactions
- (c) dangerous goods
- (d) hazardous substances.

- 5 Create a single bubble map on the topic 'Chemical reactions in the human body'.



- 6 Sort the following substances into three groups to create single bubble maps relevant to the topics:

- (a) acids
- (b) bases
- (c) salts.

caustic soda	sodium bicarbonate
sodium chloride	lemon juice
gastric juices	orange juice
magnesium chloride	sodium acetate
hydrogen chloride	magnesium oxide
ammonia	copper nitrate
antacid tablets	copper oxide
fizzy drinks	sodium sulfate

Looking back



- What is the only reliable evidence to show that a chemical reaction has taken place?
- Make a list of observations that may suggest that a chemical reaction has taken place.
- French chemist Antoine-Laurent Lavoisier provided evidence that led to the development of the Law of Conservation of Mass and the Law of Constant Proportions.
 - Use the Law of Conservation of Mass to explain why it is incorrect to say that when a candle burns it disappears.
 - State the Law of Constant Proportions.
- In an experiment to test the effect of the amount of liver on the breakdown of hydrogen peroxide, the following results were obtained.

Mass of liver (g)	Volume of oxygen released (cm ³)
0.5	2.5
1.0	5.1
2.0	9.8
2.5	11.5

- Write a word equation for the reaction occurring in this experiment.
 - Use formulae to write an equation for this chemical reaction.
 - Graph these results on graph paper.
 - What does the graph show about the effect of the liver on the rate of this reaction?
 - Why does the liver affect this reaction?
- When an aqueous solution of barium hydroxide reacts with an aqueous solution of ammonium hydroxide, the temperature of the products becomes low enough to freeze water.
 - What is an aqueous solution?
 - Is this an example of an exothermic or endothermic chemical reaction? Explain your answer.
 - Where does the energy transferred to or from the reactants go?
 - The two reactants in the chemical reaction taking place in the test tube shown at right are aqueous solutions. There is enough evidence in the photograph to identify the type of chemical reaction taking place.
 - What type of chemical reaction is it?
 - What evidence in the photograph identifies the type of reaction?
 - Write balanced equations using formulae for the following reactions.
 - aluminium metal + oxygen gas → solid aluminium oxide
 - potassium metal + oxygen gas → solid potassium oxide
 - solid carbon + oxygen gas → carbon dioxide gas
 - solid copper carbonate → solid copper oxide + carbon dioxide gas
 - iron metal + sulfur powder (S₈) → solid iron sulfide (FeS₂)
 - copper sulfate solution + zinc metal → copper metal + zinc sulfate solution
 - copper(II) sulfate solution + sodium hydroxide solution → solid copper(II) hydroxide + sodium sulfate solution
 - solid magnesium hydroxide + hydrochloric acid → magnesium chloride + water
 - State the reaction type (displacement, combination, decomposition, precipitation, combustion or neutralisation) for each of the reactions in question 7.
 - Which of the reactions in question 7 are redox reactions?



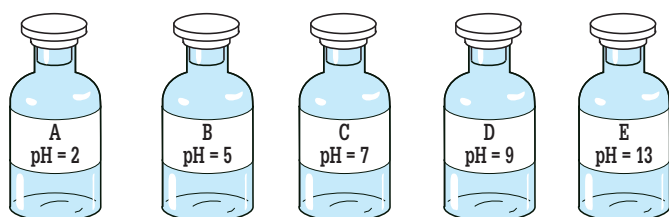
10. Many chemicals are classified as dangerous goods and/or hazardous substances.
- Describe the differences between these two categories of chemicals.
 - What do these two categories of chemicals have in common?
11. What is an MSDS and what is it used for?
12. Why are you more likely to find pure gold than pure copper in the ground?
14. Predict the salts that would result from the neutralisation reaction between:
- magnesium oxide and hydrochloric acid
 - copper(II) oxide and sulfuric acid
 - sodium hydroxide and acetic acid
 - sodium oxide and nitric acid.
15. An experiment was carried out to measure how long it took for equivalent amounts of different metals to dissolve in 100 mL of hydrochloric acid. The following results were obtained.



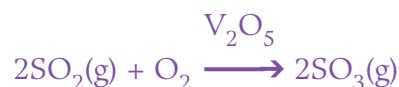
Metal	Time taken for the metal to dissolve (min)
iron	1.0
magnesium	3.0
tin	2.5
aluminium	3.5
nickel	2.0
zinc	1.5

Unfortunately, the person recording the data on the computer accidentally changed the order of the metals recorded in the table. Using a table of the known activity series, redraw the table so that the correct metal is matched with the correct time.

13. The liquids in the bottles shown below are labelled with their pH. Which of the bottles is most likely to contain:
- distilled water?
 - a strong acid?
 - a strong base?
 - vinegar?
 - bathroom surface cleaner?



16. One of the chemical reactions used during the production of sulfuric acid makes use of the catalyst vanadium oxide (V_2O_5). The chemical equation for this reaction is:



- What is a catalyst?
 - Why doesn't the V_2O_5 appear as one of the reactants?
 - What name is given to the catalysts in living things?
17. (a) Describe at least one chemical reaction that is caused by light and how the reaction is useful.
- What is chemiluminescence?
 - How is bioluminescence different from other types of chemiluminescence?