CURRICULUM FOR WALES

SCIENCE AND TECHNOLOGY

Science

FOR 11–14 YEARS

BOOK 2

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Gwasg Prifysgol Cymru
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Contents

1 Acids and alkalis

We are surrounded by acids and alkalis in our everyday lives, from the very weak acids in rain that can damage plant life and statues, to the strong acids found in car batteries that can burn skin.

Over the last century the burning of fossil fuels has increased the amounts of different pollutants in the air. Some of these pollutants make rain water more acidic.

Environmental scientists monitor pH changes in rivers to make sure the pH remains within safe limits for the ecosystems. The pH of water in swimming pools is checked regularly and can be adjusted if needed. All living organisms monitor and control acidity within their cells to ensure the pH remains constant.

- Think about a typical day – how many acids and alkalis do you come into contact with?
- What could affect the acidity of the rain in different parts of the world?
- Different living organisms need different pH levels in their cells – why do you think this is?

pH scale

The pH scale was created in 1909 by Danish industrial chemist Søren Peter Lauritz Sørensen (1868–1939) who worked at the research laboratories of the Carlsberg Brewery in Copenhagen. It was a scale that measured concentration of hydrogen ions (the H in pH).

Brewing is one of many large-scale global industries that has long sponsored scientific investigations. The scale was further developed by scientists studying bacteria in food.

Acids

Acidic substances:

- have a low pH – less than 7
- can be corrosive
- with the lowest pH are the strongest.

These are some of the acids you will use in the school lab:

- hydrochloric acid
- nitric acid
- sulfuric acid.

Alkalis

Alkaline substances:

- have a high pH – more than 7
- can be corrosive
- with the highest pH are the strongest.

Alkalis you may come across in the lab include:

- sodium hydroxide
- ammonia
- sodium bicarbonate.

You must follow safety rules carefully whenever you work with acids.

Making links

You studied the pH scale earlier in the course when measuring the pH of a substance to find out how acidic or alkaline it is. Now we look in more detail at what pH means and consider a wider range of indicators that we can use to monitor changes in pH during chemical reactions.

▲**Figure 1** Acids can be 'corrosive' or pose a 'moderate hazard' depending on their concentration.

The pH scale

All acids contain one or more hydrogen particles. When acids dissolve in water, some or all of the hydrogen particles separate from the other particles. It is these free hydrogen particles that make the solution acidic and which can be linked to the pH scale.

The pH scale measures the **concentration** of hydrogen particles in a solution. It is an inverse scale, meaning the lower the pH the higher the concentration of hydrogen particles. An increase of 1 on the pH scale equates to a ×10 decrease in concentration.

Concentration shows the mass of a substance dissolved in a fixed volume of solvent. Concentration is often measured in units of grams per decimetre cubed (g/dm^3). To change a volume given in cm^3 into one in dm^3 you divide by 1000. For example, 250 cm^3 is 0.25 dm^3.

Key term

Concentration – shows the mass of a solute dissolved in a fixed volume of solvent. It is measured in grams per cubic decimetre (g/dm^3).

Worked example

It is important to be able to find the concentration of a solution.

The volume of three solutions and the mass of solute dissolved in each solution is shown in the table. Which of the solutions A–C is the most concentrated?

Sample	Volume (cm^3)	Mass of solute (g)
A	10	8.1
B	50	22.9
C	30	17.9

- **STEP 1** Convert volume from cm^3 to dm^3 (÷ 1000).
- **STEP 2** Use the relationship:

$$\text{concentration} = \frac{\text{mass (in g)}}{\text{volume (in dm}^3\text{)}}$$

to find the concentration of each solution and add the information to the table.

Sample	Volume (cm^3)	Volume (dm^3)	Mass of solute (g)	Concentration (g/dm^3)
A	10	0.01	8.1	810
B	50	0.05	22.9	458
C	30	0.03	17.9	597

From this data it can be concluded that sample A is the most concentrated.

Science in context

Most waterways in the world have a neutral or slightly alkaline pH, but crater lakes which occur near active volcanoes are surrounded by high concentrations of acidic volcanic gases in the atmosphere. As these gases dissolve in the water in the craters, the pH can fall well below 1 – at this level of acidity a dip in the lake would burn your skin, tissues and bones.

▲**Figure 2** A volcanic crater lake, where the water is very acidic.

Worked example

It is important to be able to use the relationship between the pH value of a solution and the concentration of hydrogen particles.

A solution with a concentration of 3.65 g/dm^3 has a pH of 1. To increase the pH value by 1, the solution must be diluted ×10, so a concentration of 0.365 g/dm^3 has a pH of 2. Another dilution ×10 will raise the pH by 1 again. This example can be summarised in the table.

Concentration (g/dm^3)	pH
3.65	1
0.365	2
0.0365	3

1 What would the concentration be of a solution of the same substance with a pH of 4?

2 Complete the missing information in the table for a solution of a second substance.

Concentration (g/dm^3)	pH
	1
0.0049	3
0.000049	

3 A solution of nitric acid with a pH of 2 was diluted by adding 1 cm^3 acid to 99 cm^3 water.

a How many times more dilute is the new solution?

b What is the pH of the resulting solution?

4 Beth was investigating concentration. She made up the three solutions shown in the table, measuring the mass of the solid and dissolving this in the given volume of water.

	Volume (cm^3)	Mass (g)
A	80	18
B	150	45
C	72	17

a Convert the volumes of solutions A to C into dm^3.

b Calculate the concentrations of solutions A to C in g/dm^3.

c Put these samples A to C in order from most concentrated to least.

Check your understanding

Know

1 What happens when an acid is dissolved in water?

2 The pH of a solution is 13. What does this tell you?

Apply

3 Put these substances in order from most acidic to least: stomach acid (pH 1), milk (pH 6), vinegar (pH 3), water (pH 7).

4 Why is a more concentrated acid a greater hazard?

Indicators

You have already studied one **indicator**, Universal Indicator. Now we will look more closely at different types of indicator. Essentially, an indicator is a substance that shows a different colour in acidic conditions compared to alkaline conditions.

You could test a range of harmless substances in the home using Universal Indicator. Some possible results are shown in Table 1.

Table 1 Colours of Universal Indicator when used to test domestic substances.

