Oxford KS3 Science

Activate

Question • Progress • Succeed

Chemistry

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OXFORD

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Contents

Introduction

Learning objectives

Each spread has a set of learning objectives. These tell you what you will be able to do by the end of the lesson.

Key Words

The key words in each spread are highlighted in bold and summarised in the key-word box. They can also be found in the Glossary.

Link

Links show you where you can learn more about something mentioned in the topic.

Summary Questions

1 Questions with one conical-flask symbol are the easiest.

2 The questions get harder as you move down the list.

3 The question with three conical-flask symbols is the hardest. In these questions you need to think about how to present your answer.
In QWC questions you need to pay attention to the Quality of Written Communication.

Welcome to your *Activate* Chemistry Student Book. This introduction shows you all the different features *Activate* has to support you on your journey through Key Stage 3 Chemistry.

Being a chemist is great fun. As you work through this Student Book, you'll learn how to work like a chemist, and get answers to questions that chemistry can answer.

This book is packed full of fantastic (and foul!) facts, as well as plenty of activities to help build your confidence and skills in chemistry.

Q These boxes contain short questions. They will help you check that you have understood the text.

Maths skills

Chemists use maths to help them solve problems and carry out their investigations. These boxes contain activities to help you practise the maths you need for chemistry. They also contain useful hints and tips.

Literacy skills

Chemists need to be able to communicate their ideas clearly. These boxes contain activities and hints to help you build your reading, writing, listening, and speaking skills.

Working scientifically

Chemists work in a particular way to carry out fair and scientific investigations. These boxes contain activities and hints to help you build these skills and understand the process so that you can work scientifically.

Fantastic Fact!

These interesting facts relate to something in the topic.

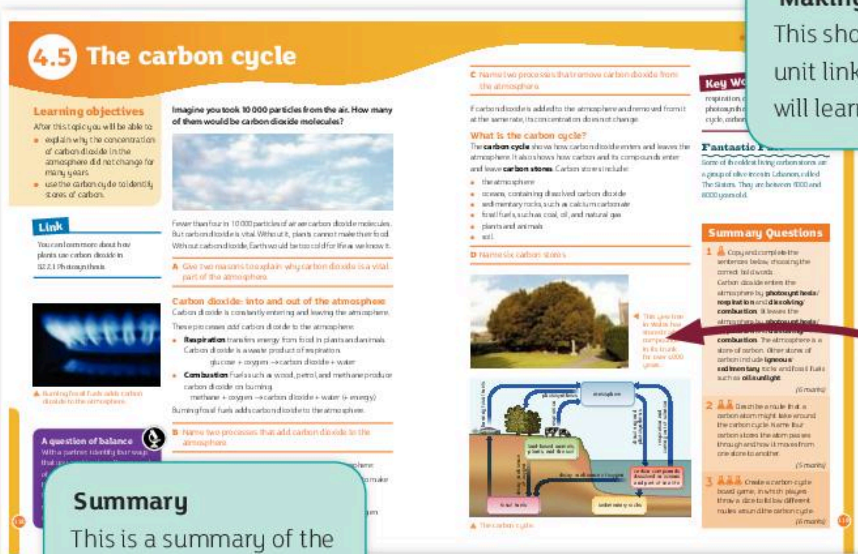
Opener
Each unit begins with an opener spread. This introduces you to some of the key topics that you will cover in the unit.

Picture Puzzlers
These puzzles relate to something in the unit – can you work out the answers?

You already know
This lists things you've already learnt that will come up again in the unit. Check through them to see if there is anything you need to recap on.

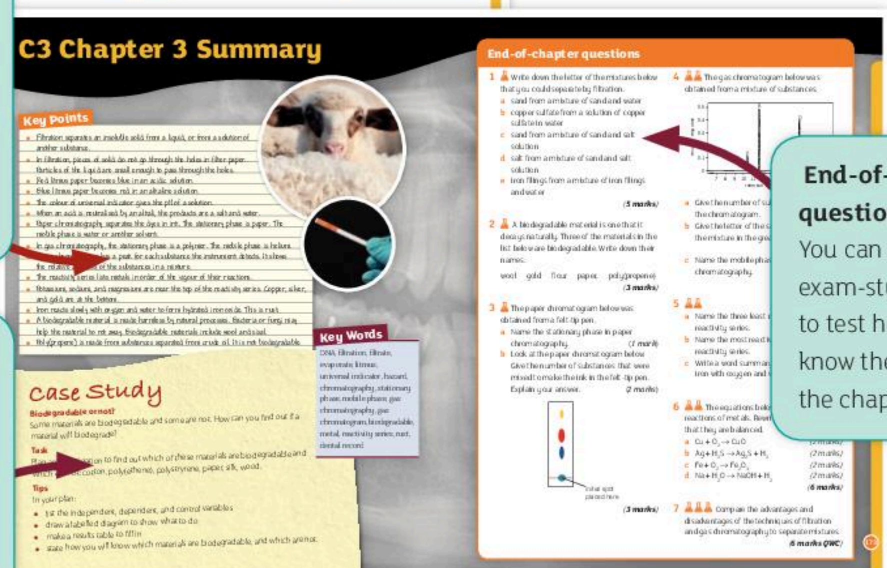
Big questions
These are some of the important questions in science that the unit will help you to answer.

Making connections
This shows how what you will learn in the unit links up with the science that you will learn in other parts of the course..



Topic spreads
Each topic in the chapter has a double-page spread containing learning objectives, practice questions, key words, and task boxes to help you work through the chapter.

Summary
This is a summary of the chapter. You can use it to check that you have understood the main ideas in the chapter and as a starting point for revision.



Big write/Maths challenge/Case study
This is an activity that you can do at the end of the chapter. It will help you to practise using your scientific skills and knowledge.

End-of-chapter questions
You can use these exam-style questions to test how well you know the topics in the chapter.

1.1 Asking scientific questions

Learning objectives

After this topic you will be able to:

- describe how scientists develop an idea into a question that can be investigated
- identify independent, dependent, and control variables.

▲ What affects the battery life of your mobile phone?

▲ The balls are changed every seven or nine games during a tennis match.

Why does the battery last longer in some mobile phones than others? What might mobile phones be like in the future? We can ask lots of different questions about the world. Some are questions that science can answer.

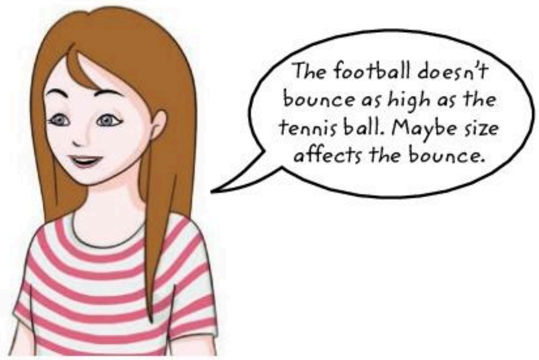
What's the question?

Scientists make **observations** of the world, and ask questions such as, 'How do fossil fuels form?' or 'Why are there are so many different animals on Earth?' These are scientific questions.

Scientists do **investigations**. They collect **data** to try to answer their questions.

Suggesting ideas

Tom and Katie are talking about balls used in sport.



Katie makes an observation about footballs and tennis balls. An observation can give you an idea that you can test in an investigation.

Developing ideas into questions

Tom watches a tennis match. New tennis balls are brought out from a refrigerator during the match.

Here are some questions that Katie and Tom might investigate:

- How does the size of a ball affect how high it bounces?
- How does the temperature of a ball affect how high it bounces?

What's a variable?

The size and temperature of the ball are not the only things that might affect the height of the bounce.

In science, anything that might affect the outcome of an investigation is called a **variable**. The thing that is affected as a result of the change is also a variable.

The temperature is the **independent variable**. It is independent because you change it. How high the ball bounces is the **dependent variable**. It is dependent because it changes when you change the temperature.

A State the two types of variable that you can change in an investigation.

Other variables

Katie and Tom think about all the other variables that might affect the bounce height. Here is their list:

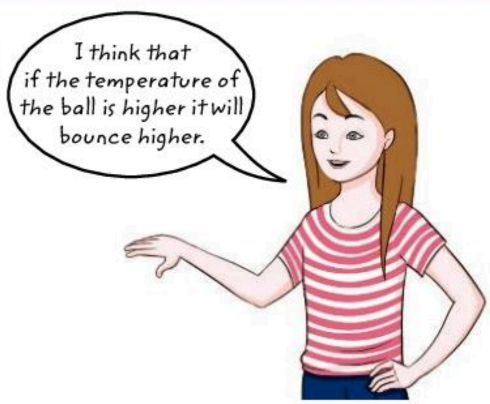
- the height you drop the ball from
- the type of ball
- the surface that you drop it onto
- the size of the ball

Katie and Tom need to keep these variables the same during their investigation so that they do not affect the bounce. These are called **control variables**.

B Name the type of variables that you keep the same in an investigation.

Making a prediction

Katie makes a **prediction** about what might happen. This is only part of the prediction. Katie should use her scientific knowledge to explain *why* she thinks that the ball will bounce higher.



Name those variables!

Imagine that you are going to investigate whether the size of a ball affects how high it bounces.

a State your dependent and indepedent variables.

b List all the variables that you would need to control.

Key Words

observation, investigation, data, variable, independent variable, dependent variable, control variable, prediction

Fantastic Fact!

Over 50 000 tennis balls are used during the Wimbledon tennis championship each year.

Summary Questions

1 Copy the sentences below, choosing the correct bold word.

You can turn an **idea/question** into an **idea/question** that you can investigate. You can answer some scientific **ideas/questions** by doing an investigation. You collect **data/observations** or make **data/observations**. Things that can change in an investigation are called **predictions/variables**. Science can answer **all/some** questions.

(7 marks)

2 A student is looking at an ice cube melting in a glass of water.

a Suggest a question that she could answer by doing an investigation. *(1 mark)*

b Explain why this is a question that science can answer.

(2 marks)

3 Suggest three questions that scientists could investigate about food, and three that they could not. Explain your choices.

(6 marks QWC)

1.2 Planning investigations

Learning objectives

After this topic you will be able to:

- describe how to write a plan for an investigation
- recognise what makes data accurate and precise
- describe a risk assessment.

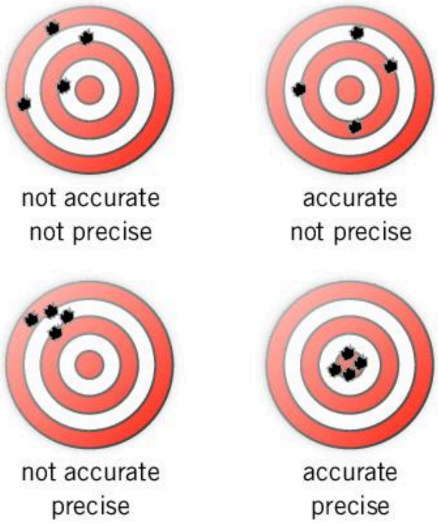
Have you ever cooked from a recipe? Did it turn out the way you wanted? The plan for an investigation or experiment is a bit like a recipe. It says what equipment and materials you are going to use, and what you are going to do with them.

Make a plan

Katie and Tom need to write a **plan** for their investigation. They need to think about how they will collect data to test their ideas. Their plan should include:

- what equipment they are going to use, and why
- what method they are going to use, and why.

A State two things that you need to include in an investigation plan.



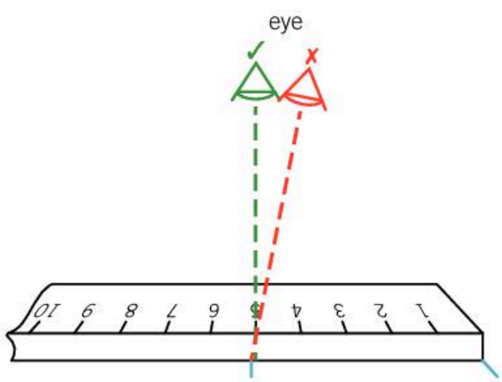
▲ Readings can be precise but not accurate.

Accurate and precise data

The measurements you make in an investigation are called data. It is important to collect data that is **accurate** and **precise**.

Accurate data is close to the true value of what you are trying to measure. For example, Tom needs to look directly at the ruler to get an accurate reading.

Precise data gives similar results if you repeat the measurement. Scientists talk about the **spread** of their sets of repeat data. Precise data has a very small spread when measurements are repeated. The repeat measurements in each set are grouped closely together.



▲ You should look straight at a scale to make an accurate measurement.

B State how to use a ruler accurately to measure length.

Uncertainty

If you look at a thermometer it might be hard to tell whether the temperature is 21.5 °C, 22.0 °C, or 22.5 °C. There is an **uncertainty** in your measurement because of the measuring instrument that you are using.

Repeatability and reproducibility

If Katie and Tom do the same investigation several times, or repeat a measurement in an investigation, the data should be similar. It is **repeatable**.

If other students do the same investigation they should get data similar to Katie and Tom. The data is **reproducible**.

Types of data

The data you collect might be words or numbers. Data can be:

- **continuous** – it can have any value, such as length or temperature
- **discrete** – it can have only whole-number values, such as number of paperclips or woodlice
- **categoric** – the value is a word, such as 'blue' or 'hot'.

How many measurements?

Katie and Tom need to plan what temperatures to test. They need to decide:

- the biggest and smallest temperatures – this is the **range**
- how many different temperatures they will test.

Is it safe?

A plan should also include a **risk assessment** . This explains how you will reduce the chance of damage to equipment, or injury to people.

What should a plan include?

Katie and Tom write a plan for their investigation. They include:

- the scientific question that they are trying to answer
- the independent and dependent variables
- a list of variables to control and how they will do it
- a prediction: what they think will happen and why
- a list of the equipment they will need
- a risk assessment
- how they will use the equipment to collect accurate and precise data.

Key Words

plan, accurate, precise, spread, uncertainty, repeatable, reproducible, continuous, discrete, categoric, range, risk assessment

Investigating dissolving

Does the temperature of water affect the mass of salt that dissolves in the water?

Write a plan to investigate this.

Summary Questions

1 Copy and complete the sentences below.

The plan for an investigation includes a list of the ______ that you will use and how you will use it. It shows how you will collect data that is ______, ______, ______, and ______. To make your investigation as safe as possible you need to do a ____ ________.

(6 marks)

2 A student investigates whether the type of surface affects the bounce of a ball.

a Explain why she should read the scale on the ruler by looking straight at it. *(2 marks)*

b Explain why the readings are not exactly the same when she repeats them. *(2 marks)*

c State and explain whether she needs to do a risk assessment. *(2 marks)*

3 Explain in detail why Katie and Tom's is a good plan.

(6 marks QWC)

1.3 Recording data

Learning objectives

After this topic you will be able to:

- describe how to make and record observations and measurements
- calculate a mean from repeat measurements
- present data appropriately in tables and graphs.

You usually collect data in a table. It is easier to see patterns in the data if you then draw a graph or chart.

Collecting data

Each time Katie and Tom change their independent variable they should take repeat measurements of their dependent variable.

Recording data

Katie and Tom make a table for their results. They need to record their measurements as they go, including all the repeat measurements.

A results table helps you to organise your data. This is Katie and Tom's results table:

Temperature	Height of bounce (cm)			
	1st Measurement	2nd Measurement	3rd Measurement	Mean
cold	45	40	35	40
warm	50	60	20	55
hot	65	75	70	70

A State the best way of recording data collected during an investigation.

Repeat readings

You should check your data for **outliers**. An outlier, or anomalous result, is a result that is very different to the others. You should repeat the measurement to replace an outlier.

In the table above, the third measurement for the warm temperature, 0.20 m, is an outlier. Katie and Tom do not include it when they work out the **mean**.

The mean is a type of average. You add up all the results and divide by the number of results. For example, the mean of the heights measured at the cold temperature in the table above is:

$$0.45\text{ m} + 0.40\text{ m} + 0.35\text{ m} = 1.2\text{ m}$$

then divide by 3 as there were 3 results:

$$\frac{1.2}{3} = 0.40\text{ m}$$

B State how to calculate the mean of a set of numbers.

Fantastic Fact!

The first ever tennis balls were hand stitched, so no two ever bounced in the same way.

Key Words

outlier, mean, line graph, bar chart, pie chart

Which graph?

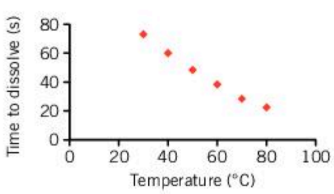
Tom and Katie have collected lots of data. They want to present their results in a graph or chart. To work out which graph or chart to plot you need to look at the variables in your investigation.

- If both your independent and your dependent variables are continuous, then you should plot a **line graph**.
- If your independent variable is categoric, you should plot a **bar chart**. In some cases you might want to display discrete or categoric data in a **pie chart**.
- For both line graphs and bar charts, you plot the independent variable on the *x* axis and the dependent variable on the *y* axis.

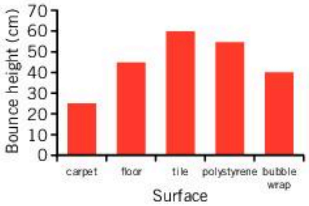
Temperature (°C)	Time to dissolve (s)
30	75
40	60

Surface	Height of bounce (cm)
Carpet	25
Floor	45

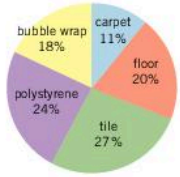
You plot a line graph:



You plot a bar chart:



... or a pie chart



C State what type of graph or chart you should plot if one of your variables is discrete.

When you draw a chart or plot a graph you should do the following:

- Choose scales for your axes so that your graph is as big as possible.
- Use a pencil and a ruler.
- Label the axes with the quantity and the unit, such as 'time (s)'.
- Write a title for your graph.

Dealing with results

A student investigated how fertiliser affects how high plants grow. Copy it and complete the final column of the table.

Mass of fertiliser (g)	Height of plant after 10 days (cm)			
	1st Measurement	2nd Measurement	3rd Measurement	Mean
2	3.2	3.7	3.6	
4	4.7	7.3	5.0	
6	5.1	5.5	5.3	

Summary Questions

1 Copy and complete the sentences below.

When you are collecting data you need to make sure that you are using ______ ______ correctly. You need to make ______ measurements to check that your data is repeatable. You need to look for ______, which are readings that are very different to the others. Then you calculate the ______.

(5 marks)

2 A student is investigating how the temperature of water affects how long it takes sugar to dissolve.

a Describe two things that he should do when collecting data. *(2 marks)*

b Draw a table that he could use for his results. *(2 marks)*

c State and explain the type of graph that he should draw. *(2 marks)*

3 Design a hint sheet for students carrying out investigations.

(6 marks)

1.4 Analysing data

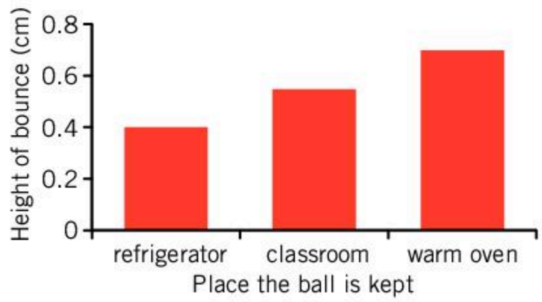
Learning objectives

After this topic you will be able to:

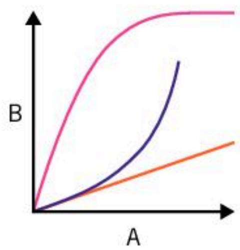
- find a pattern in data using a graph or chart
- interpret data to draw conclusions.

Katie and Tom have collected data and plotted a bar chart. Now they need to:

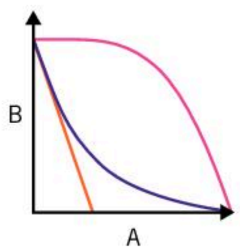
- work out what their graph tells them
- write a conclusion
- compare what they found out with their prediction.



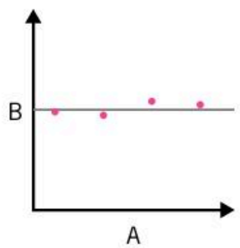
▲ Katie and Tom's bar chart.



In these graphs, if A increases then B increases.



In these graphs, if A increases then B decreases.



In this graph, if A increases B does not change.

Using graphs or charts

When you **analyse** your data, plotting a line graph or chart helps you to spot a pattern. It shows how the dependent variable depends on the independent variable.

Your scientific knowledge will help you suggest why the independent variable affects the dependent variable in this way.

Find a pattern on a line graph

Once you have plotted a line graph you need to draw a **line of best fit**. This is a line that goes through as many points as possible, with equal numbers of points above and below the line. If there are any outliers, you should ignore these when you draw your line of best fit.

A State what is meant by a line of best fit.

Writing a conclusion

Once you have analysed your graph you can write a **conclusion**.

State what you have found out

Start by saying what the investigation shows. Then describe any relationship you can see between the two variables. Use your graph to support your conclusion.

B State two things to include in your conclusion.

Key Words

analyse, line of best fit, conclusion

Tom and Katie look at their bar chart and start to write a conclusion:

Explain what you found out

Saying what your results show is only part of analysing results. You also need to use scientific knowledge to explain the pattern.

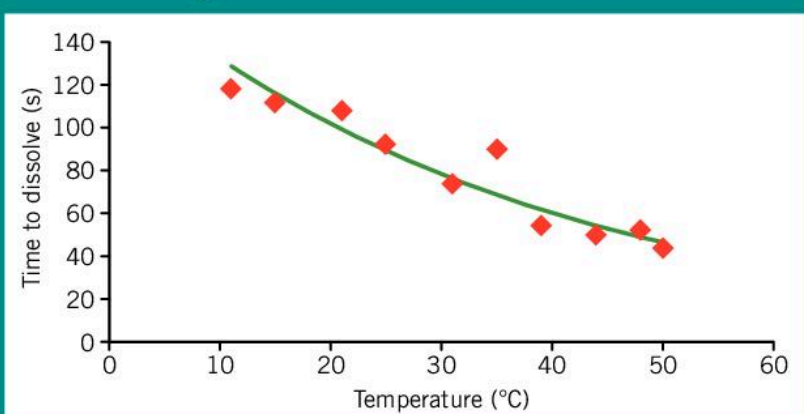
Tom begins to explain the relationship between temperature and the height of the bounce. However, to come up with a good explanation he needs to understand why balls bounce.

Comparing results with predictions

Finally, you can compare your results with your prediction.

What's the relationship?

A student plots a graph of water temperature and the time that it takes sugar to dissolve in the water.



Use information from the graph to describe what happens when you double the temperature of the water.

Link

You can learn more about why balls bounce in P1 1.1 Introduction to forces

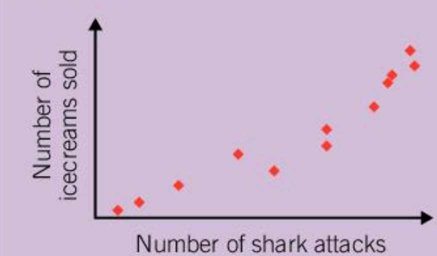
Summary Questions

1 Copy and complete the sentences below.

To analyse your data you plot a graph or chart and work out the ______ between the variables. Then you write a ______ that includes what you have found out, and explains why, using ______ ______. Finally you compare your results with your ______.

(5 marks)

2



A student has drawn a graph for an investigation into the relationship between the number of icecreams sold and the number of shark attacks in a certain period. Draw a flow chart to show how he should complete the analysis of his data and draw conclusions.

(4 marks)

3 Look at the graph in Question 2. Describe and explain in detail what the graph shows and suggest a conclusion that you can draw from the data.

(6 marks QWC)

1.5 Evaluating data

Learning objectives

After this topic you will be able to:

- describe the stages in evaluating data
- suggest ways to improve a practical investigation.

▲ Evaluating means working out what is good and what is not so good.

Key Words

evaluate, confidence, random error, systematic error

Katie and Tom have collected data and analysed it by plotting a bar chart. Now they need to evaluate their data and their methods.

There are two ways to **evaluate** your investigation. You should:

- discuss the quality of the data that you have collected
- suggest and explain improvements to your method so you can collect data of better quality if you did it again.

Your suggested improvements should increase the **confidence** that you have in your conclusion.

Evaluating the data

Katie and Tom look at their data. They had only one outlier in their experiment – the third measurement for 'warm'. If there were lots of outliers then they would have less confidence in their conclusion.

What's the spread?

The spread of data tells you how precise the data is. The spread is the difference between the highest and the lowest readings in a set of repeat measurements.

