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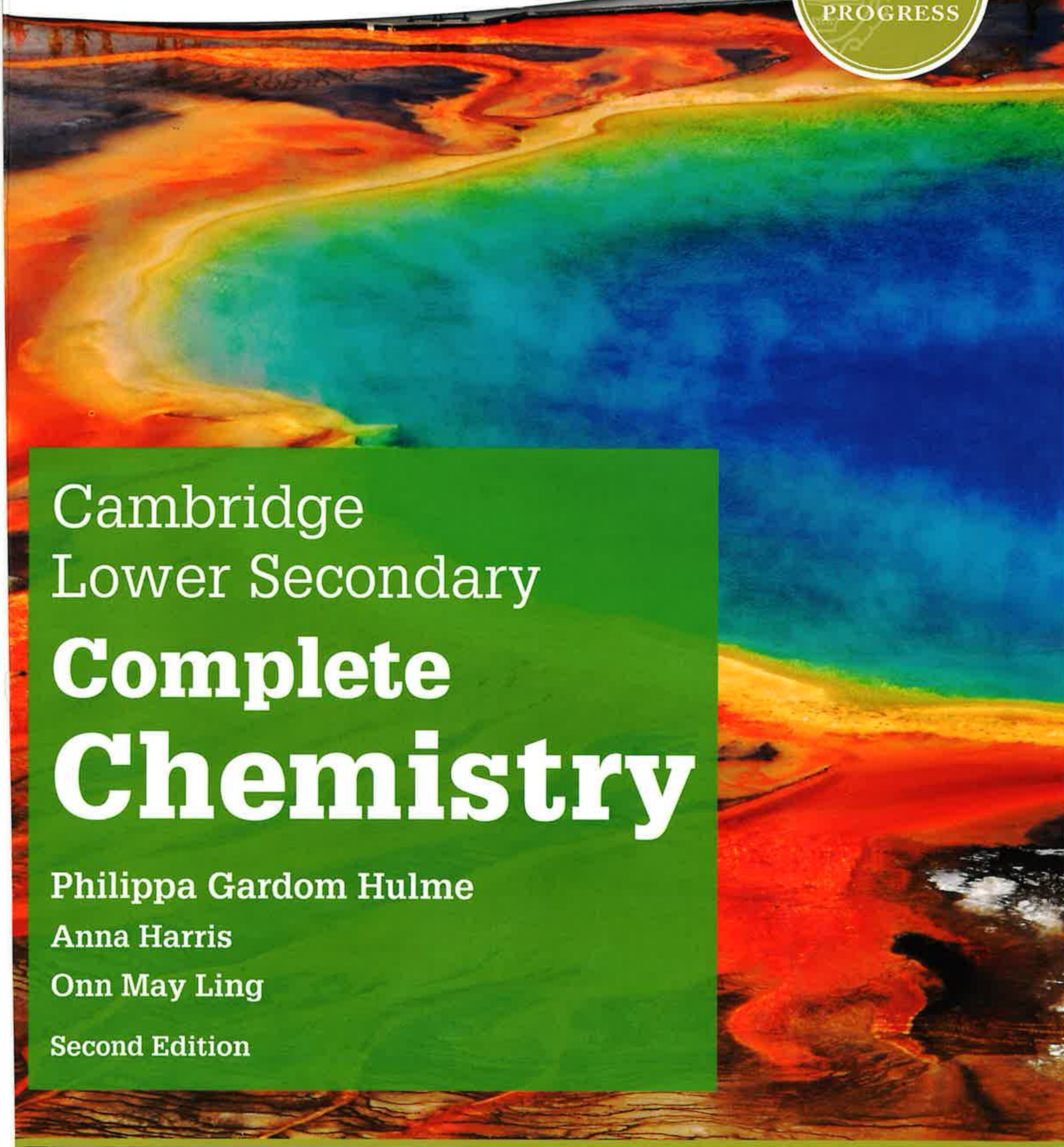

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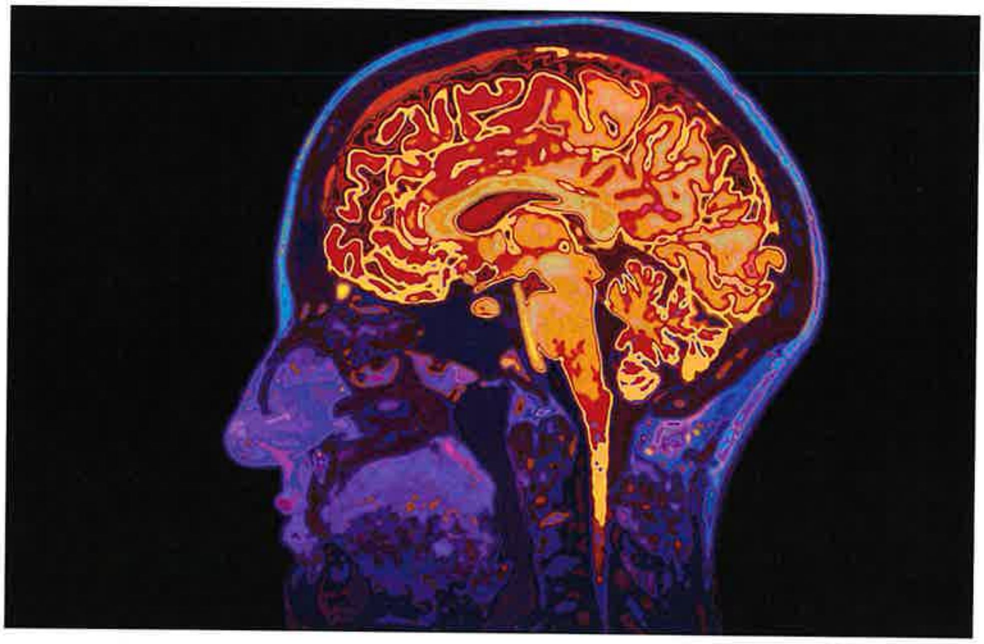
10.1 Proton number and the periodic table

Objectives

- Define the term *proton number* and *atomic number*
- Describe how proton number gives an element its position in the periodic table

MRI scans unlock some of the brain's deepest secrets. It is thanks to knowledge about atoms – and what happens inside them – that scientists have developed techniques like this.

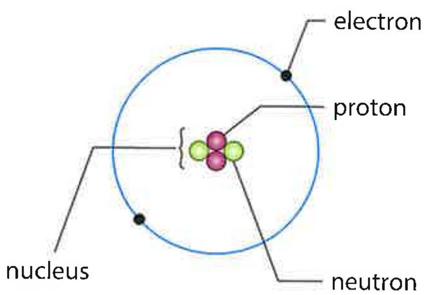


What is proton number?

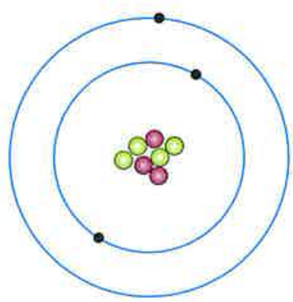
As you know, an atom has a nucleus. The nucleus is made up of two types of sub-atomic particle:

- positively charged protons
- neutrons, with no charge.

Each element has a different number of protons in its atoms. A helium atom has two protons. A lithium atom has three protons. A gold atom has 79 protons. The number of protons in an atom of an element is its **proton number**. Proton number is also called **atomic number**.



▲ *A helium atom has two protons. The proton number of helium is 2.*



▲ *A lithium atom has three protons. The proton number of lithium is 3.*

How is proton number linked to the periodic table?

In the periodic table, the elements are arranged in order of proton number.

					1 hydrogen												2 helium
3 lithium	4 beryllium											5 boron	6 carbon	7 nitrogen	8 oxygen	9 fluorine	10 neon
11 sodium	12 magnesium											13 aluminium	14 silicon	15 phosphorus	16 sulfur	17 chlorine	18 argon
19 potassium	20 calcium	21 scandium	22 titanium	23 vanadium	24 chromium	25 manganese	26 iron	27 cobalt	28 nickel	29 copper	30 zinc	31 gallium	32 germanium	33 arsenic	34 selenium	35 bromine	36 krypton
37 rubidium	38 strontium	39 yttrium	40 zirconium	41 niobium	42 molybdenum	43 technetium	44 ruthenium	45 rhodium	46 palladium	47 silver	48 cadmium	49 indium	50 tin	51 antimony	52 tellurium	53 iodine	54 xenon
55 caesium	56 barium	57–71 lanthanoids	72 hafnium	73 tantalum	74 tungsten	75 rhenium	76 osmium	77 iridium	78 platinum	79 gold	80 mercury	81 thallium	82 lead	83 bismuth	84 polonium	85 astatine	86 radon
87 francium	88 radium	89–103 actinoids	104 rutherfordium	105 dubnium	106 seaborgium	107 bohrium	108 hassium	109 meitnerium	110 darmstadtium	111 roentgenium	112 copernicium	113 nihonium	114 flerovium	115 moscovium	116 livermorium	117 tennessine	118 oganesson

57 lanthanum	58 cerium	59 praseodymium	60 neodymium	61 promethium	62 samarium	63 europium	64 gadolinium	65 terbium	66 dysprosium	67 holmium	68 erbium	69 thulium	70 ytterbium	71 lutetium
89 actinium	90 thorium	91 protactinium	92 uranium	93 neptunium	94 plutonium	95 americium	96 curium	97 berkelium	98 californium	99 einsteinium	100 fermium	101 mendelevium	102 nobelium	103 lawrencium

▲ *This periodic table shows the proton number of each element.*

Questions

1. Write the definition for *proton number*.
2. A boron atom has 5 protons and 6 neutrons. Draw and label a diagram of the nucleus of the atom.
3. Use the periodic table to give the proton numbers of these elements:
   a. oxygen, O **b.** chlorine, Cl **c.** silver, Ag
4. Give the names and chemical symbols of the elements with these proton numbers:
   a. 23 **b.** 18 **c.** 26

Key points

- The proton number of an element is the number of protons in its atoms.
- In the periodic table, the elements are arranged in proton number order.

10.2 Electrons in atoms

Objectives

- Define the term *electron configuration*
- Draw the electron configurations of 20 elements

Silver and sodium are both metal elements. Many of their physical properties are the same. But their chemical properties are different. Why?

▲ *Silver (left) and sodium (right) have similar physical properties. They are shiny when freshly cut. They conduct electricity.*

▲ *Silver and sodium have different chemical properties. Sodium reacts vigorously with water (above). Silver does not react with water.*

How many electrons?

As you know, atoms are made up of three types of sub-atomic particle:

- protons and neutrons in the nucleus
- negatively charged electrons, which orbit outside the nucleus.

A neutral atom has the same number of protons and electrons. For example, a hydrogen atom has one proton and one electron. A sodium atom has 11 protons and 11 electrons. A silver atom has 47 protons and 47 electrons.

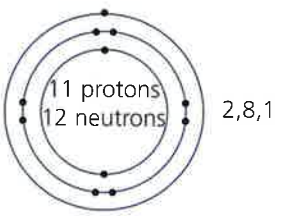
As you know, every element has a different number of protons in its atoms. This means that every element also has a different number of electrons.

The number and arrangement of electrons gives an element its chemical properties. Sodium and silver have different chemical properties because their atoms have different numbers of electrons.

How are electrons arranged in atoms?

The electrons in an atom are arranged in shells. A sodium atom has:

- two electrons in the first shell, nearest the nucleus
- eight electrons in the second shell
- one electron in the outer shell, furthest from the nucleus.



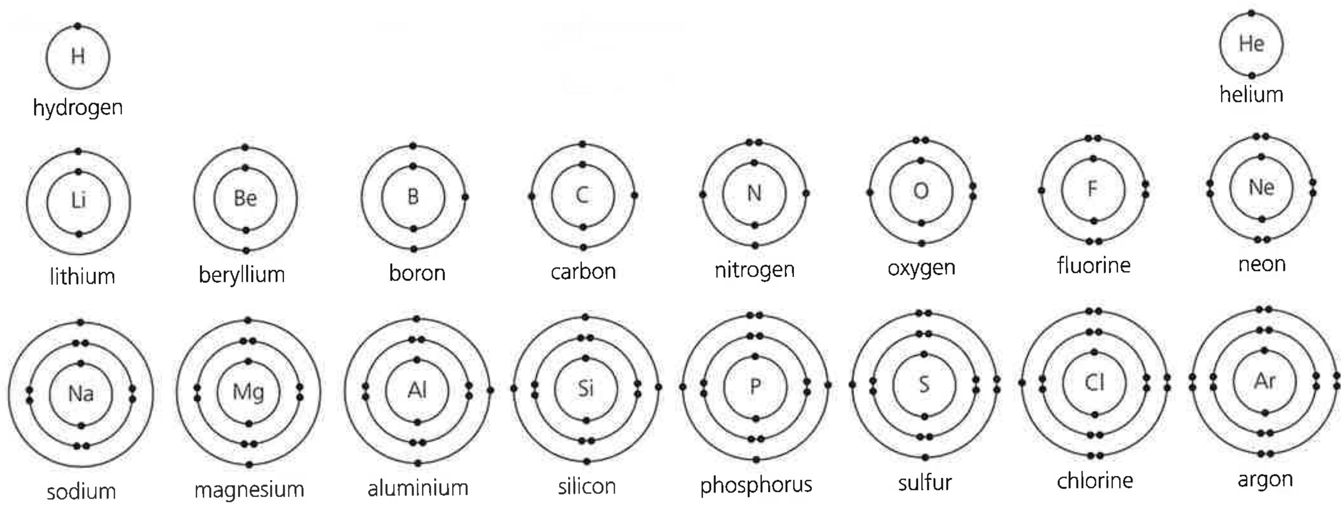
▲ *The electron configuration of a sodium atom. Each circle represents one electron.*

In atoms of all elements, each electron shell holds a maximum number of electrons:

- The first shell holds up to 2 electrons.
- The second shell holds up to 8 electrons.
- The third shell holds up to 18 electrons.

The arrangement of the electrons in an atom is its **electron configuration**. The diagram below shows the electron configurations of the first 18 elements of the periodic table. The elements are arranged as they are in the periodic table.

Can you see a pattern in the electron structures? Atoms of elements in the left column (Group 1 of the periodic table) have one electron in their outer shell. Atoms of elements in the next column (Group 2) have two electrons in their outer shell. Atoms of all elements that are in the same column of the periodic table have the same number of outer shell electrons.



▲ *Electron configuration of the first 18 elements.*

This chapter shows how electron configurations give an element its structure and – as a result – its physical properties. The next chapter shows how electron configurations explain patterns in elements' chemical properties.

Questions

1. Write the definition for *electron configuration.*
2. Give the number of electrons in atoms of:
   a. nitrogen **b.** fluorine **c.** aluminium
3. Draw the electron configurations of atoms of:
   a. lithium **b.** sodium **c.** potassium
4. Look at the electron configurations you drew to answer question 3. Describe how they are similar and how they are different.

Key points

- The electron configuration of an atom describes how its electrons are arranged.
- Each electron shell has a maximum number of electrons.

10.3 Making ions

Objectives

- Define the term *ion*
- Describe how ions are made
- Explain why atoms form ions
- Write formulae for simple ions

The goat is licking salt, sodium chloride. Why?

The goat gets sodium ions from salt. Like other animals, the goat needs sodium ions to makes its heart and nerves work.

What are ions?

An **ion** is a particle with a positive or negative charge. An ion forms when an atom gains or loses electrons. Electrons are negatively charged, so:

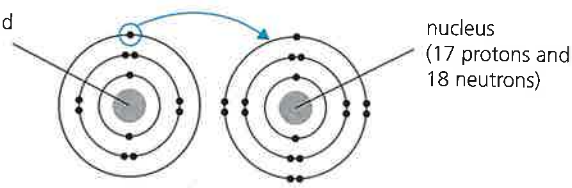
- If an atom gains one or more electrons, it becomes a negatively charged ion.
- If an atom loses one or more electrons, it becomes a positively charged ion.

A sodium ion forms when a sodium atom gives one electron to a non-metal atom. This happens in a chemical reaction.

Before the reaction:

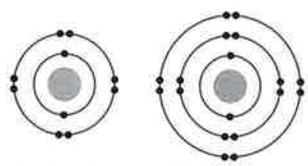
- The sodium atom has 11 positive protons and 11 negative electrons. It has no net charge.
- The chlorine atom has 17 positive protons and 17 negative electrons. It has no net charge.

In the reaction, one electron moves from the sodium atom to the chlorine atom.



This makes a sodium ion and a chloride ion.

- The sodium ion has 11 positive protons and 10 negative electrons. Its charge is +1.
- The chloride ion has 17 positive protons and 18 negative electrons. Its charge is −1.



Thinking and working scientifically

Formulae for ions

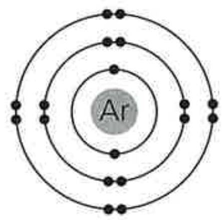
Every ion has its own chemical formula. The formula gives the chemical symbol of the element and the charge on the ion. The formula of a sodium ion is Na^+. The formula of a chloride ion is Cl^-. When you write the chemical formula of an ion:

- Write the + or – sign on the right of the chemical symbol.
- Write the + or – sign above the line.

Why do atoms form ions?

Stable atoms

The element argon makes up 1% of the air. Argon does not take part in chemical reactions. It is inert. Argon is inert because of its electron configuration. Its atoms have eight electrons in the outer shell. The outer electron shell is full. This makes the atom stable.



▲ *The electron configuration of an argon atom.*

Making stable ions

Any atom with a full outer electron shell is stable. Ions form in order to achieve this stable structure. As you can see in the diagrams below left:

- A sodium ion has eight electrons in its outer shell. Its outer shell is full. The ion is stable.
- A chloride ion has eight electrons in its outer shell. Its outer shell is full. The ion is stable.

The compound sodium chloride is made up of stable ions. This explains why sodium chloride takes part in few chemical reactions.

Questions

1. Write the definition for *ion*.
2. Most ions have eight electrons in the outer shell. Explain why.
3. Write the chemical formula for each ion below. Use the periodic table to find the chemical symbols of the elements:
   a. A potassium ion, with a charge of +1.
   b. A magnesium ion, with a charge of +2.
   c. A bromide ion, with a charge of −1.
4. The electronic configuration of a fluorine atom is shown. Predict the charge on its ion. Explain your prediction.

Key points

- An ion is an atom that has gained one or more electrons to be negatively charged, or lost one or more electrons to be positively charged.
- Atoms form ions to gain a stable electron configuration.
- The chemical formula of an ion shows the chemical symbol of the element and the charge on the ion.

10.4 Inside ionic compounds

Objectives

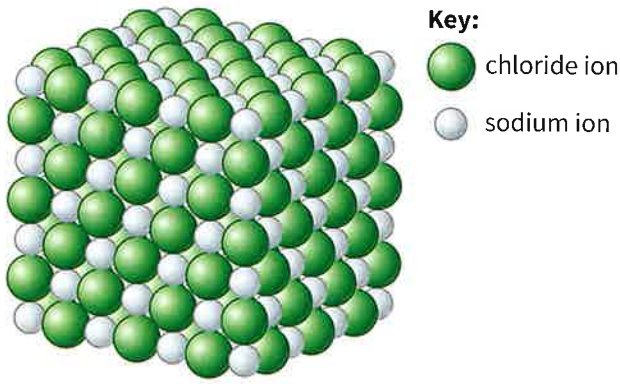
- Define the terms *ionic bonding, ionic compound*, and *giant ionic structure*
- Explain how the giant ionic structure model explains the properties of ionic compounds
- Discuss the strengths and weaknesses of a physical model

The photo shows a large crystal of salt, sodium chloride (NaCl). The crystal is made up of sodium ions and chloride ions. What holds the ions together?

What is ionic bonding?

The salt crystal is made up of millions of sodium ions and millions of chloride ions. Electrostatic attraction between the positive ions and negative ions holds the crystal together. This is **ionic bonding**.

Ionic bonds act in all directions. In the solid state, they hold the positive and negative ions in a three-dimensional pattern. The pattern is called a **giant ionic structure**.



▲ *In sodium chloride, ionic bonds hold the ions together in a giant structure.*

Because it is made up of ions, sodium chloride is an **ionic compound**. Most compounds made up of a metal and a non-metal are ionic.

▲ *Calcium oxide (CaO), nickel chloride ($NiCl_2$), and cobalt chloride ($CoCl_2$) are ionic compounds.*

Ionic bonding and physical properties

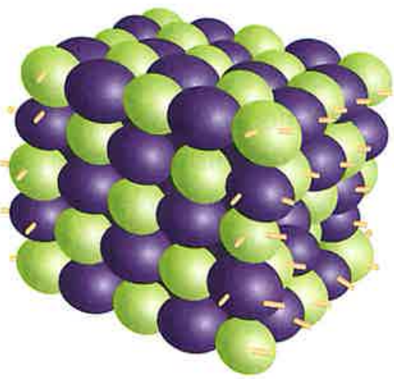
As you know, a model is an idea that explains observations and helps in making predictions. The idea of a giant ionic structure is a model. The model explains the physical properties of ionic compounds:

- Ionic compounds have high melting points. This is because the electrostatic attraction between oppositely charged ions is strong.
- Ionic compounds are brittle. If you drop a crystal of an ionic compound, it breaks between one row of ions and another. The broken pieces have straight edges.

Thinking and working scientifically

Modelling ionic bonding

Barney and Sarah use grapes to make a model of a substance with a giant ionic structure, sodium chloride. The model is a physical model, not just an idea.



▲ *A model of a giant ionic structure*

The model has strengths and limitations. Its main strength is that it shows the positions of the oppositely charged ions. One limitation is that it does not show that the ions vibrate on the spot. It does not show how the electrostatic attraction acts in all directions. It also does not explain why ionic compounds are brittle.

Key points

- An ionic compound is made of positive and negative ions.
- Ionic bonding is the electrostatic attraction between positive and negative ions.
- A giant ionic structure is the three-dimensional pattern of oppositely charged ions.
- Ionic compounds are brittle and have high melting points.

Questions

1. Write definitions for the terms *ionic bonding, ionic compound*, and *giant ionic structure.*
2. Name the type of attraction that holds positive and negative ions together in an ionic compound.
3. Explain these physical properties of an ionic compound:
   a. It has a high melting point.
   b. It is brittle.
4. Describe two strengths and two limitations of the grape model of sodium chloride.

10.5

Objectives

- Define the term *covalent bond*
- Draw dot-and-cross diagrams to show shared electron pairs in simple molecules

Covalent bonding

What comes out of the gills of a fish?

When fish digest food, one of the waste products is ammonia. The ammonia leaves the fish as a gas, through its gills. Ammonia has a bad smell.

Making covalent bonds

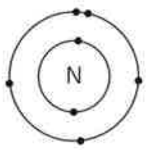
Inside ammonia

Ammonia is a compound. Its formula is NH_3. This shows that it is made up of atoms of two elements, nitrogen and hydrogen. There are three hydrogen atoms for every one nitrogen atom.

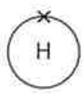
Ammonia exists as molecules. As you know, a molecule is a particle made up of two or more atoms, strongly joined together. In ammonia, each molecule has one nitrogen atom joined to three hydrogen atoms. The atoms are held together by covalent bonds. A **covalent bond** is a shared pair of electrons that joins two atoms together.

Why form covalent bonds?

Here are the electron configurations of nitrogen and hydrogen atoms:



▲ *Nitrogen*

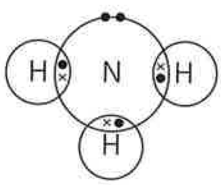


▲ *Hydrogen*

The nitrogen atom has five electrons in its outer shell. On its own, the atom is not stable. It needs three more electrons to fill its outer shell. It will then have a stable electron configuration, with eight outer electrons.