Substance	Colour with Universal Indicator	Result
cola	pale orange	weakly acidic
soap	pale blue	weakly alkaline
lemon juice	orange	strongly acidic
salt	green	neutral
toothpaste	dark green	weakly alkaline

Natural indicators

Many plants contain substances that can be used as **natural indicators** as they change colour in acids or alkalis. The indicator must be extracted from the plant material. The indicator is a coloured pigment inside the cells of the plant's flowers, fruits, leaves or roots. This part of the plant must be crushed to break down the cell walls and extract the pigment. The pigment can then be added to a range of substances with known pH values to create a colour chart. It can then be used to test an unknown substance and the colour chart shows if the unknown substance is acidic or alkaline.

Other plants that make excellent indicators include coffee, tea, black beans, lavender, strawberry and avocado skin.

Science in context

Natural pigments found in the flowers of hydrangea plants can show the acidity of the soil the plants have grown in. Blue flowers appear if the plant is grown in very acidic soil (below pH 5.5), but the flowers are pink when the soil is neutral or alkaline. At in-between values you either get purple flowers or a mixture of pink and blue on the same plant. To demonstrate the colour is not due to genetics, you can harvest the plants and place them in soil of a different pH. The colour of the flowers can change the following year.

blue flowers
pH 5.5 or lower

purple flowers
pH 5.5–6.5

pink flowers
pH 6.5 or higher

▲**Figure 4** Hydrangea flowers have different colour petals at different soil pH.

Key terms

Indicator – substance that has different colours in acidic or alkaline conditions, used to identify the pH of a solution.

Natural indicator – indicator that comes from plant or animal sources.

1. red cabbage is cut up and ground to push out the juice

2. warm water is added

3. the juice and cabbage mixture is filtered to give an indicator that is ready to use

▲**Figure 3** Making an indicator from red cabbage.

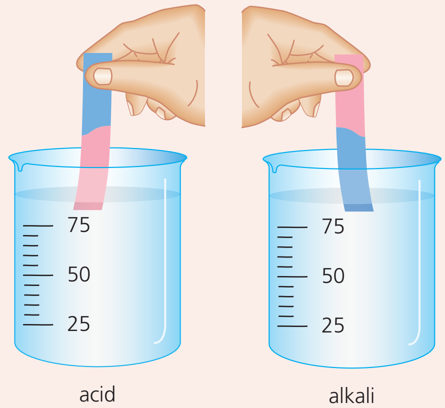
Using litmus paper to test pH

Litmus is a coloured dye, which changes colour in acidic or alkaline conditions. It is an example of a simple indicator. **Litmus** paper contains litmus dye soaked into some paper and dried. This can then be dipped into substances for testing. To test solid substances, you need to dampen the paper first.

There are two types of litmus paper:

- blue litmus paper for testing for acidity
- red litmus paper for testing for alkalinity.

Acids always turn litmus red. Alkalis always turn litmus blue. Litmus cannot tell you how concentrated the acid or alkali is, so cannot be used to give a pH value.



▲**Figure 5** Litmus paper can show if a substance is an acid or an alkali.

Synthetic indicators

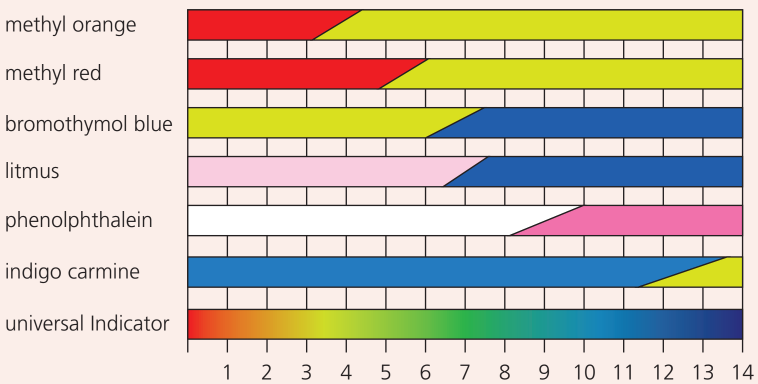
Using plant pigments as indicators can be difficult – they can be impure and may break down over time. Chemists have developed a range of more stable **synthetic indicators**.

Most indicators have just one colour at low pH and one colour at high pH. Different indicators change colour at slightly different pHs, often over a very narrow range. Universal Indicator is, in fact, a mixture of indicators to give the different colour changes over a range from 0 to 14 on the pH scale.

Key terms

Litmus – a natural indicator. Acids turn litmus red and alkalis turn litmus blue.

Synthetic indicator – indicator that is made by chemists in a laboratory.



▲**Figure 6** A range of different indicators and their colours in acidic and alkaline conditions.

Practical skills — Writing a method

Gwen wanted to extract a natural indicator from red apple skins. She planned to test the indicator using some household substances of known pH, so she can then use the indictor to work out whether other solutions are acidic or alkaline.

Her plan is shown here:

1. Peel the apple and chop the peel into small pieces.
2. Put the peel in a beaker with some water and heat over a Bunsen burner.
3. Remove the beaker and use the coloured water as an indicator.
4. Test vinegar, lemon juice and cola using the indicator.

Remember a plan should be written so that any person could follow it and achieve the same results. The colours expected depend on the concentration of the indicator made.

1. What extra details would you add to step 2 to make sure the test is fair?
2. What is the purpose of heating the peel in step 2?
3. The indicator should be a solution with no peel in it. What extra step would you take to make sure there was no peel left in the indicator? Include the equipment you would use in your answer.
4. Draw a results table for Gwen to record the test results.
5. In step 4, Gwen has chosen vinegar (pH 2), lemon juice (pH 3) and cola (pH 3). What is the problem with her choice of test substances? Suggest an improvement to her method.
6. Describe how Gwen can use her indicator to test unknown solutions.

Electronic pH meter

You can also test for acidity or alkalinity with an electronic pH meter. The advantage of these meters is the resolution (the smallest change it can measure). The meter used in Figure 7 gives a pH value to two decimal places. If you are trying to see a very small difference in pH, a meter is essential. The only disadvantages of pH meters is the cost (they are expensive compared to other methods) and they need to be maintained.

▲Figure 7 A pH meter measures pH, often to one or more decimal places.

Science in context

The first electronic pH meter was created in 1934 by chemist Arnold Beckman at the California Institute of Technology. He was asked to create a flexible method for measuring the acidity of lemon juice for a farmers cooperative, the California Fruit Growers Exchange.