A State what is meant by the spread of a set of measurements.

In their experiment the measurements for one temperature do not overlap with the measurements for another. That makes the data very precise.

A small spread in the data will give you more confidence in your conclusion. You should discuss this in your evaluation.

Errors and uncertainty

There is uncertainty in any measurement that you make. This is one of the reasons why there is usually a spread in experimental data.

There are two types of error that can affect scientific measurements. These are:

- **random error** – this can affect the spread, or cause outliers. An example is the temperature of the room suddenly changing because someone opens a door.
- **systematic error** – this can make your measurements less accurate. An example is a newtonmeter reading 1 N even when there is nothing attached to it.

You should think about possible errors as well as the outliers and spread to help you to decide how confident you are in your conclusion.

Range and number of results

Tom and Katie only measured at three different temperatures. It would be better to have a wide range.

B State whether it is better to measure a wide range or a narrow range of values.

Suggesting improvements

You might get better data by:

- including a bigger range, or taking more readings
- using different apparatus – giving a smaller spread and fewer outliers.

Evaluating data

Ali and Emma do the same tennis-ball investigation as Katie and Tom. They produce this data:

Temperature (°C)	Height of bounce (cm)			
	1st Measurement	2nd Measurement	3rd Measurement	Mean
−4	25	27	45	
4	30	26	25	
20	42	59	49	
40	54	59	61	
60	65	42	71	

a Identify the outliers.

b Calculate the mean bounce height for each value of temperature.

c Comment on the spread of data for each value of temperature.

Improving data

Use your data to decide if your method was good, or could be improved. You should say how any improvements would make the data better.

Summary Questions

1 Copy and complete the sentences below.

When you evaluate your data you need to look at how many ______ you had. Then you need to look at the spread, which is the difference between the ______ and ______ reading within each set of repeat measurements. You need to look at the ______ and ______ of values. Finally, you can propose how to improve the ______ if you did it again.

(6 marks)

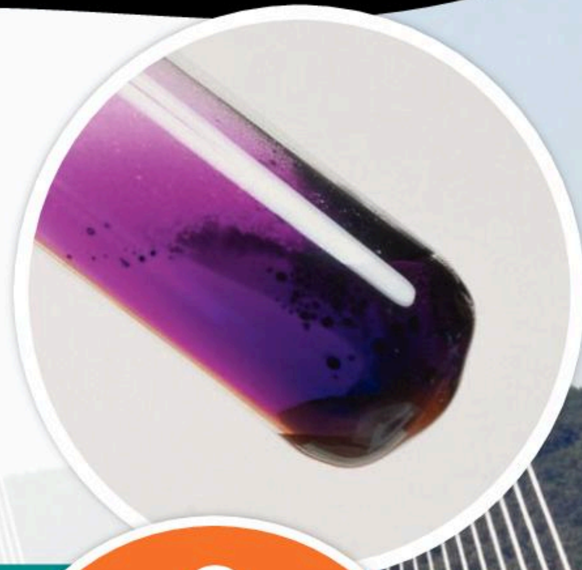
2

a State two ways that Katie and Tom could improve their data. *(2 marks)*

b Suggest one other way that they could improve the quality of their data. *(3 marks)*

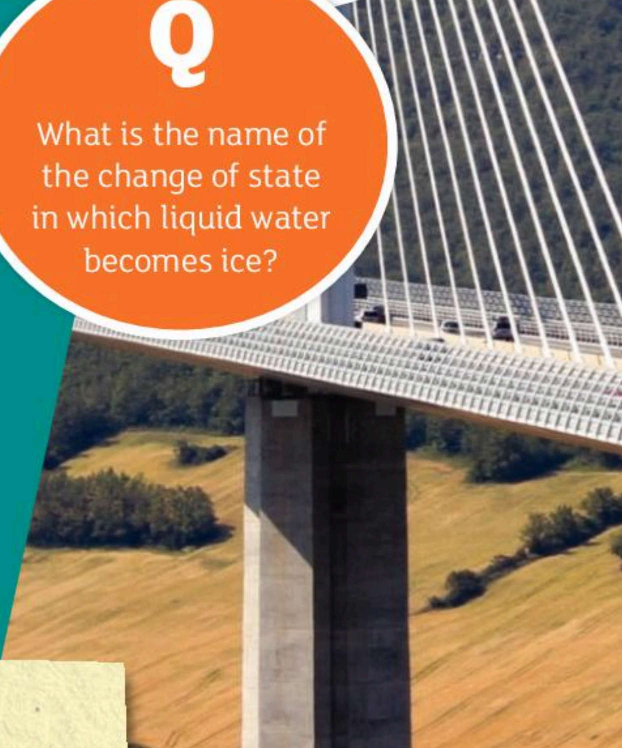
3 Explain how using a video camera could improve the quality of Katie and Tom's data. *(6 marks QWC)*

Chemistry 1



What is stuff made of? Everything is made up of chemicals – the food you eat, the plastic in your phone…and you! But what are these chemicals like inside, and why do they behave the way they do?

In C1 you will learn about the atoms that make up everything on Earth… and beyond. You will explore how chemical reactions make vital materials, and transfer energy for almost everything we do.



Q

What is the name of the change of state in which liquid water becomes ice?

You already know

- Different materials have different properties.
- The different properties of different materials make them suitable for different uses.
- Many materials can exist in the solid, liquid, and gas states.
- The state of a material depends on the temperature.
- Changes of state are reversible.
- Melting, freezing, evaporating, boiling, and condensing are changes of state.
- Changes that form new materials are not reversible.
- Changes that are not reversible include burning, oxidation, and reactions of acid.

BIG Questions

- What are materials like inside and why do they behave as they do?
- What are atoms and elements?
- How do scientists make new materials?

Picture Puzzler
Key Words



Can you solve this Picture Puzzler?

The first letter of each of these images spells out a science word that you will come across in this book.

Picture Puzzler
Close Up

Can you tell what this zoomed-in picture is?

***Clue**: It's a cold and frosty morning.*

Making connections

In **C1** you will learn about the particle model.

In **C2** you will learn how the particle model can be applied to solution chemistry.

In **C3** you will learn about the history and development of the atomic model.

1.1 The particle model

Learning objectives

After this topic you will be able to:

- describe how materials are made up of particles
- use the particle model to explain why different materials have different properties.

Look around you. Can you see things made of wood, plastic, or steel? The different types of stuff that things are made from are called materials. There are millions of materials.

What's in a material?

Materials are made up of tiny **particles**. You cannot see the particles. They are too small. There are about 8 400 000 000 000 000 000 000 000 particles in a glass of water.

A State what materials are made up of.

Are all particles the same?

Many materials are **mixtures**. Wood is a mixture. So is milk, and the air. But some materials are not mixtures. They consist of just one substance. A **substance** is made of just one type of material. Substances include gold, water, and oxygen.

▲ Gold is a single substance. All of its particles are the same.

▲ The bridge cables are made from steel. Steel is a mixture.

Fantastic Fact!

If people were the same size as gold particles, the world's population would fit into a ball less than a thousandth of a millimetre across.

In a substance, every particle is the same. One gold particle is the same as all other gold particles. One water particle is the same as all other water particles. In the air, all oxygen particles are identical.

But gold particles are not the same as oxygen particles. Oxygen particles are not the same as water particles. Every substance has its own type of particle.

B State what is meant by a substance.

What gives a substance its properties?

The **properties** of a substance describe what it looks like and how it behaves. Every substance has its own properties. The properties of a substance depend on its particles.

The table shows data for gold and water.

Substance	Relative mass of particle	Mass of 1 cm^3 of the substance (g)
gold	197	19
water	18	1

A gold particle has a greater mass than a water particle. This helps to explain why 1 cm^3 of gold weighs more than 1 cm^3 of water.

In liquid water, particles slide over each other. In an ice cube, the particles do not move around. This explains why you can pour water from a glass but you cannot pour water from an ice cube.

The properties of a substance depend on three things, or factors:

- what its particles are like
- how its particles are arranged
- how its particles move around.

C List three factors that give a substance its properties.

Vital vocab

Plan how to explain the meanings of the key words on this page. Present your explanations to a partner.

Key Words

material, particle, mixture, substance, property

Link

You can learn more about the arrangement and movement of particles in C1 1.2 States of matter

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

There are **hundreds/millions** of materials. Materials are made up of **practicals/particles**. A substance has **the same/different** properties all the way through. In a substance, all the particles are **the same/different**. The particles of different substances are **the same/different**. The properties of a substance describe its **behaviour/particles**.

(6 marks)

2 Use the data to estimate which is heavier, 10 cm^3 of water or 10 cm^3 of mercury. Show how you decided.

Data: relative mass of water particle = 18; relative mass of mercury particle = 201.

(2 marks)

3 Using all the key words, draw a visual summary to summarise and organise the information on this page.

(6 marks)

1.2 States of matter

Learning objectives

After this topic you will be able to:

- describe the properties of a substance in its three states
- use ideas about particles to explain the properties of a substance in its three states.

Do you like ice in cold drinks? An ice cube is made up of water particles. Ice is water in the solid state. Now imagine a steaming kettle. Steam is also made up of water particles. It is water in the gas state.

Water can exist in three states, as a **solid**, a **liquid**, or a **gas**. These are the **states of matter**. The particles of water in its three states are identical. But the properties of ice, liquid water, and steam are different. These pages explain why.

A Name the three states of matter.

How does state affect properties?

Most substances can exist in three states. The state of a substance depends on temperature. At room temperature, gold is solid. But if you make it hot enough, gold exists as a liquid or gas.

The table compares the properties of a substance in its three states.

State	Can you compress (squash) the substance in this state?	Does the substance flow?	Shape
solid	no	no	fixed, unless you apply a force
liquid	no	yes	takes the shape of the bottom of its container
gas	yes	yes	takes the shape of the whole container

B Identify three differences between a substance in the solid and liquid states.

How do particles explain properties?

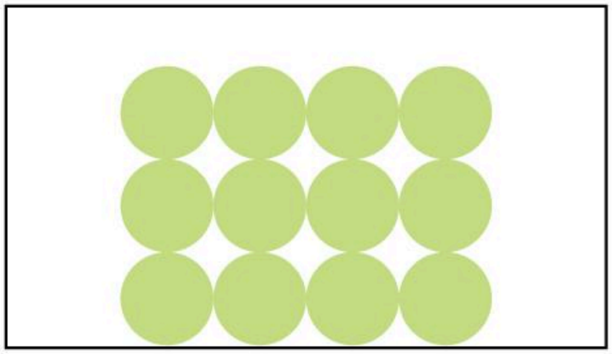
The particles of a substance do not change. All water particles are the same, in all three states. But the arrangement and movement of particles are different in each state.

The solid state

When a substance is in the solid state, its particles touch their neighbours. This explains why you cannot compress a solid. In the solid state, a substance's particles are arranged in a pattern.

▲ Ice is water in the solid state.

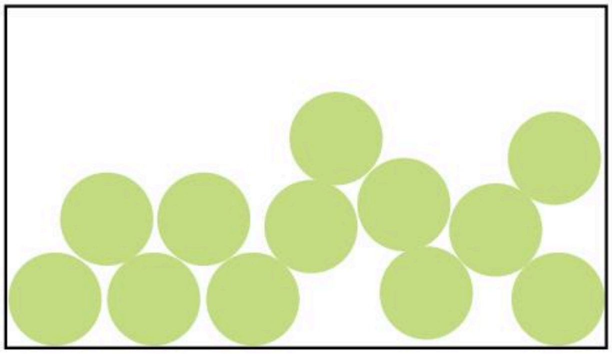
In the solid state, particles do not move around. They vibrate on the spot. This explains why solids cannot flow.



The particles of a substance in the solid state.

The liquid state

When a substance is in the liquid state, its particles touch their neighbours. This is why you cannot compress a liquid. The particles move from place to place, sliding over each other. This explains why liquids flow and why they have no fixed shape.

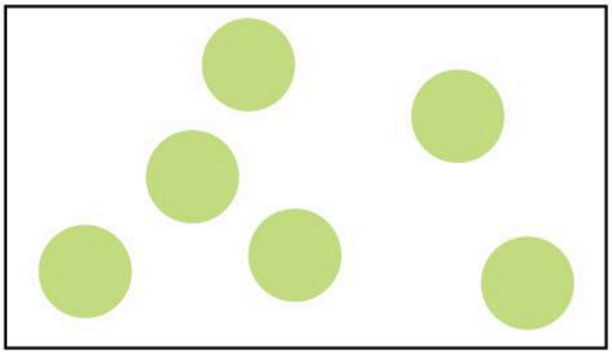


The particles of a substance in the liquid state.

C State why you cannot compress a liquid.

The gas state

In the gas state, particles spread out. So it is easy to compress a gas. The particles move throughout the whole container. This explains why gases flow.



The particles of a substance in the gas state.

Express particle?

In 2010 a Chinese train became the world's fastest passenger train. It reached a speed of 486 km/h (0.135 km/s). In the air, oxygen particles travel at about 500 m/s. Calculate which is faster – the train or the particles.

Key Words

solid, liquid, gas, states of matter

Summary Questions

1. Each sentence in the paragraph below has one or more mistakes. Write corrected versions of the sentences.

   There are two states of matter. You can compress a substance in the solid state because the particles touch each other. In the liquid and gas states, a substance flows because the particles cannot move from place to place. You cannot compress a gas because the particles are spread out.

   (4 marks)

2. Compare the properties of a substance in the liquid and gas states.

   (3 marks)

3. Use the particle model to explain in detail why the properties of water are different in its three states.

   (6 marks QWC)

1.3 Melting and freezing

Learning objectives

After this topic you will be able to:

- use the particle model to explain changes of state involving solids and liquids
- interpret data about melting points.

▲ Gallium metal is solid at room temperature. On a warm hand, it melts.

▲ Lava cools and freezes. This forms rock.

Imagine an ice cube in your hand. What happens?

When a substance changes from the solid to liquid state, it melts. **Melting** is a **change of state**. **Freezing** is the change of state from liquid to solid. Liquid gold freezes if cooled to 1063 °C.

A Name the two states involved in freezing.

Explaining melting and freezing

What happens when an ice cube melts? The surroundings transfer energy to the ice, so its particles vibrate faster. Particles move away from their places in the pattern. They continue to move around. As more particles leave the pattern, more ice melts.

When a liquid starts to freeze, its particles move more slowly as they transfer energy to the surroundings. The particles get into a pattern, and vibrate on the spot. Eventually, all the liquid freezes. The mass does not change when a substance melts or freezes. This is because no particles have been added or removed.

B Describe how particle movement changes when a substance melts.

What is a melting point?

The temperature at which a substance melts is its **melting point**.

Substance	Melting point (°C)
gallium	30
gold	1063
oxygen	–218
water	0

Melting points give information about the states of substances at different temperatures. The melting points of gallium and gold are above 20 °C. So at 20 °C, gallium and gold are solid. You cannot work out the state of oxygen from the data in the table.

C List the substances in the table in order of increasing melting point.

Key Words

melting, change of state, freezing, melting point

Using melting points

Identifying substances

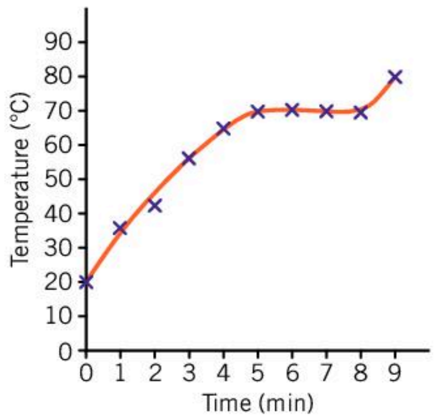
Jackson and Marcus are at university. They have three painkillers – paracetamol, aspirin, and ibuprofen. They do not know which is which. They use the Internet to find out their melting points. They record the data in the table shown on the right.

The students measure the melting point of one painkiller. It is 136 °C. They conclude that it is aspirin.

Substance	Melting point (°C)
paracetamol	169
aspirin	136
ibuprofen	76

Checking purity

A single substance has a sharp melting point. Stearic acid is solid at 20 °C. If you heat the acid, it stays solid up to 70 °C. Then it starts to melt. It stays at 70 °C until it has all melted. Then the liquid warms up.



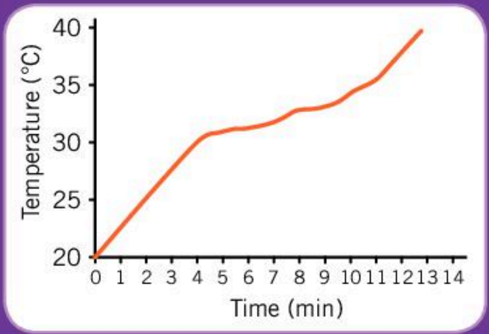
▲ The graph shows the temperature of stearic acid as it is heated.

A material that is a mixture of substances does not have a sharp melting point. Chocolate melts between 30 °C and 32 °C. This shows that it is a mixture.

▲ Apparatus used to measure melting points.

Butter wouldn't melt...

Look at the graph. Is butter a single substance or a mixture? Explain your decision.



Summary Questions

1 Copy the sentences below, choosing the correct bold words.

The change of state from solid to liquid is **freezing/melting**. As a substance melts, its particles vibrate **slower/faster**. The particles start moving **around/upwards**. The substance is now in the **liquid/solid** state. The melting point of a substance is the **speed/temperature** it melts at.

(5 marks)

2 A substance has a melting point of -7 °C. Tom says the substance is liquid at 20 °C. Ben says it could be liquid or gas. Explain who is correct. Use evidence to support your answer.

(3 marks)

3 Use the particle theory to explain in detail the difference between melting and freezing.

(6 marks QWC)

1.4 Boiling

Learning objectives

After this topic you will be able to:

- use the particle model to explain boiling
- interpret data about changes of state.

Close your eyes. Imagine water boiling. What can you hear? What can you see? When a substance is boiling it is changing from the liquid state to the gas state.

Explaining boiling

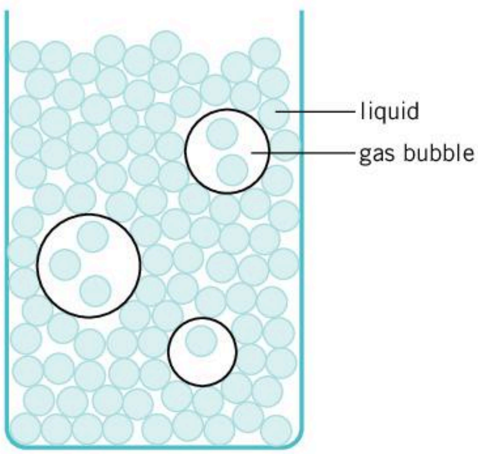
When water boils, bubbles of steam form all through the liquid. In the liquid, water particles touch their neighbours. Inside the bubbles, the water particles are spread out.

As water boils, the steam bubbles rise to the surface of the liquid. They escape into the air. The total mass of steam and water is the same as the mass of water at the start. Scientists say that mass is **conserved** in **boiling**.

A Name the substance in the bubbles in boiling water.

Link

You can learn more about evaporation in C2 2.5 Evaporation and distillation



▲ Boiling water.

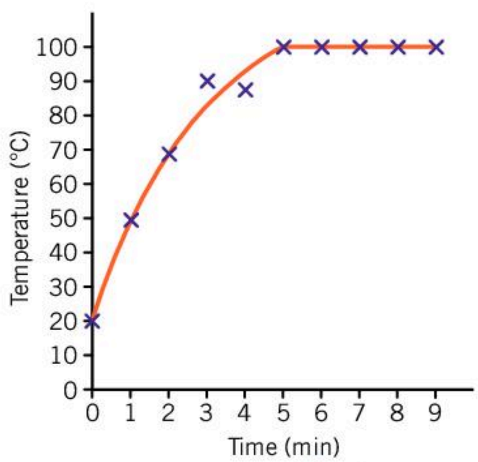
What is a boiling point?

Boiling happens if enough energy is transferred to the particles. Different substances need different amounts of energy to boil. This means that different substances boil at different temperatures. The temperature a substance boils at is its **boiling point**.

Measuring boiling point

You can measure the boiling point of a substance like this:

- Pour the liquid into a beaker.
- Heat the liquid, and measure the temperature every minute.
- Plot the results on a graph.



▲ A temperature–time graph for heating water.

Fantastic Fact!

The boiling point of a substance depends how high above the Earth's surface you are. At Mount Everest Base Camp (5364 m above sea level), water boils at 82 °C.

A student heated liquid water and plotted the graph shown on the opposite page. At first, the temperature increased. At 100 °C, the water bubbled vigorously. It was boiling. The temperature remained at 100 °C. This is the boiling point of water.

B State what is meant by the term boiling point.

Using boiling points

Identifying substances

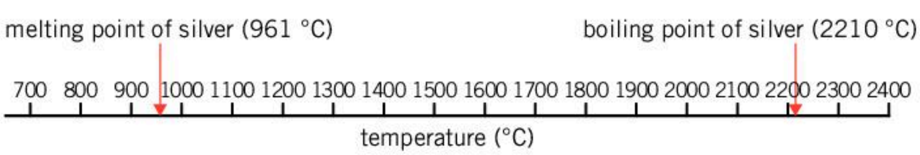
You can use data about boiling points to help identify substances. Lucy has a colourless liquid. Her teacher tells her it could be water, ethanol, or propanol. Lucy notes the boiling points of these substances in the table below.

Substance	Boiling point (°C)
water	100
ethanol	78
propanol	97

Lucy heats her liquid on an electric heater. She measures its temperature every minute. At 78 °C the liquid bubbles vigorously. It remains at 78 °C for several minutes. Lucy concludes that the liquid is ethanol.

Predicting states

If you know the melting point and the boiling point of a substance, you can predict its state at different temperatures. The melting and boiling points of silver are shown below.



At room temperature (20 °C), silver is in the solid state. At 961 °C, the melting point, silver exists as both a solid and a liquid. Between 961 °C and 2210 °C silver is a liquid. At 2210 °C, the boiling point, silver exists as both a liquid and a gas. Above 2210 °C silver exists in the gas state.

C Predict the state of silver at 1000 °C.

Mystery liquid

Sarah has a liquid. It could be water, ethanol, or propanol. Sarah heats the liquid. It bubbles vigorously at 97 °C. Use data from this page to suggest what the liquid might be.

Key Words

conserve, boiling, boiling point,

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

When a substance boils, it changes state from **liquid/gas** to **liquid/gas**. Bubbles form **at the top of/all the way through** the liquid. A certain substance boils at **any/a certain** temperature.

(4 marks)

2 Use the data to predict the state of copper at 2000 °C.

Data for copper:

melting point = 1083 °C

boiling point = 2595 °C

(1 mark)

3 Design a particle model that can explain why different substances boil at different temperatures. Use the data on this page to compare two substances using your particle model. Identify the strengths and weaknesses of your model.

(6 marks)

1.5 More changes of state

Learning objectives

After this topic you will be able to:

- describe changes of state involving gases
- use the particle model to explain evaporation, condensation, and sublimation.

Key Words

evaporation, condensation, sublimation

What happens to the water when you use a hairdryer to dry your hair? It changes state from liquid to gas without boiling. This is called evaporation.

Explaining evaporation

In a liquid, some particles have more energy than others. The particles with most energy leave the liquid surface. Then they move away from the liquid. The particles spread out, forming a gas. They mix with air particles. This is **evaporation**.

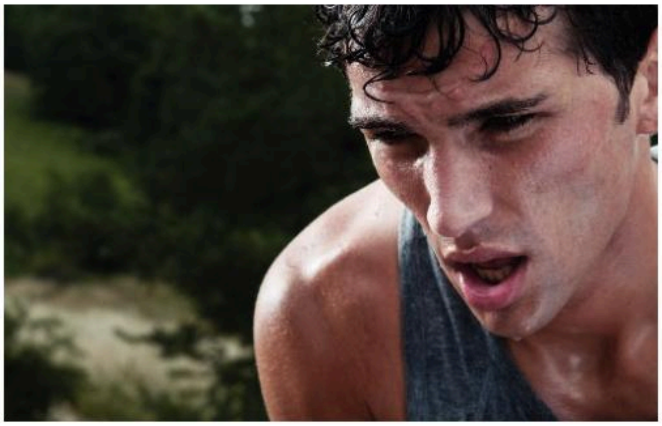
A substance can change from the liquid to the gas state by evaporating or boiling. The table below shows some differences between these two processes.

Process	How particles leave the liquid	Temperature	Does the mass change?
evaporation	Particles escape from the liquid surface.	happens at any temperature	no
boiling	Bubbles of the substance in the gas state form throughout the liquid. They rise to the surface and escape.	happens only at the boiling point	no

A State two differences between evaporation and boiling.