The hydrogen atom has one electron in its outer shell. On its own, the atom is not stable. It needs one more electron to fill its electron shell. The atom will then have a stable electron configuration.

In ammonia, nitrogen and hydrogen atoms achieve full outer shells by sharing electrons. Each shared pair of electrons is one covalent bond.



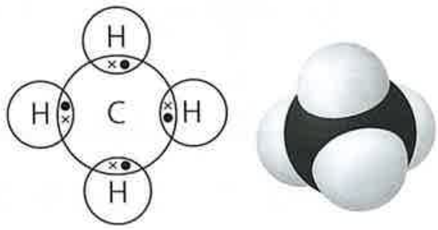
▲ *In this diagram, dots show electrons from the outer shell of the nitrogen atom. Crosses show electrons from hydrogen atoms. Each pair of electrons is a covalent bond. All the electrons are the same.*

▲ *A model of an ammonia molecule. This model shows the atom arrangement. It does not show the shared electron pairs in covalent bonds.*

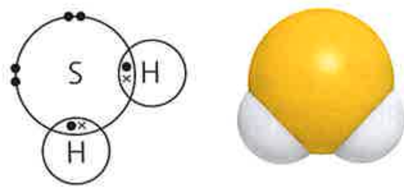
Which substances have covalent bonds?

Compounds of non-metals

Ammonia is a compound of two non-metals. Most other compounds of non-metals exist as molecules. In each molecule, every atom has a share in a full outer shell of electrons. The diagrams below show the outer electron shells only.



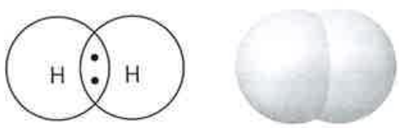
▲ *methane, CH_4*



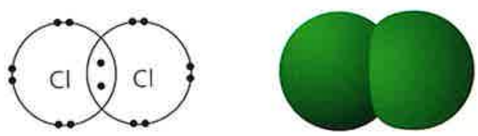
▲ *hydrogen sulfide, H_2S*

Non-metal elements

The non-metal elements helium, neon, argon, krypton, and xenon exist as single atoms. Most other non-metal elements exist as molecules, with the atoms joined by covalent bonds. In each molecule, every atom has a share in a full outer shell of electrons. The diagrams below show the outer electron shells only.



▲ *Hydrogen, H_2. Each atom contributes one electron to the shared pair in the covalent bond.*



▲ *Chlorine, Cl_2. Each atom contributes one electron to the shared pair in the covalent bond.*

Ionic or covalent?

Some substances have ionic bonds and other substances have covalent bonds:

- Ionic bonds form in compounds of a metal with a non-metal.
- Covalent bonds form in compounds of non-metals, and in non-metal elements.

Questions

1. Write the definition for a *covalent bond.*
2. Draw a dot and cross diagram of methane, CH_4. Add labels to the diagram to show how each atom has a share in a full outer shell of electrons.
3. A fluorine atom has 7 electrons in its outer shell. Draw a diagram to show the bonding in a fluorine molecule, F_2. Show the outer shells only.
4. Draw a dot-and-cross diagram to show the bonding in hydrogen chloride, HCl. Show the outer shells only.

Key points

- A covalent bond is a shared pair of electrons that joins two atoms together.

10.6 Covalent structures

Objectives

- Define the term *giant covalent structure*
- Explain the properties of substances with simple molecules and giant covalent structures

Carbon and nitrogen are non-metal elements. A carbon atom has six electrons. A nitrogen atom has seven electrons.

At 20 °C, nitrogen is a colourless gas. At the same temperature, carbon is in the solid state. One type of carbon, diamond, is sparkly and hard. Why are the properties of nitrogen and diamond so different?

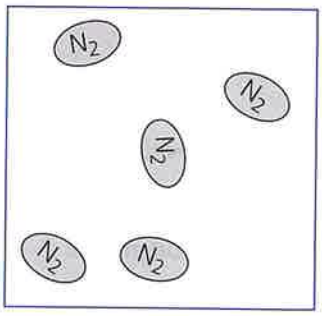
Simple molecule or giant covalent structure?

Nitrogen exists as molecules. But diamond has a giant covalent structure. The different structures explain the different properties.

Simple molecule

Each nitrogen molecule has two atoms. The two atoms are joined by three shared electron pairs. This makes a strong covalent bond.

Nitrogen molecules are attracted to each other only weakly, so little energy is needed to disrupt the pattern of molecules when solid nitrogen melts. This gives nitrogen its low melting point. Other substances that exist as simple molecules – such as oxygen and methane – also have low melting points.

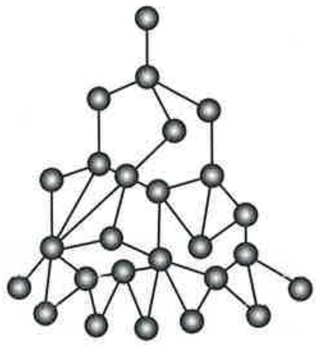


◀ *Inside each nitrogen molecule, there is a strong covalent bond. The simple molecules are attracted to each other only weakly.*

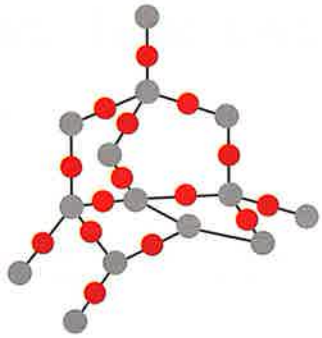
Giant structure

As you know, diamond is a type of carbon. Each carbon atom makes strong covalent bonds with four other carbon atoms. The pattern is repeated many, many times to make a giant covalent structure. A **giant covalent structure** is a three-dimensional network of atoms that are joined together by strong covalent bonds.

The structure and bonding of diamond explain its hardness and its high melting point, of 3550 °C; large amounts of energy are needed to break its covalent bonds when it melts. Other substances that exist as giant covalent structures, such as silicon dioxide, have similar properties.



▲ *Part of the structure of diamond. The pattern is repeated many times. Each sphere shows a carbon atom and each line shows a covalent bond. In diamond itself, the atoms touch each other.*



▲ *A small part of the structure of silicon dioxide. In silicon dioxide itself, the atoms touch each other.*

▲ *A crystal of quartz, which is a type of silicon dioxide.*

Thinking and working scientifically

Making conclusions from data

Substances with simple molecules have low boiling points. Substances with giant molecular structures have high boiling points.

Grace wants to know the melting points of four covalently bonded substances. She cannot measure the melting points herself as she does not have the substances or suitable apparatus. Instead, she finds the data in a reliable secondary source – a data book.

Substance	Melting point (°C)
carbon monoxide	−205
diamond	3550
silicon dioxide	1710
sulfur dioxide	−72

Grace writes a conclusion from the data:

The substances with low melting points are sulfur dioxide and carbon monoxide. They have simple molecules. The substances with high melting points are diamond and silicon dioxide. They have giant covalent structures.

Questions

1. Write the definition for *giant covalent structure*.
2. **a.** Name the type of bond that is in substances with simple molecules and giant covalent structures.

   b. Explain why atoms form this type of bond.
3. Explain why a substance with simple molecules has a lower melting point than a substance with a giant covalent structure.

Key points

- A giant covalent structure is a three-dimensional network of atoms that are joined together by covalent bonds.
- Substances with simple molecules have low melting points.
- Substances with giant covalent structures have high melting points.

10.7 More about structures

Objectives

- Describe giant metallic structures
- Summarise different types of structure
- Link the structure of an element to its position in the periodic table

The Burj Khalifa, Dubai (pictured below left), is the tallest building in the world. The tower is made of steel bars, embedded in concrete. Why was steel chosen?

▲ *Burj Khalifa*

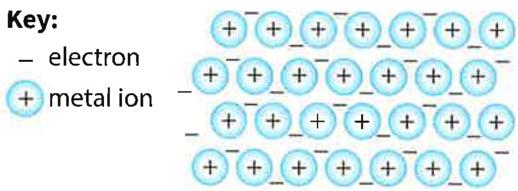
Giant metallic structures

As you know, steel is an alloy. It is mainly iron, with small amounts of other elements. Metal elements and alloys are strong because of their structure.

Chapter 3 shows metal atoms arranged in layers. In fact, the atoms have lost their outer electrons to achieve a stable electron configuration. This means that a metal structure is made up of two types of particle:

- positively charged ions
- negatively charged electrons.

The ions are in fixed positions. The electrons move around, between the ions. Electrostatic attraction between the positive ions and negative electrons holds the metal together. This is a **giant metallic structure**.



◀ *A giant metallic structure has positive metal ions held together by electrons moving around between the ions.*

Metallic bonding and physical properties

The strong electrostatic attraction between fixed positive ions and moving negative electrons gives metals these properties:

- high strength
- high melting points.

The moving electrons allow metals to conduct electricity.

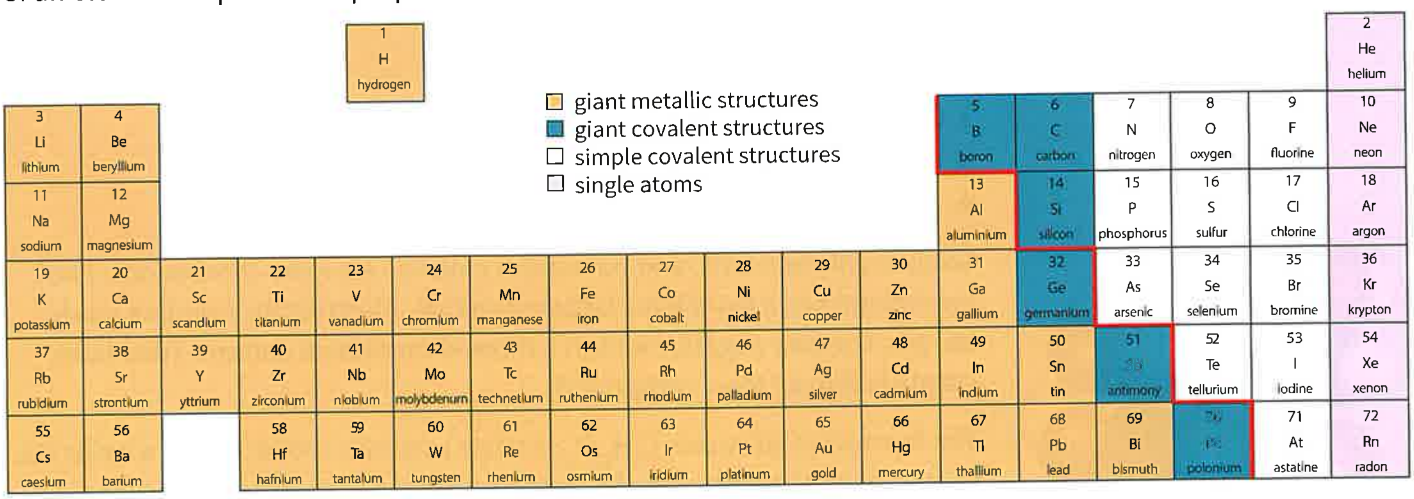
Summarising structures

The table summarises the four types of structure you have learnt about.

Name of structure	Giant or simple?	Particles in structure	Elements or compounds?	Typical state at 20 °C	Examples
ionic	giant	positive ions and negative ions	compounds	solid	sodium chloride
metallic	giant	positive ions and negative electrons	elements	solid	gold
giant covalent	giant	atoms (joined with covalent bonds)	elements and compounds	solid	carbon (diamond), silicon dioxide
simple covalent	simple	atoms (joined with covalent bonds)	elements and compounds	liquid or gas	hydrogen, carbon dioxide

Structure and the periodic table

The periodic table below shows the type of structure of each element at 20 °C. As you can see, the metal elements have giant metallic structures. Most non-metal elements exist as molecules. A few non-metal elements have giant covalent structures. You can use knowledge about the structure of an element to predict its properties.



Note: this periodic table does not show all the elements

Questions

1. Name the two types of particle in a giant metallic structure, and the force that holds these particles together.
2. Explain why most metals have high melting points.
3. Compare giant ionic and giant metallic structures. In your answer, write down how the structures are similar and different.
4. Suggest why there is no substance with a giant ionic structure shown on the periodic table.

Key points

- A giant metallic structure is the three-dimensional pattern of positive metal ions held together by moving electrons.
- The structure of an element is linked to its position in the periodic table.

Science in context

10.8 Life-saving compounds

Objectives

- Define the term *systematic review*
- Describe an application of science

Mixed with water, the contents of packets like this save lives. How?

Diarrhoea deaths

Diarrhoea takes water out of the body. It removes vital ions, including sodium, potassium, and chloride ions. If the water and ions are not replaced, diarrhoea may cause dehydration. Badly dehydrated people may die.

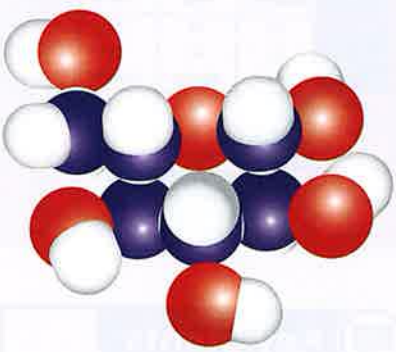
What's in the sachet?

The sachet contains oral rehydration salts (ORS). There is a mixture of these substances:

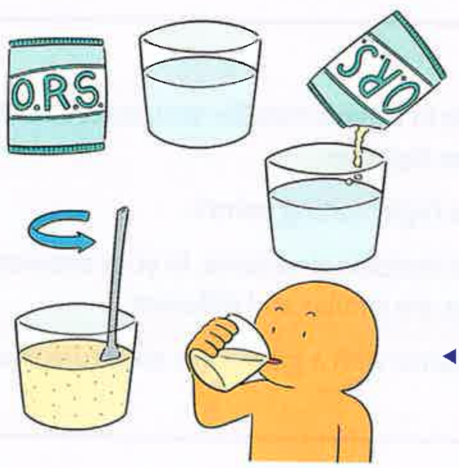
- sodium chloride
- potassium chloride
- trisodium citrate
- glucose.

Sodium chloride (salt) and potassium chloride are ionic compounds. Each tiny crystal has a giant ionic lattice structure. Electrostatic bonding holds the positive and negative ions in a three-dimensional pattern. Trisodium citrate is also an ionic compound.

The formula of glucose is $C_6H_{12}O_6$. It exists as simple molecules. In a molecule, shared pairs of electrons make up the covalent bonds that hold the atoms together. The atoms in a glucose molecule are arranged as shown on the left.



▲ *A model of a glucose molecule. It has 6 carbon atoms (shown black), 6 oxygen atoms (red) and 12 hydrogen atoms (white). Three of the hydrogen atoms are difficult to see in this model.*



◀ *Using oral rehydration solution (ORS). The solution is orange because orange flavouring and colouring have been added.*

Saving lives

When you add ORS mixture to water, it dissolves. The solution contains sodium, potassium, chloride, and citrate ions. It also contains dissolved glucose.

Drinking the solution replaces lost water and ions. Glucose helps the body to absorb sodium ions and water. Glucose also provides energy.

Thinking and working scientifically

Investigating oral rehydration solution

In 2010, three scientists at Johns Hopkins University, USA, asked this scientific question:

How many deaths does oral rehydration solution (ORS) prevent in children under 5?

The three scientists decided to use secondary data, from many other scientists, to work out the answer to their question. This is a **systematic review**.

The scientists read 404 scientific papers about the effectiveness of ORS. They did not use all of the papers, for these reasons:

- Some did not investigate ORS in young children.
- Some did not describe their methods in enough detail.
- Some did not report enough data.

The scientists ended up with 157 suitable research papers. They compared the data. They analysed it carefully. They made this conclusion:

For every 100 people who die of diarrhoea and do not take ORS, only 7 would die if they had taken ORS.

▲ *Christa Fischer Walker, one of the scientists who carried out the systematic review.*

The scientists point out that ORS is a simple method for saving lives. However, it is not available to everyone who needs it. The scientists recommend finding better ways of distributing the treatment and getting people to use it.

Key points

- Oral rehydration solution (ORS) saves lives by replacing ions and water lost in diarrhoea.
- A systematic review uses repeatable methods to collect and analyse secondary data from many scientists.

Questions

1. Write the definition for *systematic review*.
2. Name three ionic substances in ORS.
3. Explain how ORS prevents deaths from diarrhoea.

Review 10.9

1. Copy and complete the sentences below. Choose words and phrases from the list.

negative
neutron
positive
electron configuration
proton number

a. The sub-atomic particle with no charge is a __________ **[1]**

b. The arrangement of electrons in an atom is its __________ **[1]**

c. The number of protons in an atom of an element is its __________ **[1]**

d. An ion formed when an atom loses an electron has a __________ charge. **[1]**

e. An ion formed when an atom gains an electron has a __________ charge. **[1]**

2. The table shows the numbers of protons, neutrons, and electrons in the atoms of some elements.

Atom of...	Number of protons	Number of neutrons	Number of electrons
fluorine	9	10	9
sodium	11	12	11
chlorine	17	18	17

a. Give the proton number of fluorine. **[1]**

b. Draw and label a diagram of a fluorine atom nucleus. **[2]**

c. Draw the electron configuration of each atom shown in the table. **[3]**

d. Use your answer to part **c** to deduce the two elements that are in the same group of the periodic table. Give a reason for your decision. **[2]**

3. Copy and complete the table below. Use the periodic table to help you. **[12]**

Element	Chemical symbol	Proton number	Number of electrons in outer shell
boron		5	
	C		
lithium			1
magnesium			2
	Na		

4. Use the periodic table to help you to answer this question.

a. Give the proton number of aluminium, Al. **[1]**

b. Draw the electron configuration of aluminium. **[2]**

c. Give the name of one other element that has the same number of electrons in its outer shell as aluminium. **[1]**

TWS

5. Write the chemical formula for each ion below. Use the periodic table to find the chemical symbols of the elements.

a. A lithium ion, with a charge of +1. **[1]**

b. A calcium ion, with a charge of +2. **[1]**

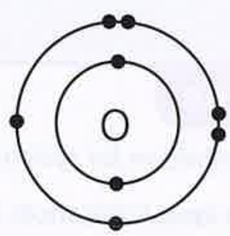
c. An iron ion, with a charge of +3. **[1]**

d. A chloride ion, with a charge of −1. **[1]**

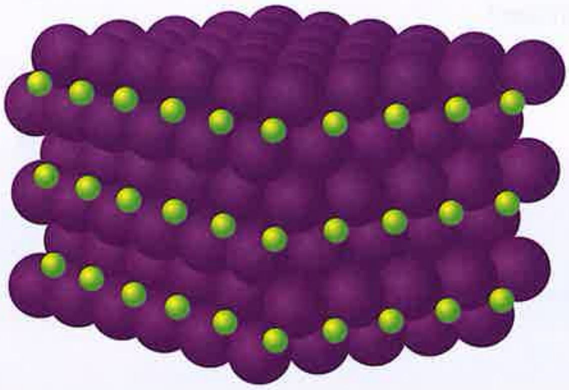
e. A nitride ion, with a charge of −3. **[1]**

TWS

6. The electron configuration of an oxygen atom is shown below. Predict the charge on an oxide ion, and explain your prediction. **[2]**



7. The picture shows the ions in magnesium iodide. The purple spheres model iodide ions. The green spheres model magnesium ions.



a. Name the type of attraction between the ions in magnesium iodide. [1]

b. Explain why magnesium iodide has a high melting point. [1]

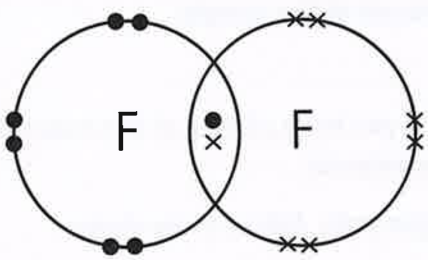
c. A magnesium ion has a charge of +2. Write its formula. [1]

d. An iodide ion has a charge of −1. Write its formula. [1]

e. Magnesium iodide has two iodide ions to every one magnesium ion. Write the chemical formula of magnesium iodide. [2]

f. Explain why magnesium iodide is brittle. [1]

8. The diagram shows the bonding in a fluorine molecule.



a. Deduce the formula of a fluorine molecule. [1]

b. Name the type of bond between the two atoms in a fluorine molecule. [1]

c. Explain why fluorine has low melting and boiling points. [1]

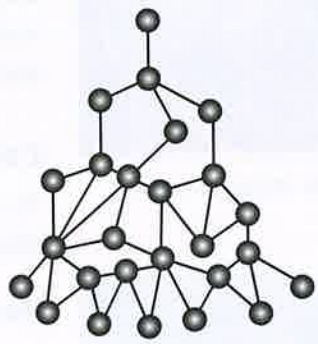
9. The picture shows a model of a hydrogen sulfide molecule. The yellow sphere represents a sulfur atom.

a. Deduce the formula of hydrogen sulfide. [1]

b. The atoms in a hydrogen sulfide molecule are joined by covalent bonds. Predict the state of hydrogen sulfide at room temperature. [1]

c. A sulfur atom has 6 electrons in its outer shell. A hydrogen atom has 1 electron. Draw a dot-and-cross diagram for a hydrogen sulfide molecule.

10. The diagram shows part of a diamond. Each line represents a covalent bond. Each sphere is a carbon atom. In diamond itself, the atoms touch each other.

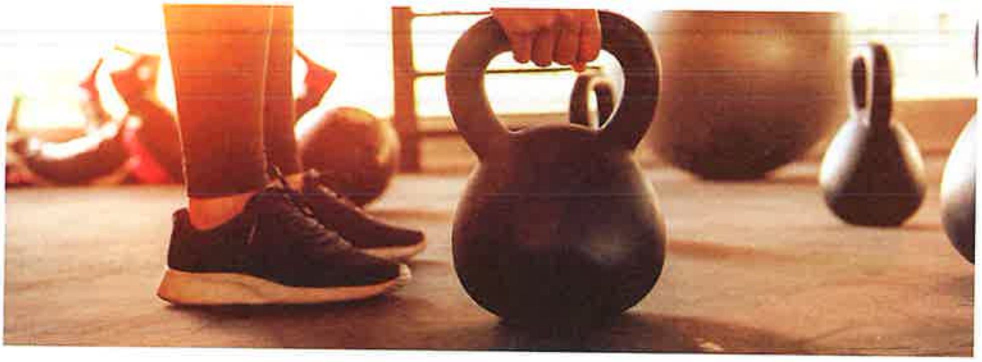


a. Name the type of structure shown in the diagram. [1]

b. Explain why diamond has high melting and boiling points. [1]

11.1 Calculating density

Su is a weightlifter. Her weight is made from iron. Why not make weights from another metal, aluminium?



Objectives

- Define the term *density*
- Calculate the density of materials in the solid, liquid, and gas states

What is density?

Su's iron weights are heavy. Their mass is 20 kg. Aluminium weights of the same size are less heavy. Their mass is only 7 kg. The iron weights have a greater mass because iron has a greater density than aluminium.

The **density** of a material is its mass in a certain volume. As you know:

- Mass is the amount of matter (stuff) in an object. It is measured in grams (g) or kilograms (kg).
- Volume is the amount of space an object takes up. It is measured in cubic centimetres (cm^3), cubic metres (m^3), or litres (*l*).