Founded in 1893, the cooperative changed its name in 1952 to today's globally well-known brand Sunkist.

Check your understanding

Know

1. What property does an indicator have?
2. What pH is neutral?
3. What colour would red litmus paper turn in an alkaline solution?

Apply

4. The pH scale is an inverse scale. Explain what this means.
5. What colour would a very strong acid be with each of these indicators:
   a phenolphthalein **b** methyl orange **c** indigo carmine?

6 What are the limitations of testing substances with litmus paper?

7 Some people have lemon juice in their tea instead of milk. When the lemon juice is added, the tea changes colour slightly. Suggest why this may happen.

8 Owen was given two solutions. One was tap water; the other was sodium hydroxide, which is a strong alkali. He needs to select one indicator from the list in Figure 6. Which indicator could he choose to use with these two solutions? Explain your choice.

Extend

9 Compare the advantages and disadvantages of testing substances with Universal Indicator and a pH meter.

Learning summary

Now you have completed **pH scale** and **Indicators** you should be able to:

- name some common acids and alkalis
- describe how to use universal indicator and litmus to determine if a solution is acidic or alkali and measure its pH
- explain what the pH scale means in terms of the concentration of hydrogen ions
- describe how to test a natural indicator so it can be used to identify acidic and alkaline solutions
- evaluate the choice of indicator.

Neutralisation reactions

There are patterns in the ways acids react with different substances to make new substances. Many of these reactions result in a change in the pH of the solution to give a neutral pH of 7.

So far you have met alkaline substances. These are substances that dissolve in water to form a solution with a pH above 7. However, these are just one example of a wider range of substances which react with acids, called **bases**. An alkaline substance is a special type of base that dissolves in water.

Acids react with many substances, but always form a **salt**.

When naming a salt, the first part of the name is the metal in the reaction and the second part is based on the acid that has reacted to form it. Some examples of salts are shown in Table 2.

Table 2 Examples of salts that form when acids react.

Acid	Type of salt	Example
hydrochloric acid	chloride salts	magnesium chloride
nitric acid	nitrate salts	magnesium nitrate
sulfuric acid	sulfate salts	magnesium sulfate

Key terms

Base – a substance that can react with an acid in a neutralisation reaction.

Neutralisation – a reaction between an acid and a base that produces a salt and water.

Salt – a compound formed in the reactions of acids.

Investigating neutralisation by monitoring pH

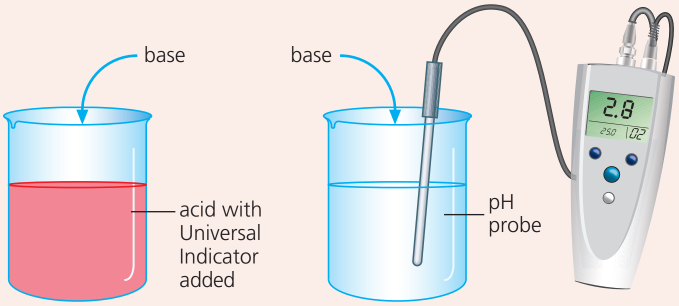
During a neutralisation reaction the pH varies. You can monitor this change using a pH indicator or a pH meter.

Here is a possible method to monitor a neutralisation reaction:

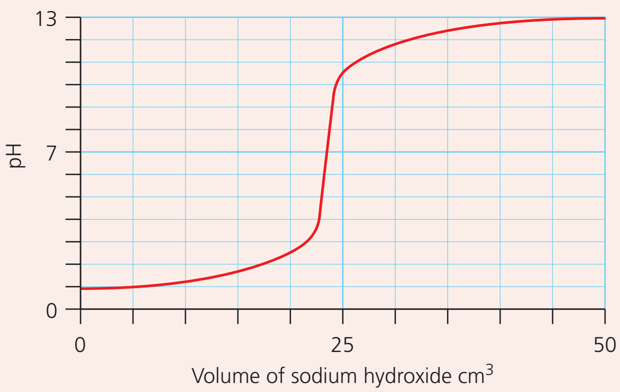
1. Measure 20 cm^3 of hydrochloric acid into a boiling tube.
2. Add a few drops of Universal Indicator (this will turn red).
3. Measure out 30 cm^3 of sodium hydroxide into a measuring cylinder.
4. Using a dropping pipette add the sodium hydroxide drop by drop until the indicator changes colour to show a neutral solution (green).
5. Work out from the measuring cylinder how much sodium hydroxide has been added.

If this reaction is monitored using a pH meter, 5 cm^3 portions of sodium hydroxide can be added and the pH values plotted on a graph.

You will often notice a rapid change in pH around the neutralisation point and can use the graph to determine the volume of sodium hydroxide needed to completely neutralise the acid.



▲**Figure 8** Monitoring pH change during neutralisation.



▲**Figure 9** Using a pH meter attached to a datalogger can give a detailed plot of pH changes throughout a reaction.

Reactions of acids and metal hydroxides

An acid always reacts with an alkali to form a salt and water.

The general equation for these reactions is:

alkali + acid → salt + water

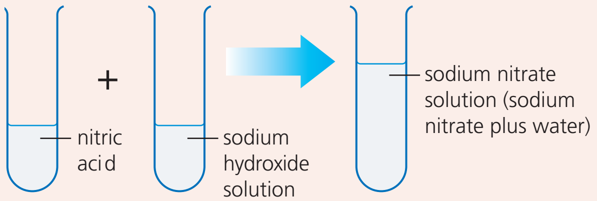
Some examples of these reactions include:

sodium hydroxide + hydrochloric acid → sodium chloride + water

potassium hydroxide + sulfuric acid → potassium sulfate + water

calcium hydroxide + nitric acid → calcium nitrate + water

To see how the products are formed and named, it helps to highlight the metal in the one colour, the acid and the second part of the salt name in another colour and, finally, the hydroxide and the water in a third colour.



▲**Figure 10** The reaction between nitric acid and sodium hydroxide

Worked example

You should be able to use the general equation for the reaction of metal hydroxides with acids to write word equations for any of these reactions.

Complete the word equation for the reaction between sulfuric acid and calcium hydroxide.