How is evaporation useful?

Why do you sweat? Sweating cools you down by evaporation. Sweat comes out of pores in your skin. Water from the sweat evaporates. The water particles need energy to move away as a gas. They take this energy from your skin. This cools you down.



Sweat helps to cool you down by evaporation.

Evaluating evaporation

Eva is investigating evaporation. She puts a small, damp tissue in a cold place. She puts a big, wet towel above a heater. The tissue dries first. Eva concludes that cold conditions speed up evaporation. Evaluate Eva's investigation: How could she improve it? Does the evidence support the conclusion?

Why is it quicker to dry your hair with a hairdryer? The hairdryer speeds up evaporation in two ways. It transfers energy to help particles leave the liquid surface. It also moves just-evaporated water particles away from your hair.

B Identify two ways that a hairdryer speeds up evaporation.

What is condensation?

Is the inside of your bedroom window ever wet after a cold night? At bedtime, water particles were mixed with air particles. They were spread out, as a gas. During the night, water particles hit the cold glass of the window. They moved closer to other water particles, until they were touching. This formed liquid water. The change of state from gas to liquid is called **condensation**. It can happen at any temperature below the boiling point.

C Identify the state formed when a substance condenses.

What is sublimation?

Where does stage smoke come from? It comes from solid carbon dioxide. Carbon dioxide is solid at temperatures below −78.5 °C. At this temperature and above, solid carbon dioxide changes state to become a gas. It does not normally exist as a liquid. The change of state from solid to gas is called **sublimation**.

At first, the carbon dioxide gas is very cold. Water particles condense around carbon dioxide particles. Tiny drops of liquid water form. It is this liquid water that makes stage smoke.

Solid grey iodine sublimes to form purple iodine gas.

D Name the change of state that occurs when a substance in the solid state changes into a gas.

▲ Stage smoke comes from solid carbon dioxide. The solid is also known as dry ice.

Summary Questions

1 Write **five** correct sentences from the sentence starters and enders below.

Sentence starters

In boiling...
In condensing...
In evaporating...

Sentence enders

...particles leave from the surface of the liquid.
...substances change from the liquid to the gas state.
...particles leave from all parts of the liquid.
...substances change from the gas to the liquid state.

(5 marks)

2 Describe the changes in behaviour of the particles when a substance condenses.

(2 marks)

3 Compare the processes of evaporation, boiling, and condensation.

(6 marks QWC)

1.6 Diffusion

Learning objectives

After this topic you will be able to:

- use the particle model to explain diffusion
- describe evidence for diffusion.

▲ Coloured ink particles diffuse through water. There is no need to stir.

Fantastic Fact!

At room temperature, particles in liquid water move at an average speed of 1600 km/h (444 m/s).

Key Words

diffusion

Link

You can learn more about diffusion in B1 1.4 Movement of substances

Do you wear perfume or deodorant? How does the smell reach your nose?

Perfume particles evaporate from your skin. The particles move around randomly. They mix with the air. As the perfume particles spread out, some enter your nose. Your nose detects the smell. The random moving and mixing of particles is called **diffusion**.

Why do substances diffuse?

Particles diffuse because they are moving. Perfume particles move randomly in the air, even if the air seems completely still. Ink particles spread through water by themselves. You do not need to shake or stir.

A State what is meant by diffusion.

What factors affect diffusion speed?

Diffusion does not always happen at the same speed. Three factors affect the speed of diffusion:

- temperature
- particle size
- the state of the diffusing substance.

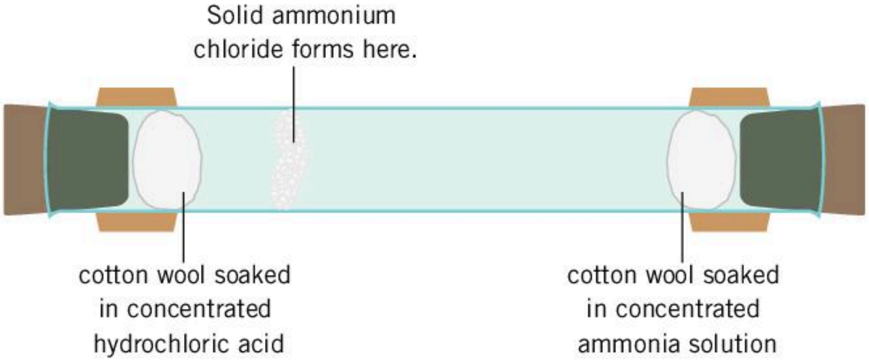
Temperature

At higher temperatures, particles are moving more quickly. Perfume particles leaving warm skin travel faster than perfume particles leaving a cold bottle.

B Explain why particles diffuse more quickly at higher temperatures.

Particle size

A teacher sets up the apparatus below to demonstrate diffusion.




▲ Particles of potassium manganate(VII) diffuse through the water.

Hydrogen chloride particles evaporate from the piece of cotton wool at the left side of the test tube. Ammonia particles evaporate from the piece of cotton wool at the right. The particles diffuse along the tube. The two types of particle meet, and form a ring of white solid. The solid is closer to the hydrogen chloride end. This shows that the hydrogen chloride particles diffuse more slowly. Hydrogen chloride particles are bigger and heavier than ammonia particles. Big, heavy particles diffuse more slowly than small, light ones.

State

Diffusion happens quickly in gases. This is because the particles are far apart. A particle in a gas travels a long way before hitting another particle.

In the liquid state, particles are closer than in the gas state. This is why diffusion is slower in liquids.

Diffusion does not happen in solids. The particles cannot move from place to place.

Fair's fair

Raj investigates how temperature affects diffusion speed. He puts purple crystals into five test tubes. He adds water of a different temperature to each test tube. He watches the purple colour spread through the water. Identify the variables Raj should change, measure, and control to make it a fair test.

Summary Questions

1. Copy and complete the sentences below.

   When food cooks, you can smell it because some ______ leave the food. The particles move ______ and mix with the ______. This is called ______. Particles diffuse because ______ is transferred. The higher the temperature, the ______ the diffusion.

   (6 marks)

2. Describe **three** pieces of evidence for diffusion.

   (3 marks)

3. The air contains particles of argon, nitrogen, and other substances. Use the data below to predict which type of particle diffuses faster. Give a reason for your choice.

   Relative masses of particles:
   nitrogen = 28 and argon = 40

   (2 marks)

4. Explain in detail the different diffusion speeds through substances in the solid, liquid, and gas states.

   (6 marks QWC)

1.7 Gas pressure

Learning objectives

After this topic you will be able to:

- use the particle model to explain gas pressure
- describe the factors that affect gas pressure.

Fantastic Fact!

Racing-car tyres reach 100 °C. Before a race, technicians pump tyres to a lower pressure than they need in the race. The air pressure in the tyre increases as it heats up.

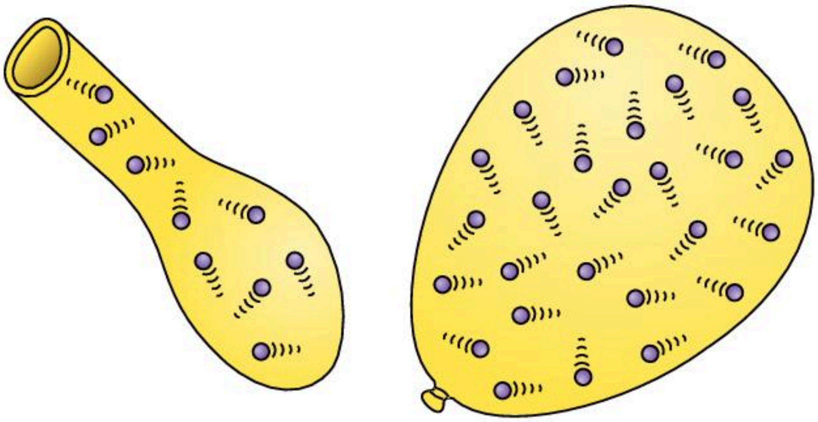
▲ The air pressure in racing-car tyres increases during a race.

Particle performance

Read the Fantastic Fact before you do this task.

Racing-car tyres are pumped full of air. Write a script for particles in a racing-car tyre. What do they say as the car goes faster and the air gets hotter? Then perform your script.

Why do balloons get bigger as you blow them up? When you blow up a balloon, you are filling it with air particles. The more air particles you add, the bigger the balloon.



▲ The more particles you blow into a balloon, the bigger the balloon.

Inside the balloon, the air particles move quickly from place to place. They bump into, or collide with, each other. They also **collide** with the rubber the balloon is made from. The collisions exert a force on the rubber. The force per unit area (every square metre) is the **gas pressure**.

Gas particles always exert pressure on the walls of their container, whatever the container is made from.

A State what is meant by gas pressure.

How does the number of particles affect pressure?

Rubber is stretchy. So when you blow more particles into a balloon, the balloon expands.

But some containers cannot expand. Adding more particles causes more frequent collisions with the walls. The pressure inside the container increases.

B Explain why adding more air increases the pressure inside a container.

How does temperature affect pressure?

Hotter and hotter

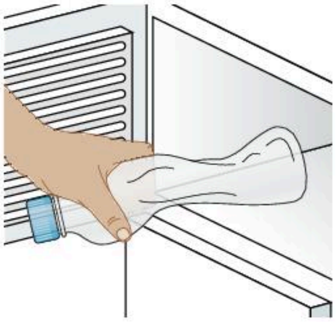
Balloons sometimes burst on hot days. Why does this happen?

As the air in a balloon gets warmer, more energy is transferred to the particles. The particles move faster. They collide with the rubber more often. The pressure inside the balloon increases.

The higher the temperature, the higher the air pressure. At first the rubber stretches. As the temperature gets even higher, the rubber cannot withstand the greater pressure. Eventually, it cannot stretch any further and the balloon bursts.

Cooling down

Imagine a plastic bottle of air in a freezer. The particles transfer energy to the freezer, and the air cools down. The particles move more slowly. They collide with the plastic less often. The pressure in the bottle decreases. The particles outside exert a higher pressure than the particles inside. The bottle collapses.



◀ In the freezer, the air pressure inside the bottle decreases.

Now imagine taking the bottle out of the freezer. The air inside the bottle warms up. Soon, the air particles inside and outside the bottle exert the same pressure. The bottle returns to its normal shape.

C Explain why a bottle collapses in the freezer.

Key Words

collide, gas pressure

Summary Questions

1 Copy the true sentences below. Write corrected versions of the false sentences.

Gas particles collide with the walls of their container.

Colliding gas particles exert pressure on the inside of the container.

The more particles in a container, the lower the pressure.

The higher the temperature, the lower the pressure.

(4 marks)

2 Jack was camping. He put a can of baked beans on his camp fire, without opening the lid. The can exploded. Use ideas about particles to explain why.

(3 marks)

3 Plan a talk that you could give to another class to explain what happens to an inflated balloon when you put it in a warm room and when you put it in a fridge.

(6 marks)

C1 Chapter 1 Summary

Key Points

- Materials are made up of tiny particles.
- A substance is made up of just one type of material.
- The properties of a substance describe what it looks like and how it behaves.
- The properties of a substance depend on what its particles are like, and how they are arranged.
- There are three states of matter – solid, liquid, and gas. For a certain substance, the particles never change. But in different states, the particles move differently, and have different arrangements.
- In the solid state, you cannot compress a substance, or make it flow.
- In the liquid state, you cannot compress a substance, but you can make it flow.
- In the gas state, you can compress a substance, and make it flow.
- The change of state from solid to liquid is melting. A substance melts at its melting point. Pure substances have sharp melting points.
- A substance changes from the liquid to the gas state by evaporating or boiling. A substance boils at its boiling point.
- The change of state from gas to liquid is condensing.
- The change of state from liquid to solid is freezing.
- Some substances change directly from the solid state to the gas state. This is subliming.
- Diffusion is the random moving and mixing of particles.
- Gas particles collide with the walls of their container. The collisions cause gas pressure.

Maths Challenge

Up in the air

The air is a mixture of substances. The table shows the percentages of the substances in the air.

Substance	Percentage of substance in dry air
nitrogen	78.08
oxygen	20.95
argon	0.93
others, including carbon dioxide	0.04

Task

Draw a graph or chart to represent the data in the table.
Decide which type of chart is best, and explain why.

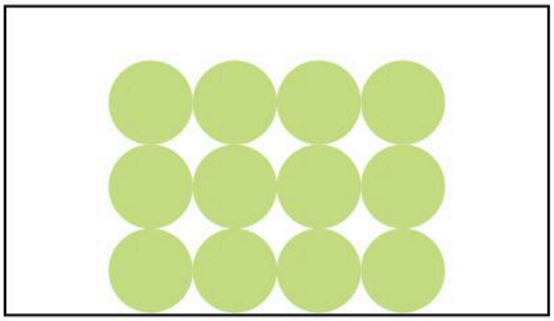
Key Words

material, particle, mixture, substance, property, solid, liquid, gas, states of matter, melting, change of state, freezing, melting point, boiling, boiling point, conserve, evaporation, condensation, sublimation, diffusion, collide, gas pressure

End-of-chapter questions

1 The diagram shows some particles in solid gold. Draw another diagram to show particles of gold in the gas state.

(2 marks)



2 Describe the arrangement and movement of particles in the liquid state.

(2 marks)

3 The table shows the melting points and boiling points of six substances.

Substance	Melting point (°C)	Boiling point (°C)
bromine	–7	59
krypton	–157	–152
mercury	–39	357
neon	–249	–246
platinum	1769	4530
silver	961	2210

a Write down the name of the substance with the highest boiling point.

(1 mark)

b Write down the names of the substances in order of increasing melting point, starting with the lowest.

(5 marks)

c Name **one** substance in the table that is in the gas state at 20 °C.

(1 mark)

d Name **two** substances in the table that are in the liquid state at 20 °C

(2 marks)

e Name **one** substance in the table that is in the liquid state at 100 °C.

(1 mark)

(10 marks)

4 Read the statements about particles in a substance in the solid state.

A The particles touch other particles.

B The particles are in a pattern.

C The particles do not move around from place to place.

D The particles vibrate.

a Write down the letter of the statement that best explains why you cannot pour a solid.

(1 mark)

b Choose one of the other statements and explain why it does not explain why you cannot pour a solid.

(1 mark)

(2 marks)

5 Olivia says that gas pressure is the result of particles colliding with each other. Is Olivia correct? Explain your answer.

(2 marks)

6 Compare the processes of boiling and evaporating.

(6 marks QWC)

2.1 Elements

Learning objectives

After this topic you will be able to:

- state what an element is
- recall the chemical symbols of six elements.

Fantastic Fact!

You are made up of elements. A 50 kg person is 32.5 kg oxygen, 9 kg carbon, 5 kg hydrogen, 1.5 kg nitrogen, 0.5 kg phosphorus, and 1.5 kg other elements.

Look at the pictures. What do the objects have in common?

▲ Jewellery.

▲ A catalytic converter. This changes harmful car exhaust gases into less harmful ones.

▲ A hard disk. This stores data on a computer.

▲ A heart pacemaker. This helps the heart to beat regularly.

All of these objects contain platinum. Platinum is a shiny substance. It is not damaged by air or water. It is easy to make platinum into different shapes.

Platinum is an example of an **element**. An element is a substance that cannot be broken down into other substances. You've probably heard of some elements: gold, silver, oxygen, chlorine, and helium are all examples of elements.

A State what an element is.

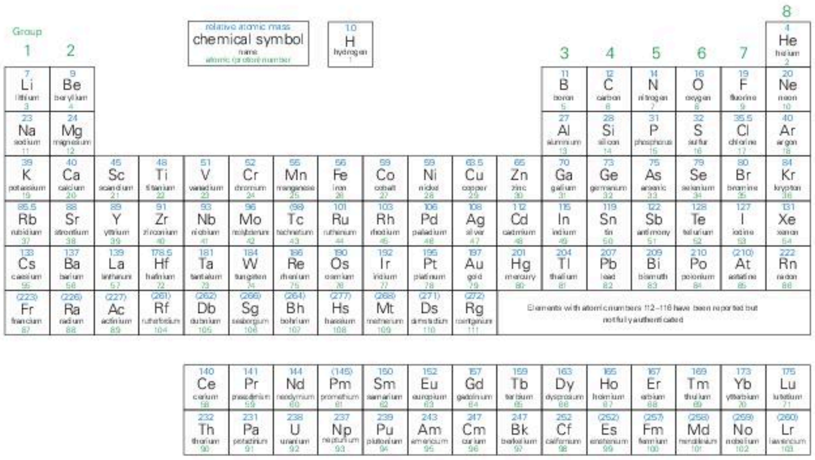
Platinum propaganda

Platinum is useful. But it is very rare. It is also expensive. In March 2013, 1 g of platinum cost £33. Write the text for a leaflet to persuade car scrapyard owners to recycle platinum used in car exhausts.

How many elements?

There are millions of materials. They are all made up of one or more elements. There are 92 elements that exist naturally. Scientists have made a few more.

The **Periodic Table** lists the elements. In the Periodic Table, elements with similar properties are grouped together.



▲ The Periodic Table lists the elements.

B State what the Periodic Table is.

What are chemical symbols?

Every element has its own **chemical symbol**. This is a one- or two-letter code for the element. Scientists all over the world use the same chemical symbols.

The table shows some chemical symbols.

Name of element	Chemical symbol
carbon	C
nitrogen	N
nickel	Ni
chlorine	Cl
gold	Au
iron	Fe
tungsten	W

For some elements, the chemical symbol is the first letter of its English name. For others, the chemical symbol is the first and second, or first and third, letters of its name. The chemical symbols of some elements come from their Latin names, for example, *aurum* for gold and *ferrum* for iron. The chemical symbol of tungsten comes from its German name, *Wolfram*.

C Write down the chemical symbols of the elements carbon, chlorine, gold, and iron.

Key Words

element, Periodic Table, chemical symbol

Link

You can learn more about the Periodic Table in C2 1.2 Groups and periods

When you write a chemical symbol, make sure the first letter is a capital letter. The second letter is lowercase.

Summary Questions

1 Write down the names of **10** elements.

(10 marks)

2 Use the Periodic Table to write the names and chemical symbols of six elements whose names begin with the letter C.

(6 marks)

3 Write a paragraph describing some uses of platinum. Choose two of these uses, and explain why the properties of platinum make it suitable for these two uses.

(6 marks QWC)

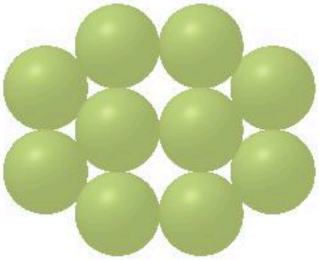
2.2 Atoms

Learning objectives

After this topic you will be able to:

- state what atoms are
- compare the properties of one atom of an element to the properties of many atoms.

▲ A silicon chip. This photograph was taken with a normal camera.

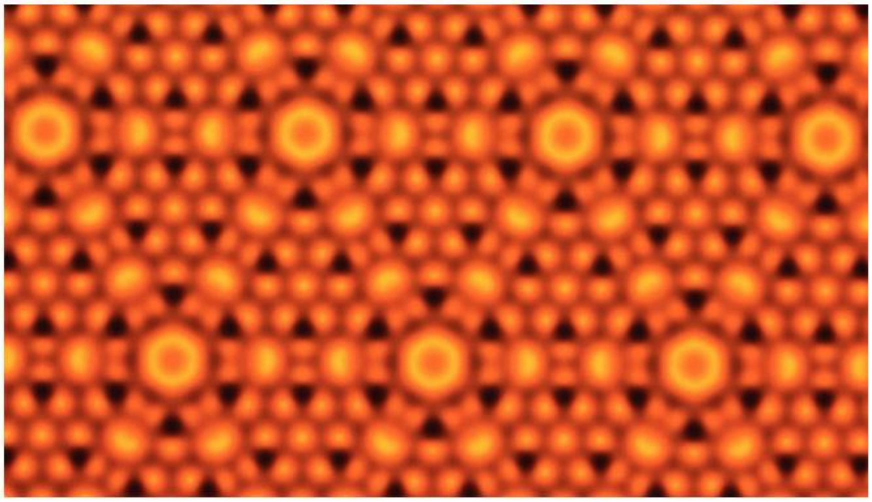


▲ This diagram shows silicon atoms in solid silicon.

Key Words

atom

Look at the picture below. What do you think it shows?



The picture shows the surface of a silicon crystal. Silicon is an element. Every computer, calculator, and mobile phone has silicon crystals inside. The crystals are called silicon chips. They contain millions of tiny electronic parts. These make the computers, calculators, and phones work.

Atoms

The picture shows atoms of silicon. An **atom** is the smallest part of an element that can exist.

The picture above was not taken with a normal camera. It was taken with a special type of microscope that can detect things as small as an atom.

A State what an atom is.

How many types of atom are there?

Every element is made up of one type of atom. All the atoms of an element are the same as each other. The atoms of one element are different to the atoms of all other elements. There are 92 elements that exist naturally, so there are 92 types of atom.

All silicon atoms are the same. But silicon atoms are different to gold atoms. For example, gold atoms are bigger.

Gold atoms are heavier than silicon atoms. This explains the data in the table on the next page.

Element	Mass of 1 cm^3 of the element (g)
gold	19.3
silicon	2.33

B Describe two differences between gold and silicon atoms.

Just one atom?

One atom on its own does not have the properties of the element. A gold atom is not yellow. It is not shiny. It is not in the solid, liquid, or gas state.

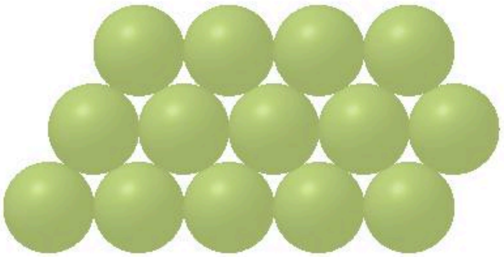
The atoms in this piece of gold are all the same.

The properties of an element are the properties of very many atoms joined together. The piece of gold in the picture has a mass of 1000 g. It is made up of about 3 000 000 000 000 000 000 000 000 atoms. Together, these atoms make the gold yellow and shiny.

The atoms are touching each other in rows. They vibrate on the spot. The gold in the picture is in the solid state. If you heat gold to 1063 °C its atoms start moving around. The gold is melting. One atom of gold cannot melt. Only a group of many atoms can melt.

Going for gold?

A gold ring has a mass of 10 g. Choose data from the paragraphs above to estimate the number of atoms in the ring.



This diagram shows gold atoms in solid gold.

Fantastic Fact!

The 2012 Olympic gold medals are only 1% gold by mass. There are 170 times more silver atoms than gold atoms in a gold medal.

Summary Questions

1 Copy and complete the sentences below.

The smallest part of an element that can exist is called an __________ . All the atoms of an element are the __________. The atoms of one element are __________ to the atoms of all other elements.

(3 marks)

2 An Olympic bronze medal is made up of three elements – copper, zinc, and tin. State the number of types of atom in the medal. Explain your answer.

(2 marks)

3 Create and illustrate a visual summary to summarise and organise the information on this spread.

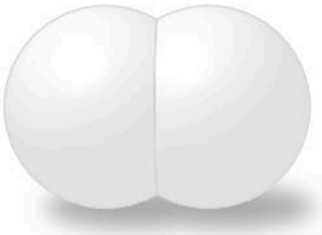
(6 marks)

2.3 Compounds

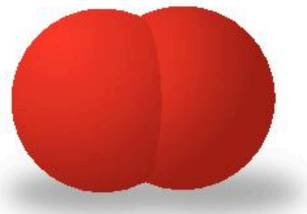
Learning objectives

After this topic you will be able to:

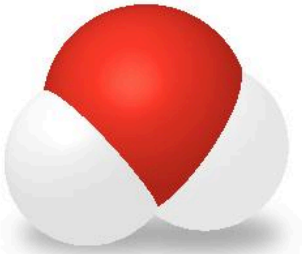
- state what a compound is
- explain why a compound has different properties to the elements in it.



▲ A hydrogen molecule consists of two hydrogen atoms.



▲ An oxygen molecule consists of two oxygen atoms.



▲ A water molecule has one oxygen atom joined to two hydrogen atoms.

How much water have you used today?

Water is vital for survival. But what is water? Water is made up of atoms of two elements, hydrogen and oxygen. This means that water is a **compound**. A compound is a substance made up of atoms of two or more elements. The atoms are strongly joined together.