▲ *Cubes of different metals have different densities.*

Each cube in the picture (above left) is made from a different metal. The volume of each cube is the same. But each metal has a different density, so each cube has a different mass.

Calculating density

To calculate the density of a material, you need a sample of the material. Start by finding the mass and volume of the sample.

▲ *Finding the mass of a solid block.*

Measuring mass

Use a balance to measure mass. If you have a block of the material, you may be able to place it directly on the balance.

If the material is in the liquid or gas state, follow these steps:

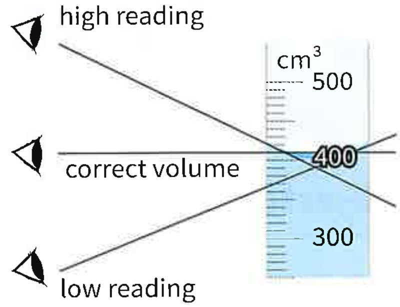
1. Find the mass of the container.
2. Add the material.
3. Find the mass of the container + material
4. Do this calculation:
   mass of material = (mass of container + material) − (mass of container)

▲ *Finding the mass of a liquid.*

Measuring volume

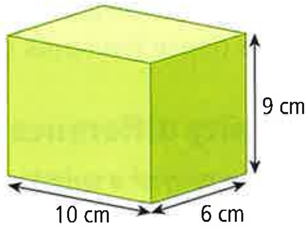
If the material is in the liquid state, find its volume with a measuring cylinder. To find the volume accurately:

- Measure the reading at the *bottom* of curved surface of the water.
- Look straight at the scale from the side, not from above or below.



▲ *Reading volume.*

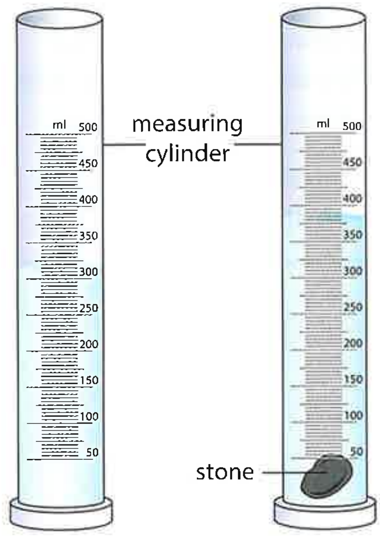
If you have a block of the material, find its volume like this:



Volume = width × length × height
= 6 cm × 10 cm × 9 cm
= 540 cm³

If you have a sample of a solid material that does not have a regular shape, like a stone, find its volume like this:

- Partly fill a measuring cylinder with water to a known volume.
- Add the stone.
- Measure the new volume.
- Calculate the volume increase. This is the volume of the stone.



Calculating density

To calculate density, use this equation:

$$density = \frac{mass}{volume}$$

Example 1

A block of wood has a mass of 270 g and a volume of 540 cm³. Calculate its density.

$density = \frac{mass}{volume}$ $density = \frac{270\,g}{540\,cm^3}$

$density = 0.5\,g/cm^3$

Example 2

A room has a volume of 30 m³. The mass of air in the room is 36 kg. Calculate the density of the air.

$density = \frac{mass}{volume}$ $density = \frac{36\,kg}{30\,m^3}$

$density = 1.2\,kg/m^3$

The next pages explain why different materials have different densities. They also show how ideas about density are useful.

Questions

1. Write the definition for *density*.
2. A silver ring has a mass of 20 g and a volume of 2 cm³. Calculate the density of silver.
3. 20 cm³ of cooking oil has a mass of 18 g. Calculate the density of the cooking oil.
4. A block of iron has sides of these lengths: 2 cm, 3 cm, and 4 cm. The mass of the block is 192 g. Calculate the density of iron.

Key points

- The density of a material is its mass in a certain volume.
- Calculate density using the formula $density = \frac{mass}{volume}$

11.2 Explaining density

Objectives

- Explain why different substances have different densities
- Explain why a substance has different densities in its three states
- Use an analogy to explain density

The glass contains cooking oil, milk, and honey. Why are the layers separate?

The layers are separate because the oil, milk, and honey have different densities. Honey, at the bottom, has the greatest density. Oil, at the top, is less dense than milk and honey.

Density differences

The density of a substance depends on two factors:

- the mass of its particles
- how closely packed its particles are.

Particle mass

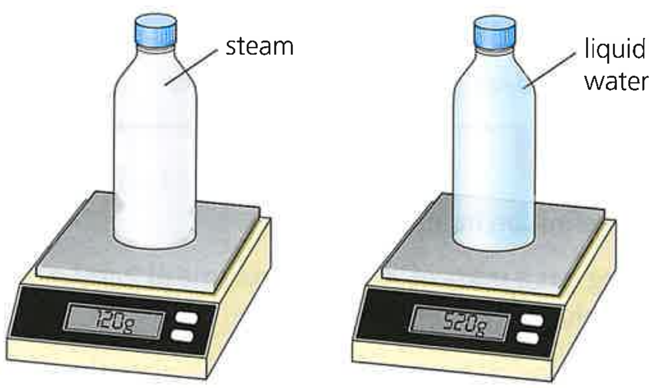
In the solid state, substances with the heaviest particles have the greatest densities. The table shows the densities of three metal elements. All the values are given to 2 significant figures.

Metal	Relative mass of atoms	Density (g/cm^3)
magnesium	24	1.8
aluminium	27	2.7
gold	197	19

Particle packing

The particles of a substance in the liquid state are more closely packed than the particles in the gas state. The substance has a greater density in the liquid state than in the gas state.

For most substances, the density of a substance in the solid state is a little greater than its density in the liquid state. This is because its particles are a little more closely packed in the solid state.



▲ *500 cm^3 of steam has a smaller mass than 500 cm^3 of liquid water. This is because the particles are further apart in steam.*

Thinking and working scientifically

Modelling density

You can use dried peas to explain why a substance has different densities in its three states. The peas are an analogy for the particle model. As you know, an analogy is a comparison between one thing and another that helps to explain something.

- In the photo, the peas touch each other. They are not in a pattern. If you move the jar gently, the peas move around randomly, sliding over each other. This is an analogy for the liquid state.
- If you shake the jar hard, the peas move far apart. This is an analogy for the gas state.

A volume of 100 cm^3 in the gas model has fewer particles than the same volume in the liquid model. This gives 100 cm^3 of the gas model less mass than 100 cm^3 of the liquid model. The substance has a lower density in the gas state.

The main strength of this analogy is that it helps to explain density. One limitation is that, in the model, you need to move the jar to move the particles. In reality, the particles move themselves.

▲ *Peas in a jar*

Questions

1. Give two factors that affect density.
2. Use the table opposite to state the densities of aluminium and gold, including units. Explain the difference in density.
3. Explain why a substance has a greater density in the liquid state than in the gas state.
4. The mass of a chromium atom is 52. The mass of a tungsten atom is 184. Predict which of the two metals has the higher density. Explain your prediction.
5. TWS Jodie has some chocolates. Suggest how she could use the chocolates as a model to explain why a substance has a greater density in the solid state than in the gas state.

TWS

Key points

- The greater the mass of the particles of a substance, the greater its density.
- Density depends on state. The density of most substances is greatest in the solid state, and least in the gas state.
- Models and analogies have strengths and limitations.

Science in context

11.3

Objective

- Describe how scientists build on others' work to develop science knowledge over time

Using density

For thousands of years, people have appreciated jewellery. They made necklaces and rings from gold and silver. They decorated the necklaces with gemstones, such as red rubies and green emeralds.

The work of al-Biruni

More than 1000 years ago, Abu Rayhan al-Biruni was born in what is now Uzbekistan. He became a great scientist and mathematician. He wrote books on many topics, including astronomy, geology, and medicines. Al-Biruni also built on the work of earlier scientists to design new instruments to make accurate measurements.

Today, most scientists specialise in one area of research. They often work in teams. They write about their findings in scientific papers, which are published in journals. All over the world, scientists read the journals. They may do new research of their own, building on what they have read.

▲ *Al-Biruni lived more than 1000 years ago.*

Finding density

Quartz and diamond look similar. It is not easy see which is which. Quartz is common and cheap, so a cheating trader could make a lot of money by pretending that a lump of quartz was diamond.

A thousand years ago, Al-Biruni asked himself a question:

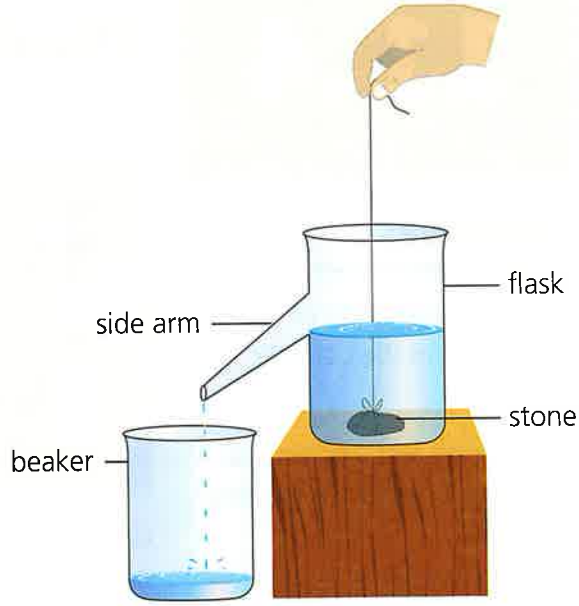
How can I identify gemstones reliably?

Al-Biruni wondered if he could use density to identify gemstones. He knew how to measure mass. But gemstones do not have regular shapes. How could he measure their volume?

Al-Biruni designed a piece of apparatus to measure volume accurately. It was a flask with a side arm, a bit like the picture above right.

▲ *Quartz (top) and rough diamonds look similar.*

Al-Biruni filled the flask until water overflowed through the side arm, into the beaker. He emptied the beaker. He put it under the side arm again. Then he lowered the gemstone into the flask. Water flowed into the beaker. He measured the volume of the water, which was equal to the volume of the gemstone.



▲ *Al-Biruni's apparatus*

Al-Biruni used this equation to calculate gemstone densities:

$$density = \frac{mass}{volume}$$

The table shows some of al-Biruni's density values.

Material	Density calculated by al-Biruni (g/cm^3)	Modern value for density (g/cm^3)
quartz	2.58	2.58
ruby	4.01	4.40
pearl	2.70	2.70

Precision

Al-Biruni made measurements with great precision. It was another 700 years before scientists in Europe could measure density with the same level of precision.

Other properties

Al-Biruni did not only measure density. He built on the work of earlier scientists and worked out how to use other properties to classify gemstones, including hardness, colour, crystal shape, and whether the gemstone splits white light into a rainbow.

Gemstones and modern science

Scientists and jewellers still use a method like al-Biruni's to find gemstone density. They also use other techniques to identify gemstones. They measure how well a gemstone conducts electricity, or how much it changes the direction of light.

Questions

1. Name the gemstone in the table above with the highest density.
2. A gemstone has a mass of 2.00 g and a volume of 0.78 cm^3.
   a. Calculate the density of the gemstone.
   b. Use your result, and data from the table above, to suggest the identity of the gemstone.
3. Describe one way in which modern scientists work in ways that are similar to al-Biruni.
4. Describe one way in which modern scientists work differently to al-Biruni.

Key points

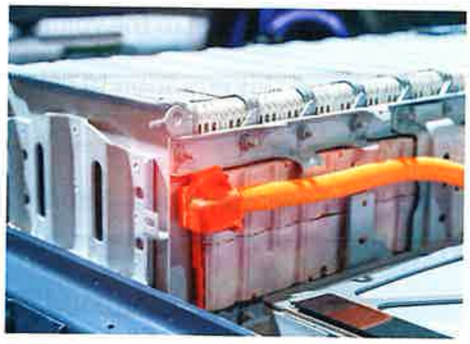
- Scientists build on others' work to develop science knowledge over time.

11.4 The periodic table: Group 1

Objectives

- Give the position of Group 1 in the periodic table
- Describe and explain the Group 1 pattern in melting points
- Present data, describe trends, and make conclusions

An electric car needs a big battery pack. What metal is in the battery?



Car batteries rely on lithium. Lithium is a metal element. It is in the column on the left of the periodic table. This column is called **Group 1**. The other Group 1 elements are sodium, potassium, rubidium, caesium, and francium.

Group1

							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg							

▶ *Group 1 is on the left of the periodic table.*

▲ *As more people buy electric cars, more lithium will be needed. Bolivia has huge reserves of lithium in salt flats like these.*

▼ *Group 1 metals are soft.*

How are Group 1 elements like other metal elements?

The elements of Group 1 are metals. Like other metals, the Group 1 elements:

- conduct electricity
- are shiny when freshly cut.

The Group 1 elements are softer than most other elements. It is easy to cut them with a knife.

Thinking and working scientifically

Melting point pattern

Banjeet asks a scientific question:

What is the pattern in melting points for the Group 1 elements?

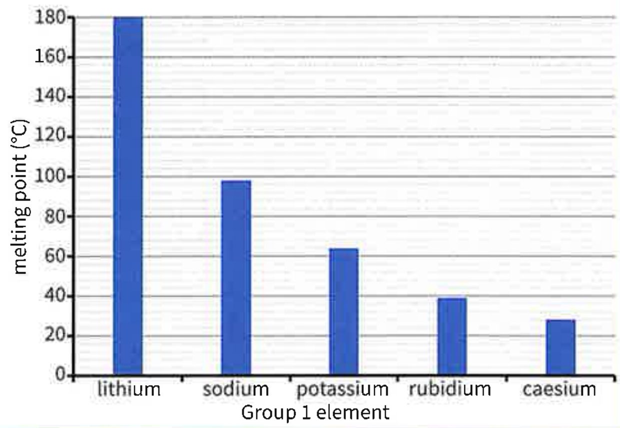
He cannot measure the melting points himself, so he chooses a trustworthy secondary source. He finds the data. He records the data in a table. The independent variable is in the left column.

Element	Melting point (°C)
lithium	180
sodium	98
potassium	64
rubidium	39
caesium	28

Banjeet plots the data on a bar chart. He chooses a bar chart because the independent variable (the element) is categoric. As you know, a categoric variable is one that is described by words.

Banjeet writes a conclusion:

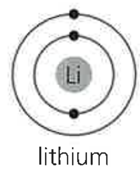
From lithium, at the top of Group 1, to caesium, at the bottom of Group 1, melting point decreases.



▶ *Bar chart showing the melting points of the Group 1 elements.*

Explaining the melting point pattern

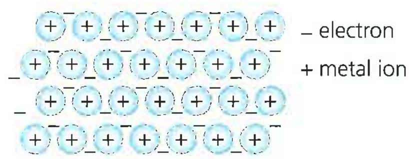
The Group 1 elements have electron configurations like lithium, shown right. From top to bottom of the group, the outer electron gets further from the nucleus.



▲ *The electron configuration of lithium*

The Group 1 elements have giant metallic structures. The ions form when each atom loses its one outer electron. The electrons move around, between the ions.

From top to bottom of the group, the positive ions get bigger. This means that electrostatic attractions between positive ions and negative electrons get weaker. As attractions get weaker, ions leave their fixed positions more easily, so melting point decreases.



▲ *The giant metallic structure of a Group 1 element.*

Questions

1. Give the names and chemical symbols of the elements in Group 1.
2. Describe the pattern in melting points of the Group 1 elements.
3. Explain the pattern in melting points of the Group 1 elements.
4. TWS The table shows the boiling points of the Group 1 elements.

Element	Boiling point (°C)
lithium	1330
sodium	890
potassium	774
rubidium	688

a. Plot the data on a bar chart.

b. TWS Describe the pattern in boiling points.

Key points

- Group 1 is the left column of the periodic table.
- Melting point decreases from top to bottom of Group 1 because electrostatic attractions in the metallic structure decrease.

11.5 More about Group 1

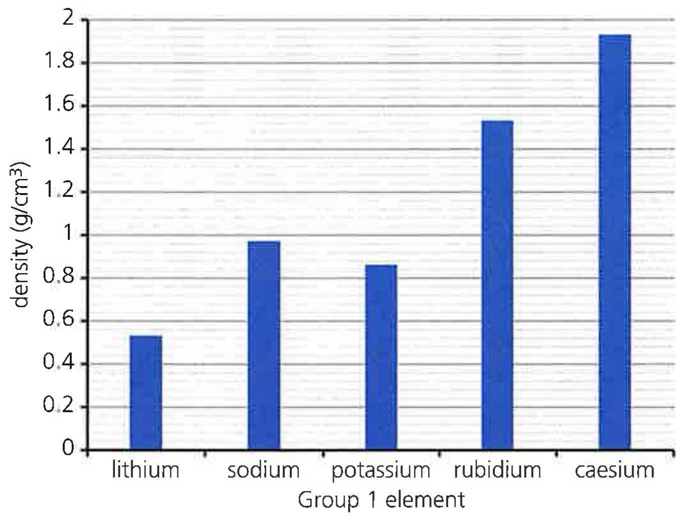
Objectives

- Describe the Group 1 pattern in density
- Describe and explain the pattern in the reactions of the Group 1 elements with water

This is an atomic clock. It is accurate to 1 second in 2 million years. The clock relies on the movement of electrons in caesium atoms. In the periodic table, caesium is near the bottom of Group 1.

Patterns in physical properties

As you know, physical properties are properties that you can observe or measure without changing a material. You have seen that the Group 1 elements have patterns in melting point and boiling point. There is also a pattern in another physical property – density.



▲ *Bar chart showing the densities of the Group 1 elements.*

Density

The table and bar chart show the densities of the Group 1 elements.

Element	Density (g/cm^3)
lithium	0.53
sodium	0.97
potassium	0.86
rubidium	1.53
caesium	1.93

The data show that, overall, density increases from top to bottom of Group 1. The density of potassium does not fit the pattern.

Patterns in chemical properties

Reactions with water

As you know, the chemical properties of a substance describe its chemical reactions. All the Group 1 elements react with water. There is a pattern.

As you saw in Unit 9.7, sodium reacts vigorously with water. The products are sodium hydroxide solution and hydrogen gas.

sodium + water ⟶ sodium hydroxide + hydrogen

The other Group 1 elements also react with water to make a solution of a hydroxide and hydrogen. For example:

lithium + water ⟶ lithium hydroxide + hydrogen

potassium + water ⟶ potassium hydroxide + hydrogen

The reactions get more vigorous from top to bottom of the group.

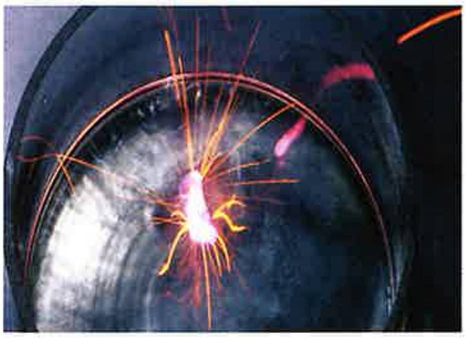
Explaining the pattern

When a Group 1 element reacts with water, each atom gives its outer electron to an atom of another element. From top to bottom of Group 1, the outer electron gets further from the nucleus. The electrostatic attraction between the nucleus and outer electron gets less, so the outer electron is easier to give away. This makes the reactions more and more vigorous from top to bottom.

Patterns in other groups of the periodic table

Every vertical column in the periodic table is a group. In every group, there is a pattern in physical and chemical properties. The patterns are different for different groups.

▲ *Lithium, at the top of Group 1, reacts quite vigorously with water.*



▲ *Potassium, lower in Group 1, reacts very vigorously with water.*

Questions

1. Describe the pattern in density from top to bottom of Group 1.
2. Predict the products of the reaction of rubidium with water.
3. Explain why the reactions of the Group 1 elements with water get more vigorous from top to bottom of the group.
4. TWS The table shows the relative electrical conductivities of some of the Group 1 elements – the higher the value, the better the element conducts electricity.

Element	Relative electrical conductivity
lithium	11
sodium	21
potassium	14
rubidium	8
caesium	5

a. Plot the data on a bar chart.

TWS b. Describe the pattern in electrical conductivity.

Key points

- Overall, density increases from top to bottom of Group 1.
- All the Group 1 elements react with water to make a solution of a hydroxide and hydrogen gas. The reactions get more vigorous from top to bottom of the group.

Extension

11.6

Objectives

- Describe patterns in the physical and chemical properties of the Group 2 elements
- Describe an investigation on the reactions of the Group 2 elements

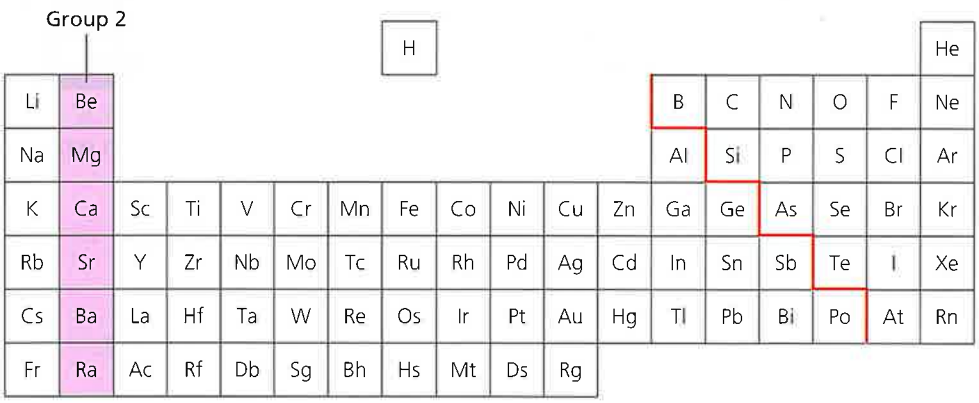
The periodic table: Group 2

Scientists hope that the James Webb Space Telescope will show us the formation of the first galaxies. Its 18 mirror segments create a mirror of 6.5 m diameter – the biggest ever launched into space.

The mirror segments are made of beryllium, coated with gold. The scientists chose beryllium because it is strong for its weight. It holds its shape well over a range of temperatures.

Group 2 in the periodic table

Beryllium is an element in **Group 2** of the periodic table.



▸ *Group 2 is the second column in the periodic table.*

Physical properties

Like all groups of the periodic table, the Group 2 elements have patterns in their physical properties. The table (left) shows the melting points of the Group 2 elements.

- the independent variable is the element
- the dependent variable is the melting point (°C)

Group 2 element	melting point (°C)
beryllium	1287
magnesium	650
calcium	842
strontium	777
barium	727
radium	700

▲ *Melting points in Group 2.*

These data show that, in general, melting point decreases from top to bottom of Group 2. The melting point of magnesium does not fit the pattern.

Chemical properties

As you saw in Unit 10.2, atoms of all Group 2 elements have two electrons in the outer shell. Their similar electron configurations give them similar chemical properties. For example, all Group 2 elements react with dilute hydrochloric acid. The products are a solution of a chloride and hydrogen gas. For example:

strontium + hydrochloric acid ⟶ strontium chloride + hydrogen

Thinking and working scientifically

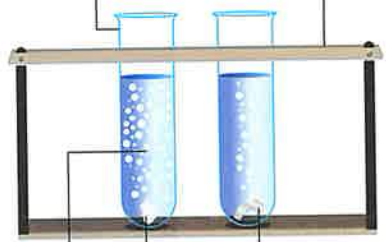
The Group 2 elements and hydrochloric acid

Catherine asks a scientific question:

What is the pattern in reactivity of the Group 2 elements with hydrochloric acid?