▶ **STEP 1** Write out the reactants.

sulfuric acid + calcium hydroxide ⟶

▶ **STEP 2** Name the salt formed.

sulfuric acid + calcium hydroxide ⟶ calcium sulfate

▶ **STEP 3** Complete the equation by adding any other products based on the general equation.

sulfuric acid + calcium hydroxide ⟶ calcium sulfate + water

1 Name the salt formed in each of these reactions:

- **a** nitric acid + magnesium hydroxide ⟶ ___________ ________ + water
- **b** hydrochloric acid + aluminium hydroxide ⟶ _____________ _________+ water
- **c** sulfuric acid + lithium hydroxide ⟶ ____________ _________+ water

2 Identify the acid used in each of these reactions:

- **a** __________________ acid + calcium hydroxide ⟶ calcium sulfate + water
- **b** __________________ acid + iron hydroxide ⟶ iron nitrate + water
- **c** __________________ acid + copper hydroxide ⟶ copper chloride + water

3 Write word equations for these reactions:

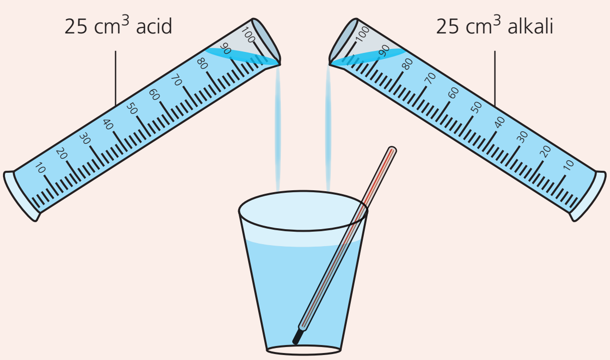
- **a** magnesium hydroxide and sulfuric acid
- **b** zinc hydroxide and hydrochloric acid.

Investigating neutralisation by monitoring temperature

The reaction between an acid and a metal hydroxide is **exothermic**. This means the temperature of the solution increases as the reaction takes place. The greater the concentration of the acid, the higher the temperature rises. A polystyrene cup is used to insulate the reaction. This prevent transfer of energy to the surroundings, so that any temperature change measurements are more reliable.

Key term

Exothermic – a reaction in which energy is transferred from the reacting substances to the surroundings, causing the temperature of the surroundings to increase.



▲**Figure 11** Neutralisation reactions are exothermic, so they can be monitored using the temperature rise.

Practical skills — Planning an investigation – variables

Rhys wanted to investigate how the concentration of acid affected the temperature change in a neutralisation reaction.

Here is his method:

1. In a polystyrene cup add 20 cm³ of sodium hydroxide.
2. Record the start temperature.
3. Measure out 20 cm³ of 36.5 g/dm³ hydrochloric acid.
4. Add this to the polystyrene cup and record the highest temperature reached.
5. Repeat steps 3 and 4 with different concentrations of hydrochloric acid.

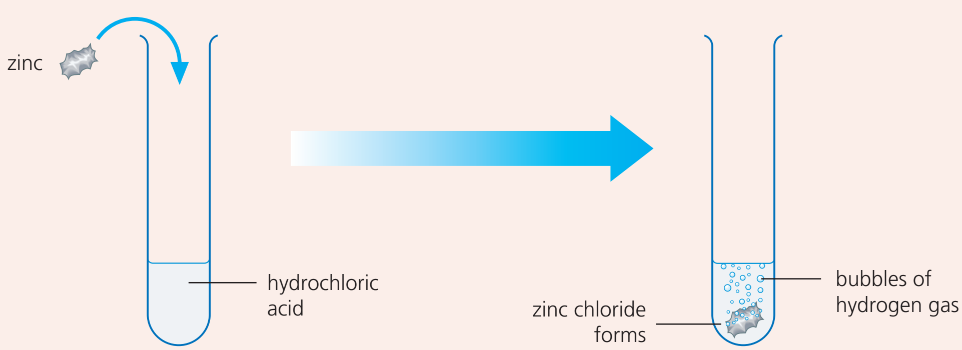
Consider Rhys's method and answer these questions:

1. What is the independent variable?
2. What is the dependent variable?
3. What are the control variables?
4. What type of graph should Rhys plot and why?
5. What label (including units) would go on the *x*-axis?
6. What label (including units) would go on the *y*-axis?

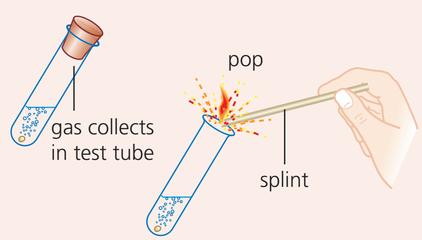
Reactions of acids with metals

An acid always reacts with a metal to produce a salt and hydrogen gas.

acid + metal
acid + metal carbonate
acid + alkali (metal hydroxide)



▲**Figure 12** The reaction between zinc metal and hydrochloric acid.



▲**Figure 13** To confirm the bubbles of gas formed are hydrogen, you can perform the squeaky-pop test which you met in book 1.

The general equation for these reactions is:

metal + acid → salt + hydrogen

Examples of these reactions include:

magnesium + hydrochloric acid → magnesium chloride + hydrogen

iron + nitric acid → iron nitrate + hydrogen

copper + sulfuric acid → copper sulfate + hydrogen

Reactions of acids with metal oxides

The general equation for the reaction of a metal oxide and an acid is:

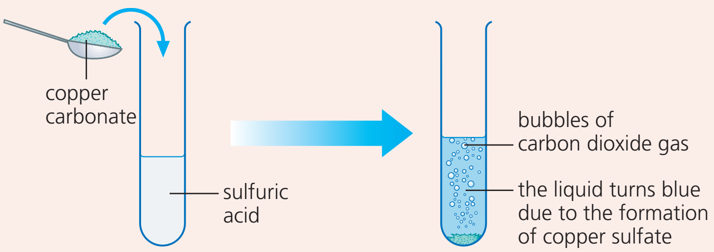
metal oxide + acid → salt + water

Examples of these reactions include:

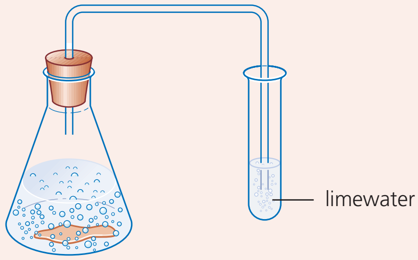
copper oxide + hydrochloric acid → copper chloride + water
calcium oxide + nitric acid → calcium nitrate + water
sodium oxide + sulfuric acid → sodium sulfate + water

Reactions of acids with metal carbonates

An acid always reacts with a carbonate to produce a salt, water and carbon dioxide gas.