The properties of a compound are different to the properties of the elements it is made up of.

A State what a compound is.

Why is water different to its elements?

Hydrogen is a gas at room temperature. Mixed with air, and ignited with a spark, it explodes. Hydrogen atoms go round in pairs. These are **molecules** of hydrogen. A molecule is a group of two or more atoms strongly joined together.

Oxygen is a gas at room temperature. You cannot see or smell it. Oxygen exists as molecules. Each molecule is made up of two oxygen atoms. In the air, oxygen molecules mix with atoms and molecules of other substances.

Water exists as molecules. The molecules are made up of atoms of two elements. This means that water is a compound.

Water molecules are different to hydrogen molecules and oxygen molecules. This is why water has different properties to hydrogen and oxygen. For example, water has a higher boiling point than hydrogen.

Key Words

compound, molecule

Weak forces hold molecules close to each other in liquid hydrogen. Stronger forces hold molecules close together in liquid water. It takes more energy to separate water molecules from each other than to separate hydrogen molecules from each other. Water has a higher boiling point than hydrogen.

B State which has a higher boiling point, water or hydrogen.

What is salt?

Do you add salt to your food? Salt is a compound. Its scientific name is sodium chloride. It contains atoms of two elements, sodium and chlorine.

- Sodium is a shiny metal. It fizzes in water.
- Chlorine is a smelly green poisonous gas.

So why doesn't salt smell? Or poison you? Or fizz in your mouth?

In salt, the atoms of sodium and chlorine are not just mixed up. They are joined together to make one substance – sodium chloride. This compound has different properties to the elements in it.

C Describe one difference in properties between sodium chloride and sodium.

Fantastic Fact!

Tooth enamel is a compound of calcium (a shiny metal that fizzes in water), phosphorus (a poisonous solid that catches fire easily), and oxygen (a gas that helps things burn).

Link

You can learn more about boiling points in C1 1.4 Boiling

Organising ideas

Make a table showing properties of sodium, chlorine, and sodium chloride. Use the table to help you plan and then write some paragraphs comparing the properties of the three substances.

Summary Questions

1. Copy the sentences below, choosing the correct bold words.

   A compound is a substance made up of atoms of **one**/**two** or more elements. The properties of a compound are **the same as**/**different to** the properties of its elements. A molecule is a group of **two**/**three** or more atoms **weakly**/**strongly** joined together.

   (4 marks)

2. Suggest an explanation for this boiling-point data:
   oxygen = −183 °C; water = 100 °C

   (3 marks)

3. Write a paragraph to compare the properties of hydrogen, oxygen, and water.

   (6 marks QWC)

2.4 Chemical formulae

Learning objectives

After this topic you will be able to:

- write the chemical names for some simple compounds
- write and interpret chemical formulae.

Link

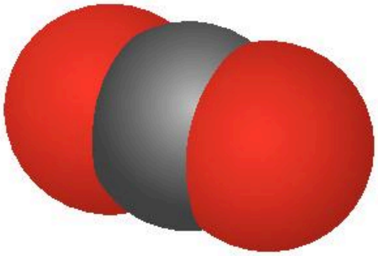
You can learn more about the property differences between compounds and elements in C1 2.3 Compounds

Are the windows closed? If so, there is probably more carbon dioxide in the room now than there was 10 minutes ago. Every cell in your body makes carbon dioxide. You breathe it out. Carbon dioxide is a compound. It is made up of two elements – carbon and oxygen.

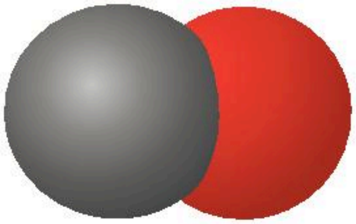
Carbon monoxide is another compound. It also consists of atoms of carbon and oxygen. But carbon monoxide is poisonous. It can be deadly if you breathe it in.

Why are carbon compounds different?

You already know that the properties of a compound depend on the elements in it. The numbers of atoms of each element also make a difference.



A carbon dioxide molecule has one carbon atom and two oxygen atoms.



A carbon monoxide molecule has one carbon atom and one oxygen atom.

Carbon dioxide always has 12 g of carbon for every 32 g of oxygen. The amounts of carbon and oxygen in carbon monoxide are different. Carbon monoxide has 12 g of carbon for every 16 g of oxygen.

A State the number and types of atoms that make up one carbon dioxide molecule.

What's water?

Water contains 2 g of hydrogen for every 16 g of oxygen. Nitrogen dioxide contains 14 g of nitrogen for every 32 g of oxygen. Which compound has the higher proportion of oxygen? Show your working.

How do we name compounds?

Compounds made up of oxygen and another element have two-word names. The second word is *oxide*.

Elements in compound	Name of compound
aluminium and oxygen	aluminium oxide
zinc and oxygen	zinc oxide

Some elements form more than one type of oxide.

Molecule of compound made up of…	Name of compound
1 carbon atom and 1 oxygen atom	carbon **mon**oxide
1 carbon atom and 2 oxygen atoms	carbon **di**oxide

The compound of sodium and chlorine is called sodium chloride. Chlori***n***e becomes chlori***d***e.

B Name the compound of sodium and chlorine.

What is a chemical formula?

A **chemical formula** shows the relative number of atoms of each element in a compound – 'relative number' means how many of one type of atom there are compared to another. For example:

- The chemical formula of carbon dioxide is CO_2. This shows that there is one carbon atom for every two oxygen atoms.
- The chemical formula of carbon monoxide is CO. This shows that there is one carbon atom for every oxygen atom.

When you are writing chemical formulae, the numbers should be:

- to the right of their chemical symbol, just below the line
- smaller than the chemical symbols.

Key Words

chemical formula

Summary Questions

1 Copy and complete the sentences below.

The formula of carbon dioxide is ________. This shows that a molecule of carbon dioxide is made up of ________ carbon atom and ________ atoms of ________. The relative masses of carbon and oxygen in carbon dioxide are ________.

(5 marks)

2 The chemical formula of water is H_2O. State the number of atoms of each element in a water molecule.

(2 marks)

3 Draw and label diagrams to show how you could make models of the molecules on this spread. If possible, make the models.

(6 marks)

C1 Chapter 2 Summary

Key Points

- All materials are made up of one or more elements.
- Elements are substances that cannot be broken down.
- There are 92 elements that exist naturally.
- The Periodic Table lists all the elements.
- Every element has its own chemical symbol.
- An atom is the smallest part of an element that can exist.
- Every element is made up of one type of atom. All the atoms of an element are the same.
- The atoms of one element are different to the atoms of all other elements.
- The properties of a substance are the properties of many atoms, not just a single atom.
- A compound is a substance made up of atoms of two or more elements, strongly joined together.
- The properties of a compound are different to the properties of the elements that it is made from.
- A molecule is a group of two or more atoms that are strongly joined together.
- A chemical formula shows the relative number of atoms of each element in a compound.

Key Words

element, Periodic Table, chemical symbol, atom, compound, molecule, chemical formula

BIG Write

Science web

You work for a company that makes on-line revision resources for school students. Your boss wants you to write some new webpages for Key Stage 3 science.

Task

Write the text for the revision pages about elements, atoms, compounds, and chemical formulae.

Tips

- Before you start writing, decide what to include on each web page. Work out how many pages you will need. Do not try to include too much information on a page.
- Include diagrams and examples to help students understand the text.
- Highlight key words and explain their meanings.

End-of-chapter questions

1 Carbon dioxide is a compound made up of two elements.

a State what is meant by the word element. *(1 mark)*

b State the number of types of atom in the element carbon. *(1 mark)*

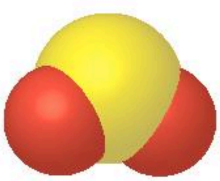
c One of the elements in carbon dioxide is carbon. Name the other element. *(1 mark)*

d State the number of types of atom in carbon dioxide. *(1 mark)*

e Copy and complete the sentences below. The formula of carbon dioxide is CO_2. There is __________ atom of carbon for every two atoms of __________. *(2 marks)*

(6 marks)

2 The diagram below shows a molecule of sulfur dioxide. Each sphere represents one atom. Different-coloured spheres represent atoms of different elements.



a State the total number of atoms in the molecule. *(1 mark)*

b State the number of different types of atom in the molecule. *(1 mark)*

c State whether sulfur dioxide is an element or a compound. Explain your decision. *(2 marks)*

d Copy and complete the table below. *(2 marks)*

Name of element	Number of atoms of this element in one sulfur dioxide molecule
sulfur	
	2

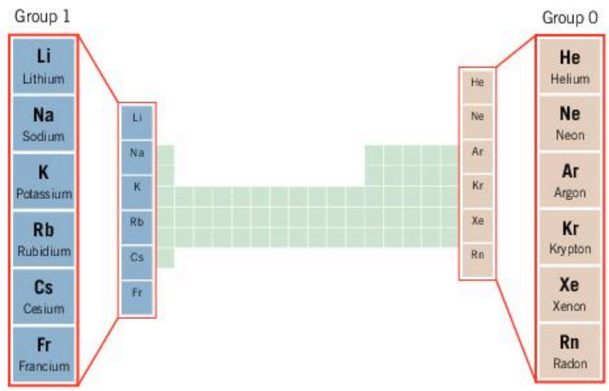
e Write the formula of sulfur dioxide. *(2 marks)*

(8 marks)

3 Describe **two** differences between elements and compounds.

(2 marks)

4 The table below shows data for six elements. The diagram shows their positions in the Periodic Table.



Name of element	Chemical symbol	Melting point (°C)
lithium	Li	180
sodium	Na	98
potassium	K	64
neon	Ne	–249
argon	Ar	–189
krypton	Kr	–157

Compare the melting point patterns for the Group 1 and Group 0 elements.

(6 marks QWC)

3.1 Chemical reactions

Learning objectives

After this topic you will be able to:

- describe what happens to atoms in chemical reactions
- explain why chemical reactions are useful
- compare chemical reactions to physical changes.

▲ Chemical reactions mean you can fry an egg.

Reaction, reaction, reaction

'Chemical reactions?' says Rick. 'They're all bangs and bad smells.' Is he right? Read over the examples from this page to help you decide. Make a visual summary to help you organise your ideas, and then write down what you plan to say to Rick.

Key Words

chemical reaction, reversible, catalyst, physical change

What did you have for breakfast today?

Chemical reactions make food and drink. Chemical reactions in cows produce milk from grass. Chemical reactions in plants produce maize, for cornflakes. Chemical reactions convert raw egg to fried egg. Burning gas for cooking is another chemical reaction.

What are chemical reactions?

A **chemical reaction** is a change in which atoms are rearranged to create new substances. The atoms are joined together in one way before the reaction and in a different way after the reaction.

All chemical reactions:

- make new substances.
- transfer energy to or from the surroundings.

Most chemical reactions are not easily **reversible**. At the end of the reaction it is very difficult to get back the substances you started with.

A State what happens to the atoms in a chemical reaction.

How do you know if it's a chemical reaction?

You do an experiment in the lab. How do you know if it involved chemical reactions? There are many clues to look out for. You might:

- see huge flames … or tiny sparks

- notice a sweet smell … or a foul stink

- feel the chemicals getting hotter … or colder

- hear a loud bang … or gentle fizzing.

B State three pieces of evidence that may suggest that a chemical reaction is happening.

Why are chemical reactions useful?

Chemical reactions are very useful. They make many useful substances. These include:

- medicines, such as paracetamol
- fabrics, such as polyester
- building materials, such as cement.

Chemical reactions also transfer energy. This transfer can be useful. Burning petrol makes vehicles go. Burning coal heats water to produce steam to generate electricity.

Some chemical reactions are not useful. Rusting is a chemical reaction. It may damage cars, boats, and bridges. Chemical reactions make food rot.

C State three examples of useful products made in chemical reactions.

Are all chemical reactions fast?

Some reactions happen quickly. Others are much slower. Chemists use **catalysts** to speed up slow reactions if they want to make a product more quickly. Different reactions need different catalysts. A catalyst is not used up in a reaction.

Are all changes chemical reactions?

Not all changes involve chemical reactions. If you warm chocolate, it melts. But you still have chocolate. Changes of state, and dissolving, are reversible. This means you can get back what you started with. This is called a **physical change**.

D Give examples of two types of physical change.

▲ This car burns methane gas instead of petrol. Chemical reactions make methane from human waste at a sewage works.

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

Chemical reactions involve re-arranging **atoms**/**states**. Chemical reactions **always**/**sometimes** make new substances. They **are**/**are not** easily reversible. They **always**/**never** involve energy transfers. Physical changes include changes of **substance**/**state**. They **are**/**are not** reversible.

(6 marks)

2 State which of the changes listed below are chemical changes, and which are physical changes.

- **a** burning diesel to make carbon dioxide and water *(1 mark)*
- **b** dissolving sugar in tea to make it taste sweet *(1 mark)*
- **c** boiling water to make steam *(1 mark)*
- **d** baking raw cake to make cooked cake *(1 mark)*

3 Compare chemical changes with physical changes. Include examples to illustrate your answer.

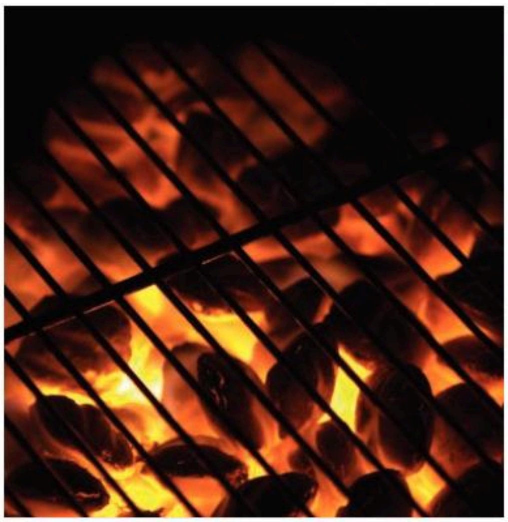
(6 marks QWC)

3.2 Word equations

Learning objectives

After this topic you will be able to:

- identify reactants and products in word equations
- write word equations to represent chemical reactions.



▲ Charcoal is a form of carbon. It reacts with oxygen from the air to make carbon dioxide.

Risky reaction

Many reactions have **hazards**. A hazard is a possible source of danger. You must control the **risks** from hazards. Risk is the chance of damage or injury from a hazard. Burning magnesium has two hazards:

- The bright flame could be harmful to eyesight.
- The flame is difficult to put out.

Suggest how to control the risks from these hazards.

Do you like barbeques? What happens when charcoal burns?

Charcoal is a form of carbon. In the burning reaction, carbon reacts with oxygen from the air. The reaction makes a new substance, carbon dioxide. It forms as an invisible gas. In this reaction, two elements join together to make a compound.

A Name the two elements that react to make carbon dioxide.

Representing reactions

Many other pairs of elements join together in chemical reactions. You can mix iron filings and sulfur powder. They do not react. But if you heat them, the mixture glows red. A chemical reaction happens, and a new substance forms. The new substance looks different to the substances you started with. It has different properties. The new substance is iron sulfide.

▲ A mixture of iron and sulfur has different properties to iron sulfide.

In chemical reactions, the starting substances are called **reactants**. The substances made in the reaction are called **products**. In the reaction of iron with sulfur, the reactants are iron and sulfur. There is one product – iron sulfide.

B Name the reactants and products in the reaction of carbon with oxygen to make carbon dioxide.

Key Words

reactant, product, word equation, hazard, risk

Word equations represent reactions in a simple way.
A word equation shows:

- reactants on the left
- products on the right.

The arrow means *reacts to make*. It is different to an equals sign (=) in a maths equation.

The word equation for the reaction of iron and sulfur is:

iron + sulfur → iron sulphide

C Write a word equation for the reaction of iron and sulfur to make iron sulfide.

Re-arranging atoms

Magnesium burns in air. It reacts with oxygen. The product is magnesium oxide.

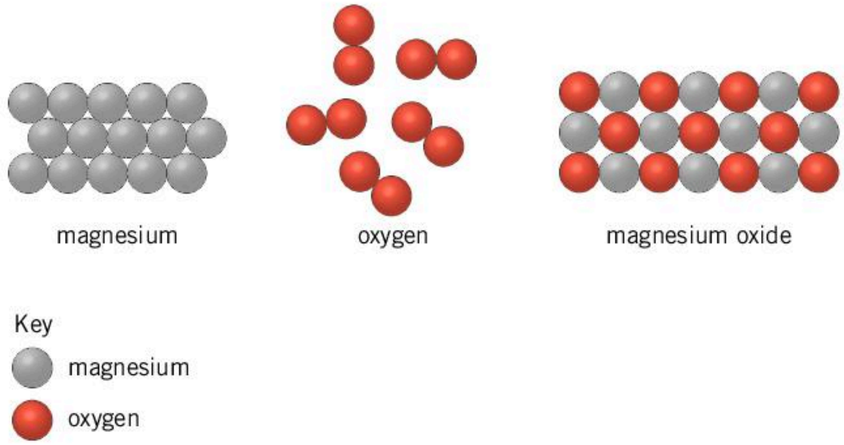
magnesium + oxygen → magnesium oxide

In this reaction there are many signs that a chemical reaction is taking place. There is a bright white flame, transferring energy to the surroundings.

The reactants and products look different.

- reactants – shiny magnesium and invisible oxygen gas
- product – white magnesium oxide powder

In every chemical reaction, the atoms get re-arranged. The diagrams show how the atoms are arranged in magnesium, oxygen, and magnesium oxide.



Summary Questions

1 Match the sentence starters and endings.

Sentence starters
Reactants are...
Products are...
Hazards are...
Risks are...

Sentence endings
...possible sources of danger.
...the chances of damage or injury from hazards.
...the starting substances in chemical reactions.
...the substances made in chemical reactions.

(4 marks)

2 Name the reactants and products in each reaction below.

a aluminium + iodine → aluminium iodide *(2 marks)*

b sodium + chlorine → sodium chloride *(2 marks)*

c lithium + bromine → lithium bromide *(2 marks)*

3 Write word equations for the reactions below.

a sulfur and oxygen producing sulfur dioxide *(2 marks)*

b potassium and chlorine *(2 marks)*

4 Use information from this page to compare the burning reactions of carbon and magnesium. Include word equations in your answer. *(6 marks QWC)*

3.3 Burning fuels

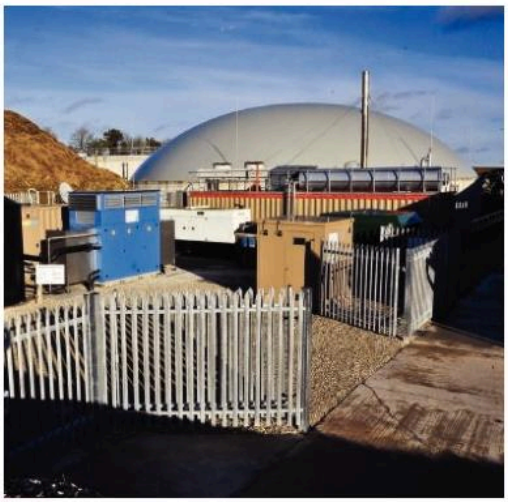
Learning objectives

After this topic you will be able to:

- predict products of combustion reactions
- categorise oxidation reactions as useful or not.

How do you heat your home? Many central-heating systems burn methane gas. Methane comes from under the ground, or under the sea. It was formed from tiny plants and animals that lived millions of years ago.

If you live in Poundbury, Dorset, your methane might come from another source. Waste from chocolate and cereal factories produces methane in just a few weeks.



▲ This apparatus makes methane from waste.

What are fuels?

Methane is a **fuel**. A fuel is a material that burns to transfer energy by heating. Fuels include petrol, diesel, coal, hydrogen, and waste cooking oil.

▲ This vehicle burns waste cooking oil.

A State the meaning of the word fuel.

Key Words

fuel, combustion, fossil fuel, non-renewable, oxidation

What happens when fuels burn?

Fuels burn in chemical reactions. Burning is also called **combustion**. Methane is a compound of carbon and hydrogen. Its chemical formula is CH_4. When it burns, it reacts with oxygen from the air. The reaction makes two products, carbon dioxide and water:

methane + oxygen → carbon dioxide + water

Petrol is a mixture of compounds. Most of its compounds consist of atoms of hydrogen and carbon. Petrol makes mainly carbon dioxide and water when it burns in car engines.

Foul Fact!

In Cirencester, Gloucestershire, methane made from chicken poo burns in a power station to generate electricity.

B Name the two elements that methane is made up of.

Petrol, diesel, coal, and methane from under the ground or sea, are **fossil fuels**. They are **non-renewable**. This means that they cannot be replaced once they have been used. They will run out one day.

North Sea oil and methane gas are fossil fuels.

Hydrogen – future fuel?

A few types of car burn hydrogen in their engines. In this reaction, hydrogen joins with oxygen. There is one product.

hydrogen + oxygen → water

Some people think that hydrogen should be used to fuel more cars. This is because the only product of its combustion is harmless water. Burning methane, petrol, and diesel produce carbon dioxide and water. Extra carbon dioxide in the air is harmful to the environment. It is a cause of climate change.

But where does the hydrogen to fuel cars come from? Companies make hydrogen from methane, or water. The processes they use to make the hydrogen also produce harmful gases.

C Name the two reactants when hydrogen burns in air.

What are oxidation reactions?

Burning reactions are **oxidation** reactions. In oxidation reactions, substances react with oxygen. Rusting is another oxidation reaction. In rusting, iron reacts with oxygen and water.

D State one example of an oxidation reaction.

Fuels for the future

Should we fuel cars with petrol and diesel or find other fuels, such as hydrogen or waste cooking oil? Organise your ideas in a table, then write a few paragraphs to explain your decision.

Link

You can learn more about climate change in C2 4.6 Climate change

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

- **a** Fuels burn to transfer **useless/useful** energy. *(1 mark)*
- **b** Combustion is another word for **burning/melting**. *(1 mark)*
- **c** When a substance burns it reacts with **nitrogen/oxygen** from the air. *(1 mark)*
- **d** Methane is a **compound/element** of carbon and hydrogen. It burns to make carbon dioxide and **water/hydrogen**. *(2 marks)*

2 Cooking oil contains compounds of carbon, hydrogen, and oxygen. Predict two products of its combustion. *(2 marks)*

3 Nathan says that burning any fuel contributes to climate change. Riana thinks Nathan is wrong. Use cartoon pictures and speech bubbles to show them having a conversation about burning fuels. *(6 marks)*

3.4 Thermal decomposition

Learning objectives

After this topic you will be able to:

- identify decomposition reactions from word equations
- use a pattern to predict products of decomposition reactions.

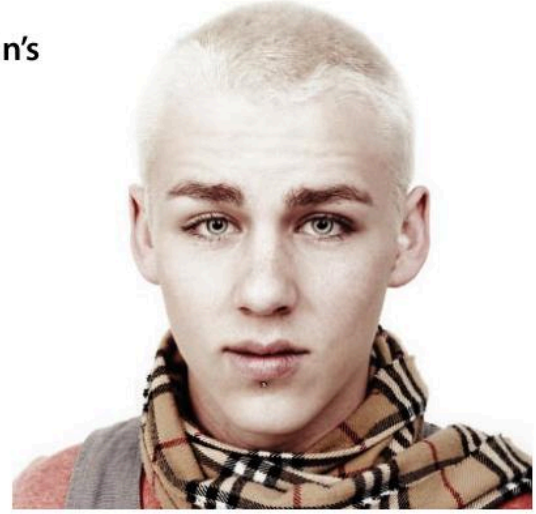
▲ Copper carbonate.

Key Words

decomposition, thermal decomposition, discrete

▲ Copper oxide and carbon dioxide form when copper carbonate decomposes.

What made this man's hair so blond?



He put hydrogen peroxide in his hair. Hydrogen peroxide is a compound. It has atoms of two elements, hydrogen and oxygen. Its formula is H_2O_2.

You cannot bleach hair with old hydrogen peroxide. This is because hydrogen peroxide molecules break up. When this happens there are two products – water and oxygen.

hydrogen peroxide → water + oxygen

This is a **decomposition** reaction. In decomposition reactions, a compound breaks down into simpler compounds or elements.

A State what a decomposition reaction is.

Decomposition reactions

Copper carbonate is a green compound. It is made up of atoms of three elements – copper, carbon, and oxygen.

If you heat copper carbonate, it breaks down. The reaction makes copper oxide and carbon dioxide. Copper oxide is black. It remains in the test tube. Carbon dioxide forms as a gas.

copper carbonate → copper oxide + carbon dioxide

You can show that the gas is carbon dioxide by bubbling it through limewater. The limewater goes cloudy.