She makes a hypothesis. As you know, a hypothesis is a possible explanation that is based on evidence, and can be tested further.

My hypothesis – From top to bottom of the group, the outer electrons get further from the nucleus, and so easier to give away. This means that the reactions will get more vigorous from top to bottom of the group.



Catherine sets up the apparatus opposite. She makes a prediction:

My prediction – Calcium is below magnesium in Group 2. I predict that the reaction with calcium will be more vigorous.

Catherine collects the gas in the bubbles. She tests the gas with a lighted splint. The splint goes out with a squeaky pop. The gas is hydrogen.

Catherine observes that the calcium reacts more vigorously than magnesium. She makes a conclusion:

My conclusion – The reaction of calcium is more vigorous than the reaction of magnesium. So, for the elements I tested, the reactions get more vigorous going down the group. This is because the outer electrons get further from the nucleus and are easier to give away.

Catherine describes the limitations of her investigation and suggests an improvement.

Limitations – I only tested two Group 2 elements. I could be more certain of my conclusion if I reacted more Group 2 elements with hydrochloric acid.

Key points

- There are patterns in the physical and chemical properties of the Group 2 elements.
- All Group 2 elements react with hydrochloric acid. The products are a solution of a chloride and hydrogen gas. The reactions get more vigorous from top to bottom.

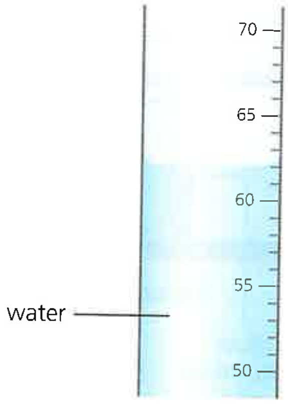
Questions

1. Describe the trend in melting point for the Group 2 elements.
2. Predict the products of the reaction of barium and dilute hydrochloric acid.
3. Write a word equation for the reaction of calcium with dilute hydrochloric acid.
4. Explain why the reactions of the Group 2 elements with hydrochloric acid get more vigorous from top to bottom of the group.

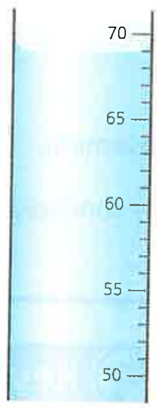
Review 11.7

1. Pawel has a stone. He wants to find its density.

   a. He pours water into a measuring cylinder until it is half full. The diagram shows the surface of the water. Write down the water volume, in cm^3. **[1]**



   b. Pawel places the stone in the water. The water surface of the water moves up. The diagram shows the new surface of the water.



   Use the diagram and your answer to part **a** to work out the volume of the stone. **[2]**

   c. The mass of the stone is 24 g. Use the equation below to calculate the density of the stone. Include units in your answer.

$$density = \frac{mass}{volume}$$ **[2]**

2. The electronic structure of lithium can be written in the form 2.1. This shows that there are two electrons in the first electron shell, nearest the nucleus, and one electron in the outer electron shell, furthest from the nucleus.

   a. Write the electronic structures for sodium and potassium in the same format. **[2]**

   b. Describe one way in which the electronic structures of lithium, sodium, and potassium are similar to each other. **[1]**

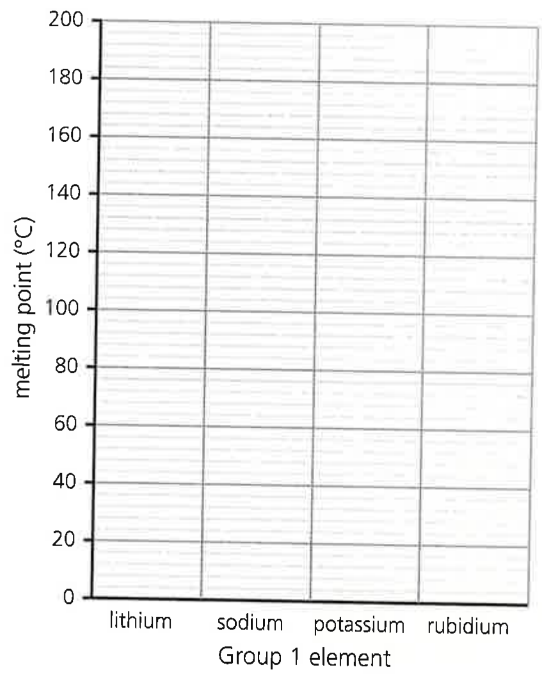
   c. Describe the link between the atomic structure of an element, and the periodic table group the element is in. **[1]**

3. The table gives the melting points of four elements in Group 1 of the periodic table.

Element	Melting point (°C)
lithium	180
sodium	98
potassium	64
rubidium	39

   a. Draw a bar chart to show the melting points of the Group 1 elements. **[2]**

   Label the axes as shown below.



   b. Describe the trend in the melting points of Group 1 elements. **[1]**

4. Katya watches as her teacher adds a small piece of sodium to water. She makes these observations.

   The sodium moves around on the surface of the water. Bubbles are formed.

After the reaction finished, the teacher added universal indicator to the solution. The indicator went purple.

a. Name the gas in the bubbles. **[1]**

b. Explain why the indicator went purple. **[1]**

c. Write a word equation for the reaction of sodium with water. **[2]**

d. Potassium also reacts with water.

i. Describe one way in which this reaction is similar to the reaction of sodium with water. **[1]**

ii. Describe one way in which the reaction of potassium with water is different from the reaction of sodium with water. **[1]**

e. Describe the trend (pattern) in the reactions of the first three Group 1 elements (lithium, sodium, and potassium) with water. **[1]**

TWS

5. The table gives the relative sizes of the atoms of the Group 1 elements.

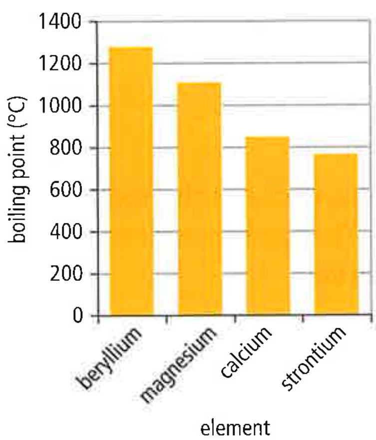
Element	Relative size of atom
lithium	16
sodium	19
potassium	24

a. Describe the trend shown in the table. **[1]**

b. Use ideas about the electronic structures of the elements to suggest a reason for the trend you described in part **a**. **[1]**

TWS

6. The bar chart shows the melting points of four Group 2 elements. Beryllium is at the top of the group, followed by magnesium, calcium, and strontium.



a. Describe the trend shown by the bar chart. **[2]**

b. Barium is below strontium in the periodic table. Use the bar chart to predict the melting point of barium. **[1]**

TWS

7. Paulo investigates how vigorously the Group 2 elements react with water. He wants to find out if there is a trend in these reactions.

a. Name the independent variable (the variable he changes) and the dependent variable (the variable he observes). **[1]**

b. Identify one variable Paulo should keep constant. **[1]**

c. Paulo decides to collect evidence from first-hand experience for the reactions of magnesium and calcium with water. He collects evidence from secondary sources for the reaction of strontium with water. Suggest why he decides not to add strontium to water himself. **[1]**

TWS

8. The Group 7 elements are non-metals.

a. From the list below, choose two properties of the Group 7 elements.

do not conduct electricity
good conductors of heat
all have high melting points
all are solid at room temperature
poor conductors of heat
good conductors of electricity **[2]**

TWS

b. The table gives the melting and boiling points of four Group 7 elements.

Element	Melting point (°C)	Boiling point (°C)
fluorine	–220	–118
chlorine		–35
bromine	–7	59
iodine	114	184

i. Name the element in Group 7 that is liquid at 20 °C. **[1]**

ii. Describe the trend in boiling points in Group 7. **[1]**

iii. Use the trend in melting points to predict the melting point of chlorine. **[1]**

TWS

12.1 Mass and energy in chemical reactions

Objective

- Give definitions for the terms *mass is conserved, energy is conserved, symbol equation*, and *balancing numbers*

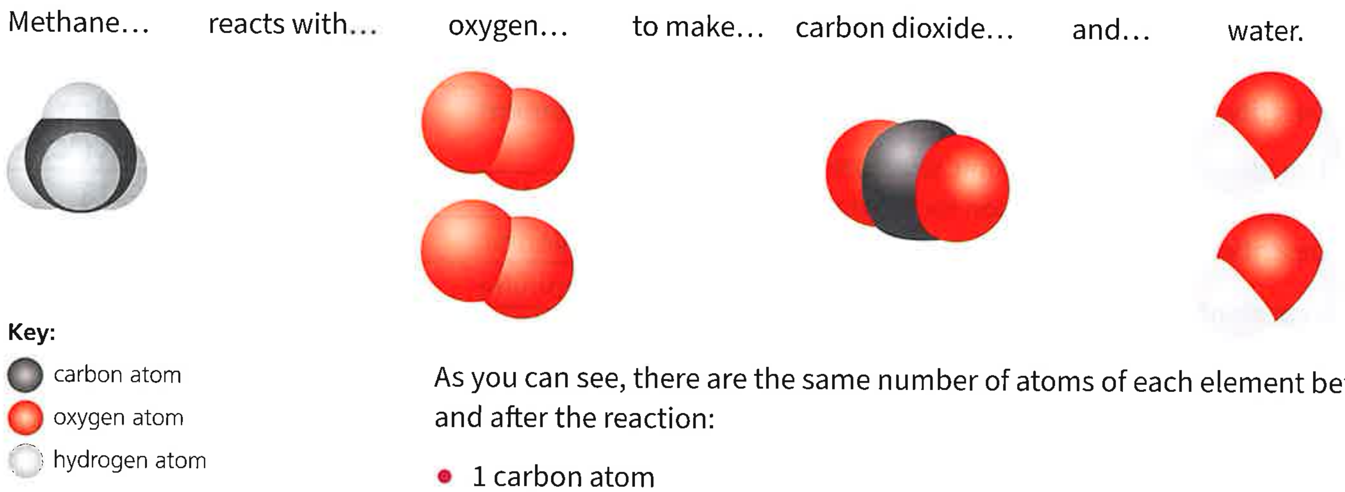
The fuel for the bus is methane. Where does the methane come from?

Bacteria make the methane from human waste. The waste comes from toilets, via a sewage works.

Conserving mass

In the bus engine, there is a chemical reaction. The fuel, methane, reacts with oxygen from the air. The combustion reaction has two products – carbon dioxide and water.

As in all chemical reactions, the atoms rearrange and join together differently. The diagram below models the reaction. Each sphere represents one atom.



As you can see, there are the same number of atoms of each element before and after the reaction:

- 1 carbon atom
- 4 hydrogen atoms
- 4 oxygen atoms.

Since the number of atoms does not change, the mass of reactants is equal to the mass of products. The total mass does not change. As in all chemical reactions, **mass is conserved**.

Conserving energy

The combustion of methane is an exothermic chemical reaction. At the start, energy is stored in the methane and oxygen molecules. As methane burns, thermal energy is transferred to the surroundings (in this case, to the bus engine and – in the end – to the air). The total amount of energy does not change. **Energy is conserved**.

Energy is conserved in all chemical reactions, whether they are exothermic or endothermic.

Symbol equations

You can show the reaction of methane with oxygen as a word equation:

methane + oxygen ⟶ carbon dioxide + water

The word equation shows the reactants on the left, and the products on the right. The arrow means 'reacts to make'.

Symbol equations also show chemical reactions. For example:

methane	+	oxygen	⟶	carbon dioxide	+	water
CH_4	+	$2O_2$	⟶	CO_2	+	$2H_2O$

The symbol equation shows the chemical formula for each substance:

- CH_4 for methane
- O_2 for oxygen
- CO_2 for carbon dioxide
- H_2O for water.

As in the word equation, the reactants are on the left, and the products are on the right. The arrow means 'reacts to make'.

The numbers shown above in red are balancing numbers. **Balancing numbers** show the relative numbers of particles of the reactants and products. The symbol equation above shows that:

- One methane molecule reacts with two oxygen molecules to make one carbon dioxide molecule and two water molecules.

Or that:

- One billion methane molecules react with two billion oxygen molecules to make one billion carbon dioxide molecules and two billion water molecules.

And so on. A balancing number is written to the left of its chemical formula. It is written on the line, and is the same size as the letters in the formula.

Key points

- Mass is conserved in chemical reactions – the total mass of products equals the total mass of reactants.
- Energy is conserved in chemical reactions – the total amount of energy does not change.
- Symbol equations show chemical reactions with chemical formulae.
- Balancing numbers show the relative numbers of particles of reactants and products.

Questions

1. Write definitions for *mass is conserved* and *energy is conserved* in a chemical reaction.
2. Give the meaning of the arrow in word and symbol equations. TWS
3. Look at the symbol equation for the combustion of methane.
   a. Name the two elements whose atoms are in a methane molecule.
   b. Write the names and formulae of the products of the reaction.
   c. Give the number of oxygen molecules that react with one million methane molecules. TWS

Extension 12.2

Objective

- Write balanced symbol equations for chemical reactions

▲ *A precipitate of silver iodide*

Writing symbol equations

Darpan mixes two colourless solutions, silver nitrate and potassium iodide. There is a chemical reaction. The reaction makes two products – silver iodide (a yellow precipitate) and potassium nitrate (a colourless solution). Here is the word equation for the reaction:

silver nitrate + potassium iodide ⟶ potassium nitrate + silver iodide

How do you write a symbol equation for the reaction?

Symbol equations

As you know, symbol equations show the reactants and products in a chemical reaction. They also show:

- the chemical formulae of the reactants and products
- the relative numbers of particles of reactants and products
- the states of the reactants and products.

The symbol equation for the precipitation reaction in the photo is:

potassium iodide	+	silver nitrate	⟶	silver iodide	+	potassium nitrate
$KI(aq)$	+	$AgNO_3(aq)$	⟶	$AgI(s)$	+	$KNO_3(aq)$

There are no balancing numbers because there are the same numbers of atoms of each element in the reactants and products.

State symbols

The letters in brackets are state symbols. State symbols show the state of the substances in a reaction. They are given below. Write one state symbol to the right of each formula. Do not use capital letters.

- (s) for solid
- (l) for liquid
- (g) for gas
- (aq) for a substance dissolved in water.

Writing symbol equations

Magnesium and oxygen

▲ *Burning magnesium*

Magnesium burns brightly in oxygen. The product is magnesium oxide. Follow the steps below to write a balanced symbol equation for the reaction.

1. Write a word equation, with the chemical formula under each substance. Do not guess the chemical formulae – look them up, or ask your teacher.

magnesium	+	oxygen	⟶	magnesium oxide
Mg	+	O_2	⟶	MgO

2. Balance the amounts of oxygen. There are two oxygen atoms on the left, and one on the right. Write a big number 2 to the left of MgO. Do not change or add any little numbers.

$$Mg + O_2 \longrightarrow \mathbf{2}MgO$$

The big 2 applies to every atom in the formula that follows it. Here it means that there are two magnesium atoms and two oxygen atoms. The equation now shows two oxygen atoms on each side of the arrow.

3. Balance the amounts of magnesium. Write a big 2 on the left of the Mg. The equation now shows two magnesium atoms on each side of the arrow. The equation is balanced.

$$\mathbf{2}Mg + O_2 \longrightarrow \mathbf{2}MgO$$

4. Add state symbols: $\mathbf{2}Mg(s) + O_2(g) \longrightarrow \mathbf{2}MgO(s)$

Zinc and hydrochloric acid

Zinc reacts with dilute hydrochloric acid to make zinc chloride solution and hydrogen gas. Follow these steps to write a balanced symbol equation for the reaction:

1. Write the word equation, with the chemical formula under each substance.

zinc	+	hydrochloric acid	$\longrightarrow$	zinc chloride	+	hydrogen
Zn	+	HCl	$\longrightarrow$	$ZnCl_2$	+	H_2

2. Balance the amounts of hydrogen. There is one hydrogen atom on the left of the arrow, and there are two hydrogen atoms on the right. Write a big number 2 to the left of HCl.

$$Zn + \mathbf{2}HCl \longrightarrow ZnCl_2 + H_2$$

3. The equation is now balanced. It shows:
   - one Zn on each side of the arrow
   - two H on each side of the arrow
   - two Cl on each side of the arrow.

4. Add state symbols: $Zn(s) + \mathbf{2}HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$

▲ *The reaction of zinc with hydrochloric acid.*

Questions

Write balanced symbol equations for these chemical reactions:

1. The reaction of solid lithium (Li) with oxygen gas (O_2) to make solid lithium oxide (Li_2O).
2. The reaction of solid magnesium (Mg) with dilute hydrochloric acid (HCl) to make magnesium chloride solution ($MgCl_2$) and hydrogen gas (H_2).
3. The reaction of nitrogen gas (N_2) with oxygen gas (O_2) to make nitrogen monoxide gas (NO).

Key points

To write a balanced symbol equation:

- Write a word equation for the reaction, with the chemical formula below each name.
- Balance the equation by writing balancing numbers where needed.
- Add state symbols.

12.3

Metal displacement reactions

Objectives

- Define the term *metal displacement reaction*
- Predict whether given pairs of substances take part in displacement reactions

A worker is using a chemical reaction to make liquid iron. The liquid iron cools and freezes, joining the rails together. The reaction is called the thermite reaction.

aluminium + iron oxide ⟶ aluminium oxide + iron

Classifying chemical reactions

There are several types of chemical reaction, including combustion, corrosion, and precipitation. The reaction of aluminium with iron is an example of another type of chemical reaction – displacement.

Displacement reactions

Part of the reactivity series

calcium
magnesium
aluminium
zinc
iron
copper
silver
gold

The reactivity series

As you know, the reactivity series lists metals in order of how vigorously they react with other substances. Calcium reacts vigorously with oxygen, water, and acids. It is near the top of the reactivity series. Gold, at the bottom of the reactivity series, is inert. It does not take part in chemical reactions.

Displacement reactions involving metal oxides

In a **metal displacement reaction**, a more reactive metal displaces – or pushes out – a less reactive metal from its compound.

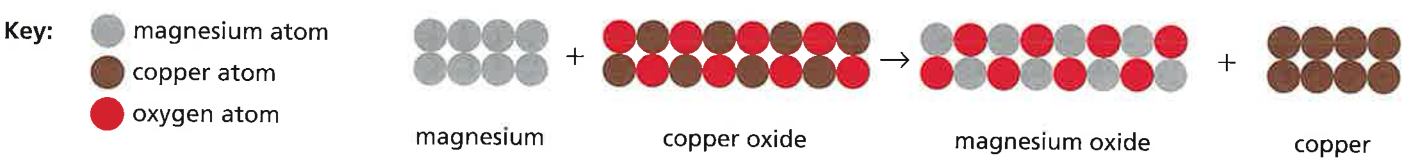
The reactivity series shows that aluminium is more reactive than iron. In the thermite reaction, aluminium pushes iron out of iron oxide. The products are aluminium oxide and iron.

In another displacement reaction, magnesium reacts with copper oxide:

magnesium + copper oxide ⟶ magnesium oxide + copper

The particle diagram below models what happens. For each substance, a small part of the giant structure is shown. Each circle represents one atom. The charges on the ions, and the electrons, are not shown.

▼ *Particle diagram for the reaction of magnesium with copper oxide.*



Thinking and working scientifically

Carrying out an investigation

Alex heats some pairs of substances. He looks for signs of reaction and observes any products made, and writes his results in a table.

Metal element	Metal oxide	Observations
iron	copper oxide	glows red, pink-brown metal formed
copper	iron oxide	no reaction
zinc	copper oxide	glows red, pink-brown metal formed
copper	zinc oxide	no reaction
zinc	iron oxide	glows red, silver-coloured metal formed

Alex writes word equations for the reactions:

iron + copper oxide ⟶ iron oxide + copper

zinc + copper oxide ⟶ zinc oxide + copper

zinc + iron oxide ⟶ zinc oxide + iron

Alex writes a conclusion:

My results confirm that displacement reactions happen when the metal on its own is higher in the reactivity series than the metal in the compound. If the metal on its own is less reactive than the metal in the compound, there is no reaction.

Displacement reactions in solution

A more reactive metal also displaces a less reactive metal from its compounds in solution.

Mandeep adds magnesium to blue copper sulfate solution. After a few minutes, she sees copper metal in the test tube. The blue solution becomes paler.

There has been a displacement reaction. Magnesium is more reactive than copper, so magnesium displaces copper from copper sulfate solution:

magnesium + copper sulfate ⟶ magnesium sulfate + copper

$Mg(s) + CuSO_4(aq) \longrightarrow MgSO_4(aq) + Cu(s)$

Later, Mandeep adds copper to magnesium chloride solution. Nothing happens. There is no reaction, because copper is less reactive than magnesium. Copper cannot displace magnesium from magnesium compounds.

▲ *Iron displaces copper from copper sulfate solution.*

Questions

1. Give the meaning of the term *metal displacement reaction*.
2. Decide which of these pairs of substances react. Write word equations for the reactions that occur:
   a. Magnesium and iron oxide
   b. Zinc and magnesium oxide
   c. Zinc and copper sulfate solution
   d. Copper and silver nitrate solution.

Key points

- In a metal displacement reaction, a more reactive metal displaces – pushes out – a less reactive metal from its compound.

Science in context

12.4 Extracting metals

Objectives

- Define the term *ore*
- Describe the link between the position of a metal in the reactivity series, and how the metal is extracted from its ore
- Describe an application of science

The 55 km Hong Kong-Zhuhai-Macau Bridge is the longest sea-crossing bridge in the world. It is made from steel. Engineers used thousands of tonnes of iron to make the steel. Where did the iron come from?

▲ *This lead statuette was made in Greece over 3000 years ago.*

Extracting metals with carbon

In the Earth's crust, most metals are joined to other elements, in compounds. These compounds are mixed with other substances in rocks. A rock that a metal can be extracted from is an **ore**.

Extracting carbon

There are two steps in getting iron from its ore:

1. Separate iron oxide from the compounds it is mixed with.
2. Use a chemical reaction to get iron from iron oxide.

In the chemical reaction, iron is heated with charcoal. Charcoal is a type of carbon.

iron oxide + carbon ⟶ iron + carbon dioxide

Extracting lead

People have used lead for up to 8000 years. As you know, lead is now used for roofing and to protect from X-rays. Lead exists as lead sulfide in the Earth's crust. It is extracted like this:

1. Heat lead sulfide in air:
   lead sulfide + oxygen ⟶ lead oxide + sulfur dioxide
2. Heat the lead oxide with carbon:
   lead oxide + carbon ⟶ lead + carbon dioxide

Extracting other metals with carbon

Carbon is not a metal. But we can place it in the reactivity series, as shown left. The metals below carbon can be extracted from their oxides by heating with carbon. Carbon is chosen because it is cheap and easy to obtain.

Part of the reactivity series

sodium
calcium
magnesium
aluminium
carbon
zinc
lead
iron
copper
silver
gold

Using electricity to extract metals

The cans below are made from aluminium. Aluminium is above carbon in the reactivity series. In the Earth's crust, it exists as aluminium oxide. Carbon cannot remove oxygen from aluminium oxide. Electricity is used instead. There are two main steps:

1. Dissolve pure aluminium oxide in a special solvent.
2. Pass a 100 000 amp electric current through the solution. The electricity splits up the aluminium oxide. This makes liquid aluminium and oxygen.

◀ *Aluminium drink cans*

Other reactive metals are also extracted from their compounds by electricity. For example, sodium is extracted by passing an electric current through seawater.