▲**Figure 14** The reaction between copper carbonate and sulfuric acid.



▲**Figure 15** To confirm the bubbles of gas formed are carbon dioxide, you can test the gas in limewater and observe the limewater become cloudy.

The general equation for these reactions is:

metal carbonate + acid → salt + water + carbon dioxide

Examples of these reactions include:

calcium carbonate + hydrochloric acid → calcium chloride + water + carbon dioxide
magnesium carbonate + nitric acid → magnesium nitrate + water + carbon dioxide
copper carbonate + sulfuric acid → copper sulfate + water + carbon dioxide

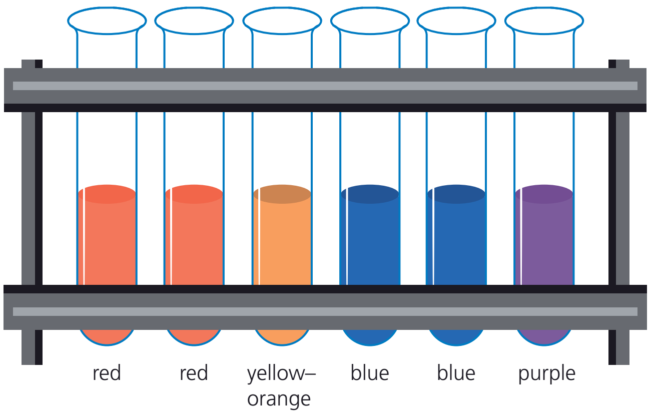
Practical skills — Suggesting improvements

Elis investigated this neutralisation reaction:

sodium hydroxide + nitric acid → sodium nitrate + water

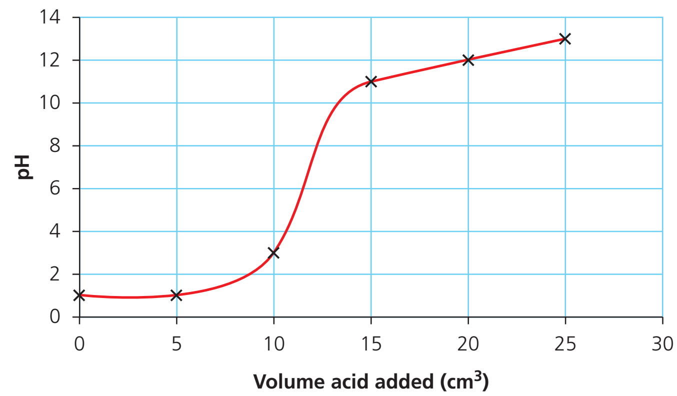
He added 5 cm^3 portions of acid to 20 cm^3 of sodium hydroxide solution and monitored the pH using Universal Indicator.

His results table and graph are shown here.



▲**Figure 16** Elis' results

Volume hydrochloric acid added (cm^3)	Colour of Universal Indicator	pH
0	red	1
5	red	1
10	yellow–orange	3
15	blue	11
20	blue	12
25	purple	13



▲**Figure 17** Elis plotted his data on a line graph.

1 How could Elis' method be improved to give better quality data?

Check your understanding

Know

1 Give **two** methods to monitor the pH during a neutralisation reaction between an acid and an alkali.

2 Name the acid used to produce these salts:

- **a** calcium nitrate
- **b** copper sulfate
- **c** sodium chloride.

Apply

3 Write the word equations for **three** possible reactions that would produce copper chloride.

Extend

4 Describe the similarities and differences when magnesium is reacted with hydrochloric acid and when magnesium carbonate is reacted with hydrochloric acid. Include a word equation for both reactions in your answer. Describe how you would test any gases produced and the results you would expect.

Learning summary

Now you have completed **Neutralisation reactions** you should be able to:

- describe what happens when an acid and an alkali, or an acid and a base react together
- explain how to investigate the pH change during neutralisation reactions
- explain how to investigate the temperature change during neutralisation reactions
- name the salt formed and write word equations for a range of acid–base reactions.

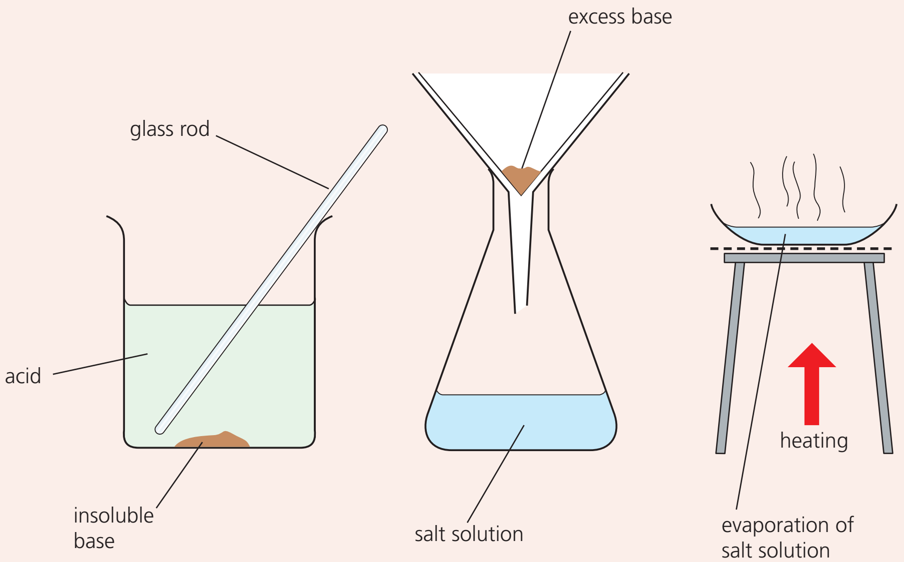
Isolating salt crystals

We can use neutralisation reactions to make a sample of a pure salt. The method needed to produce and extract the salt crystals will be different depending on the salt you want to make.

If an alkali solution is used, you must first work out exactly how much acid reacts with the alkali by using Universal Indicator to monitor the pH change and recording the volume needed to exactly neutralise the acid. This information is required so that the final reaction mixture does not contain any unreacted acid or alkali. The reaction is repeated without the indicator, to give a mixture of just the salt and water.