Other types of carbonate decompose on heating:

lead carbonate → lead oxide + carbon dioxide

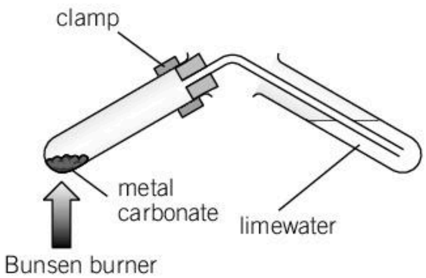
zinc carbonate → zinc oxide + carbon dioxide

When a substance breaks down on heating, the reaction is a **thermal decomposition** reaction.

B Name the products of the thermal decomposition reaction of lead carbonate.

Comparing reactions

Edward compares thermal decomposition reactions. He heats different carbonates. He measures the time for the limewater to start looking milky.

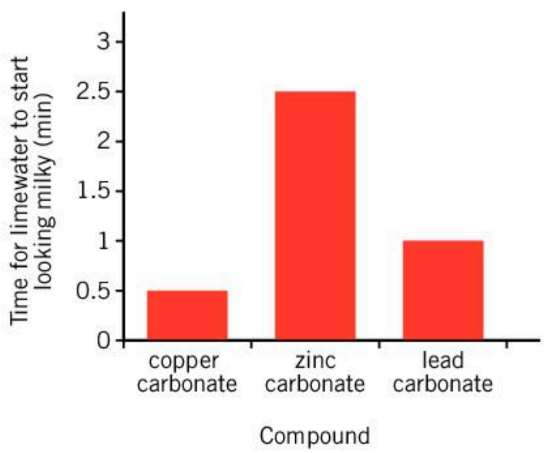


◀ Edward's apparatus.

Edward writes his results in a table.

Compound	Time for limewater to start looking milky (min)
copper carbonate	0.5
zinc carbonate	2.5
lead carbonate	1.0

He presents his results on a bar chart. This is because the variable he changes is **discrete**. A discrete variable is described by words, or by numbers that can only have certain values, such as shoe sizes.



▲ This bar chart shows the time for carbonate compounds to start decomposing.

C State what a discrete variable is.

All's fair?

Think about Edward's investigation. Discuss the variables with a partner. Which variable does he change and which does he measure? Which should he keep the same to make the investigation fair? What does the bar chart show? What conclusion could Edward make?

Summary Questions

1 Copy and complete the sentences below.

In a decomposition reaction, a _______ breaks down to make _______ compounds and elements. Copper carbonate decomposes to make _______ oxide and _______ dioxide gas. You can use _______ to test for the gas.

(5 marks)

2 Choose the reactions below that are decomposition reactions. Explain each choice.

a calcium + oxygen → calcium oxide *(1 mark)*

b zinc carbonate → zinc oxide + carbon dioxide *(1 mark)*

c hydrogen peroxide → water + oxygen *(1 mark)*

d aluminium + iodine → aluminium iodide *(1 mark)*

3 Compare combustion reactions with decomposition reactions. Include examples to illustrate your answer.

(6 marks QWC)

3.5 Conservation of mass

Learning objectives

After this topic you will be able to:

- explain conservation of mass in chemical reactions
- calculate masses of reactants and products.

▲ When it is burnt the substances in wood react with oxygen.

▲ Burning magnesium.

What happens to wood in campfires?

Wood is a mixture of many substances. On burning, the substances react with oxygen.

The reactions make many products, including ash and carbon dioxide. The total mass of reactants is equal to the total mass of products.

mass of wood + mass of oxygen = total mass of all products

In any chemical reaction, the total mass of reactants is equal to the total mass of products. This is called **conservation of mass**. Mass is also conserved in physical changes.

A State what conservation of mass means.

Calculating masses

Samindee has some magnesium. She finds its mass. She burns the magnesium. She finds the mass of the product.

mass of magnesium = 0.24 g

mass of product = 0.80 g

Samindee writes a word equation. She adds the masses she knows.

magnesium	+ oxygen →	magnesium oxide
0.24 g		0.80 g

Samindee calculates the mass of oxygen that reacted:

total mass of reactants = total mass of products

0.24 g + mass of oxygen = 0.80 g

mass of oxygen = 0.80 g − 0.24 g

mass of oxygen = 0.56 g

Writing balanced equations

Word equations show reactants and products in reactions. **Balanced symbol equations** also show:

- the formulae of reactants and products
- how the atoms are rearranged
- the relative amounts of reactants and products.

Burning carbon

- First, write a word equation:

carbon + oxygen → carbon dioxide

- Write chemical symbols or formulae for each reactant and product. You cannot guess these.

$$C + O_2 \rightarrow CO_2$$

- Now balance the equation. There must be the same number of atoms of each element on each side of the equation. The equation shows one atom of carbon on each side of the arrow, and two atoms of oxygen. It is balanced.

B State what balanced symbol equations show.

Burning magnesium

- Write a word equation and add symbols and formulae:

magnesium + oxygen → magnesium oxide

$$Mg + O_2 \rightarrow MgO$$

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

$$Mg + O_2 \rightarrow 2MgO$$

The big 2 applies to both Mg and O in magnesium oxide.

- Now balance the amounts of magnesium. There is one atom on the left, and two on the right.
Add a big 2 to the left of the Mg. The equation is balanced.

$$2Mg + O_2 \rightarrow 2MgO$$

Mass matters

Look at Samindee's calculation. Calculate the masses of reactants and products if she started with 0.48 g of magnesium.

Key Words

conservation of mass, balanced symbol equation

Summary Questions

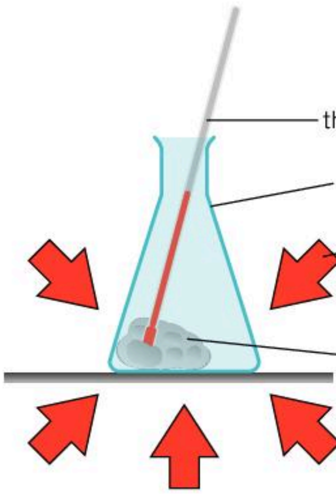
1. Copy and complete the sentences below.
   In chemical reactions, the total mass of reactants ______ the total mass of products. This is called ______ of mass.
   (2 marks)
2. Kezi heats 12.5 g of zinc carbonate. It decomposes to make 8.1 g of zinc oxide. Calculate the mass of carbon dioxide made.
   (2 marks)
3. Copper carbonate ($CuCO_3$) decomposes to make copper oxide (CuO) and carbon dioxide (CO_2). Write a balanced equation for the reaction.
   (3 marks)
4. Draw diagrams to show how you could make models to represent the equations on this page. If possible, make the models.
   (6 marks)

3.6 Exothermic and endothermic

Learning objectives

After this topic you will be able to:

- describe the characteristics of exothermic and endothermic changes
- classify changes as exothermic or endothermic.



▲ The reaction of citric acid with sodium hydrogen carbonate is endothermic.

Have you ever used a cold pack on an injury? How did the pack get cold?

One type of cold pack includes two substances. An outer bag contains liquid water. An inner bag contains solid ammonium nitrate. When you break the inner bag, the water and ammonium nitrate mix. The solid dissolves in the water, and the mixture cools. The injury transfers energy to the mixture. The mixture slowly returns to the temperature of the surroundings.

▲ A cold pack on a sports injury.

What is an endothermic change?

The process in the cold pack is an **endothermic change**. The surroundings transfer energy to substances in an endothermic change. Some chemical reactions are endothermic. Melting and boiling are also endothermic. So is the formation of some solutions.

Tom has some citric acid crystals. Their temperature is 20 °C. He adds sodium hydrogen carbonate powder. There is a chemical reaction. The reacting mixture feels cold. Its temperature goes down to 10 °C. The temperature decrease shows that the reaction is endothermic.

Once the reaction is complete, Tom leaves his mixture of products in the lab. After a while its temperature returns to 20 °C.

A State what an endothermic change is.

Foul Fact!

You can get frostbite from cold packs if you don't use them properly. Never leave them on your skin for longer than the pack says.

What is an exothermic change?

Some changes transfer energy to the surroundings. These are **exothermic changes**. Burning wax warms up the surroundings. All burning reactions do the same. They are exothermic.

▲ Burning reactions transfer energy to the surroundings. They are exothermic.

Zoe has some dilute sulfuric acid. She also has some sodium hydroxide solution. The temperature of both solutions is 20 °C. Zoe mixes them. There is a chemical reaction. She measures the temperature again. It is 30 °C. The temperature increase shows that the reaction is exothermic.

Once the reaction is complete, Zoe leaves the mixture of products in the lab. After a while its temperature returns to 20 °C. Some changes of state are examples of exothermic changes, for example, condensing and freezing.

Literacy

Here's an easy way to remember the difference between exothermic and endothermic reactions:

Exothermic reactions transfer energy out. You go out through an **ex**it.

Endothermic reactions transfer energy in. You go in through an **en**trance.

Key Words

endothermic change, exothermic change

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

All chemical reactions involve **colour/energy** transfers. If the temperature increases, the change is **exothermic/endothermic**. If the temperature decreases, the change is **exothermic/endothermic**. Boiling and melting are **exothermic/endothermic** changes.

(4 marks)

2 The table shows the temperature changes when some substances dissolve in water. Write down the names of the substances that dissolve exothermically. Explain your choices.

(3 marks)

Name of substance	Temperature before dissolving (°C)	Temperature after dissolving (°C)
potassium chloride	20	10
calcium chloride	20	35
sodium hydrogen carbonate	20	15
sodium carbonate	20	24

3 Write a paragraph to compare exothermic and endothermic changes. Include examples to illustrate your answer.

(6 marks QWC)

C1 Chapter 3 Summary

Key Points

- Physical changes are reversible. They include changes of state and dissolving.
- Chemical reactions are not reversible.
- In a chemical reaction, atoms are re-arranged to make new substances.
- In a chemical reaction, the total mass of reactants is equal to the total mass of products. This is conservation of mass.
- In a chemical reaction, the starting substances are called reactants. The substances that are made in the reaction are called products.
- Word equations represent reactions simply. They show reactants on the left and products on the right. The arrow means *reacts to make*.
- In a balanced symbol equation, chemical formulae represent the reactants and products. The equation shows how atoms are re-arranged. It gives the relative amounts of reactants and products.
- Chemical reactions can make useful products and transfer energy.
- In oxidation reactions, substances join with oxygen to form oxides.
- Oxidation reactions include burning and rusting. Burning is also called combustion.
- In a thermal decomposition reaction, a compound breaks down when it is heated. The products are simpler compounds, and elements.
- Exothermic changes transfer energy to the surroundings.
- Endothermic changes transfer energy from the surroundings.
- A hazard is a possible source of danger.
- A risk is the chance of damage or injury from a hazard.

BIG Write

Tune in

Radio 99 makes exciting discussion programmes. And you will be on next week! A listener has sent in this text: "Rusting, explosions, making drugs… They are all chemical reactions. Chemistry should be banned."

Task

Plan what to say to convince listeners that chemical reactions are very important, and that chemistry must not be banned.

Tips

- Give examples of useful chemical reactions, and ask listeners to imagine a world without chemistry. What would they miss?

Key Words

chemical reaction, physical change, catalyst, reactant, product, word equation, hazard, risk, fuel, combustion, fossil fuel, non-renewable, oxidation, decomposition, thermal decomposition, discrete, conservation of mass, balanced symbol equation, endothermic change, exothermic change

End-of-chapter questions

1 Izzy heats some magnesium in a Bunsen burner. It burns with a bright flame. A white ash forms.

a Describe **two** observations that show this is a chemical reaction. *(2 marks)*

b State what happens to the atoms in a chemical reaction. *(1 mark)*

(3 marks)

2 Marcus plans an investigation to find out which fuel makes water hotter, ethanol or propanol.Marcus burns each fuel in turn to heat water. He measures how hot the water gets.

a State whether the burning reactions are exothermic or endothermic. Explain your decision. *(2 marks)*

b Name the independent variable in the investigation. *(1 mark)*

c Name **two** variables that Marcus must keep the same. *(2 marks)*

d Explain why he must keep these variables the same. *(1 mark)*

(6 marks)

3 Sze-Kie heats some calcium carbonate in a test tube. There is a chemical reaction:

calcium carbonate →
calcium oxide + carbon dioxide

a State what type of reaction the word equation shows. Choose from the list below. *(1 mark)*

combustion
oxidation
thermal decomposition
exothermic

b Name the product(s) of the reaction. *(1 mark)*

c Sze-Kie started with 100 g of calcium carbonate. At the end of the reaction, there was 56 g of calcium oxide in the test tube. Calculate the mass of carbon dioxide made. Show your working. *(2 marks)*

(4 marks)

4 Burning methane is a chemical reaction. Here are some ways of representing this reaction.

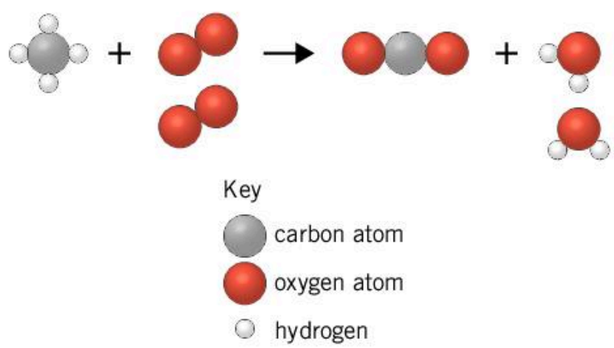
Equation X

methane + oxygen → carbon dioxide + water

Equation Y

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

Diagram Z



a Explain how Equation X, Equation Y, and Diagram Z all show that burning methane is a chemical reaction. *(2 marks)*

b Compare the advantages and disadvantages of representing the reaction with Equation X, Equation Y, and Diagram Z. *(6 marks QWC)*

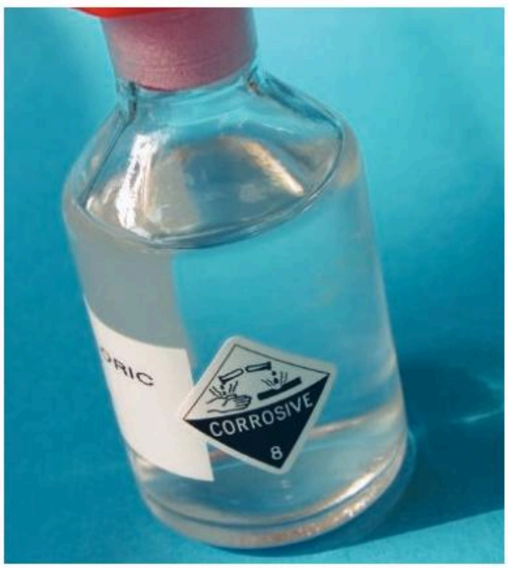
(8 marks)

4.1 Acids and alkalis

Learning objectives

After this topic you will be able to:

- compare the properties of acids and alkalis
- describe differences between concentrated and dilute solutions of an acid.



▲ These solutions are corrosive.

▲ Vinegar contains ethanoic acid.

What do vomit, vinegar, and lemons have in common?

They all taste sour. This is because they contain **acids**. Vomit includes an acid from the stomach, hydrochloric acid. This acid helps digest foods. Vinegar is a solution of ethanoic acid and other substances. Lemons contain citric acid.

Alkalis are the chemical opposite of acids. Soap solution is an alkali, and so is toothpaste. Most alkalis feel soapy.

A List the chemical names of three acids.

Using acids and alkalis safely

It is safe to eat the acid in lemons, and to use alkaline soap. But there are hazards linked to some acids and alkalis.

The bottle opposite has a hazard symbol. The symbol shows that the solution in the bottle is **corrosive**. It could burn your skin and eyes.

You can control risks from corrosive solutions by:

- wearing eye protection
- keeping the solution off your skin.

If a solution is very corrosive, a teacher might wear protective gloves when using it.

B State two hazards of using a corrosive solution.

Concentrated or dilute?

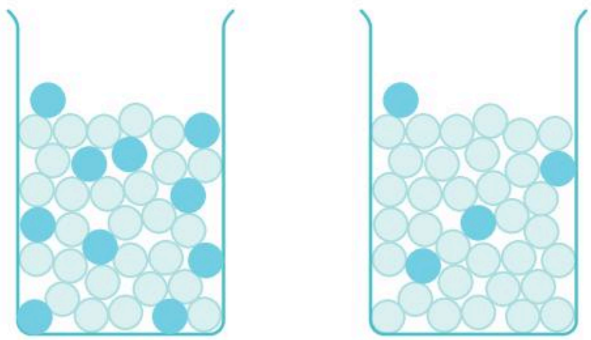
Pure ethanoic acid causes severe burns. It catches fire easily.

Vinegar contains ethanoic acid. It is safe to eat, and does not catch fire. Why is there a difference? Pure ethanoic acid contains no water. Dissolving in water changes some properties.

The amount of water makes a difference, too. Both the bottles at the top of the next page contain hydrochloric acid. Hydrochloric acid is a solution of hydrogen chloride in water.

- Acid A has 370 g of hydrogen chloride in 1 litre of solution.
- Acid B has 3.70 g of hydrogen chloride in 1 litre of solution.

Acid A has more hydrogen chloride per litre than acid B. Acid A is **concentrated**. Acid B is **dilute**. The concentrated solution burns skin and eyes. The dilute solution hurts if it gets into a cut but has no other hazards.



▲ The solution on the left is more concentrated. It has more acid particles per litre. Not to scale.

The hazards of using acids and alkalis depend on:

- the acid or alkali you are using
- whether the solution is concentrated or dilute.

C State one difference between a concentrated solution of an acid and a dilute solution of the same acid.

Safe handling

A teacher has a solution of an alkali. The solution is corrosive – it causes severe burns and is dangerous to the eyes. Describe how to control the risks from these hazards. Do you think the teacher should allow your class to use the alkali? Explain your decision.

Foul Fact!

William Beaumont discovered stomach acid when treating a shooting victim. Beaumont removed stomach juices through holes in the skin and stomach. He tested the juices with different foods.

Key Words

acid, alkali, corrosive, concentrated, dilute

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

Acids **taste sour/feel soapy**. Some acidic and alkaline solutions are **corrosive/correlated**. A concentrated solution of an acid is **more/less** corrosive than a dilute solution. A concentrated solution has **fewer/more** acid particles per litre than a dilute solution.

(4 marks)

2 Calculate which is more concentrated – 20 g of alkali in 250 cm^3 of solution or 10 g of the same alkali in 500 cm^3 of solution. Show your working.

(3 marks)

3 Use the information on this spread to compare the properties of acids and alkalis.

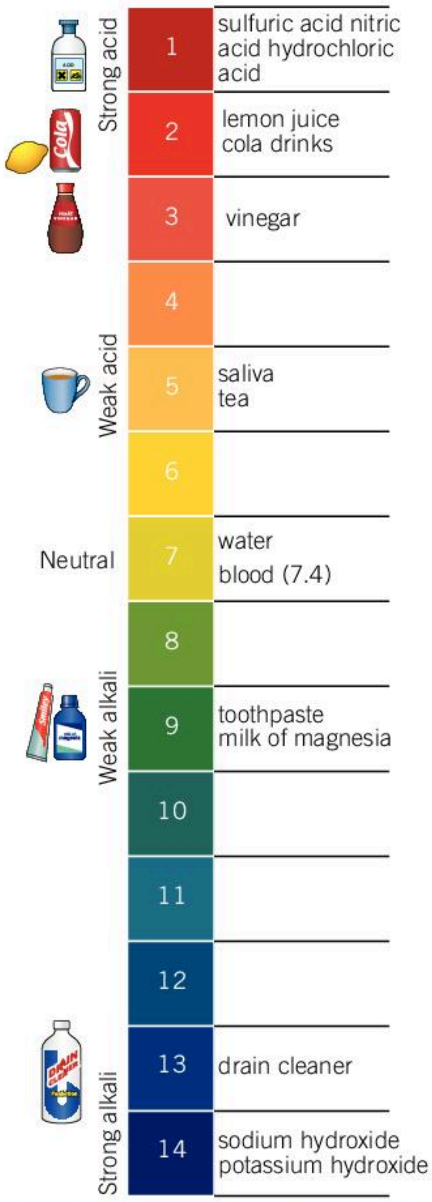
(6 marks QWC)

4.2 Indicators and pH

Learning objectives

After this topic you will be able to:

- use the pH scale to measure acidity and alkalinity
- describe how indicators categorise solutions as acidic, alkaline, or neutral.



▲ Universal indicator changes colour depending on the pH.

A student has two beakers. One contains an acid and the other contains an alkaline solution. How can he find out which is which?

You can use an **indicator** to find out whether a solution is acidic or alkaline. An indicator contains a dye. The dye turns a different colour in acidic and alkaline solutions.

A State what an indicator is.

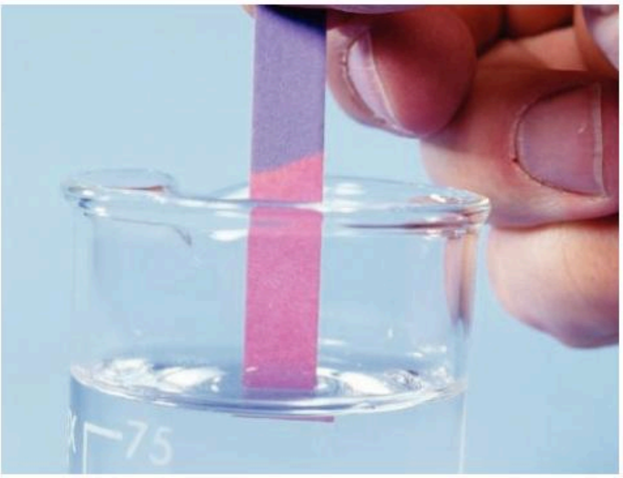
Which plants make good indicators?

You can make indicators from plants. The table shows the colours of some plant indicators in acidic and alkaline solutions.

Juice extracted from…	Colour in dilute hydrochloric acid	Colour in dilute sodium hydroxide solution (an alkali)
red cabbage	red	yellow/green
hibiscus flower	dark pink/red	dark green
beetroot	red/purple	yellow

At school, you might use **litmus** indicator. Litmus is a solution of dyes from lichens.

- Red litmus paper turns blue on adding alkali.
- Blue litmus paper turns red on adding acid.



◀ Using litmus paper.

B State the colour change when a student adds an acid to blue litmus paper.

How acidic? How alkaline?

Which is more acidic, vinegar or stomach acid? How can you find out? You cannot use blue litmus paper. Both acids would make it red.

Instead, you need **universal indicator**. Universal indicator is a mixture of dyes. It changes colour to show how acidic or alkaline a solution is.

What is the pH scale?

The **pH scale** is a measure of how acidic or alkaline a solution is. On the pH scale:

- An acid has a pH of less than 7. The lower the pH, the more acidic the solution.
- An alkaline solution has a pH of more than 7. The higher the pH, the more alkaline the solution.

Some solutions are **neutral**. This means they are neither acidic nor alkaline. The pH of a neutral solution is exactly 7.

Universal indicator is a different colour at each pH. The scale shows the colours of universal indicator in solutions of different pH.

Acidity

Amie collected the data in the table. Use the data to list the names of the solutions in order of increasing acidity, starting with the least acidic.

Solution	pH
milk	6.6
urine	6.1
orange juice	3.2
black coffee	5.5
lemon juice	2.3
vinegar	2.8

▲ Universal indicator turns orange in vinegar. It turns red in stomach acid.

C State the pH of a neutral solution.

Foul Fact!

Murderer John Haig, also known as the Acid Bath Murderer, disposed of the bodies of his victims in baths of concentrated sulfuric acid. The acid pH was between 0 and 1.

Key Words

indicator, litmus, universal indicator, pH scale, neutral

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

Adding an acid to red litmus paper makes the litmus paper go **red/blue**. On the pH scale, acids have a pH of **less than/more than** 7. The higher the pH, the **more/less** acidic the solution. A solution is alkaline if its pH is **more than/less than** 7. A solution of pH of **7/0** is neutral.

(5 marks)

2 John has a solution. It turns yellow when he adds red-cabbage juice. Predict what colour the solution would turn if he added hibiscus-flower juice. Explain your answer.

(2 marks)

3 Using information from this page, create a chart to show the colours of dilute hydrochloric acid and dilute sodium hydroxide solution in five different indicators.

(6 marks)

4.3 Neutralisation

Learning objectives

After this topic you will be able to:

- describe how pH changes in neutralisation reactions
- state examples of useful neutralisation reactions.

▲ Indigestion tablets neutralise stomach acid.