Extracting gold

Gold is at the bottom of the reactivity series. It is unreactive. It is found as an element in the Earth's crust. The metal is easily separated from the substances it is mixed with.

Some gold is found in stream beds, mixed with sand and gravel. You can separate gold by placing the mixture in a pan, and adding water. Gold has a higher density than sand and gravel. It sinks to the bottom of the pan.

◀ *Panning for gold*

Questions

1. Write the definition for *ore*.
2. Name two metals that are extracted from their compounds by heating with carbon, and two that are extracted using electricity.
3. Give examples to show why extracting metals from their compounds is useful.
4. Predict whether magnesium is extracted from its ore by heating with carbon or with electricity. Give a reason for your prediction.

Key points

- An ore is a rock that a metal can be extracted from.
- Metals above carbon in the reactivity series are extracted from their compounds by electricity.
- Zinc, and the metals below it, are extracted from their compounds by heating with carbon.

Science in context

12.5

Extracting copper

Copper is vital. It makes water pipes, electric wires, and heat exchangers. But how do copper mining and extraction affect the environment?

Objectives

- Describe environmental impacts of copper mining and extraction
- Describe how science applications reduce harmful environmental impacts

Why find new ways of extracting copper?

Environmental impacts

The picture above shows a copper mine. Around the mine are huge piles of waste rock. The land cannot be used for farming or houses. Few plants and animals survive.

Noisy lorries and machinery pollute the air. Getting copper ore out of the ground and extracting copper from the ore need huge amounts of energy. The processes also make large amounts of greenhouse gases, such as carbon dioxide. As you know, extra greenhouse gases in the atmosphere cause climate change.

Increasing demand

The solar cells in this solar farm are connected by copper cables. The wind turbines are connected by undersea copper cables. As more electricity is generated by solar cells and wind turbines, world demand for copper increases.

▲ *Solar cells in the desert*

▲ *Wind turbines in the sea*

Better ways of extracting copper

Scientists are working hard to find better ways to extract copper. Compared with extracting copper from mined copper ore, these methods:

- are less harmful to the environment
- need less energy
- cost less money.

▲ *Copper waste*

Recycling

Some companies collect used copper objects, such as water pipes and computer parts. They heat the objects to 1085 °C. The copper melts. The liquid copper is poured into moulds. In the moulds, the copper freezes, making ingots. The ingots are sold and made into new objects.

This method of copper recycling has been used for hundreds of years.

▲ *Copper ingots*

Extracting copper from waste

Some devices contain very small amounts of copper. So does copper mine waste. Companies may extract copper from these like this:

1. Spray sulfuric acid onto the waste. This makes copper sulfate solution.
2. Add waste iron to the copper sulfate solution. Iron is higher in the reactivity series than copper, so there is a displacement reaction. The products are iron sulfate solution and solid copper:

   iron + copper sulfate ⟶ iron sulfate + copper

Phytomining: using plants to extract copper

Some plant species grow well on soil that is mixed with copper ore waste. Copper ions enter plants through their roots. The plants store copper ions in their cells.

Scientists are investigating how to extract copper from these plants. One way is to harvest the crop and burn the plants. The ash is rich in copper compounds.

▲ *This plant grows in copper-rich soil.*

Questions

1. Describe three harmful impacts of copper mining and extraction.
2. Explain why the world needs more and more copper.
3. Choose one of these methods: recycling, extracting copper from waste, phytomining. Write a paragraph to explain how the method works and why its environmental impacts are less harmful than extracting copper from mined copper ore.

Key points

- Copper mining has harmful impacts on the environment.
- Copper recycling methods have lower environmental impacts.

12.6 Making salts from acids and metals

Objectives

- Define the term *salt*
- Describe how to make a salt from a metal and acid
- Choose suitable equipment
- Do a risk assessment

The pictures show crystals. What do they have in common?

▲ *Magnesium chloride crystals*

▲ *Nickel nitrate crystals*

▲ *Copper sulfate crystals*

The crystals are all salts. A **salt** is a compound made when a metal ion replaces the hydrogen ion in an acid.

Thinking and working scientifically

Making a salt

Seeta is making a salt from magnesium and hydrochloric acid. The equation for the reaction is:

magnesium	+	hydrochloric acid	→	magnesium chloride	+	hydrogen
Mg	+	2HCl	→	$MgCl_2$	+	H_2

Doing a risk assessment

Seeta carries out a risk assessment. She identifies hazards and risks linked to the reactants, the products, and the equipment. She decides how to reduce the chance and consequences of injury from each risk.

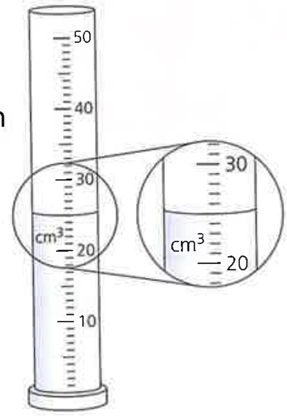
Hazard	Risk	Reduce chance of injury and damage by...
magnesium	flammable	keep magnesium away from flames
dilute hydrochloric acid magnesium chloride solution	corrosive – damages eyes and skin	do not touch wear eye protection
hydrogen gas	mixture with air explosive	use small quantities of reactants to make only a small quantity of hydrogen
hot equipment and solutions	burns	wait to cool before touching
breaking apparatus	cuts	wear eye protection

▲ *Flammable hazard symbol*

▲ *Corrosive hazard symbol*

The chemical reaction

Seeta measures out 25 cm^3 of hydrochloric acid. She uses a measuring cylinder. She does not use a beaker because a measuring cylinder measures smaller differences in volume.



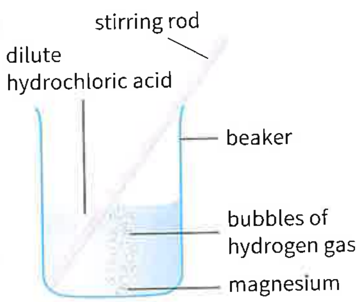
Seeta pours the acid into a beaker. She does not use a conical flask because it is easier to stir the mixture in the beaker.

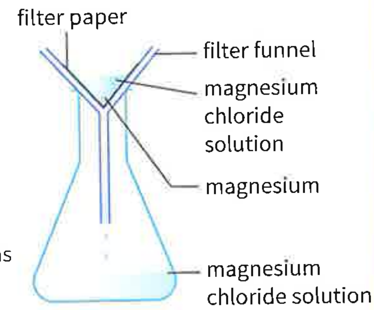
Next, Seeta adds magnesium to the acid. Bubbles of hydrogen gas form. Soon, the bubbles stop. All the magnesium has reacted. Seeta adds more pieces of magnesium, one by one. She stops when some magnesium remains in the beaker. This shows that all the acid has reacted.

Separating magnesium chloride from the mixture

The beaker contains a mixture. The mixture includes:

- magnesium chloride solution
- solid magnesium.





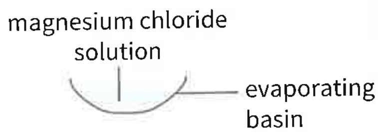
Filtration

Seeta filters the mixture. She chooses a conical flask, not a beaker, because the conical flask holds the filter funnel upright.

Evaporation

Seeta pours the magnesium chloride solution into an evaporating dish. She chooses an evaporating basin because of its shape – there is a big surface for water to evaporate from.

Seeta heats the solution over a water bath. Water evaporates. After a while, white crystals start to form around the edge. Seeta stops heating.



▲ *Evaporation removes water from the solution.*

Crystallisation

Seeta waits for the evaporating basin to cool.
She moves it to a warm, dry place. The water continues to evaporate, but more slowly. This allows time for crystals to form. Seeta has made her salt, magnesium chloride.

Key points

- Make a salt in a chemical reaction. Purify by filtration, evaporation, and crystallisation.
- Do a risk assessment by identifying hazards and risks, and describing how to reduce chance of injury or damage.

Questions

1. Define the term *salt*.
2. Jay makes a salt from an acid and a metal. Name the process to separate the salt solution from unreacted metal.
3. Write a word equation for the reaction of zinc with hydrochloric acid. Name the salt made.
4. Suggest the metal and acid you could use to make iron sulfate crystals.

12.7 More about salts

Objectives

- Choose reactants to make different salts

The picture shows a sculpture. It is made from salts that were dissolved in the waters of Lake Qinghai, in China.

As you know, a salt is a compound made when a metal ion replaces the hydrogen ion in an acid. The salts in the lake exist naturally. You can also make salts in chemical reactions – unit 12.6 describes how to make magnesium chloride, for example.

Making salts – choosing reactants

One of the reactants to make a salt is an acid. Different acids make different salts:

- hydrochloric acid, HCl, makes chlorides
- sulfuric acid, H_2SO_4, makes sulfates
- nitric acid, HNO_3, makes nitrates.

The other reactant must include atoms of the metal element in the salt that is being made. The picture below shows some different salts.

▲ *Some salts: sodium manganate, zinc sulfate, copper sulfate, potassium dichromate, nickel chloride, cobalt sulfate.*

Thinking and working scientifically

Making zinc sulfate

Lim wants to make zinc sulfate. He needs two reactants. One of the reactants is sulfuric acid. The other reactant must include zinc. There is a choice of zinc-containing reactants: zinc metal, zinc oxide, or zinc carbonate.

Each of the zinc-containing substances reacts with sulfuric acid to make zinc sulfate. The other products are different:

Reaction 1

zinc	+	sulfuric acid	→	zinc sulfate	+	hydrogen
Zn	+	H_2SO_4	→	$ZnSO_4$	+	H_2

Reaction 2

zinc oxide	+	sulfuric acid	→	zinc sulfate	+	water
ZnO	+	H_2SO_4	→	$ZnSO_4$	+	H_2O

Reaction 3

zinc carbonate	+	sulfuric acid	→	zinc sulfate	+	carbon dioxide	+	water
$ZnCO_3$	+	H_2SO_4	→	$ZnSO_4$	+	CO_2	+	H_2O

There are several factors to consider when choosing the metal-containing reactant, including:

- What are the other products of the reaction?
- Is it easy to separate the salt from the other products?
- Is the metal-containing reactant easily available, and what is its cost?

For example, reaction 1 has two disadvantages compared to reactions 2 and 3:

- Zinc is more expensive than zinc oxide and zinc carbonate.
- Hydrogen (made in reaction 1) is flammable, but the products of the other reactions are not.

Lim decides to make his zinc sulfate from zinc carbonate.

Questions

1. Name the acid to make each of these salts in the laboratory:

  a. Nickel chloride

  b. Cobalt sulfate

  c. Sodium nitrate

2. Suggest two reactants that react together to make copper sulfate.

3. A chemist makes nickel chloride from hydrochloric acid and nickel carbonate. Write a word equation for the reaction.

Key points

- A salt is made in a chemical reaction between an acid and a metal-containing substance, for example an oxide or carbonate.

Thinking and working scientifically

12.8

Making salts from acids and carbonates

Objectives

- Describe how to make a salt from an acid and an insoluble carbonate
- Evaluate a method and suggest improvements

Fungi can damage crops. Fungicides destroy fungi. Some farmers use fungicides from natural sources, such as the neem tree. Some farmers use fungicides made in factories, such as copper sulfate.

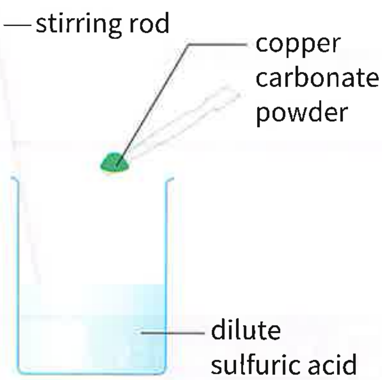
Making copper sulfate

Choosing reactants

Copper sulfate is a salt. It is made in the reactions below:

- **Reaction 1**
  copper + sulfuric acid ⟶ copper sulfate + hydrogen
  The acid must be concentrated and the temperature high.
- **Reaction 2**
  copper oxide + sulfuric acid ⟶ copper sulfate + water
  Dilute acid may be used.
- **Reaction 3**
  copper carbonate + sulfuric acid ⟶ copper sulfate + carbon dioxide + water

Dilute acid may be used.
In industry, copper sulfate is made in reactions 1 and 2. At school, you can use reaction 2 or 3. Reaction 1 is too hazardous.



▲ *Copper carbonate and sulfuric acid react together to make copper sulfate solution, water, and bubbles of carbon dioxide gas.*

The chemical reaction

Dan plans to make copper sulfate in this chemical reaction:

copper carbonate + sulfuric acid ⟶ copper sulfate + carbon dioxide + water

$$CuCO_3 + H_2SO_4 \longrightarrow CuSO_4 + CO_2 + H_2O$$

Dan does a risk assessment. Then he starts his investigation.

Dan measures out 25 cm^3 of acid. He pours it into a beaker. He adds one spatula measure of copper carbonate powder. Carbon dioxide gas forms, so the mixture bubbles. Dan continues to add copper carbonate, one spatula at a time. He stops when some copper carbonate remains in the beaker, and there is no more bubbling. This shows that all the acid has reacted.

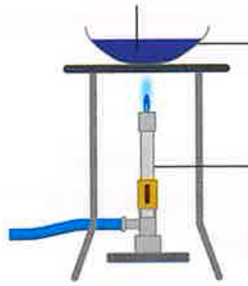
Making crystals from the mixture

The beaker now contains a mixture. The mixture includes:

- copper sulfate solution
- copper carbonate powder that has not reacted.

Filtration

Dan filters the mixture. Unreacted copper carbonate remains in the filter paper. He collects copper sulfate solution in an evaporating basin. He chooses an evaporating basin, not a conical flask. This means he does not need to pour the solution from one container to another.



▲ *On heating, water evaporates from the copper sulfate solution.*

Evaporation

Dan heats the copper sulfate solution. Some of the water evaporates. Some of the solution spits out. After a while, blue crystals start to form around the edge. Dan stops heating.

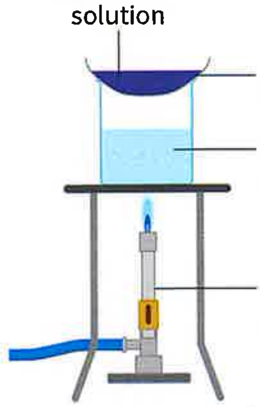
Crystallisation

Dan waits for the evaporating basin to cool. He moves it to a warm, dry place. The water evaporates slowly. This gives time for crystals to form.

Evaluating and improving methods

Dan makes a smaller mass of copper sulfate crystals than expected. He lost some of the product in the evaporation stage.

Dan wants to improve his method. He repeats the whole experiment. This time, he does not heat the copper sulfate solution over a flame. Instead, he uses a water bath. This heats the solution more evenly. The solution does not spit. Dan makes a greater mass of crystals.



▲ *Heating over a water bath.*

Questions

1. Write a word equation for the reaction of copper carbonate with dilute sulfuric acid.
2. List the four stages in making a salt from an acid and a carbonate.
3. TWS Explain why carrying out the evaporation step by heating over a water bath is better than heating directly with a Bunsen burner.
4. Write the word equation for the reaction of zinc carbonate with hydrochloric acid. Name the salt made in the reaction.
5. Suggest the metal carbonate and acid you could use to make magnesium nitrate crystals.

Key points

- You can make a salt in a chemical reaction of an acid with an insoluble carbonate. Then purify by filtration, evaporation, and crystallisation.

12.9 Rates of reaction

Objectives

- Define the term *rate of reaction*
- Describe how to follow the rate of a reaction that makes a gas
- Explain how to collect reliable results

Some chemical reactions happen very quickly. Others are much slower.

▲ *Chemical reactions in fireworks are fast.*

▲ *Rusting reactions are slow.*

What is rate of reaction?

The **rate of a reaction** is a measure of how quickly a reactant is used up, or how quickly a product forms. Chemists need to control rates of reactions. They may slow down rusting reactions. They may want to speed up reactions that make useful products, such as soap, fertilisers, or medicines.

Before chemists can control reaction rates, they need to find out how fast a reaction is. You cannot tell how quickly a reaction happens by looking at its equation. You need to do an experiment to find out.

Following a reaction

Vijay wants to find out about the rate of the reaction of magnesium with hydrochloric acid. Here is the equation for the reaction:

magnesium + hydrochloric acid → magnesium chloride + hydrogen

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

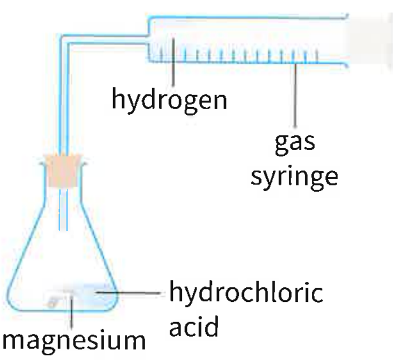
Obtaining and presenting evidence

Vijay sets up the apparatus shown. He drops a piece of magnesium into the acid. He sees bubbles. The bubbles contain hydrogen gas. As the hydrogen gas forms, it goes into the gas syringe. The plunger moves out.

Vijay measures the total volume of gas made by the end of each minute. He draws a table for his results:

- The independent variable (time) is in the left column.
- The dependent variable (volume of gas) is in the big right column.

Vijay wants to reduce error and obtain reliable results, so he repeats the investigation three times. The table has space for the three results, and for average values.



▲ *Apparatus to follow the reaction of magnesium with hydrochloric acid.*

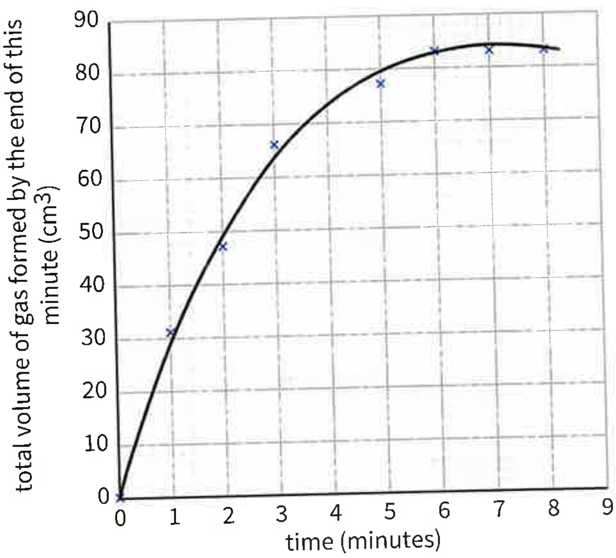
Time (minutes)	Total volume of gas formed by the end of this minute (cm^3)			
	test 1	test 2	test 3	average
0	0	0	0	0
1	31	30	32	31
2	45	47	49	47
3	64	68	66	66
4	69	69	66	
5	76	76	79	77
6	83	85	81	83
7	83	83	83	83
8	84	82	83	83

Vijay chooses how to present his results. The variable he changes, and the variable he measures, are continuous. This means he can plot a line graph:

- The scale for the independent variable is on the *x*-axis.
- The scale for the dependent variable is on the *y*-axis.

Vijay spaces the numbers on the axes evenly.

Vijay draws a cross for each point. He then draws a line of best fit. This is a smooth curve. The number of points above and below the line are equal.



▲ *Graph showing total volume of gas made by the end of each minute.*

Describing patterns and interpreting results

At first, the graph rises steeply. This shows that hydrogen is formed quickly at the start of the reaction. The rate of the reaction is fast. Then the slope of the graph gets less steep. This shows that the reaction is slowing down. The rate of the reaction is slower.

From the sixth minute onwards, the graph does not go up any more. No more hydrogen gas is being made. This shows that the reaction has finished. All the magnesium has been used up, so there is nothing left for the acid to react with.

Questions

1. Give an example of a fast reaction, and a slow reaction.
2. Use the graph to estimate the volume of gas made during the first 4 minutes of the reaction. TWS
3. Explain how the graph shows when the reaction has finished.
4. Explain why Vijay repeated the experiment three times.
5. Use data in the table to calculate the mean volume of gas collected by the end of the fourth minute. TWS

Key points

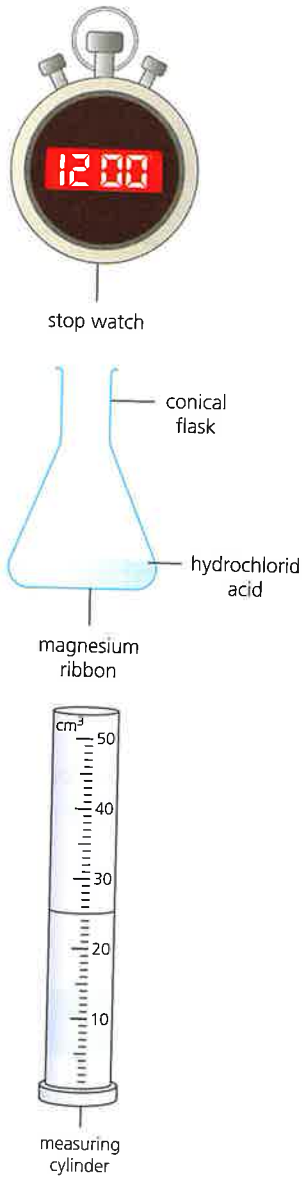
In a reaction that makes a gas, the total amount of gas made by the end of each minute shows how the rate of reaction changes with time.

12.10 Concentration and reaction rate

Objective

- Describe and explain how concentration affects reaction rate

Tara is a chemist. She works for a company that makes medicines. The company wants to make its medicines quickly and cheaply. Tara investigates the conditions that speed up reactions that make medicines.



▲ *Apparatus to investigate the effect of acid concentration on rate of reaction.*

Thinking and working scientifically

Planning an investigation

Two students are investigating this scientific question:

In acid reactions, how does the concentration of acid affect reaction rate?

Their teacher gives them the apparatus shown on the left. The students will use the stopwatch to measure time accurately, and the measuring cylinder to measure volume accurately.

The students list the variables in the investigation:

- concentration of acid
- time for magnesium ribbon to finish reacting
- length of magnesium ribbon
- temperature
- volume of acid

The students think that changing one variable will affect another variable, so they decide to do a fair test. In the test, the students will:

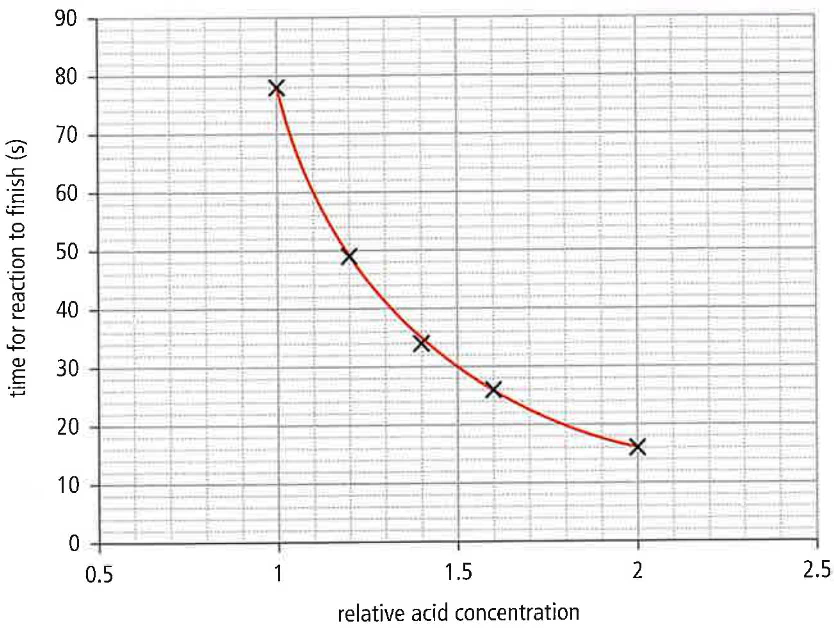
- change the concentration of acid. This is the independent variable.
- measure the time for the magnesium to finish reacting. This is the dependent variable.