If an insoluble base, such as some metal oxides or some metal carbonates, is used it can be added in **excess**. To be sure that all of the acid has reacted, you need to keep adding the base until no more reacts and the unreacted solid is visible. You will then have a mixture of unreacted base, dissolved salt and water. An additional filtration step is required to extract the unreacted base. This will leave just the salt and water in the solution in the flask.

The final step when using either an alkali or a base is to separate the dissolved salt from the water by evaporating the water.



▲**Figure 18** Production and extraction of a salt from an acid–base reaction.

Making links

You have studied both filtration and evaporation as techniques for extracting salt from a mixture earlier in your course, in the topic on **Extraction, refinement and analysis**. Filtration was used to remove the undissolved solids from the mixture, and evaporation was used to remove the water from the dissolved salt to produce the pure salt sample.

Key term

Excess – more substance than is needed to react fully. Some of this substance will be left over at the end of the reaction.

Practical skills — Choosing and using equipment

When making a salt such as copper sulfate from an insoluble base like copper oxide by reacting with sulfuric acid, the techniques used are:

- warming the reaction mixture
- filtration
- evaporation.

1 Create an equipment list for this method.

2 Draw a scientific diagram or diagrams for the method, showing how the equipment is used in each process.

Different salts and their crystals

The type of salt you make will depend on the metal found in the base (see page 7). Most salt crystals are colourless, but salts containing certain metals, like copper, iron and cobalt, form coloured salts.

▲**Figure 19** Copper sulfate, copper chloride and copper nitrate crystals.

Crystal formation with different cooling rates

The size of the crystals that form depends on the rate of evaporation of water from a solution of the salt.

If the water is evaporated rapidly by heating, many small crystals will form. This is what you expect during the process of evaporation by heating over a Bunsen burner. If the rate of evaporation is slow, such as leaving the solution to evaporate on a warm windowsill for several days, the crystals formed will be much larger.

When we isolate pure salt crystals from a reaction, we can compare how much salt we made, the **actual yield**, to how much we expected to make, as a percentage of that **theoretical yield**. This is called the **percentage yield**.

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

A 100% yield means that no product has been lost during the reaction or in any extraction steps. Percentage yield is usually lower than 100%. A lower percentage yield can happen because:

- not all of the reactants were used up
- product was lost during filtering
- product was lost when evaporating
- product was lost when transferring solutions.

Sometimes the calculation will give a percentage yield greater than 100%. This happens if there are impurities in the product, such as water if the product has not been fully dried.

Key terms

Actual yield – the mass of product made during the reaction. This mass is measured.

Theoretical yield – the maximum possible mass of product that can be made from the reaction. This mass is calculated.

Percentage yield – a comparison between the maximum theoretical mass that could be made and the actual mass produced in a reaction.

Science in context

It is not only salt crystals in the lab that show the effect of cooling rate on crystal size. Igneous rocks form when magma (molten rock) cools. The igneous rocks that are found on the surface of the Moon include gabbro and basalt. Both rocks have the same chemical composition. Gabbro has large crystals that formed slowly as the magma cooled below the Moon's surface. Basalt, which cooled much faster at the surface, has much smaller crystals.

Worked example

You need to be able to use the equation to calculate the percentage yield of a salt produced, from the actual amount produced and the amount that was expected to be produced.

In a reaction it was expected that 5 g of salt would be produced. After extracting the pure salt, 3.2 g of product was isolated. Calculate the percentage yield.

▶ **STEP 1** Identify the theoretical and actual yield from information in the question.

In a reaction it was expected that 5 g of salt would be produced. After extracting the pure salt, 3.2 g of product was isolated.

▶ **STEP 2** Substitute these values into the percentage yield calculation:

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{3.2}{5} \times 100$$

▶ **STEP 3** Complete the calculation: $\frac{3.2}{5} \times 100 = 64\,\%$

1 In an experiment to make crystals of a salt, the theoretical yield was 9 g. The actual yield was 8.7 g. Calculate the percentage yield.

2 A student expected to make 10.6 g of a salt. After extraction, 7.2 g of the salt was obtained. Calculate the percentage yield.

3 In a reaction, 4.7 g of salt was isolated. The theoretical maximum yield was 6.7 g. Calculate the percentage yield.

Check your understanding

Know

1 What does theoretical yield mean?

2 Why do we need to use filtration if excess insoluble base is used to the make a salt?

Apply

3 What would you expect to see during and at the end of a reaction between copper carbonate and hydrochloric acid if the carbonate is in excess?

4 Excess copper oxide is added to sulfuric acid. The first step in isolating the salt is filtration. After the filtration step, what is left in the flask? What is on the filter paper?

5 In a reaction, David expected to make 4 g of copper sulfate salt. After isolating the salt, he had 2.4 g. Calculate the percentage yield and give two possible reasons why it is not 100 %.

Extend

6 Describe how you would isolate pure crystals of the salt from this reaction.

calcium carbonate + hydrochloric acid → calcium chloride + carbon dioxide + water

7 A student isolated very large, dark blue crystals from a reaction with copper oxide. What can you deduce about the reaction and isolation from this information?

Learning summary

Now you have completed **Isolating salt crystals** you should be able to:

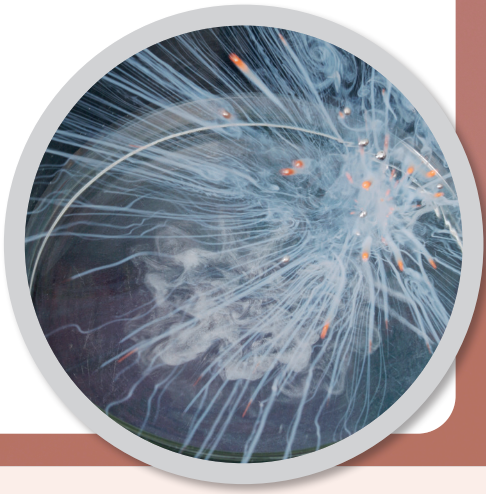
- outline a method to isolate crystals of a pure salt
- identify the equipment needed to form crystals of a soluble or insoluble salt
- state the chemicals required to produce a particular salt
- recognise the effect of cooling rate on crystal size
- calculate the percentage yield of salt formed in a reaction.

2 Atomic structure and the Periodic Table

The Ancient Greeks had ideas about atoms. Some great thinkers believed that everything was made up from the four elements: air, fire, water and earth. Others thought that all substances were made from small particles. The word 'atom' comes from the Greek word *atomos* which means indivisible (cannot be split into smaller pieces), so even the Ancient Greeks thought that atoms could not be divided into anything smaller. Over 2000 years passed before scientists explored this idea again.