Volume of sodium hydroxide added (cm³)	pH
0	1
1	2
2	2
3	2
4	3
5	4
6	5
7	7

Key Words

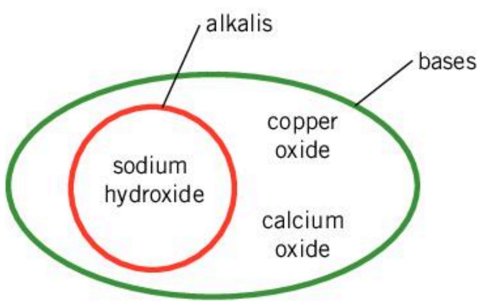
neutralisation, base

Have you ever had stomach ache? Did you take an indigestion tablet?

Extra stomach acid makes your stomach hurt. An indigestion tablet reacts with this acid in a **neutralisation** reaction. In a neutralisation reaction an acid reacts with a substance that cancels it out. The pH gets closer to 7.

Which substances neutralise acids?

A **base** is a substance that neutralises an acid. Bases include sodium hydroxide, calcium oxide, and copper oxide. Some bases are soluble in water. A soluble base is an alkali.



◀ Alkalis are bases that dissolve in water.

A State one difference between a base and an alkali.

pH changes in neutralisation reactions

Gwil has 10 cm^3 of acid. He adds universal indicator. He looks at the colour of the mixture, and compares it to the indicator colour chart. He records the pH.

Then Gwil adds 1 cm^3 of sodium hydroxide solution. The pH increases. Gwil writes down the new pH. He continues to add sodium hydroxide solution. The pH gets closer to 7. The alkali is neutralising the acid. Gwil stops adding alkali when the pH is 7. His mixture is neutral.

B State what volume of sodium hydroxide solution was needed to neutralise the acid.

How is neutralisation useful?

Soil for crops

Some soils are more acidic than others. Every plant has its favourite soil pH.

Deepa lives in India. She has a farm. She wants to grow tea. She tests the soil. Its pH is 4.5. The soil is too acidic to grow tea.

Plant	Soil pH range that the plant grows best in
apple tree	5.0–6.8
cabbage	6.0–7.0
onion	6.0–6.5
tea	5.0–6.0
tomato	5.5–7.0

▲ Tea plants grow best in soil of pH 5.0 to 6.0.

Deepa adds a base to the soil. The base neutralises some of the soil acid. The soil pH increases to pH 5.0. It is now suitable for growing tea.

Acidic lakes

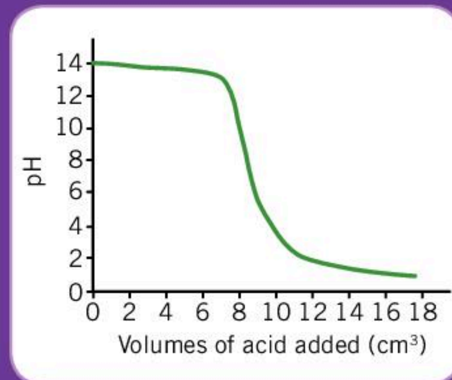
◀ Adding a base to an acidic lake.

In some places, gases from burning coal make sulfur dioxide gas. The gas dissolves in rainwater to make acid rain. The rain falls in lakes, making lakes more acidic. Some water animals and plants cannot live in these lakes.
Environment organisations may add bases to acid lakes. The pH of the lake water increases.

C Describe two situations in which neutralisation reactions are useful.

Data logger details

Ralph has a solution. He adds acid to the solution. A pH probe reads the pH. The probe is attached to a data logger, which sends the data to a computer. The computer draws a graph of the data. Describe in detail what the graph shows.



Summary Questions

1 Copy and complete the sentences below.

A base cancels out an acid in a _______ reaction. An alkali is a soluble _______. You can measure pH with an _______ or a pH probe attached to a _______ logger.

(4 marks)

2 The soil in Freya's farm is pH 7.0. Use data from this page to suggest three crops she could try growing. Explain your choices.

(2 marks)

3 Explain to gardeners why they should measure soil pH, and how they can change soil pH.

(6 marks QWC)

4.4 Making salts

Learning objectives

After this topic you will be able to:

- describe what a salt is
- predict the salts that form when acids react with metals or bases.

▲ Sodium chloride.

▲ Copper sulfate.

▲ Bolivian salt flats.

Here are the formulae of three acids. What do they have in common?

- HCl – hydrochloric acid
- HNO_3 – nitric acid
- H_2SO_4 – sulfuric acid

The formulae show that the acids are compounds. They all include hydrogen atoms.

What are salts?

A **salt** is a compound that forms when an acid reacts with a metal element or compound. The hydrogen atoms of the acid are replaced by atoms of the metal element. The pictures on the left show two salts.

Sodium chloride is the salt you may add to food. Its formula is NaCl. A sodium atom has replaced the hydrogen of hydrochloric acid.

Farmers use copper sulfate to kill fungus. Its formula is $CuSO_4$. Copper atoms have replaced the hydrogen atoms of sulfuric acid.

A Describe what a salt is.

Which reactions make salts?

Many salts exist naturally. Sodium chloride makes the sea salty. It also exists underground. There are huge amounts of salts in Bolivian salt flats.

You can also make salts in chemical reactions.

Acids and metals

Reacting an acid with a metal makes two products – a salt, and hydrogen. For example:

magnesium + hydrochloric acid → magnesium chloride + hydrogen

zinc + sulfuric acid → zinc sulfate + hydrogen

Key Words

salt

Acids and bases

Reacting an acid with a base also makes a salt. The products are a salt, and water. For example:

sodium hydroxide + hydrochloric acid → sodium chloride + water

copper oxide + nitric acid → copper nitrate + water

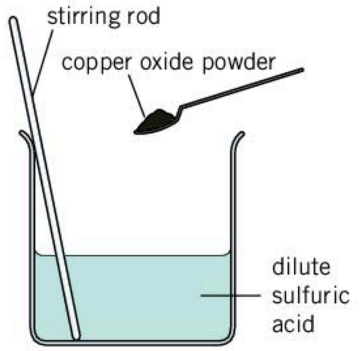
The reactions show that:

- hydrochloric acid is a chloride maker
- sulfuric acid is a sulfate maker
- nitric acid is a nitrate maker.

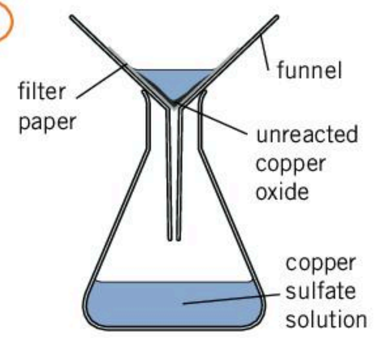
B Name the salt made when sodium hydroxide reacts with hydrochloric acid.

How can you make salt crystals?

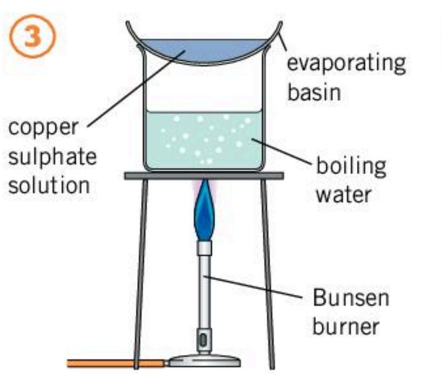
The reactions of acids with metal or bases make salt solutions. Removing water makes salt crystals. The diagrams show how to make copper sulfate crystals.

1


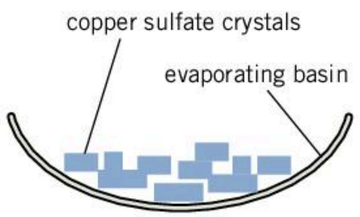
▲ Add copper oxide powder (a base) to dilute sulfuric acid. Keep adding until some copper oxide is left over. All the acid has now reacted.

2


▲ Filter to remove the extra copper oxide.

3


▲ Heat the copper sulfate solution in an evaporating basin until most of the water evaporates.

4


▲ Leave the evaporating basin in a warm place. The rest of the water evaporates. Copper sulfate crystals remain.

Making magnesium salts

You can make magnesium chloride crystals from magnesium and hydrochloric acid. The method is similar to that for making copper sulphate. The only difference is that magnesium, not copper oxide, is left over in the first stage. Write clear and detailed instructions for making magnesium chloride.

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

A salt is **an element/a compound**. In a salt, the **hydrogen/oxygen** atoms of an acid are replaced by metal atoms. When an acid reacts with a metal, the products are a salt and **water/hydrogen**. When a base reacts with an acid, the products are a salt and **water/hydrogen**.

(4 marks)

2 Predict the products of the reaction of magnesium with sulfuric acid.

(2 marks)

3 Predict the products of the reaction of zinc oxide with nitric acid.

(2 marks)

4 Describe and explain the stages in making copper chloride crystals from an insoluble base and an acid.

(6 marks)

C1 Chapter 4 Summary

Key Points

- The pH scale shows how acidic or alkaline a solution is.
- Acids have pH values below 7. The lower the pH, the more acidic the solution.
- Alkaline solutions have pH values above 7. The higher the pH, the more alkaline the solution.
- Neutral solutions are neither acidic nor alkaline. Their pH is exactly 7.
- Indicators change colour to show whether a solution is acidic or alkaline.
- Universal indicator changes colour to show the pH of a solution.
- Litmus is an indicator. Blue litmus paper turns red on adding acid. Red litmus paper turns blue on adding an alkaline solution.
- In a neutralisation reaction, an acid cancels out a base, or a base cancels out an acid.
- A base is a substance that neutralises an acid.
- An alkali is a soluble base.
- Adding bases or acids to soil can change its pH, making it suitable for different crops.
- Adding a base to an acidic lake increases the lake pH, making it suitable for different plants and animals.
- If an acid reacts with a base, there are two products – a salt, and water.
- If an acid reacts with a metal, there are two products – a salt, and hydrogen.
- Sulfuric acid makes sulfate salts, hydrochloric acid makes chloride salts, and nitric acid makes nitrate salts.

Case study

Useful neutral

Neutralisation happens when an acid cancels out a base or when a base cancels out an acid.

Task

Prepare a piece of writing that explains how neutralisation reactions are useful.

Tips

- Start by drawing a visual summary to help you organise your ideas.
- Make sure your paragraphs are in a sensible order.
- Swap your work with another student and discuss improvements.

Key Words

acid, alkali, alkaline solution, acidic solution, corrosive, concentrated, dilute, indicator, litmus, universal indicator, pH scale, neutral, neutralisation, base, salt

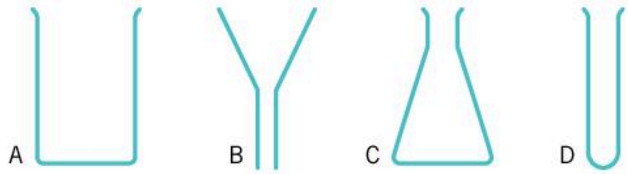
End-of-chapter questions

1 A scientist measures the pH of samples of sweat, blood, and urine from one person. Copy the table. Write down whether each sample is acidic, alkaline, or neutral.

Name of mixture	pH	Acidic, alkaline, or neutral?
sweat	5.3	
blood	7.4	
urine	6.8	

(***3 marks***)

2 Joe wants to make a red-cabbage indicator. He has the apparatus below.



- **a** First, Joe heats a mixture of chopped red cabbage and water. Write the letter of the best apparatus for this. *(1 mark)*
- **b** Next, Joe filters the mixture. He keeps the solution. Write the letters of the best **two** pieces of apparatus for this. *(2 marks)*
- **c** Lastly, Joe adds the red-cabbage solution to acidic and alkaline solutions. Write the letter of the best apparatus for this. *(1 mark)*

(***4 marks***)

3 The table below gives the preferred soil pH of some fruit plants.

Fruit plant	Preferred soil pH
blueberry	4.0–5.0
sweet cherry	6.0–7.5
cranberry	4.2–5.0
pineapple	5.0–6.0
strawberry	5.0–6.5

- **a** Name the plant in the table that can grow well in alkaline soil. *(1 mark)*
- **b** Name the plant in the table that can grow in the most acidic soil. *(1 mark)*
- **c** The soil pH in Andy's garden is 6.0. Name **three** fruit plants that might grow well in this soil. *(3 marks)*
- **d** The soil pH in Clare's garden is 8.0. She wants to grow strawberry plants. State the type of substance she should add to the soil so that the pH is suitable. Explain your answer. *(2 marks)*

(***7 marks***)

4 Describe and explain the stages in making magnesium chloride crystals from an acid and a metal. Include the names of the acid and the metal.

(***6 marks QWC***)

Chemistry 2

Where do we get the materials we need? In this unit you will learn about the structure of the Earth, and the rocks of its crust. You will discover how we separate mixtures, and use chemical reactions, to obtain the materials we need from the Earth and its atmosphere.

You will also explore patterns in chemical reactions. You will identify patterns in the properties of elements, and learn how to use the Periodic Table to predict properties.

Q

Write the names of ten elements.

You already know

- Dissolving, mixing, and changes of state are reversible changes.
- Some changes result in the formation of new materials and are not reversible.
- Techniques such as filtering, sieving, and evaporating can be used to separate mixtures.
- You can classify rocks according to their properties.
- The properties of rocks depend on how they were formed.
- Different materials have different properties.
- All materials are made up of one or more elements.
- There are 92 naturally occurring elements.
- All the elements are listed in the Periodic Table.

BIG Questions

- How do we obtain the materials we use?
- How does the Periodic Table help us predict element properties?
- What are the patterns in the properties of metals?

Picture Puzzler
Key Words





Can you solve this Picture Puzzler?

The first letter of each of these images spells out a science word that you will come across in this unit.

Picture Puzzler
Close Up

Can you tell what this zoomed-in picture is?

***Clue**: Made of lots of layers.*

Making connections

In **C1** you learnt about elements and compounds.

In **C2** you will learn how elements can be grouped into metals and non-metals.

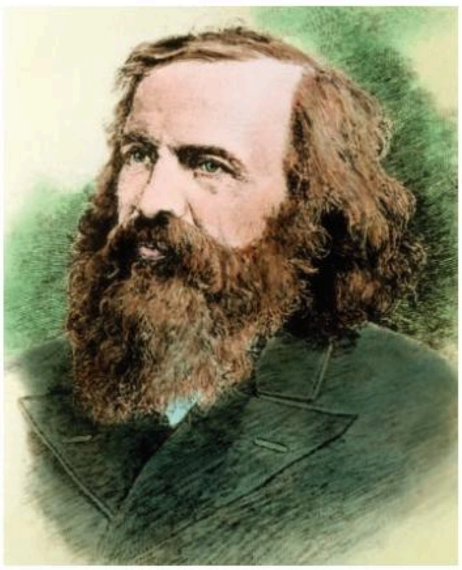
In **C3** you will learn how to use the Periodic Table in the classification of elements.

1.1 Metals and non-metals

Learning objectives

After this topic you will be able to:

- explain how elements are classified as metals and non-metals
- use patterns to classify an element as a metal or non-metal.

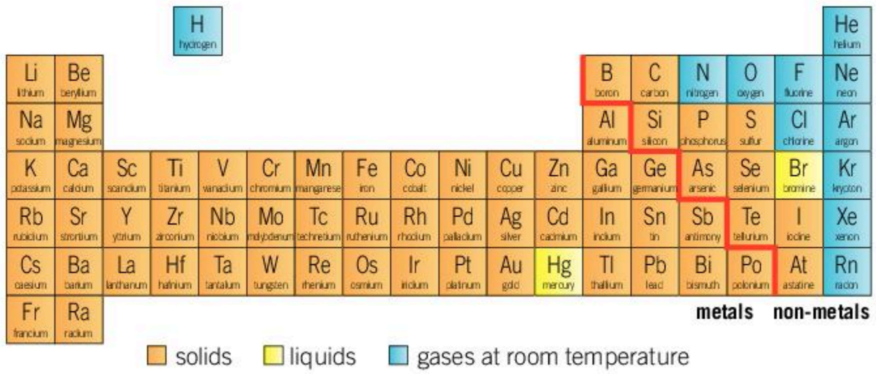


▲ In 1869 Russian scientist Dmitri Mendeleev used patterns in properties to create the first Periodic Table.

Making predictions

When Mendeleev created the Periodic Table in 1869 there were only 60 known elements. Using patterns in the table he was able to predict that new elements would be discovered. He left gaps in the table so that new elements could be filled in.

There are 92 elements that exist naturally. Can you remember all their properties? Luckily, you don't need to. There are patterns in element properties. You can predict the properties of an element from its place in the Periodic Table.



▲ The Periodic Table. This version does not include every element.

Metal or non-metal?

There are many ways of sorting elements. One classification has just two categories – **metals** and **non-metals**. In the Periodic Table, metals are on the left of the stepped line. Non-metals are on the right.

▲ Silver is a metal.

▲ Sulfur is a non-metal.

A State one way of sorting the elements in the Periodic Table.

How can you tell whether an element is a metal or a non-metal? You can examine its properties:

Properties of a typical metal (when solid)	Properties of a typical non-metal (when solid)
good conductor of electricity	poor conductor of electricity
good conductor of heat	poor conductor of heat
shiny	dull
high density (heavy for its size)	low density (light for its size)
malleable (you can hammer it into different shapes)	brittle (breaks easily)
ductile (you can pull it into wires)	
sonorous (makes a ringing sound when hit)	not sonorous

Most metals have high melting points. They are usually solid at 20 °C. Many non-metals have low boiling points. For example, oxygen and chlorine are gases at 20 °C.

B State six properties of a typical non-metal.

Do all elements fit the pattern?

Most elements are easy to classify as metals or non-metals. But the system is not perfect. Mercury is a metal. It is liquid at 20 °C. Its melting point is lower than that of some non-metals.

The elements near the stepped line are **metalloids**. Their properties are between those of metals and non-metals.

Do metals and non-metals react differently?

The properties in the table on the opposite page are **physical properties**. They describe things you can observe and measure.

Metals and non-metals also have different **chemical properties**. Chemical properties describe chemical reactions. Many metals and non-metals react with oxygen. The products are oxides. For example:

metal: magnesium + oxygen → magnesium oxide

non-metal: sulfur + oxygen → sulfur dioxide

Many non-metal oxides are gases at 20 °C. They dissolve in water to form acidic solutions. Sulfur dioxide and nitrogen dioxide are examples of acidic gases. They are formed when some fuels burn. They dissolve in rain to make rain acidic. **Acid rain** makes lakes acidic. It also damages trees.

Most metal oxides are solids at 20 °C. They are basic. If they dissolve in water, they form alkaline solutions.

C Describe one difference between metal oxides and non-metal oxides.

Metal or non-metal?

Decide whether each element below is a metal or non-metal.

	Element X	Element Y	Element Z
melting point (°C)	3000	–220	660
relative electrical conductivity (the highest number is the best conductor)	11	0	39
oxide	basic	acidic	reacts with acids and bases

▲ Silicon is a metalloid. It is a semiconductor of electricity.

Link

You can learn more about physical and chemical changes in C1 3.1 Chemical reactions

Key Words

metal, non-metal, metalloid, physical property, chemical property, acid rain

Summary Questions

1 Sort these properties into two lists – properties of metals and properties of non-metals.

sonorous	good conductor of electricity
low melting point	dull
high density	malleable
brittle	basic oxide

(8 marks)

2 Element A is on the left of the Periodic Table. Predict six of its properties.

(6 marks)

3 Compare the properties of metals and non-metals.

(6 marks QWC)

1.2 Groups and periods

Learning objectives

After this topic you will be able to:

- use patterns to predict properties of elements
- compare patterns in properties in the groups and periods of the Periodic Table.

▲ Palladium is an element. It is used in catalytic converters in cars, surgical instruments, and some flutes.

Palladium is metal. What can you predict about its properties? The picture shows that palladium is shiny. You might have predicted that it is a good conductor of heat and of electricity.

If you find palladium in the Periodic Table, you can make even better predictions.

What are groups?

In the Periodic Table, the vertical columns are called **groups**. The elements in a group have similar properties. Going down a group, there is a pattern in the properties such as melting point, boiling point, and **density**. Density is how much mass something has for its volume.

group number

1	2											3	4	5	6	7	0
			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															

▲ Some groups of the Periodic Table.

A State the name given to the vertical columns in the Periodic Table.

The tables show data for elements near palladium in the Periodic Table. Each table shows the elements in one group.

Element	Melting point (°C)
iron	1535
ruthenium	2500
osmium	3000

Element	Melting point (°C)
cobalt	1492
rhodium	1970
iridium	2440

Element	Melting point (°C)
nickel	1453
palladium	
platinum	1769

Sophie studies the data. She makes this prediction:

For the groups headed by iron and cobalt, melting point increases from top to bottom. The nickel group is likely to show the same pattern. So I predict that the melting point of palladium is between 1453 °C and 1769 °C.

A data book gives the melting point of palladium as 1550 °C. Sophie's prediction is correct.

Link

You can learn more about density in P2 3.3 Pressure in gases

Key Words

group, density, period

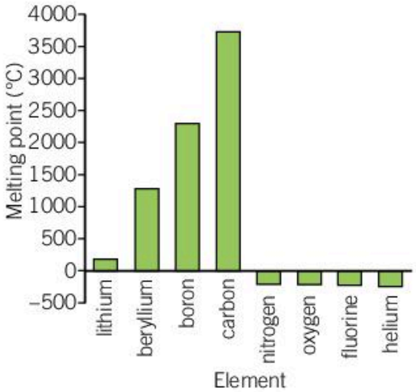
What are periods?

The horizontal rows of the Periodic Table are called **periods**. Going across a period, there are patterns in the properties of the elements.

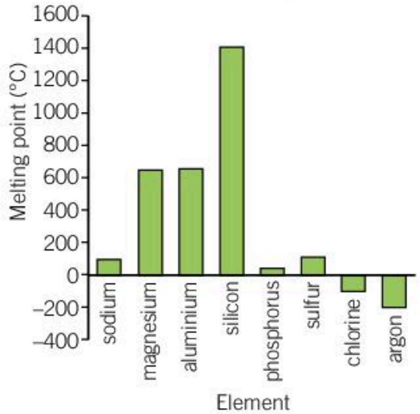
The bar charts show the melting points of the Period 2 and Period 3 elements.

Period 1				H														He
Period 2	Li	Be											B	C	N	O	F	Ne
Period 3	Na	Mg											Al	Si	P	S	Cl	Ar
Period 4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Period 5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Period 6	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Period 7	Fr	Ra	Ac															

▲ Some periods of the Periodic Table.



▲ The melting points of Period 2 elements.



▲ The melting points of Period 3 elements.

Adam describes the patterns shown on the bar charts.

For Period 2, the melting point increases from left to right for the first four elements. The melting points of the other elements are low. The pattern is similar for Period 3.

B State the name given to the horizontal rows in the Periodic Table.

Predictable patterns?

The tables show the sizes of atoms of the Period 2 and Period 3 elements. Draw bar charts to display these data. Write a sentence to compare the atom size patterns for Period 2 and Period 3.

Period 2	
Element	**Atomic radius (nm)**
lithium	0.123
beryllium	0.089
boron	0.082
carbon	0.070
nitrogen	0.065
oxygen	0.066
fluorine	0.064

Period 3	
Element	**Atomic radius (nm)**
sodium	0.157
magnesium	0.136
aluminium	0.125
silicon	0.117
phosphorus	0.110
sulfur	0.104
chlorine	0.009

Fantastic Fact

The Periodic Table has this name because there is a repeating pattern of properties, like the repeating pattern of menstrual periods.

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

The vertical columns of the Periodic Table are **groups/periods**. The horizontal rows are **groups/periods**. There are patterns in element properties **down/across** groups and **down/across** periods.

(4 marks)

2 The tables give density data. Draw two bar charts to display the data. Use your bar charts, and the Periodic Table, to predict the density of palladium.