The other three variables are control variables. The students will keep these constant, so the test is fair.

The students wonder what range of acid concentration values to use. As you know, range is the difference between the lowest and highest values of a variable. The teacher tells them to use relative concentration values between 1 and 2. The students decide to collect data for five values between these concentrations.

Presenting evidence

The students carry out the chemical reaction with five concentrations of acid. They write their results in a table. Next, they plot the points on a graph, and draw a line of best fit.



▲ *Graph showing the effect of acid concentration on the time for magnesium to finish reacting.*

Analysing evidence

The students write a conclusion for their investigation.

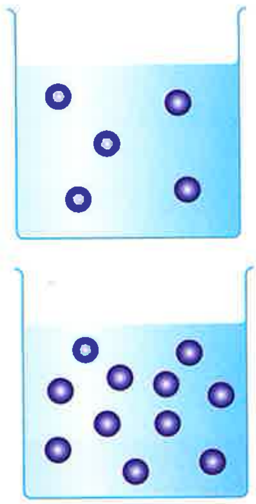
The graph shows that, as acid concentration increases, the time for the magnesium ribbon to finish reacting decreases. This means that when the acid concentration is higher, the rate of reaction is faster.

The students need to improve their conclusion by adding a scientific explanation.

Why does increasing concentration increase reaction rate?

As you know, the concentration of a solution tells you how much solute is dissolved in the solvent. The higher the concentration, the greater the number of acid particles that are dissolved in a certain volume of solution.

Substances can only react when their particles hit each other, or collide. The higher the concentration of solution, the more frequently its particles collide with the other reactant...and the faster the reaction.



▲ *The beaker above shows acid of lower concentration than the beaker below. Water particles are not shown. Not to scale.*

Questions

TWS **1.** Explain why the students displayed their results on a line graph, not a bar chart.

2. a. Describe the relationship between acid concentration and reaction rate.

b. Use the particle model to explain this relationship.

3. A student wonders whether the results would be similar if they used a different acid. Suggest how they could investigate.

Key points

For reactions involving solutions, the higher the concentration of solution, the faster the reaction.

12.11 Temperature and reaction rate

Objective

- Describe and explain how temperature affects reaction rate

Farai and Ibrahim chop potatoes. Ibrahim adds his potatoes to boiling water, at 100 °C. They cook in 15 minutes. Farai adds potatoes to boiling oil, at 200 °C. They cook more quickly.

The chemical reactions that happen when potatoes cook are quicker at higher temperatures. The reaction rates are faster. Is this true for other reactions?

▲ *The higher the temperature, the faster food cooks.*

Thinking and working scientifically

Investigating temperature and reaction rate

Farai decides to investigate how temperature affects reaction rate. He thinks that one variable will affect another variable, so he plans a fair test.

Making a hypothesis

Farai makes a hypothesis.

My hypothesis – Reactions happen when particles collide. At higher temperatures, particles move faster and collide more frequently. So, as temperature increases, reaction rate will also increase.

Carrying out an investigation

Sodium thiosulfate solution reacts with hydrochloric acid to make four products:

sodium thiosulfate + hydrochloric acid ⟶
sodium chloride + water + sulfur dioxide + sulfur

Sulfur is insoluble in water, so it forms as a precipitate. The tiny pieces of solid sulfur make the reaction mixture cloudy.

Farai sets up the apparatus shown. He pours sodium thiosulfate solution into the flask. Then he adds hydrochloric acid. He starts the timer. Gradually, solid sulfur forms. After 244 seconds, the mixture is so cloudy that Farai can no longer see the cross through the flask.

Farai repeats the chemical reaction two more times at the same temperature. He wants to reduce error and obtain reliable results.

Farai makes a prediction:

My prediction – At higher temperatures, the reaction will be quicker, so the cross will disappear after a shorter time.

▲ *The reaction of sodium thiosulfate solution with hydrochloric acid.*

Farai does the same experiment at four different temperatures. Will his prediction be correct?

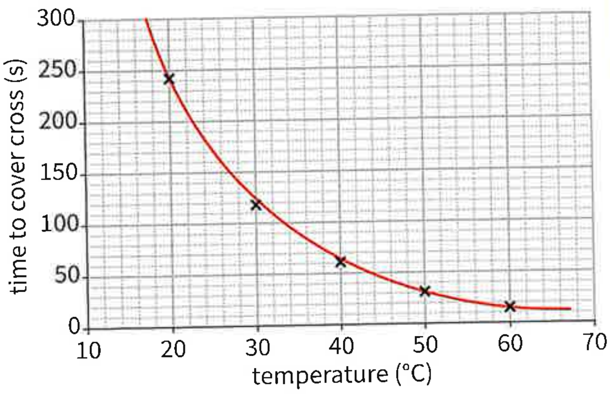
Presenting results

Farai writes his results in a table.

Temperature of acid (°C)	Time to cover cross (seconds)			
	Test 1	Test 2	Test 3	average (mean)
20	244	240	242	242
30	119	117	118	118
40	59	61	63	61
50	67	32	30	31
60	13	16	16	15

Farai notices that the first result for 50 °C is very different to the other results at this temperature. The result is anomalous. He thinks that this is because the acid had cooled down before he used it. He decides not to include this result when calculating the average time for 50 °C.

The independent variable (temperature) and dependent variable (time) are both continuous. Farai draws a line graph.



▲ *Graph showing time to cover cross at different temperatures.*

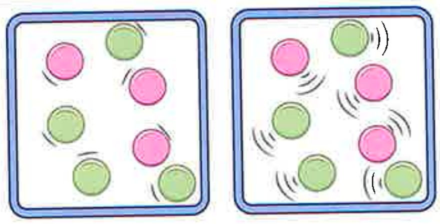
Analysing evidence

The graph shows that the higher the temperature, the faster the reaction. As temperature increases, so does the rate of reaction.

Farai's prediction is correct. The evidence supports the hypothesis on which he based his prediction.

Why does increasing temperature increase reaction rate?

As you know, substances can only react when their particles collide. At higher temperatures (shown in the box on the far right) particles move faster and collide more frequently. This explains why increasing the temperature increases the reaction rate.



▲ *At higher temperatures, particles move faster. There are more frequent and more successful collisions.*

Questions

TWS **1.** Explain why the student repeated his investigation three times.

2. a. Describe the relationship between temperature and rate of reaction.

b. Use the particle model to explain this relationship.

3. A student wonders whether increasing temperature increases the rate of the reaction of magnesium with hydrochloric acid. Describe an investigation she could do to find out.

Key points

- Increasing temperature increases reaction rate. This is because particles move faster and collide more frequently at higher temperatures.

12.12 Surface area and reaction rate

Objective

- Describe and explain how surface area affects reaction rate

In 1965 in London, England, an explosion at a flour mill killed 4 people and injured 31. Why does flour explode?

Flour has tiny grains. In the air, the grains spread out. Particles from the air – including oxygen molecules – surround the flour grains. Then someone lights a match. A flour grain catches fire. It lights the grains near it. A flame flashes through the flour cloud. This is the explosion. Other powders form explosive mixtures with air, including sugar, sawdust, and aluminium.

▲ *A test explosion of aluminium powder.*

Thinking and working scientifically

Investigating surface area and reaction rate

Planning an investigation

Saffron wants to investigate reactions involving powders. She asks a scientific question:

My question – Do powders react quicker than big lumps of solid?

Saffron uses her scientific knowledge to make a hypothesis:

My hypothesis – Reactions happen when particles collide. Only the surface particles of a solid can react. A certain mass of powder has more surface particles than the same mass of big lumps, so a powder reacts more quickly than big lumps.

Saffron decides to investigate the reaction of calcium carbonate with hydrochloric acid:

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

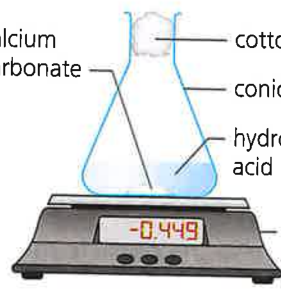
$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Saffron sets up the apparatus shown.

As carbon dioxide is made, it escapes from the apparatus. The mass of the flask and its contents decreases.

Saffron makes a prediction:

My prediction – The mass will decrease most quickly with the powder.



▲ *Apparatus to investigate how surface area affects reaction rate.*

Carrying out an investigation

Saffron adds a big lump of calcium carbonate to dilute hydrochloric acid. She measures the time for the mass to decrease by 1.0 g.

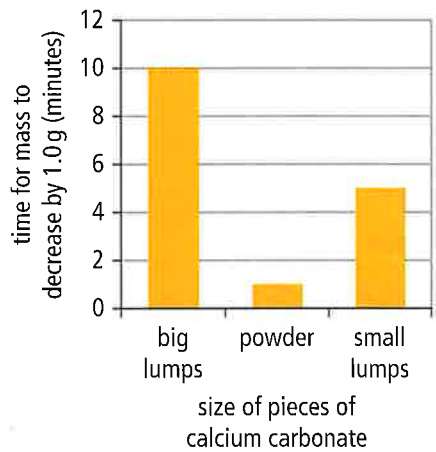
Saffron does the same experiment two more times – with small lumps of calcium carbonate, and with calcium carbonate powder.

Presenting results

Saffron records her results in a table.

Size of calcium carbonate pieces	Time for total mass to decrease by 1 g (min)
Big lump	10
Powder	1
Small lumps	5

Saffron draws a bar chart because the independent variable (the size of the calcium carbonate pieces) is discrete.



▲ *Bar chart showing how surface area affects reaction rate.*

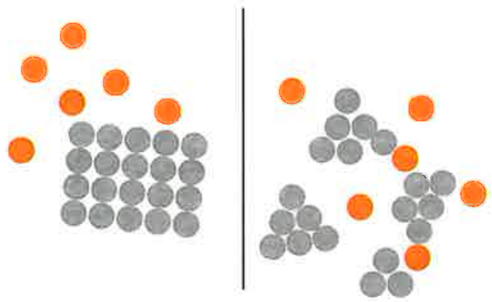
Analysing results

Saffron's prediction is correct. The evidence supports the hypothesis on which she based her prediction.

Why does increasing surface area increase reaction rate?

Ten grams of powder has a greater surface area than one 10 g lump of the same substance. There are more particles on the surface of the powder than on the surface of the lump.

Substances can only react when their particles collide. If a substance is in the solid state, only its surface particles can react. The greater the surface area, the faster the reaction.



▲ *The greater the number of particles on the surface, the faster the reaction.*

▲ *The sugar in both piles has the same mass. The sugar on the right has the greater surface area.*

Questions

TWS **1.** Write down three control variables in Saffron's investigation.

2. a. Describe the relationship between surface area and rate of reaction.

b. Use the particle model to explain this relationship.

3. Write down two other factors that affect the rate of a reaction.

Key points

- Increasing surface area increases reaction rate. This is because the greater the surface area, the greater the number of particles available for reaction.

Review 12.13

1. This question is about displacement reactions. The list below shows part of the reactivity series. Use it to help you answer the question.

   zinc
   iron
   lead
   copper

   a. Predict which of the pairs of substances below will react. **[2]**

      i. Copper and zinc oxide

      ii. Lead and copper oxide

      iii. Zinc and lead oxide

      iv. Lead and iron oxide

   b. Write word equations for the pairs of substances in part **a** that react. **[4]**

2. Caz puts a piece of zinc in some copper sulfate solution. A reaction takes place. The word equation for the reaction is:
   zinc + copper sulfate ⟶ copper + zinc sulfate

   a. Name the products of the reaction. **[1]**

   b. Explain why the reaction is a displacement reaction. **[1]**

   c. Caz places a piece of zinc in some nickel nitrate solution. A displacement reaction takes place.

      i. Explain whether nickel or zinc is the more reactive metal. **[2]**

      ii. Write a word equation for the reaction. **[2]**

      iii. Predict what would happen if Caz placed a piece of nickel in zinc chloride solution. Give a reason for your prediction. **[2]**

3. Name the salts made when the following pairs of substances react.

   a. Magnesium and sulfuric acid **[1]**

   b. Zinc and hydrochloric acid **[1]**

   c. Magnesium and nitric acid **[1]**

   d. Copper carbonate and hydrochloric acid **[1]**

   e. Zinc and sulfuric acid **[1]**

4. Lia plans to make zinc chloride crystals. She decides to react zinc metal with hydrochloric acid.

   a. The products of the reaction are zinc chloride solution and hydrogen gas. Write a word equation for the reaction. **[2]**

   b. Lia uses a secondary source to list the hazards of the reactants and products.

Substance	Hazard
zinc metal	Low hazard
dilute hydrochloric acid	Low hazard. May cause harm in eyes or in a cut.
hydrogen gas	Extremely flammable. Forms explosive mixture with air.
zinc chloride solution (dilute)	Low hazard
zinc chloride crystals and concentrated solutions	Corrosive. Burn skin. Harmful if swallowed.

   Lia takes the precautions below to reduce risks from the hazards. Give one reason for each precaution.

      i. Be careful not to spill the acid. **[1]**

      ii. Wear eye protection at all stages of the experiment. **[1]**

      iii. Do not touch the zinc chloride crystals. **[1]**

c. Lia makes zinc chloride solution. She pours the solution into an evaporating dish. She does not heat the solution directly. Instead, she heats the solution over a water bath. Suggest why. **[1]**

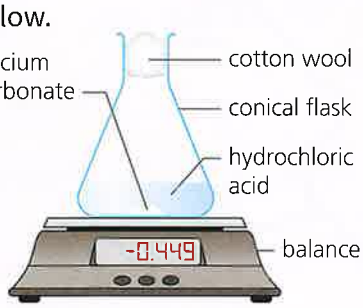
5. Rashid investigates the reaction of hydrochloric acid with calcium carbonate.

The equation for the reaction is:

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

a. Predict which product of the reaction is formed as a gas. **[1]**

b. Rashid sets up the apparatus below.



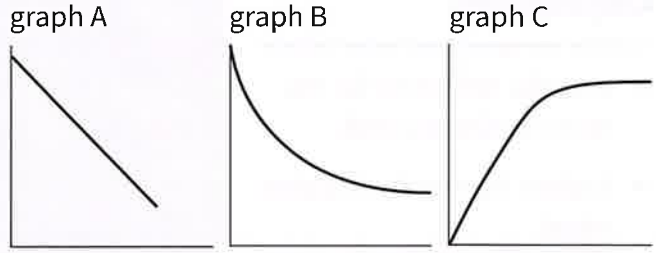
i. Rashid predicts that, as the reaction progresses, the mass of the reaction mixture in the flask will decrease. Which of the reasons below best explains why the mass decreases? **[1]**

A The product that is formed as a gas dissolves in the reaction mixture.

B The product that is formed as a gas escapes into the air.

C The product that is formed as a gas is made up of atoms of two elements.

ii. Rashid records the mass of the reactant mixture every minute. He plots a graph of his results.
Predict which of the graphs below best represents Rashid's results. **[1]**



c. Rashid wants to investigate how the size of the pieces of calcium carbonate affect the reaction rate.
He has three sizes of calcium carbonate pieces – big lumps, small lumps, and powder. He decides to measure the time taken for 1.0 g of gas to be made with each size of calcium carbonate pieces.

i. Name the variable he changes. **[1]**

ii. Name the variable he measures. **[1]**

iii. Name two variables Rashid must keep constant. **[1]**

iv. Rashid finds that the powder reacts most quickly.
Which of the reasons below best explains why? **[1]**

A For a certain mass of calcium carbonate, the powder has the smallest surface area.

B For a certain mass of calcium carbonate, the powder has the biggest surface area.

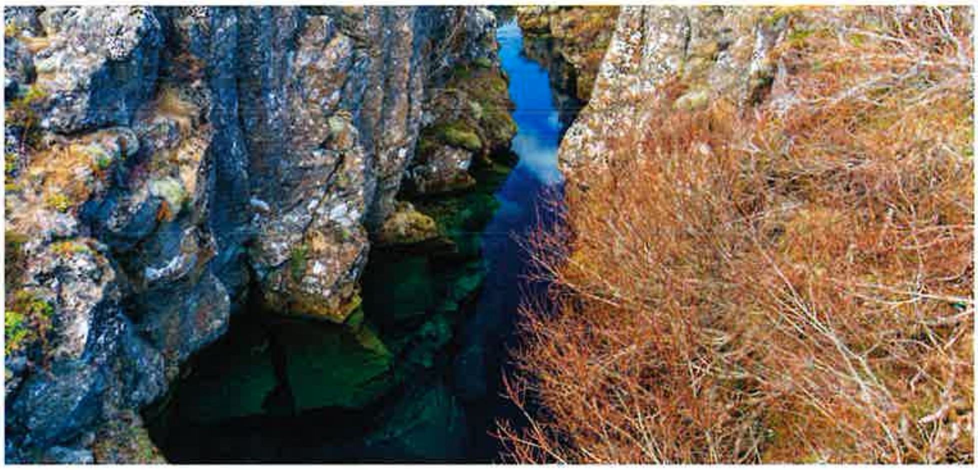
C For a certain mass of calcium carbonate, the powder has the highest concentration.

13.1 Continental drift

Objectives

- Give the definition for the term *continental drift*
- Explain how tectonic plates move

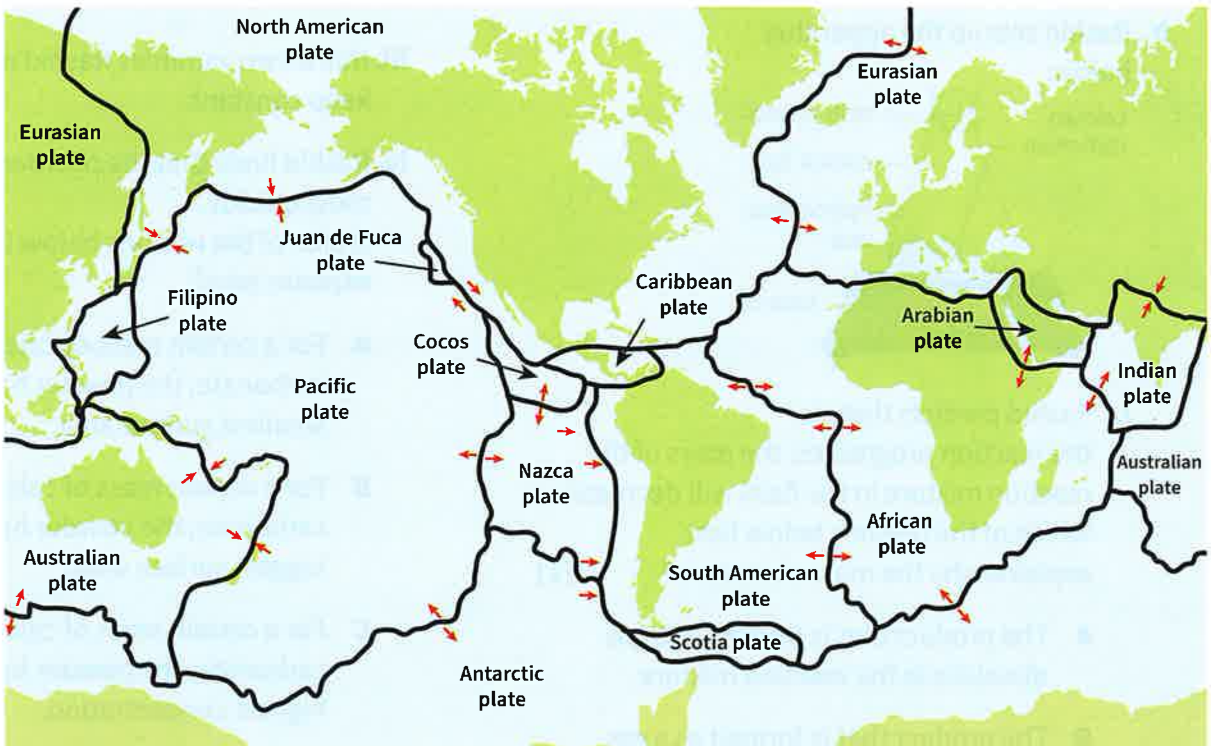
Every year, the gap between the rocks gets wider. Can you explain why?



Tectonic plates

The gap is in Iceland. It separates two tectonic plates. On one side is the North American plate. On the other side is the Eurasian plate.

As you know, the surface of the Earth consists of about 12 tectonic plates. Each is a slab of solid rock. It is made up of a piece of the Earth's crust and the top part of the mantle below it.

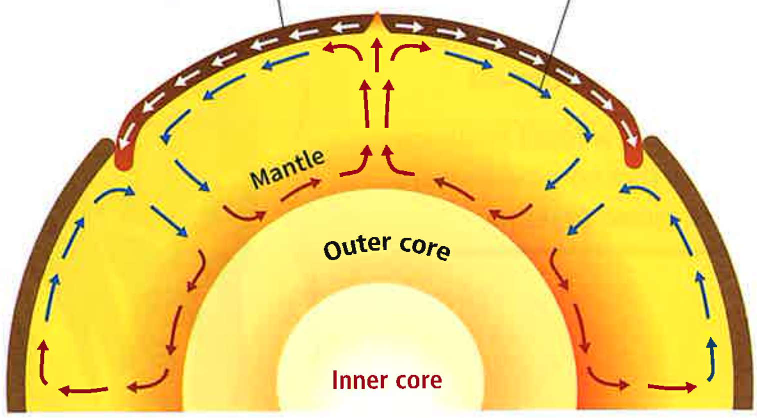


The map shows the Earth's tectonic plates. The arrows show how the plates are moving. The red dots show the positions of earthquakes and volcanoes. They are mostly at plate boundaries, where tectonic plates meet. This is evidence for tectonic plates.

Continental drift

Why do tectonic plates move?

Tectonic plate rock is less dense than the mantle below it, so the plates rest on the mantle. Deep inside the Earth, natural processes heat the mantle. The heat drives convection currents in the mantle. The convection currents make the tectonic plates move.



▲ *Convection currents in the mantle.*

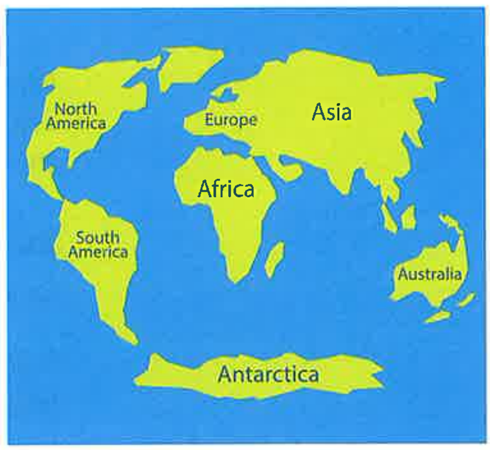
Where have tectonic plates moved?

Tectonic plates move slowly, at speeds of a few centimetres a year. Over millions of years, tectonic plates have moved many kilometres. This is **continental drift**.

The maps below show how the continents have moved over the past 225 million years.

▲ *Permian period, 225 million years ago*

▲ *Jurassic period, 150 million years ago*



▲ *Present day*

Questions

1. Give the definition for *continental drift*.
2. Explain what makes tectonic plates move.
3. Look at the map opposite
   a. Name two plates that are moving towards each other.
   b. Name two plates that are moving away from each other.