The way that matter behaves when it reacts with other substances fascinated scientists in the eighteenth and nineteenth centuries. They saw patterns in behaviours and started to group similar substances together. They used these patterns to make predictions about how newly discovered substances would behave. This led to ideas that are fundamental to modern chemistry.

- How can all matter in the Universe only be made of 100 different types of atoms?
- If atoms are the building blocks of matter, how did they form?
- Have you ever made a prediction based on patterns you have seen before?



Atoms and atomic structure

Elements

The whole Universe is made up of millions of different substances. To help us make sense of these, it is useful to put them into groups, such as metals, rocks, plastics or smart materials. All these different substances are made from one or more of just 98 **elements**, all of which occur naturally on Earth. Even in the human body, blood, muscle, bone and brains are made out of relatively few different elements that are strongly joined together in various ways.

Key terms

Element – a substance that is made up of only one type of atom.

Atom – the simplest unit of matter. All substances are made out of atoms.

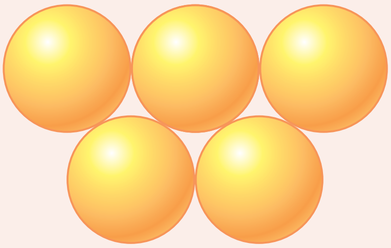
Atoms

Each element is made up of only one kind of **atom**. Atoms are the smallest parts of a substance – they are the basic particles from which all substances are built up. Since the early 1800s, scientists have known that atoms are the building blocks of all matter.

The theory of atoms

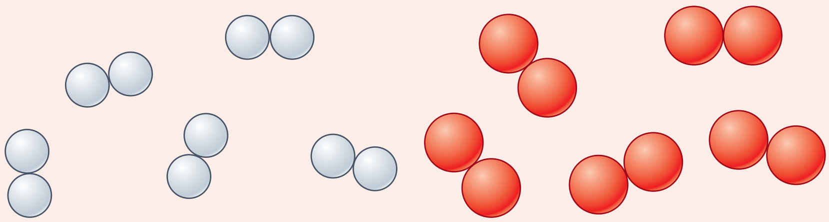
Atomic theory can be summarised:

- Everything is made up of tiny particles called atoms.
- Atoms cannot be destroyed.
- Atoms cannot be broken up into smaller pieces.
- In an element, all the atoms are identical (Figure 1).

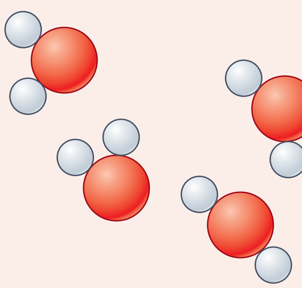


▲**Figure 1** This is a solid element. All atoms are the same type.

- Atoms can join together and make bigger particles, now called **molecules** (Figure 2).
- If the molecule is made of different types of atoms joined together, it is called a **compound** (Figure 3).
- Atoms combine in simple ratios of whole numbers when they form compounds.
- Compounds can also form when two or more different ions join together in a fixed ratio.



▲**Figure 2** Hydrogen and oxygen are both elements that exist as molecules.



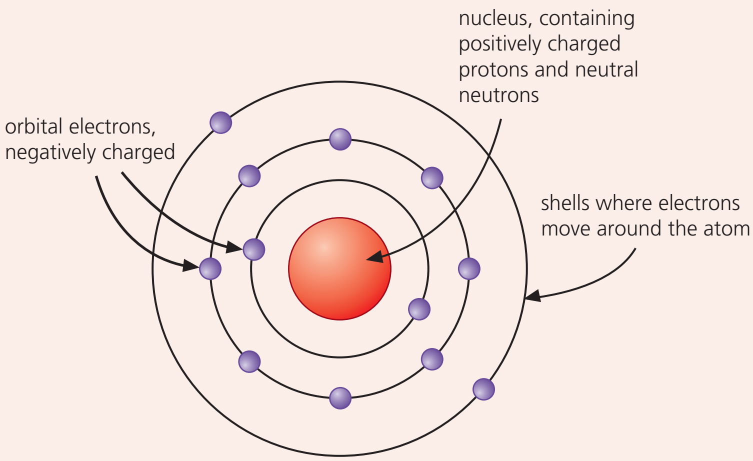
◀**Figure 3** Water is a compound made up of hydrogen and oxygen atoms joined together.

Atomic structure

In the 20th Century scientists discovered a more complex internal structure common to all atoms. Modern-day atomic theory proposes three subatomic particles with different properties.

Protons and **electrons** are charged particles, but **neutrons** have no charge – they are neutral.

Protons and neutrons are found in the **nucleus** at the centre of the atom, and electrons move in circles around the nucleus, like planets in orbits around the Sun. We call these orbits **electron shells**.



▲**Figure 4** The modern-day model for atomic structure.

Key terms

Ions – charged particles that form when atoms gain or lose electrons.

Molecule – a substance that is made up of two or more atoms chemically joined together. The atoms can be the same type, as in a molecule of an element, or different types to make up a molecule of a compound.

Compound – a substance that is made up of two or more different types of atoms or ions, chemically joined together in a fixed ratio.

Key terms

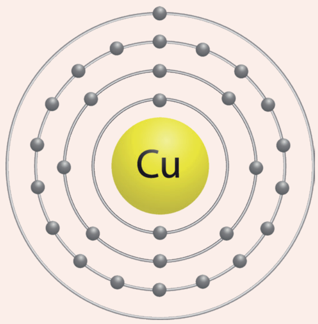
Protons – positive subatomic particles.

Electrons – negatively charged subatomic particles.

Neutrons – subatomic particles with no charge (neutral).

Nucleus – the centre of an atom, containing protons and neutrons.

Electron shells – orbits around the nucleus that contain electrons.



▲**Figure 5** A diagram showing the electrons in shells in a calcium atom.

Science in context

At the Conseil Européen pour la Recherche Nucléaire (better known as CERN) in Geneva, Switzerland, particle physicists are looking deep into the structure of atoms. This large-scale laboratory hosts scientists from all over the world who work together to try and discover what makes up matter. One scientist here was so frustrated about how difficult it was to share data across different computers he set about solving this. The World Wide Web was invented and Tim Berners-Lee's (1955–present) computer became the first web server.