Element	Density (g/cm^3)	Element	Density (g/cm^3)
cobalt	8.9	nickel	8.9
rhodium	12.4	palladium	
iridium	22.5	platinum	21.4

(3 marks)

3 Draw a big outline of the Periodic Table. Add labels to summarise the information on this spread.

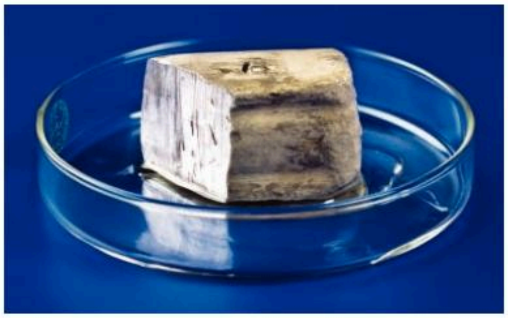
(6 marks)

1.3 The elements of Group 1

Learning objectives

After this topic you will be able to:

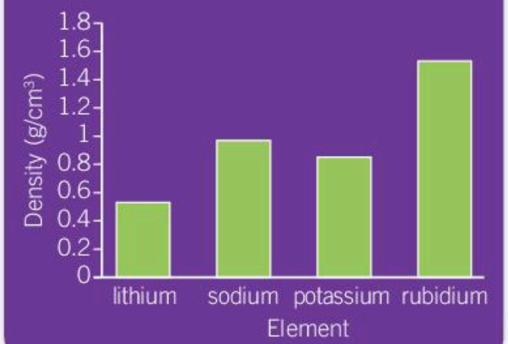
- interpret data to describe patterns in properties of the Group 1 elements
- use patterns to predict properties of Group 1 elements.



▲ Sodium is a good conductor of heat. It is a coolant in nuclear power stations.

Which conclusion?

The bar chart shows densities for Group 1 elements. Sam says there is no pattern. Ben says there is a pattern – overall, density increases down the group. Use the bar chart to work out an even better description of the pattern.



What do the pictures have in common?

▲ A mobile-phone battery.

▲ Engine-lubricating grease.

▲ Red fireworks.

They all rely on compounds of lithium. Lithium is in **Group 1**, on the left of the Periodic Table.

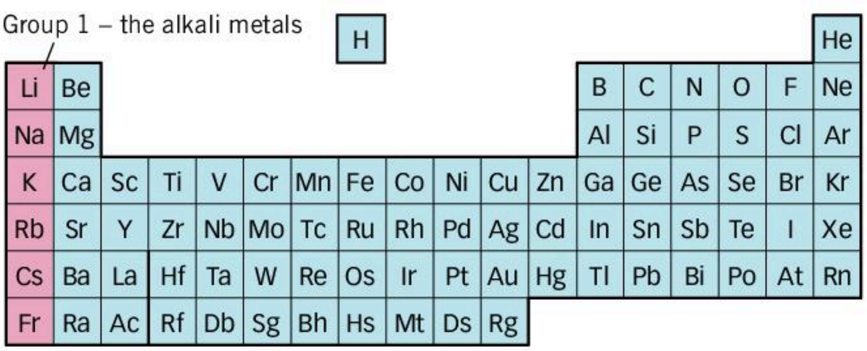
Are Group 1 elements like other metals?

The Group 1 elements are to the left of the stepped line. This shows that they are metals. In many ways, Group 1 elements are like other metals:

- They are good conductors of electricity and heat.
- They are shiny when freshly cut.

In some ways, Group 1 elements are different to other metals. The table shows that Group 1 elements have lower melting points than other metals.

Element	Is the element in Group 1?	Melting point (°C)
lithium	yes	180
sodium	yes	98
potassium	yes	64
rubidium	yes	39
copper	no	1083
platinum	no	1796



▲ The Group 1 elements.

A State one way in which Group 1 elements differ from other metals.

Are there patterns in Group 1 properties?

The Group 1 elements show patterns in physical and chemical properties.

Physical properties

The data on the opposite page shows that melting point decreases from top to bottom of Group 1. The data below shows that boiling point also decreases from top to bottom of Group 1.

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

B State what happens to the boiling point as you move down Group 1.

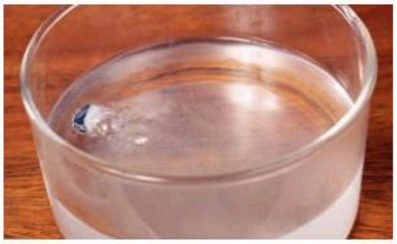
Chemical properties

The Group 1 elements are very **reactive**. This means that they easily take part in chemical reactions.

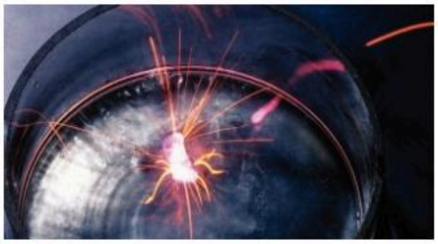
All the Group 1 elements have exciting reactions with water. The reactions make hydrogen gas. The gas moves the reacting element around on the water. The reactions also make alkaline solutions, so universal indicator turns purple.

lithium + water → lithium hydroxide + hydrogen

There is a pattern in the reactions. They all produce hydrogen and a metal hydroxide. The reactions get more vigorous going down the group.



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



▲ The reaction of potassium with water is very vigorous.

C Name the gas produced when Group 1 elements react with water.

Key Words

Group 1, reactive

Summary Questions

1 Write five correct sentences from the sentence starters and enders.

Sentence starters	Sentence enders
From top to bottom of Group 1…	…have low densities.
From bottom to top of Group 1…	…conduct electricity.
All Group 1 elements…	…melting point increases.
	…boiling point decreases.
	…react with water to make hydrogen and an alkaline solution.
	…the vigour of the reaction with water increases.

(5 marks)

2 The table gives hardness values for some Group 1 elements. The bigger the value, the harder the element.

Element	Mohs hardness
lithium	0.6
sodium	0.5
potassium	
rubidium	0.3
caesium	0.2

a Plot the hardness values on a bar chart. *(6 marks)*

b Describe the pattern in hardness. *(2 marks)*

c Predict the hardness of potassium. Explain your prediction. *(2 marks)*

3 Describe in detail patterns in the physical and chemical properties of the Group 1 elements. *(6 marks QWC)*

1.4 The elements of Group 7

Learning objectives

After this topic you will be able to:

- use patterns to predict properties of Group 7 elements
- describe displacement reactions.

Foul Fact

Five thousand soldiers died from chlorine poisoning in World War 1.

▲ Chlorine is pale green and bromine is dark red. In the solid state iodine crystals are grey-black. Iodine vapour is purple.

Key Words

Group 7, halogen, displace, displacement reaction

Better bar charts

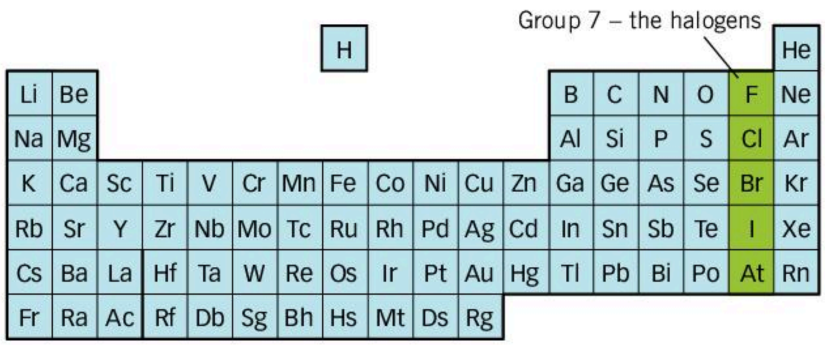
Plot a bar chart for the Group 7 boiling-point data on the opposite page. Swap bar charts with a partner. Can you suggest improvements?

Have you ever smelt chlorine in tap water? Chlorine and its compounds do a vital job. Tiny amounts destroy deadly bacteria, making water safe to drink and swim in.

A State one use of chlorine.

Are Group 7 elements like other non-metals?

Chlorine is in **Group 7** of the Periodic Table. The other elements of the group are fluorine, bromine, iodine, and astatine. The Group 7 elements are also called **halogens**.



▲ Group 7 is towards the right of the Periodic Table.

The halogens have low melting points, like most non-metals. They do not conduct electricity. Iodine is a brittle solid at room temperature.

B Name the elements in Group 7.

Are there patterns in Group 7 properties?

Physical properties

The table shows melting- and boiling-point data.

Element	Melting point (°C)	Boiling point (°C)	State at room temperature
fluorine	−220	−188	gas
chlorine	−101	−35	gas
bromine	−7	59	liquid
iodine	114	184	solid

In Group 7, melting point increases from top to bottom. This is different to Group 1, where melting point decreases from top to bottom.

C Describe the pattern in boiling points for the Group 7 elements.

The colours of the elements get darker from top to bottom.

Chemical properties

The Group 7 elements are reactive. All the Group 7 elements react with iron. The word equations summarise the reactions.

iron + chlorine → iron chloride

iron + bromine → iron bromide

iron + iodine → iron iodide

The reaction of chlorine with iron is very vigorous. There is a bright flame. The reactions get less vigorous going down the group. This is different to Group 1, in which reactions get more vigorous from top to bottom.

▲ Iron reacts vigorously with chlorine.

D Describe how the reaction of the Group 7 elements with iron changes going down the group.

What are displacement reactions?

Angus adds chlorine solution to potassium bromide solution. He records his observations.

	Appearance
chlorine solution (before reaction)	pale green
potassium bromide solution (before reaction)	colourless
mixture after reaction	orange

The orange substance is bromine. It is a product of the reaction. In the reaction, chlorine **displaces** bromine from potassium bromide. Elements nearer the top of Group 7 displace elements lower in the group from their compounds. Examples of **displacement reactions** are:

chlorine + potassium bromide → potassium chloride + bromine

bromine + potassium iodide → potassium bromide + iodine

◀ Chlorine solution reacting with potassium bromide solution.

Summary Questions

1 Copy and complete the sentences below.

The Group 7 elements are also called the ______. The halogens are on the ______ of the stepped line. This means they are ______. The melting and boiling points ______ from top to bottom. The reactions get ______ vigorous from top to bottom.

(5 marks)

2 Predict which of the reactions below will happen. Explain your choices.

a fluorine + potassium chloride → potassium fluoride + chlorine

b iodine + potassium chloride → potassium iodide + chlorine

c bromine + sodium iodide → sodium bromide + iodine

d chlorine + sodium bromide → sodium chloride + bromine

(3 marks)

3 Describe the patterns in the physical and chemical properties of the Group 7 elements.

(6 marks QWC)

1.5 The elements of Group 0

Learning objectives

After this topic you will be able to:

- describe the physical and chemical properties of the Group 0 elements
- use patterns to predict properties of Group 0 elements.

What do double glazing, bar-code scanners, and helium balloons have in common?

They all make use of elements in the same group of the Periodic Table, **Group 0**. Group 0 includes helium, neon, argon, krypton, xenon, and radon. The elements of Group 0 are also called the **noble gases**.

A Name the six noble gases.

▲ Eye surgeons use krypton lasers to repair tears in the retina at the back of the eye.

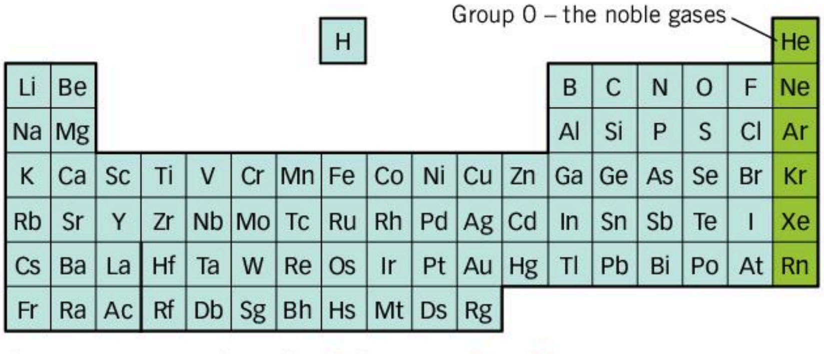
Are there patterns in Group 0 properties?

Physical properties

The noble gases have very low melting and boiling points, like many other non-metals. They are colourless gases at room temperature. The table shows their boiling points.

Element	Boiling point (°C)
helium	–269
neon	–246
argon	–186
krypton	–152
xenon	–108

B Describe the pattern in boiling points for the Group 0 elements



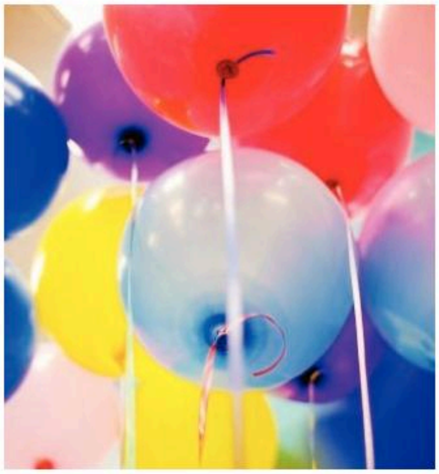
▲ Group 0 is on the right of the Periodic Table.

Key Words

Group 0, noble gases, unreactive

The noble gases glow brightly when high-voltage electricity passes through them. This property explains why noble gases are used in advertising signs. The letters contain neon gas.

▲ This sign contains neon gas.


▲ Helium has a lower density than the air. This is why it is used in helium balloons.


▲ Argon is a better insulator than air, so it is used in the gap between the two panes of glass in double glazing.

Chemical properties

The noble gases take part in very few reactions. Scientists say they are **unreactive**. From top to bottom of the group, the noble gases get slightly more reactive.

- As far as we know, helium and neon never take part in chemical reactions.
- By the year 2000, a group of Finnish scientists had made the compound argon fluorohydride, but it only existed at temperatures below −265 °C.
- Krypton reacts with the most reactive element there is, fluorine, to make krypton difluoride, KrF_2.
- Xenon, like the other Group 0 elements, is very unreactive. However, it does form compounds with fluorine and oxygen.

C State the meaning of the word unreactive.

Where do noble gases come from?

All the noble gases exist in the atmosphere, mixed with other gases. Companies use distillation to separate them from the air. Helium is also found mixed with natural gas under the ground or under the sea. It is expensive to separate helium from the mixture.

Using Group 0

Imagine you work for an advertising agency. You have been asked to make a magazine advert to explain why the noble gases are important.

First, discuss with a partner what the advert will include. Make notes to summarise your ideas. Then create your advert. Make sure it is eye-catching and persuasive.

Summary Questions

1 Each sentence below has one mistake. Copy the sentences, correcting the mistakes.

The noble gases are all in Group 1 of the Periodic Table. The element at the top of the group is neon. The noble gases are metals. They have vigorous reactions. From bottom to top of the group, boiling point increases.

(5 marks)

2 The table shows the melting points of the noble gases. Describe the pattern, and predict the melting point of argon.

Element	Melting point (°C)
helium	−270
neon	−249
argon	
krypton	−157
xenon	−112

(2 marks)

3 Write a song or rap to summarise the patterns in properties of the noble gases, and their uses.

(6 marks)

C2 Chapter 1 Summary

Key Points

- In the Periodic Table, metals are on the left of the stepped line, and non-metals are on the right.
- Most metals have high melting points. They are good conductors of heat and electricity. They are shiny and have high densities. They are malleable, ductile, and sonorous.
- Most non-metals have low melting points. They are poor conductors of heat and electricity. In the solid state they are dull and brittle.
- Metal oxides are basic. Those that dissolve in water form alkaline solutions. Non-metal oxides are acidic.
- Physical properties describe things you can observe and measure.
- Chemical properties describe how substances take part in chemical reactions.
- You can use the arrangement of elements in the Periodic Table to explain and predict patterns in physical and chemical properties.
- In the Periodic Table, the horizontal rows are periods.
- In the Periodic Table, the vertical columns are groups.
- Going across periods and down groups, there are patterns in the elements' properties.
- Group 1 elements have low melting and boiling points, and low densities. They are reactive.
- Group 1 elements react vigorously with water to make hydroxides and hydrogen. The reactions get more vigorous from top to bottom of the group.
- Going down Group 7, melting and boiling points increase. The colours of the elements get darker. They are reactive.
- In a displacement reaction a more reactive element displaces a less reactive element from its compounds.
- Group 0 elements are called the noble gases. They are unreactive.

Key Words

metal, non-metal, metalloid, physical property, chemical property, acid rain, group, density, period, Group 1, reactive, halogen, Group 7, Group 0, displacement reaction, displace, noble gas, unreactive

Maths challenge

The elements of Group 3

The table opposite shows some properties of the Group 3 elements.

Element	Density (g/cm^3)	Boiling point (°C)
boron	2.3	3930
aluminium	2.7	2470
gallium	5.9	2400
indium	7.3	2000
thallium	11.8	1460

Task

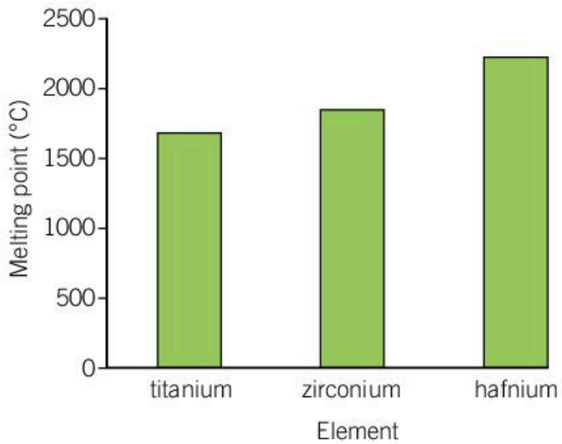
Display the data on two bar charts. Then write a few sentences to describe the patterns in properties.

Tips

- For both bar charts, write the names of the elements on the *x*-axis.
- Each bar chart needs a different label and a different scale for the *y*-axis.
- Make sure the *y*-axis scales are even.

End-of-chapter questions

1 The bar chart shows the melting points of three elements in the same group of the Periodic Table.



a Describe the pattern shown on the bar chart. *(2 marks)*

b Use the bar chart to estimate the melting point of zirconium. *(2 marks)*

(4 marks)

2 Read the text below. Then answer the questions.

Russian chemist Mendeleev created the Periodic Table in 1869. He arranged the 60 elements then known in order of the mass of their atoms. He grouped together elements with similar properties. He left gaps for elements he predicted would be discovered later. One gap was below aluminium. Mendeleev predicted some properties for this missing element. He predicted a low melting point, and a density of 6.0 g/cm^3.

In 1875 French chemist Boisbaudran discovered the missing element. He called it gallium. In 1876 he measured the melting point of gallium as being between 29 °C and 30 °C. Later, he found the melting point of six samples of gallium. His results are in the table.

Sample number	Melting point (°C)
1	30.14
2	30.16
3	30.14
4	30.15
5	30.16
6	30.16

a Explain why Mendeleev left gaps in his Periodic Table. *(1 mark)*

b State whether or not Mendeleev was correct in his prediction for the melting point of the missing element. Explain your decision. *(2 marks)*

c Suggest why Boisbaudran measured the melting point of six samples of gallium. *(1 mark)*

d Use the data in the table to calculate the mean melting point of the samples of gallium. *(1 mark)*

e Boisbaudran took a sample of gallium and worked out its density. He obtained a value of 4.7 g/cm^3. Suggest why he decided to take a fresh sample of gallium and do the experiment again. *(2 marks)*

(7 marks)

3 Compare the patterns in properties of the Group 1 elements with the patterns in properties of the Group 7 elements.

(6 marks QWC)

2.1 Mixtures

Learning objectives

After this topic you will be able to:

- describe particle arrangements in mixtures
- explain how to identify pure substances.

▲ A mixture of two elements, iron and sulfur.

▲ A compound, iron sulfide.

Link

You can learn more about compounds in C1 2.3 Compounds

Have you cleaned your teeth today? Toothpaste is a mixture. A mixture is made up of several different substances. The substances are not chemically joined together. They are just mixed up.

A State what is meant by a mixture.

How are mixtures and compounds different?

The photo on the left shows a mixture of two elements, iron and sulfur. The elements are not joined together. You can see yellow sulfur powder and shiny grey iron. You can use a magnet to separate the mixture. The iron sticks to the magnet, leaving sulfur powder behind.

The photo below shows one dark-grey substance. The substance is a compound, iron sulfide. In the compound, atoms of iron and sulfur are strongly joined together. You could not separate them using a magnet. You would need a chemical reaction to separate them.

The table shows how mixtures and compounds are different.

	Mixture	Compound
Are its substances joined together?	No.	Yes – atoms of its elements are chemically joined together.
What are its properties?	The substances in the mixture keep their own properties.	A compound has different properties to those of its elements.
Is it easy to separate?	Yes.	You need to do chemical reactions to split a compound into its elements.
How much of each substance does it contain?	You can change the amounts of substances.	The relative amounts of each element cannot change.

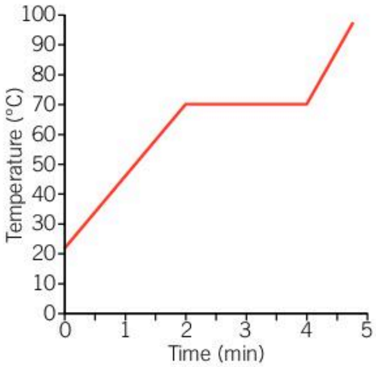
B State two differences between mixtures and compounds.

How can you identify pure substances?

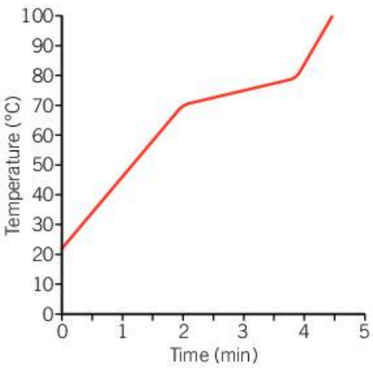
A pure substance has a sharp melting point. Shilpa has two samples of stearic acid, X and Y. One sample is **pure** – it has no other substances mixed with it. Shilpa's other sample is **impure**. Different substances are mixed with it.

Shilpa sets up the apparatus shown at the top of the next page to find out which sample is pure.

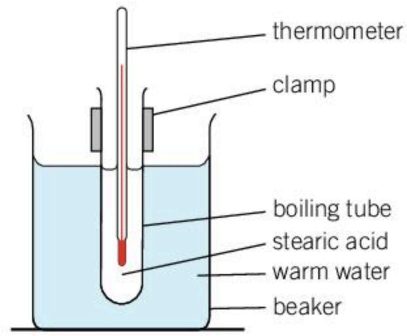
Shilpa heats Sample X. She records the temperature every minute. She plots a graph. She does the same for Sample Y.



▲ Sample X graph.



▲ Sample Y graph.



▲ Shilpa's apparatus.

Sample X has a sharp melting point. Its temperature stays at 70 °C until all the solid has melted. This shows that Sample X is pure. Sample Y melts between 70 °C and 80 °C. It does not have a sharp melting point. It is impure.

C Describe how to find out if a sample of a substance is pure.

Are there other mixtures?

Most materials are mixtures. Some exist naturally:

- Most rocks are mixtures of compounds.
- Seawater is a mixture of water, sodium chloride, and other salts.

Chemists make mixtures that are suitable for their purpose. They work out the best amounts of each substance to add to the mixture. For example, toothpaste may include a chemical called hydrated silica to remove plaque, sodium fluoride to prevent cavities, sodium lauryl sulfate to make foam, carrageenan to thicken the toothpaste, and titanium oxide to make it white.

Toothpaste tales

Write the text for a new toothpaste box. Include the ingredients and write down a reason why each one is included. Make sure the reasons are easy for people who use the toothpaste to understand.

Key Words

mixture, pure, impure

Summary Questions

1 Copy the sentences that are true. Write corrected versions of the sentences that are false.

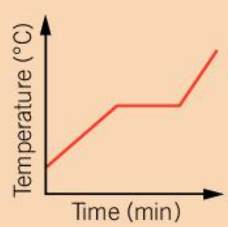
a A mixture is made up of different substances that are chemically joined together.

b You cannot change the amounts of substances in a mixture.

c A pure substance has no other substances mixed with it.

(3 marks)

2 Tim heats a sample. He plots the temperature every minute. Use the graph to decide whether the sample is a pure substance or a mixture of substances. Explain your decision.



(2 marks)

3 Write a paragraph to compare mixtures and compounds.

(6 marks QWC)

2.2 Solutions

Learning objectives

After this topic you will be able to:

- describe solutions using key words
- use the particle model to explain dissolving.

Do you like coffee? When you add water to coffee powder, you make a solution. A solution is a mixture of a liquid with a solid or gas. All parts of the mixture are the same. You cannot see the separate substances.

Catherine adds sugar to water, and stirs. The sugar **dissolves** in the water. Water is the **solvent**. Sugar is the **solute**.

A State what a solution is.

▲ The mass of solution on the left is the same as the total mass of sugar and water on the right.

Does a solute disappear when it dissolves?

You cannot see sugar in a solution. But if you taste the solution, you know the sugar is there. You must never taste things in the laboratory – they might be poisonous.