Key points

- Continental drift is the movement of tectonic plates over millions of years.
- Tectonic plates move as a result of convection currents in the mantle below.

13.2

Objectives

- Explain how fossilised trees show that Antarctica once had a warmer climate
- Explain how fossil evidence shows that continents were once joined together

Evidence from fossils

In 1912, Robert Falcon Scott and his team were returning from the South pole. They rested in a rocky area, and searched for fossils. The explorers were excited by their fossil finds. They took the fossils away with them.

Nine months later, a rescue team found the heavy fossils again, next to the explorers' frozen bodies. Why did the explorers keep the fossils? What made them so special?

Evidence from trees

Scott wrote that one of the fossils was:

A piece of coal with beautifully traced leaves in layers, and some excellently preserved impressions of thick stems.

We now know that the fossils are remains of an extinct tree, called *Glossopteris.*

▲ *A fossil from the extinct tree species* Glossopteris*, found in India.*

▲ *A* Glossopteris *tree probably looked like this. Some were 30 m tall.*

Today, trees do not grow on Antarctica. It is too cold in the area around the South pole. The fossilised leaves are evidence that the land that is now Antarctica once had a warmer climate. The continent must have been further north, away from the South pole.

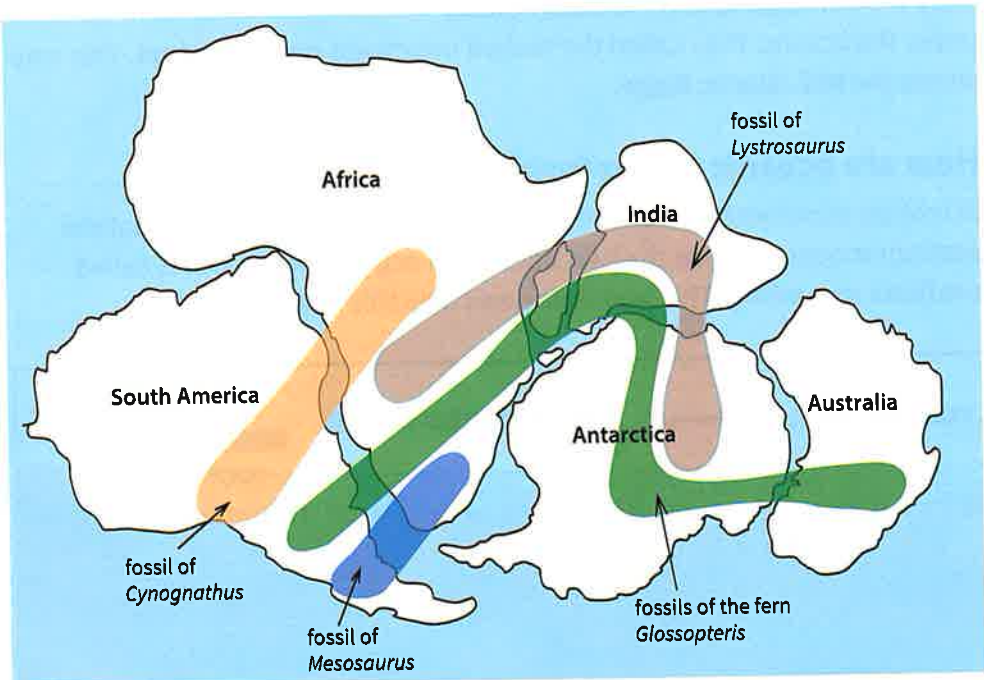
Before these fossils were found in the Antarctic, people had found fossils of the same tree species, *Glossopteris*, on four continents – Africa, Australia, India, and South America. This suggests that the continents were once joined together.

▲ *A reconstruction of* Lystrosaurus. *Its fossilised remains have been found in Africa, India, Antarctica, China, and Mongolia.*

Evidence from animals

As you know, Alfred Wegener used fossil evidence to support his 1912 hypothesis that the continents were once a single piece of land. The land broke up, he said, and the pieces drifted apart.

Wegener used fossil evidence from several species, including *Glossopteris* and an extinct lizard, *Mesosaurus* (see Unit 6.2). Fossil remains of *Lystrosaurus* also provided evidence for Wegener's hypothesis. The animal had just two teeth, and used its beak to tear leaves from plants.



◂ *Each colour on this map shows the areas that fossils of one species have been found in.*

Questions

1. Explain how fossilised trees show that the land that is now Antarctica once had a warmer climate.
2. Look at the map, and name the two continents on which fossil remains of *Cynognathus* have been found.
3. Look at the map. Give evidence from two species that show that India and Africa were once joined together.

Key points

- Fossil evidence suggests that Antarctica was once further from the South pole than it is now.
- Fossil evidence suggests that the continents were once joined together.

13.3 Evidence from seafloor spreading

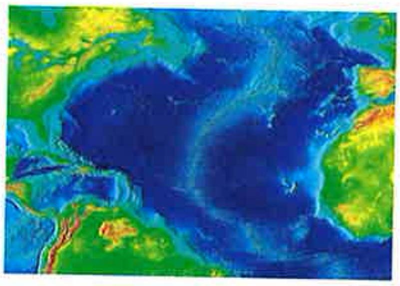
Objectives

- Define the terms *oceanic ridge* and *seafloor spreading*
- Explain how symmetrical magnetic stripes on the two sides of an oceanic ridge provide evidence for seafloor spreading

The picture shows a seafloor mapping instrument. It is towed by a ship. It sends sound waves to the seafloor. The sound waves are reflected, detected, and processed to make an image of the seafloor. How do seafloor images provide evidence for plate tectonics?

Oceanic ridges

In spite of evidence from fossils and continent shapes, most scientists rejected Wegener's hypothesis at first. They did not know *how* continents could move apart.

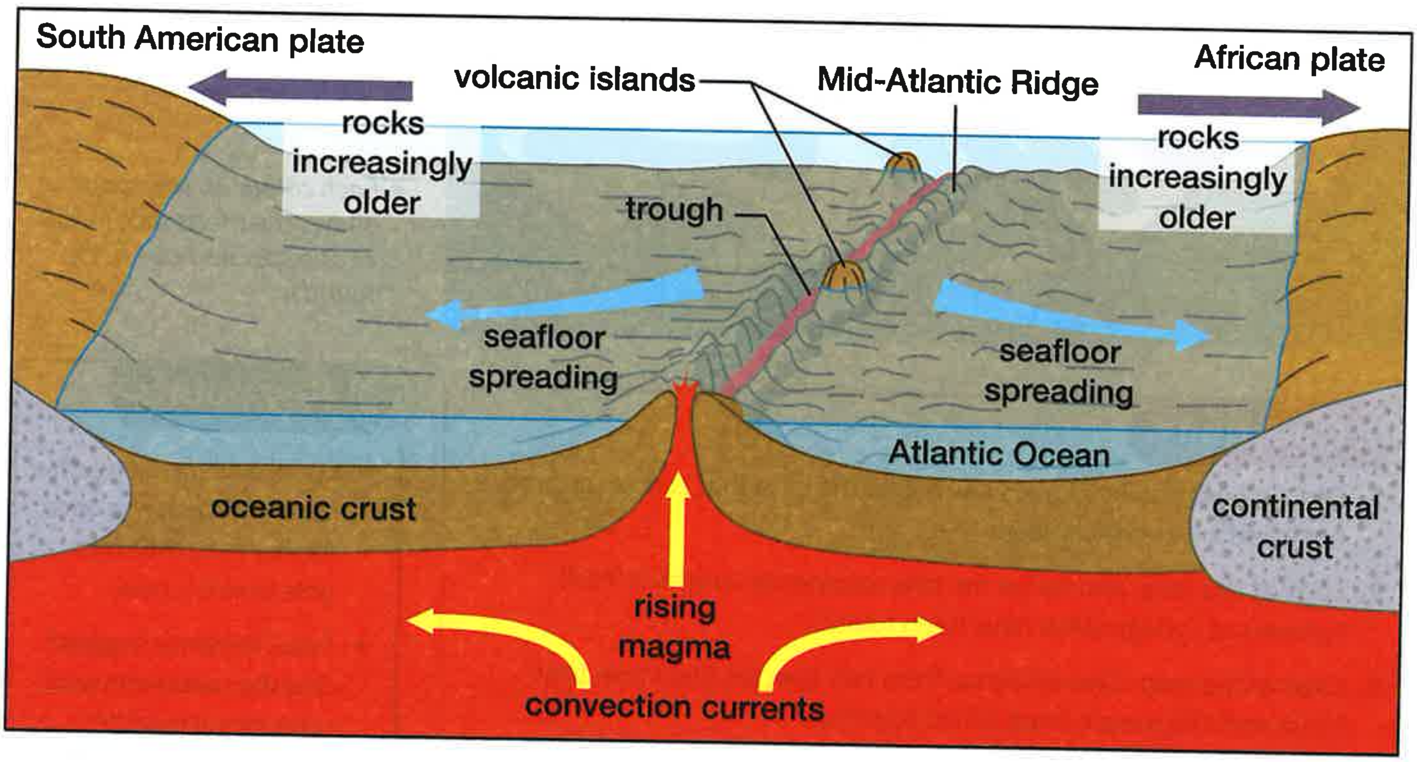


▲ *A mid-oceanic ridge.*

The answer came when scientists started to investigate the seafloor in the 1950s. They were amazed to find mountain chains under the oceans. They called the seabed mountains **oceanic ridges**. This map shows the Mid-Atlantic Ridge.

How are oceanic ridges formed?

Scientists wondered how oceanic ridges are formed. It turns out that the seafloor moves away on the two sides of an oceanic ridge. This is called **seafloor spreading**. The diagram shows how this happens.



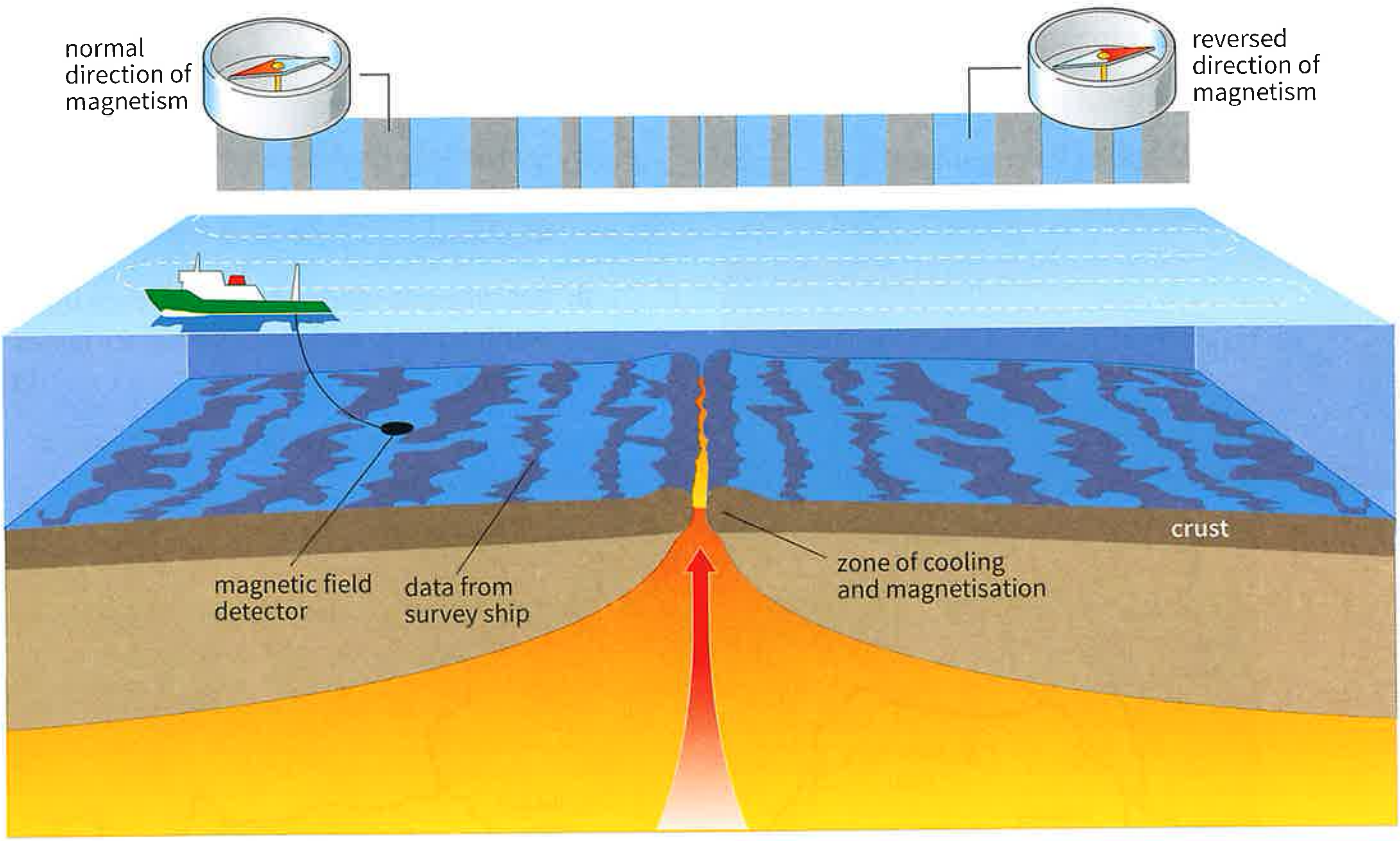
Magnetic stripes

At an oceanic ridge, hot liquid rock – magma – cools and freezes. This makes new rock. Much magma is rich in iron compounds. This magma forms rock that is magnetised in the direction of the Earth's magnetic field.

Every now and again, the Earth's magnetic poles flip. The magnetic North pole becomes the magnetic South pole, and the magnetic South pole becomes the magnetic North pole. Rock formed in these times is magnetised in the opposite direction.

The pattern of symmetrical stripes in the rock on both sides of mid-ocean ridges is evidence for seafloor spreading. By 1966, many scientists knew about this evidence. They understood *how* the continents could drift apart. They accepted the idea of plate tectonics.

▼ *Rock magnetism on the two sides of the oceanic ridge has the same stripe pattern.*



Questions

1. Write definitions for the terms *oceanic ridge* and *seafloor spreading*.
2. Explain how seafloor spreading occurs.
3. Explain why there is a pattern of magnetic stripes on the two sides of a mid-ocean ridge.

Key points

- An oceanic ridge is a mountain chain on the ocean floor.
- Seafloor spreading is the movement of the seafloor away from the two sides of an oceanic ridge.
- The symmetrical pattern of stripes in the rock on the two sides of a mid-ocean ridge is evidence for seafloor spreading.

Review 13.4

You may need to refer to Chapter 6 to help you to answer some of the questions.

1. This question is about tectonic plates.

   a. Give the approximate number of tectonic plates on the Earth. **[1]**

   b. Give the state of the rock in a tectonic plate. **[1]**

   c. Compare the density of a tectonic plate to the density of the mantle below it. **[1]**

   d. Explain how tectonic plates move. **[2]**

2. This question is about continental drift.

   a. Write the definition for continental drift. **[1]**

   b. Fossilised leaves have been found in Antarctica.

   Explain how the fossils are evidence that Antarctica was once not at the South Pole. **[1]**

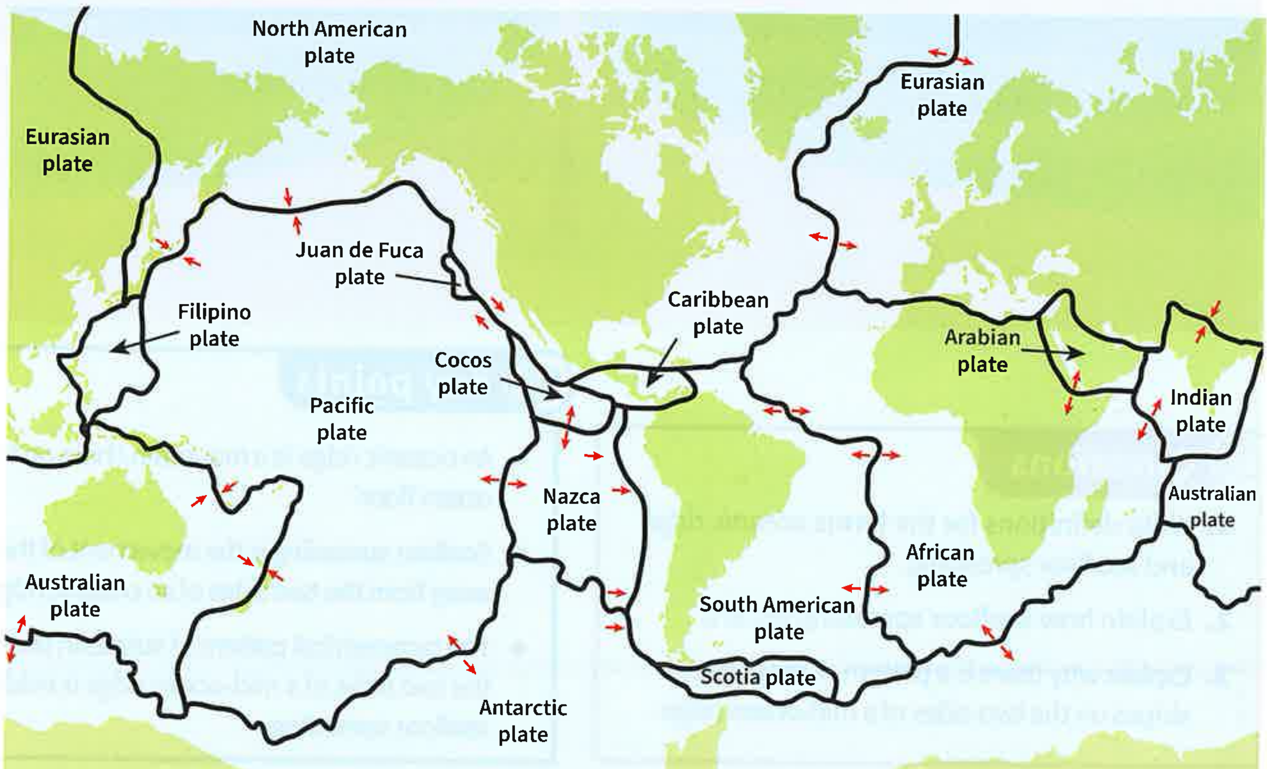
   c. The picture on the stamp shows what an extinct animal, *Cynognathus*, might have looked like.

   Fossilised remains of *Cynognathus* have been found on two continents, South America and Africa.

   i. Explain how the fossils are evidence that South America and Africa were once joined together. **[1]**

   ii. Describe one other piece of evidence that South America and Africa were once joined together. **[1]**

3. Use the tectonic plate map below to help you to answer this question.



a. Find the Pacific plate and the Nazca plate on the map. State whether the two plates are moving towards each other or away from each other. **[1]**

b. There is an oceanic ridge on the Pacific–Nazca plate boundary.

i. Give the definition for an oceanic ridge. **[1]**

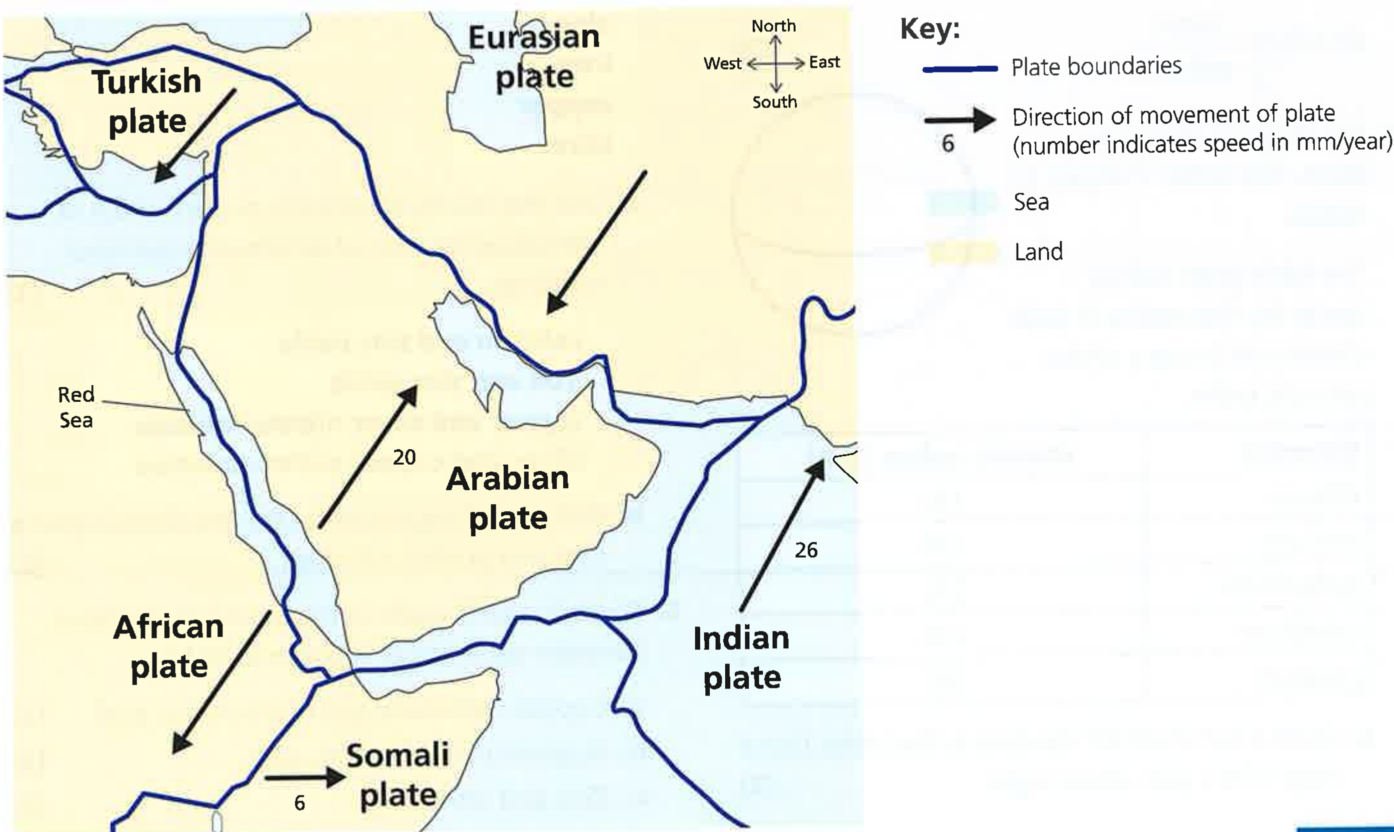
ii. An oceanic ridge forms from magma that rises up, between the two plates. Name the change of state that happens when the magma cools and becomes solid. **[1]**

c. Find the South American plate on the map.

i. State whether the South American plate is moving towards, or away from, the Nazca plate. **[1]**

ii. Describe how mountains formed on the West (left) of South America. You may need to look at Unit 6.3 to help you to answer this question. **[2]**

4. Use the map below to help you to answer this question. The map shows some minor tectonic plates, which are not labelled on the world map above.



a. Explain why the Red Sea is getting wider. **[3]**

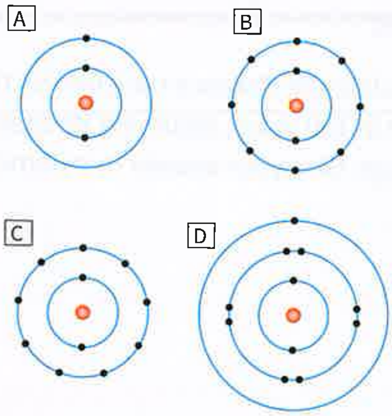
b. There is a mountain chain on the boundary of the Arabian and Eurasian plates. Use information from the map to explain why. **[3]**

c. Explain why there are frequent earthquakes on the boundary of the Arabian and Turkish plates. **[1]**

d. Calculate the distance travelled by the Arabian plate in 100 years, assuming its speed does not change. Give your answer in millimetres. **[2]**

Stage 9 Review

1. A student draws the electron configurations of four atoms.



a. Which electron arrangement is incorrect? **[1]**

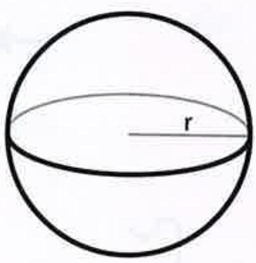
b. Which two elements are in the same group of the periodic table? **[1]**

c. Which element has a proton number of 10? **[1]**

2. A student has a block of chromium. Its volume is 4 cm³. It has a mass of 28 g. Use the equation below to calculate its density.

$$density = \frac{mass}{volume}$$ **[3]**

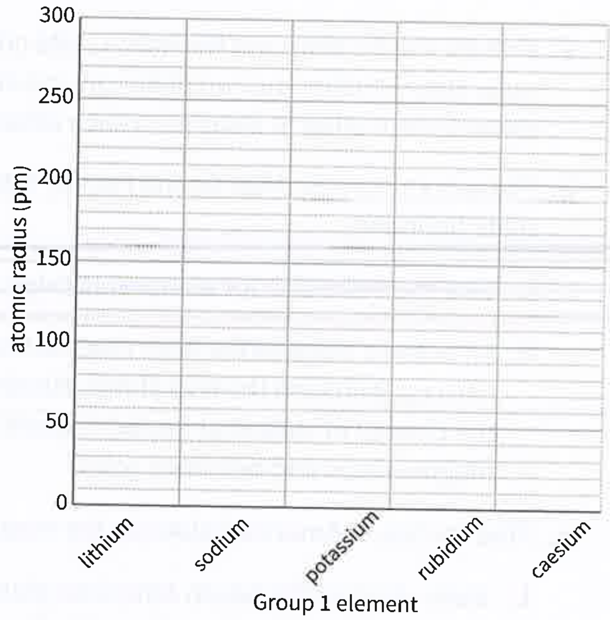
3. The diagram shows an atom. The letter 'r' shows its radius.