Subatomic particles

The subatomic particles have different masses. Atoms are so tiny that their masses cannot be measured usefully in grams. We compare masses of the particles to each other. One proton and one neutron have the same mass, but electrons have a very small mass. This means that the mass of the atom is largely found in the nucleus and most of the rest of the atom is empty space.

The mass and charge of subatomic particles is summarised in Table 1.

Table 1 Mass and charge of subatomic particles.

Name of subatomic particle	Relative mass	Relative charge
proton	1	+1
neutron	1	0
electron	(almost nothing)	–1

Once scientists had this model for atomic structure, they could use it to begin to explain several observations. The number of subatomic particles in the nucleus explained why different elements had atoms of differing mass. Scientists could also begin to explain patterns in how different elements behaved.

▶ Drawing atomic structure

The modern model of atomic structure allows us to represent atoms as two-dimensional diagrams.

Calculating numbers of subatomic particles

Before we can begin to draw atomic structures for different elements, we must calculate the number of each subatomic particle in a particular atom. To do this, we need two key pieces of information:

- the **atomic number**, which is the number of protons
- the **mass number**, which is the total number of protons plus neutrons found in the nucleus.

Key terms

Atomic number – the number of protons in the nucleus of an atom.

Mass number – the number of neutrons and protons in the nucleus of an atom.

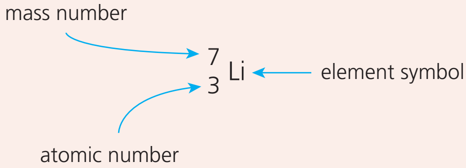
Nuclear symbol – the element's symbol with the values for atomic number and mass number.

We use a **nuclear symbol** to show these values. This is made up of the letter or letters of the element's symbol, which we can look up on the Periodic Table (page 26), with these two values written to the left. The atomic number can also be found on the Periodic Table, because as we shall see on page 26, the elements are placed in order of increasing atomic number.

As protons are positively charged and an atom has an overall neutral charge, the number of negatively charged electrons in an atom must equal the number of protons.

We can use these values to calculate the number of each subatomic particle in a particular atom.

In a similar way, if we are told the numbers of each subatomic particle present in an atom we can write the nuclear symbol.



▲**Figure 6** The nuclear symbol for lithium.

Worked example

Being able to calculate the numbers of each subatomic particle in an atom is the first step in drawing atomic structure diagrams.

Calculate the numbers of each subatomic particle in an atom of fluorine with the nuclear symbol $^{19}_{9}\mathrm{F}$.

▶ **STEP 1** Identify the atomic number: 9.

This is equal to the number of protons and also equal to the number of electrons. It can be helpful to enter the information into a table.

▶ **STEP 2** Identify the mass number: 19.

▶ **STEP 3** To calculate the number of neutrons, subtract the atomic number from the mass number:

$19 - 9 = 10$

1 Work out the numbers of protons, neutrons and electrons in atoms with these nuclear symbols:

a nitrogen, $^{14}_{7}\mathrm{N}$ **b neon,** $^{20}_{10}\mathrm{Ne}$ **c sulfur,** $^{32}_{16}\mathrm{S}$

Worked example

Once you know the numbers of each of the subatomic particles, you must be able to show the information in a correctly written nuclear symbol.

What is the nuclear symbol for an atom of the element sodium that has 11 protons and 12 neutrons?

▶ **STEP 1** Look up the chemical symbol on the Periodic Table: Na.

▶ **STEP 2** The number of protons is 11. This is equal to the atomic number, which is written to the left of the element symbol, at the bottom corner: $_{11}\mathrm{Na}$.

▶ **STEP 3** Add together the number of protons and neutrons. This is the mass number:

$11 + 12 = 23$

▶ **STEP 4** Put this information into the nuclear symbol: $^{23}_{11}\mathrm{Na}$.

1 What is the nuclear symbol for an atom of the element hydrogen that has 1 proton and 0 neutrons?

2 An atom of the element silicon has 14 protons and 14 neutrons. Write the nuclear symbol for an atom of this element.

3 What is the nuclear symbol for an atom of the element magnesium that has 12 protons and 12 neutrons?

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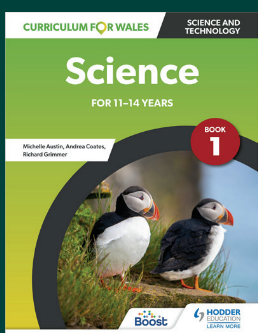

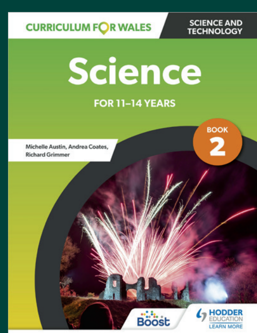

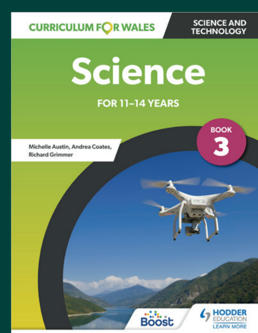

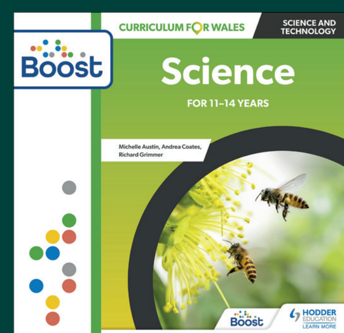

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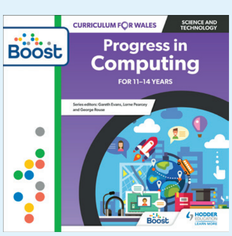

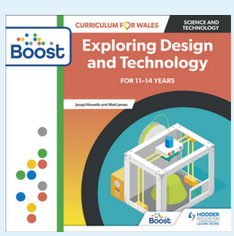

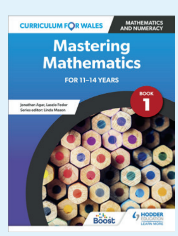

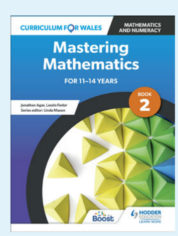

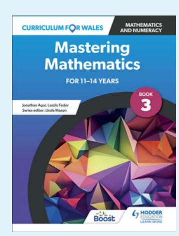

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