The table gives radius values for the atoms of each element in Group 1 of the periodic table.

Element	Atomic radius (pm)
lithium	152
sodium	186
potassium	231
rubidium	244
caesium	262

a. Draw a bar chart for the data in the table. Use a copy of the axes above right. **[3]**



b. Describe the pattern shown on the graph. **[1]**

c. The radius of a sodium ion, Na^+, is 95 pm.

i. Compare the radius of a sodium ion to a sodium atom. **[1]**

ii. Suggest a reason for the difference in radius of a sodium ion and a sodium atom. In your answer, include diagrams of the electron configurations of the atom and ion. **[3]**

4. Part of the reactivity series is given below.

calcium
zinc
iron
copper
silver

a. Use the reactivity series to predict which of the following pairs of substances can react together. **[1]**

calcium and zinc oxide
iron and zinc oxide
copper and silver nitrate solution
silver and copper sulfate solution

b. Write word equations for the reactions in part **a** that you predict will react. **[2]**

5. Name the salts made in the chemical reactions between each pair of substances below.

a. Copper carbonate and hydrochloric acid **[1]**

b. Magnesium and sulfuric acid **[1]**

c. Zinc and nitric acid **[1]**

d. Zinc carbonate and hydrochloric acid **[1]**

6. Copy and complete the word equation below.

   a. magnesium + nitric acid ⟶ [1]

   b. zinc + sulfuric acid ⟶ [1]

   c. magnesium + hydrochloric acid ⟶ [1]

   d. copper carbonate+ hydrochloric acid ⟶ [1]

7. Zara wants to make zinc chloride. She adds zinc to hydrochloric acid, until a little zinc remains unreacted. Then she filters the mixture.

   a. Explain why she filters the mixture. [1]

   b. Describe how Zara can make zinc chloride crystals from zinc chloride solution. Use the words *evaporation* and *crystallisation* in your answer. [4]

8. A scientist investigates the question *How does temperature affect the speed of rusting?* She places six identical iron nails in boiling tubes. The nails are exposed to both air and water. She places each boiling tube in an oven or fridge at a different temperature. She observes the nails regularly.

   Her results are in the table.

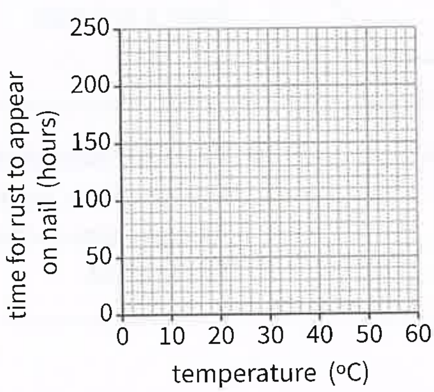
Temperature (°C)	Time for rust to appear on iron nail (hours)
10	240
20	120
30	100
40	30
50	15
60	7

   a. Finish labelling the axes on a copy of the graph axes below. [2]

   b. Plot the data in the table on your graph. [2]

   c. Draw a line of best fit. [1]

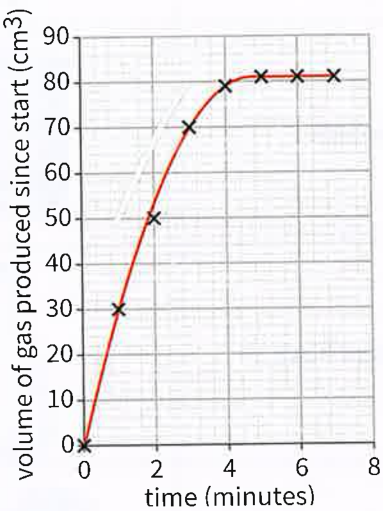
   d. Draw a circle around the anomalous result. [1]



9. Abbas investigates the reaction of zinc with hydrochloric acid. He pours 25 cm^3 of the acid into a conical flask. He adds small pieces of zinc. He collects the gas in a syringe.

   a. The products of the reaction are zinc chloride and hydrogen. Write a word equation for the reaction. [1]

   b. Abbas measures the volume of gas collected every minute. He plots a graph of his results.



   i. Between which times is the reaction fastest? Choose from the list below. [1]

   Between 0 and 1 minute. Between 2 and 3 minutes. Between 3 and 4 minutes.

   ii. After how many minutes does the reaction finish? [1]

   iii. What is the total volume of gas made in the investigation? [1]

   c. Abbas wants to find out how the rate of reaction changes if he increases the concentration of acid.

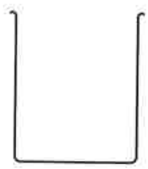
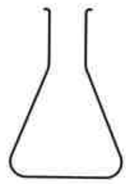
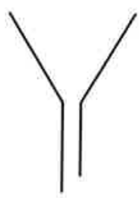
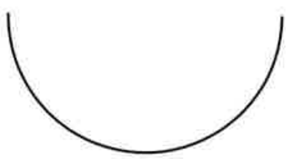
   i. Name two variables he should keep the same in his investigation. [2]

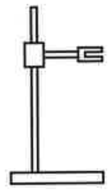
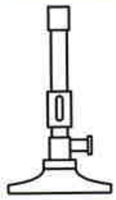
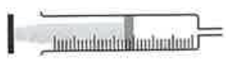
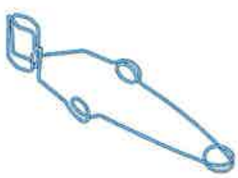
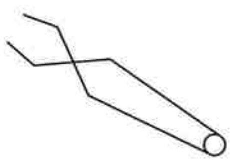
   ii. Explain why he should keep these variables the same. [1]

Reference 1

Choosing apparatus

There are many different types of scientific apparatus. The table below shows what they look like, how to draw them, and what you can use them for.

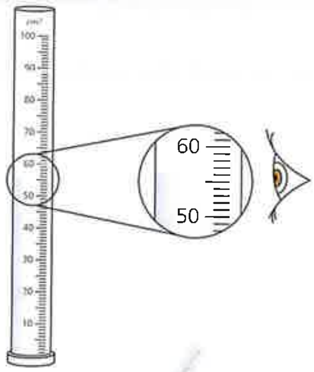
Apparatus name	What it looks like	Diagram	What you can use it for
test tube			• heating solids and liquids • mixing substances • small-scale chemical reactions
boiling tube			• a boiling tube is a big test tube; you can use it for doing the same things as a test tube
beaker			• heating liquids and solutions • mixing substances
conical flask			• heating liquids and solutions • mixing substances
filter funnel			• to separate solids from liquids, using filter paper
evaporating dish			• to evaporate a liquid from a solution
condenser			• to cool a substance in the gas state, so that it condenses to the liquid state

stand, clamp, and boss			• to hold apparatus safely in place
Bunsen burner			• to heat the contents of beakers or test tubes • to heat solids
tripod			• to support apparatus above a Bunsen burner
gauze			• to spread out thermal energy from a Bunsen burner • to support apparatus, such as beakers, over a Bunsen burner
pipette			• to transfer liquids or solutions from one container to another
syringe			• to transfer liquids and solutions • to measure volumes of liquids or solutions
spatula			• to transfer solids from one container to another
tongs and test tube holders			• to hold hot apparatus, or to hold a test tube in a hot flame

Reference 2

Working accurately and safely

You need to make accurate measurements in science practicals. You will need to choose the correct measuring instrument, and use it properly.



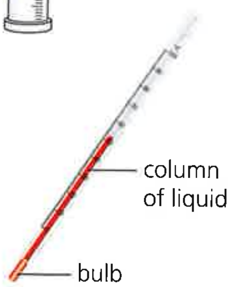
Measuring cylinder

Measuring cylinders measure volumes of liquids or solutions. A measuring cylinder is better for this job than a beaker because it measures smaller differences in volume.

To measure volume:

1. Place the measuring cylinder on a flat surface.
2. Bend down so that your eyes are level with the surface of liquid.
3. Use the scale to read the volume. You need to look at the bottom of the curved surface of the liquid. The curved surface is called the **meniscus**.

Measuring cylinders measure volume in cubic centimetres, cm^3, or millilitres, ml. One cm^3 is the same as one ml.



▲ *The different parts of a thermometer.*

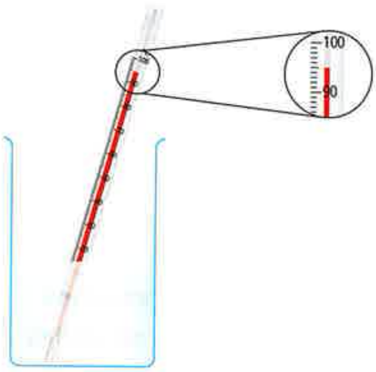
Thermometer

The diagram to the left shows an alcohol thermometer. The liquid expands when the bulb is in a hot liquid and moves up the column. The liquid contracts when the bulb is in a cold liquid.

To measure temperature:

1. Look at the scale on the thermometer. Work out the temperature difference represented by each small division.
2. Place the bulb of the thermometer in the liquid.
3. Bend down so that your eyes are level with the liquid in the thermometer.
4. Use the scale to read the temperature.

Most thermometers measure temperature in degrees Celsius, °C.



▲ *The temperature of the liquid is 95 °C.*

▲ *The balance measures mass.*

Balance

A **balance** is used to measure mass. Sometimes you need to find the mass of something that you can only measure in a container, like liquid in a beaker. To use a balance to find the mass of liquid in a beaker:

1. Place the empty beaker on the pan. Read its mass.
2. Pour the liquid into the beaker. Read the new mass.
3. Calculate the mass of the liquid like this:

   (mass of liquid) = (mass of beaker + liquid) – (mass of beaker)

Balances normally measure mass in grams, g, or kilograms, kg.

Working safely

Hazard symbols

Hazards are the possible dangers linked to using substances or doing experiments. Hazardous substances display **hazard symbols**. The table shows some hazard symbols. It also shows how to reduce risks from each hazard.

Hazard symbol	What it means	Reduce risks from this hazard by...
	Corrosive – the substance attacks and destroys living tissue, such as skin and eyes.	• wearing eye protection • avoiding contact with the skin
	Irritant – the substance is not corrosive, but will make the skin go red or form blisters.	• wearing eye protection • avoiding contact with the skin
	Toxic – can cause death, for example, if it is swallowed or breathed in.	• wearing eye protection • wearing gloves • wearing a mask, or using the substance in a fume cupboard
	Flammable – catches fire easily.	• wearing eye protection • keeping away from flames and sparks
	Explosive – the substance may explode if it comes into contact with a flame or heat.	• wearing eye protection • keeping away from flames and sparks
	Dangerous to the environment – the substance may pollute the environment.	• taking care with disposal

Other hazards

The table does not list all the hazards of doing practical work in science. You need to follow the guidance below to work safely. Always follow your teacher's safety advice, too.

- Take care not to touch hot apparatus, even if it does not look hot.
- Take care not to break glass apparatus – leave it in a safe place on the table, where it cannot roll off.
- Support apparatus safely. For example, you might need to weigh down a clamp stand if you are hanging heavy loads from the clamp.
- If you are using an electrical circuit, switch it off before making any change to the circuit.
- Remember that wires may get hot, even with a low voltage.
- Never connect wires across the terminals of a battery.
- Do not look directly at the Sun, or at a laser beam.
- Wear eye protection – whatever you are doing in the laboratory!

Glossary

Accurate Accurate data is data that is close to the true value.

Acidic A solution is acidic if its pH is less than 7.

Acidity A chemical property that describes how acidic a substance is.

Alkaline A solution is alkaline if its pH is greater than 7.

Alkalinity A chemical property that describes how alkaline a substance is.

Alloy A mixture of a metal with one or more other elements.

Analogy A comparison between one thing and another that helps to explain something. It can be used as a model.

Atom The smallest part of an element that can exist.

Atomic number The number of protons in an atom of an element. Also called the proton number.

Balancing number The balancing numbers in a chemical equation show the ratio of the numbers of particles of the reactants and products. A balancing number is written to the left of its chemical formula.

Boiling The change of state from liquid to gas that only happens if the liquid is hot enough.

Boiling point The temperature at which a substance boils.

Brittle A material is brittle if it breaks easily when hit with a hammer.

Changes of state The change that happens when a substance changes from one state to another.

Chemical formula The chemical formula of a substance gives the relative number of atoms of each element in the substance.

Chemical properties Properties that describe how substances change in chemical reactions.

Chemical reaction A change in which atoms are rearranged and join together differently to make new substances.

Chemical symbol The internationally recognised one- or two-letter code for an element.

Chromatography A method to separate and identify the substances in a mixture. It works if all the substances in a mixture dissolve in the same solvent.

Collaborate To work together.

Combustion reaction A burning reaction, in which a substance reacts quickly with oxygen and gives out light and heat.

Compound A substance made up of atoms of two or more substances, strongly joined together.

Compress Make smaller by pressing.

Concentrated A solution containing a large amount of solute dissolved in a solvent.

Concentration The amount of solute that is dissolved in a certain volume of solution or solvent.

Condensing or condensation The change of state from gas to liquid.

Conductor A substance that allows heat and/or electricity to pass through it easily.

Continental drift The movement of tectonic plates over millions of years.

Corrosion A chemical reaction that happens slowly on the surface of a metal.

Covalent bond A shared pair of electrons that holds two atoms together.

Crust The outer layer of the Earth, made of solid rock.

Density The mass of a material in a certain volume. It is calculated using the formula $density = \frac{mass}{volume}$.

Desalination The process of removing salt from seawater.

Dilute A solution containing a small amount of solute dissolved in a large volume of solvent.

Ductile A material is ductile if it can be pulled into wires.

Electron A tiny sub-atomic particle with a negative charge that moves around in an atom, outside the nucleus. It has a single negative charge. Its relative mass is $\frac{1}{2000}$.

Electron configuration The arrangement of electrons in an atom or ion.

Element A substance that is made of one type of atom that cannot be split into other substances.

Endothermic change A physical or chemical change that transfers energy from the surroundings to the reaction mixture.

Energy conservation Energy is never made or lost but can be transferred from one form to another, although this is not always a form that can be used.

Evaporating or evaporation The change of state from liquid to gas that can happen at any temperature.

Exothermic change A physical or chemical change that transfers energy to the surroundings from the reaction mixture.

Flammable If a material burns easily, it is flammable.

Fold mountains Mountains that form when tectonic plates push together.

Freezing The change of state from liquid to solid.

Giant covalent structure A three-dimensional network of atoms that are joined together by covalent bonds.

Giant ionic structure The three-dimensional structure of positive and negative ions in an ionic compound.

Giant metallic structure A three-dimensional pattern of positive metal ions held together by moving electrons.

Group 1 The elements in the left column of the periodic table – lithium, sodium, potassium, rubidium, caesium.

Group 2 The elements in the second column of the periodic table – beryllium, magnesium, calcium, strontium, barium.

Hazard A possible source of danger.

Hazard symbol A warning symbol on a substance that shows what harm it might cause if not handled properly.

Indicator A solution of a dye that turns a different colour in acidic and alkaline solutions.

Inert A substance is inert if it does not take part in chemical reactions.

Inner core The solid iron and nickel at the centre of the Earth.

Insoluble A substance is insoluble in a solvent if it cannot dissolve in the solvent.

Insulator A substance that does not conduct electricity is an insulator.

Ion A particle with a positive or negative charge, formed when an atom loses or gains electrons.

Ionic bonding The electrostatic attraction between positive and negative ions in a giant ionic structure. Ionic bonds act in all directions.

Ionic compound A compound made up of ions. Most compounds made up of a metal and a non-metal are ionic.

Isotopes Atoms of the same element that have different numbers of neutrons are called isotopes.

Lava Liquid rock that is on, or above, the surface of the Earth.

Malleable A material is malleable if it can be hammered into shape without cracking.

Mantle The layer of the Earth beneath the crust. It is solid but can flow slowly. It goes down almost halfway to the centre of the Earth.

Mass conservation Mass is conserved when the total mass of the substances before a change is equal to the total mass of the substances after the change. Mass is conserved in changes such as chemical reactions, dissolving, and changes of state.

Mass number The total number of protons and neutrons in an atom.

Materials The different types of matter that things are made from.

Melting The change of state from solid to liquid.

Melting point The temperature at which a substance changes from the solid to the liquid state.

Metal An element on the left of the stepped line of the periodic table. Most metals are good conductors of heat and electricity.

Metal displacement reaction In a metal displacement reaction, a more reactive metal displaces (pushes out) a less reactive metal from its compound.

Mineral salts/minerals Dissolved compounds needed by plant and animal cells to grow and remain healthy.

Mixture A mixture contains two or more substances that are not joined together.

Model A way of representing something that you cannot see or experience directly. A model may be a physical model built on a different scale to the original system, or it may take the form of equations.

Model of plate tectonics The model that suggests that the Earth's crust and uppermost mantle are made of about 12 slabs of solid rock. It can explain earthquakes, volcanoes and the formation of some mountains.

Molecule A particle made up of two or more atoms, strongly joined together.

Neutral (1) A solution is neutral if its pH is 7 – for example, pure water is neutral. (2) A particle is neutral if it is neither positively nor negatively charged, for example an atom of an element or a neutron in the nucleus of an atom.

Neutralisation A type of chemical reaction in which an alkali reacts with an acid and the pH gets closer to 7.

Neutron A tiny sub-atomic particle with no charge that is found in the nucleus of an atom. The relative mass of a neutron is 1.

Non-metal An element on the right of the stepped line of the periodic table. Most non-metals do not conduct heat or electricity.

Nucleon number The total number of protons and neutrons in an atom.

Nucleons Protons and neutrons.

Nucleus The central part of an atom, made up of protons and neutrons.

Oceanic ridge A mountain chain on the sea floor.

Ore A rock that a metal can be extracted from.

Outer core The liquid iron and nickel between the Earth's mantle and inner core.

Particle model This describes the arrangement and movement of particles in a substance.

Particles The tiny pieces of matter that everything is made from.

Peer review The checking of scientific research by other experts.

Physical properties Properties that you can observe or measure without changing a material.

Precipitate A suspension of tiny solid particles mixed with a liquid or solution.

Precipitation reaction A chemical reaction in which two reactants in solution react together to make a precipitate.

Products The substances that are made in a chemical reaction.

Properties The properties of a substance describe what it is like and what it does.

Proton A tiny sub-atomic particle with a positive charge that is found in the nucleus of an atom. The relative mass of a proton is 1.

Proton number The number of protons in an atom of an element. Also called the atomic number.

Pure substance A substance that consists of one substance only. It is not mixed with anything, and all its particles are identical.

Purity This describes how much of a substance is in a mixture.

Rate of a reaction The rate of a chemical reaction is the amount of reactant used up, or the amount of product made, in a given time.

Reactants The starting substances in a chemical reaction.

Reactivity series A list of metals in order of how readily they react with other substances, such as water, oxygen, and dilute acids.

Reactivity The tendency of a substance to take part in a chemical reaction.

Reliable You can obtain reliable data by making enough measurements.

Risk The chance of injury from a hazard. A combination of the probability that something will happen and the consequence if it did.

Salt A compound made when a metal ion replaces the hydrogen ion in an acid.

Saturated solution A solution in which no more solute can dissolve. The solution is in contact with undissolved solute.

Scientific question A question that can be answered using evidence or data.

Seafloor spreading The movement of the seafloor away from the two sides of an oceanic ridge.

Secondary data Evidence or data that has been collected by someone else.

Solubility The maximum mass of solute that can dissolve in 100 g of solvent.

Soluble A substance is soluble in a solvent if it can dissolve in the solvent.

Solute The substance that dissolves in a solvent to make a solution.

Solution A mixture that forms when a substance dissolves in a liquid.

Solvent In a solution, the liquid in which the solute is dissolved.

Sonorous Metals are sonorous – they make a ringing sound when hit.

States of matter Most substances can exist as a solid, liquid, or gas. These are the states of matter.

Steels Alloys of iron.

Strong A material is strong if a large force is needed to break it.

Sub-atomic particles The particles that make up an atom, including protons and neutrons in the nucleus, and electrons outside the nucleus.

Substance A material that has one type of matter.

Symbol equation A symbol equation uses chemical formulae to represent a chemical reaction. It shows the relative number of particles of each of the reactants and products.

Systematic review A systematic review uses repeatable methods to collect and analyse secondary data from many scientists.

Tectonic plates The 12 or so slabs of solid rock that make up the Earth's crust and uppermost mantle.

Universal indicator A mixture of dyes that changes colour to show how acidic or alkaline a solution is.

Vacuum A space that has no particles, and so no matter.

Vitamins Substances needed in tiny amounts in the diet to help chemical reactions take place in cells.

Volcano An opening in the Earth's crust that liquid rock and other materials escape from.

Word equation A word equation summarises a chemical reaction in words. It shows the reactants and products. The arrow means 'react to make'.

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The periodic table of the elements

1 H Hydrogen																		2 He Helium
3 Li Lithium	4 Be Beryllium												5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium												13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium		21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium		39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	53 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57-71 lanthanoids	71 Lu Lutetium	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89-103 aclinoids	103 Lr Lawrencium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrecium

Note: the numbers shown are the proton numbers of the elements.

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