Some solutions are coloured. Coffee solution is brown, and copper sulfate solution is blue. The colours show that the solute is there.

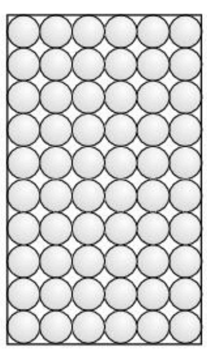
You can also use mass to find out whether something is a solution:

- The mass of one litre of pure water is 1000 g.
- The mass of a solution made by dissolving 20 g of sugar in 1000 g of water is (1000 g + 20 g) = 1020 g.

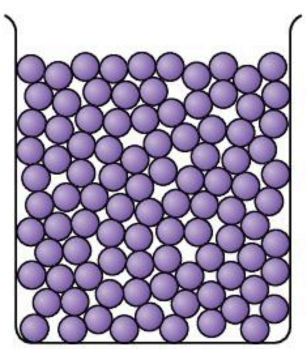
B Identify the solute in coffee solution.

How can we explain dissolving?

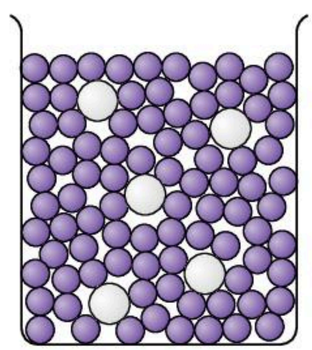
When sugar dissolves, water particles surround each sugar particle. The sugar particles can mix with the liquid. They are arranged randomly, and move around.



▲ Particles in solid sugar.



▲ Particles in liquid water.



▲ Particles in sugar solution.

Solution masses

Sarah dissolves 3 g of copper sulfate in 100 g of water. Calculate the mass of the solution.

Foul Fact

Some solvents can kill. Sniffing butane from deodorant causes unconsciousness, an irregular heartbeat, and frostbite.

You can use rice and beans to model particles in a solution. In the photo, rice grains represent water particles. Beans represent sugar particles.

C Describe the arrangement of particles in a solution.

Is water the only solvent?

Nail varnish does not dissolve in water. That's why it does not come off in the shower. But nail varnish does dissolve in a chemical called propanone. That's why nail-varnish remover is mainly propanone.

Some glues are solutions. They contain a sticky substance dissolved in a solvent. As the solvent evaporates, the glue dries.

Can gases dissolve?

Many gases dissolve in solvents. Carbon dioxide gas makes drinks fizzy. In the bottle, there is a solution. Carbon dioxide, sugar, and flavourings are dissolved in water. When you open the bottle, gas leaves the solution.

▲ Fizzy drinks contain dissolved carbon dioxide gas.

Modelling dissolving

Plan how to use rice and beans, and other materials, to explain dissolving to primary-school children. Draw diagrams to show what you will do, and write notes to remind you what to say.

Key Words

solution, dissolve, solvent, solute

▲ Rice and beans can model particles in a solution.

Link

You can learn more about solutes and solvents in C2 2.5 Evaporation and distillation

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

When salt dissolves in water, a **solvent/solute/solution** forms. Salt is the **solvent/solute/solution** and water is the **solvent/solute/solution**. In the solution, **water/salt** particles surround the **water/salt** particles.

(5 marks)

2 Laura has three beakers. Each contains 200 cm^3 of a colourless liquid. Describe how Laura could find out which beakers contain pure water, and which contain solutions. Explain your answer.

(3 marks)

3 Draw a visual summary of the information on this page. Include examples and pictures.

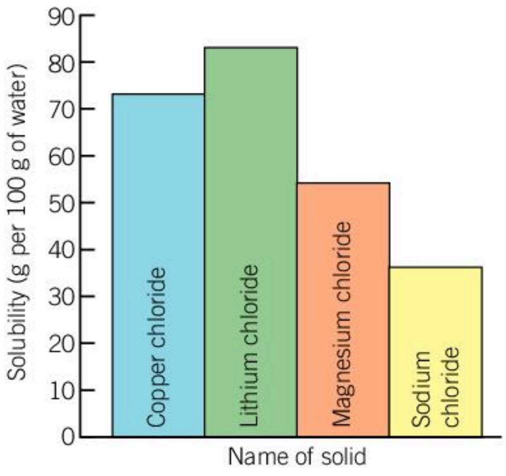
(6 marks)

2.3 Solubility

Learning objectives

After this topic you will be able to:

- explain what a saturated solution is
- explain the meaning of solubility.



Imagine a glass of water. Could you dissolve more salt, or more sugar, in the water? How could you find out?

At room temperature you can dissolve more than 200 g of sugar in 100 g of water. That's more than 40 teaspoons. But if you add even more sugar to the solution, it just falls to the bottom. It does not dissolve. You have made a **saturated solution**.

A saturated solution contains the maximum mass of a substance that will dissolve. There is always some undissolved substance in the container.

You can make a saturated solution of salt (sodium chloride) by adding more than 36 g of salt to 100 g of water.

A State the meaning of the term saturated solution.

What is solubility?

The mass of solute that dissolves in 100 g of water to make a saturated solution is called the **solubility** of the solute. Every substance has its own solubility. The table gives solubility values for sugar and salt.

Substance	Solubility at 20 °C (g/100 g of water)
sugar (sucrose)	202
salt (sodium chloride)	36

The data shows that more sugar than salt can dissolve in 100 g of water. Sugar is more **soluble** than salt. The greater the mass of a substance you can dissolve in 100 g of water, the more soluble the substance.

The bar chart opposite shows the solubilities of four more substances.

B Name the most and least soluble substances shown on the bar chart.

Some substances cannot dissolve in water. They are **insoluble**. Chalk (calcium carbonate) and sand (silicon dioxide) are insoluble in water.

Key Words

saturated solution, solubility, soluble, insoluble

How does temperature affect solubility?

Think again about dissolving sugar. Can you dissolve more sugar in hot water, or in cold water?

Temperature (°C)	Solubility of sugar (g/100 g of water)
20	202
40	236
60	289
80	365
100	476

The data shows that the higher the temperature, the greater the mass of sugar that dissolves.

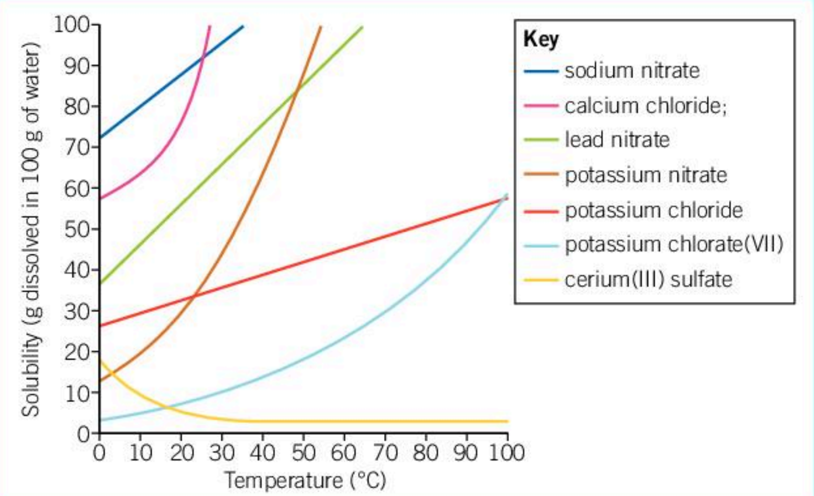
Most substances get more soluble as temperature increases. But the increase is greater for some substances than for others. Compare the solubility values of sugar at 20 °C and at 100 °C to those of salt.

Temperature (°C)	Solubility of salt (g/100 g of water)
20	36
100	39

▲ The solubility of potassium manganate (VII) is 6.3 g/100 g of water at 20 °C.

Grappling with graphs

The graph shows how the solubilities of six substances change with temperature. With a partner, take it in turns to choose a line on the graph and describe what it shows. Next, compare pairs of curves. Finally, choose two curves to compare in writing.



Fantastic Fact

One of the most soluble salts is potassium nitrite. You can dissolve 306 g of this salt in 100 g of water at 20 °C.

Summary Questions

1 Write four sentences from the sentence starters and enders below.

Sentence starters	Sentence enders
A saturated solution…	…does not dissolve.
An insoluble substance …	…is the mass of substance that dissolves in 100 g of water.
Solubility …	…is a solution that contains the greatest mass of solid that can dissolve.
	…contains undissolved solid.

(4 marks)

2 Plot the values in the table on a graph, and draw the line or curve of best fit. Describe the relationship shown.

Temperature (°C)	Solubility of zinc bromide (g/100 g of water)
20	446
40	590
60	616
80	647
100	669

(4 marks)

3 Design an experiment that you could do to compare the solubility of sugar and salt.

(6 marks)

2.4 Filtration

Learning objectives

After this topic you will be able to:

- explain how filtration works
- describe how to filter a mixture.

Link

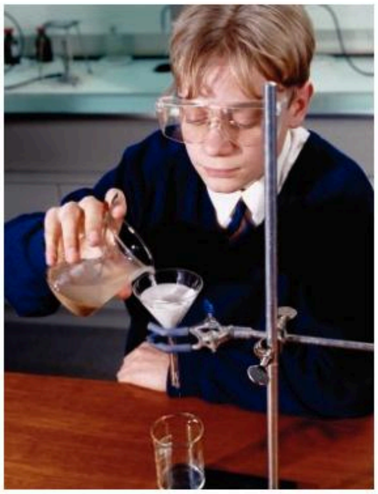
You can learn more about separating a solution from an insoluble solid in C1 4.4 Making salts

▲ An oil filter.

Solubility puzzle

Sandeep measures the solubility of zinc sulfate. Little by little, he adds zinc sulfate to water in a beaker. Eventually, no more dissolves. There is some solid at the bottom of the beaker. Discuss how Sandeep could use filtration, and measure masses, to find the solubility of zinc sulfate.

Look at the pictures. What do they have in common?



All the pictures show **filtration**. Filtration, or **filtering**, separates a liquid from an insoluble solid. Filtering also separates a solution from a solid that is mixed with it, but not dissolved.

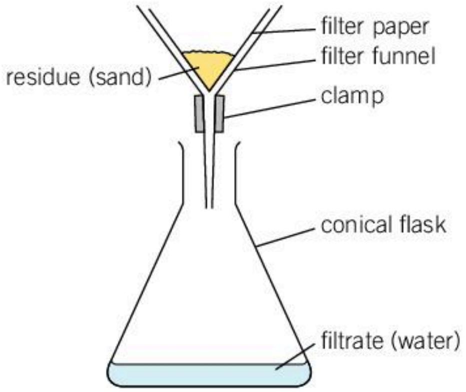
A State two types of mixture that can be separated by filtration.

How does filtering work?

You can separate sand from water by pouring the mixture into filter paper. Water passes through the filter paper. Sand does not.

Filter paper has tiny holes in it. Water particles are smaller than the tiny holes. In the liquid state, water passes through the holes. This is called the **filtrate**.

Grains of sand are bigger than the tiny holes, so they cannot pass through. The grains of sand stay in the filter paper. This is called the **residue**.



B Martha filters a mixture of glitter and water. Name the filtrate and the residue.

How is filtration useful?

Filtration has many uses:

- It separates coffee solution from ground-up coffee beans.
- Oil filters in cars contain materials such as cotton, or wood fibre. These materials trap solid bits of dirt. Liquid oil passes through gaps between the fibres. The dirt would damage the engine if it stayed in the oil.
- Sand filters help make water safe to drink. One type works like this:
  - River water passes slowly through sand and gravel.
  - As the water moves downwards, bits of dirt get stuck in the sand. Tiny creatures living in the sand remove bacteria. Water leaving the filter is nearly ready to drink.

C List three uses of filtration.

▲ Sand filtration helps make water safe to drink.

▲ This is a LifeStraw. It contains hollow fibres. The fibres filter the water, removing bacteria and parasites.

Separating a solution from an insoluble solid

If you have a mixture of sand and salt, you can separate the sand like this:

- Add water to the mixture.
- Stir. The salt dissolves. The sand does not.
- Pour the mixture into a filter paper funnel. Salt solution passes through the paper. The residue is sand.

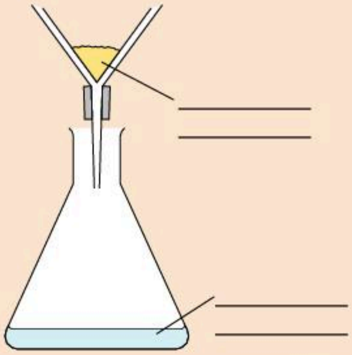
Key Words

filtration, filtering, filtrate, residue

Summary Questions

1. Use the words below to finish labelling the diagram.

   residue filtrate insoluble solid liquid



(4 marks)

2. Naomi adds 100 g of different compounds to separate beakers of water, and stirs to dissolve. Each beaker contains 100 g of water. She filters each mixture, and measures the mass of solid that remains. Use the data to work out the most and least soluble substances. Show your working.

Name of substance	Mass of substance added to 100 g of water (g)	Mass of residue after filtering (g)
calcium chloride	100	25
calcium hydrogen carbonate	100	84
calcium bromide	100	0
calcium iodide	100	33

(4 marks)

3. Design a model you could make to explain filtering. Draw labelled diagrams to show your ideas. Identify the advantages and disadvantages of the model.

(6 marks)

2.5 Evaporation and distillation

Learning objectives

After this topic you will be able to:

- explain how to use evaporation to separate mixtures
- explain how distillation works.

▲ These salt pans on the island of Gozo, Malta are formed when seawater evaporates, leaving behind salt.

Link

You can learn more about evaporation and condensation in C1 1.5 More changes of state

▲ Bolivia's salt desert.

For many centuries, people have obtained salt from seawater. How do they do this?

Evaporation separates salt from seawater. The Sun transfers energy to the water molecules and they leave the surface of the solution. When all the water has evaporated, solid salt remains.

A Describe how salt can be separated from seawater.

When else is evaporation useful?

Have you ever made copper sulfate crystals from copper oxide and sulfuric acid? First, you mix the reactants. They react to make copper sulfate solution. You filter the solution to remove extra copper oxide powder.

Then you heat the solution with a Bunsen burner. Some of the water quickly evaporates. You leave the remaining solution in a warm place. The rest of the water evaporates slowly. Solid copper sulfate crystals slowly form.

▲ Copper sulfate crystals. The more slowly the water evaporates, the bigger the crystals formed.

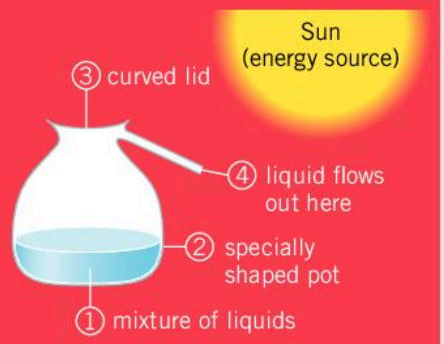
▲ Evaporation makes some glues dry. The solvent evaporates. A sticky substance remains, joining the surfaces.

Lithium is important for batteries. Huge amounts of lithium compounds are dissolved in water under a desert in Bolivia. The government plans to bring the solution to the surface. The water will evaporate. Solid lithium compounds will remain.

B State three uses of evaporation.

Ancient filters

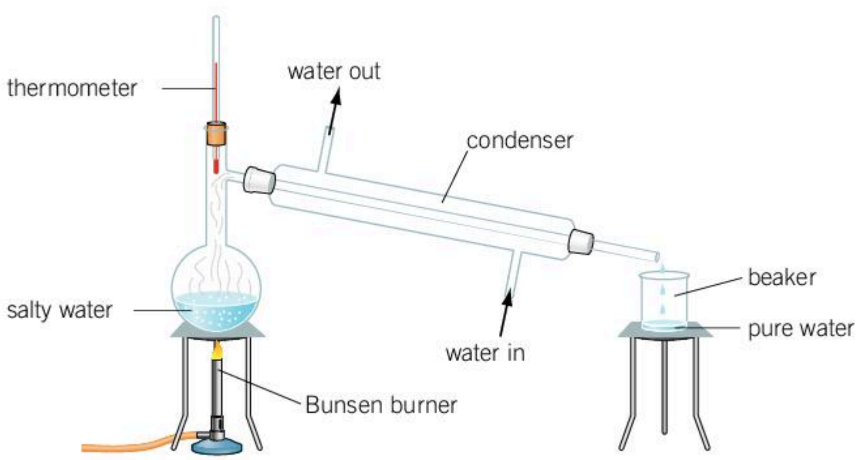
Jabir ibn Hayyan lived in Persia almost 2000 years ago. He developed some of the earliest distillation apparatus, called the alembic. Here is a diagram of his alembic. Discuss with a partner how the alembic might work. Then write a paragraph describing your ideas.



What is distillation?

Imagine you are all alone on a desert island. There is nothing to drink. How could you get drinking water from the sea?

You could use **distillation**. Distillation is a process that uses evaporation and condensation to obtain a solvent from a solution. In the laboratory you can use the apparatus below.



It works like this:

- Water in the salt solution boils.
- Steam leaves the solution.
- Steam travels through the condenser, and cools down.
- The steam condenses to form liquid water.
- Liquid water drips into the beaker.

Saudi Arabia has little rain, and no permanent rivers. The country uses distillation to obtain drinking water from seawater.

You can also use distillation to separate water from inky water.

Key Words

distillation

Summary Questions

1 The sentences below describe how distillation works. Write the sentences in a sensible order. The first, middle, and last ones have been done for you.

B **The solution is heated.**
E The solvent condenses.
C The solvent runs down the condenser.
A **The solvent particles cool down.**
D Solvent particles leave the solution.
F Solvent particles enter the condenser.
G **The solvent drips into a beaker.**

(4 marks)

2 State whether you would use evaporation or distillation to obtain the substances below from their mixtures. Give a reason for each decision.

a copper chloride crystals from a solution of copper chloride
b propanone, the solvent in nail varnish remover
c ethanol, the solvent in some types of glue
d solid potassium chloride from potassium chloride solution

(4 marks)

3 Compare how evaporation and distillation separate mixtures.

(6 marks QWC)

2.6 Chromatography

Learning objectives

After this topic you will be able to:

- explain how chromatography separates mixtures
- analyse chromatograms to identify substances in mixtures.

▲ The coatings of these chocolates contain mixtures of dyes.

Key Words

chromatography, chromatogram

Link

You can learn more about chromatography in C3 3.3 Message in a bottle

Foul Fact

Detectives have used chromatography to look for explosives on the body hair of bomber suspects.

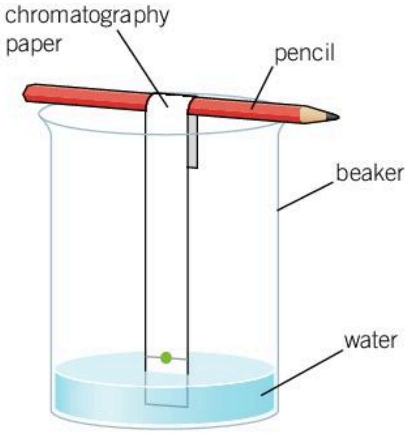
Do you like sugar-coated chocolates? Which is your favourite colour?

The coloured crunchy coatings contain mixtures of dyes. You can use **chromatography** to find out which dyes are in which colours. Chromatography separates substances in a mixture. It works when the substances in a mixture are soluble in the same solvent.

A State what chromatography does.

How does chromatography work?

To find out which dyes are in a green felt-tip pen, sets up the apparatus below. Water moves up the paper. As it passes the green spot, the dyes in the ink dissolve. Water carries the dyes upwards. Some dyes move faster than others, so the dyes separate. This makes a **chromatogram**.



▲ Poppy's apparatus.

▲ Chromatogram of ink from a green felt-tip pen.

In this chromatogram, the blue dye has moved further than the yellow dye. This might be because the blue dye is more soluble. Or it might be because the yellow dye sticks more strongly to the paper.

B State what a chromatogram is.

How is chromatography useful?

Aidan grinds up a spinach leaf in a pestle and mortar. He puts a spot of spinach juice near the bottom of some chromatography paper. He dips the paper in a solvent.

The solvent travels up the paper, taking spinach juice with it. This makes a chromatogram. The chromatogram shows the pigments (colours) in spinach. Each pigment is a different nutrient.

◀ Aidan's chromatogram.

Scientists have used a different sort of chromatography to identify food nutrients. Cassava is an important food in Nigeria. Scientists used chromatography to compare the amounts of vitamin A in different sorts of cassava. Children may go blind if they don't have enough vitamin A in their diet.

The scientists found that dark-green cassava leaves have more vitamin A than light-green leaves. Yellow cassava roots have more vitamin A than white roots. They advise people to eat dark-green leaves and yellow roots.

▲ Yellow cassava roots.

▲ Cassava leaves.

Clever chromatography

Make notes about three uses of chromatography. Organise your notes in a logical order. Then write a few paragraphs describing how chromatography is useful. Ask a partner to check your writing to make sure you have used scientific words correctly.

Link

You can learn more about nutrients in B2 1.1 Nutrients

Summary Questions

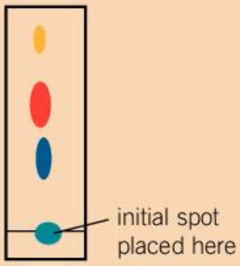
1. Copy and complete the sentences below.

   Chromatography separates substances in ______. It works if all the substances in the mixture are soluble in ______. The picture made by chromatography is called ______.

   (3 marks)

2. Explain why, in chromatography, some substances travel further up the paper than others.

   (3 marks)



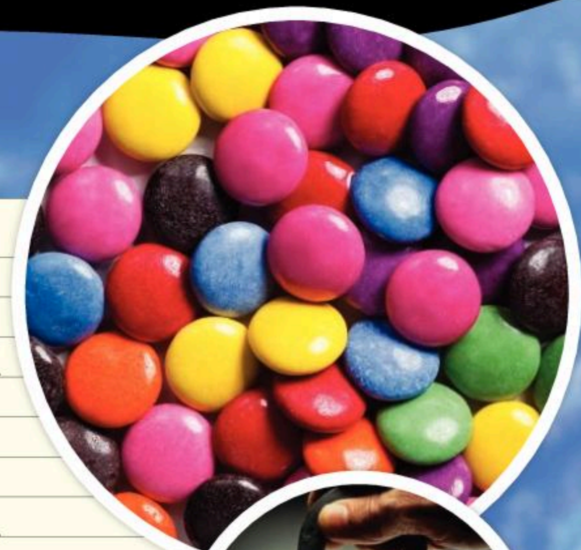
3. Look at the chromatogram above. It was obtained from the leaves of three plants. Write down which plant the unknown sample is from. Explain your choice.

   (2 marks)

4. A teacher has found a rude note in his classroom. There are three students who might have written it. Write instructions for how he can use chromatography to find out which student wrote the note. Point out possible problems with the method, or in using the results.

   (6 marks)

C2 Chapter 2 Summary



Key Points

- A mixture is made up of substances that are not chemically joined together.
- In a mixture, the substances keep their own properties. You can change the amounts of the substances.
- A pure substance has a sharp melting point. An impure substance does not.
- A solution is a mixture of a liquid with a solid or gas. All parts of the solution are the same. You cannot see the separate substances.
- In a solution, the substance that dissolves is called the solute.
- In a solution, the liquid in which the solute dissolves is called the solvent. Solvents include water, propanone, and ethanol.
- When a substance dissolves, solvent particles surround the solute particles.
- A saturated solution is a solution in which no more solute can dissolve.
- The solubility of a substance is the mass that dissolves in 100 g of water. Every substance has its own solubility.
- The solubility of a substance varies with temperature.
- Substances that cannot dissolve in a certain solvent are insoluble in that solvent.
- Filtration separates a liquid from an insoluble solid. It also separates a solution from a solid that is mixed with it, but not dissolved.
- You can separate a solute from its solution by evaporation.
- You can separate a solvent from its solution by distillation.
- You can separate substances in a mixture by chromatography if all the substances are soluble in the same solvent.

BIG Write

Dissolving words

You work for a company that publishes revision guides. Your boss wants to you write the page on dissolving for Key Stage 3 science.

Task:

Write the text for the revision page on dissolving. Include labelled diagrams to illustrate your page.

Tips:

- Before you start, make a rough draft of the page to show what it will include.
- Highlight key words, and explain their meanings.

Key Words

mixture, pure, impure, solution, dissolve, solvent, solute, saturated solution, solubility, soluble, insoluble, filtration, filtering, residue, filtrate, distillation, chromatography, chromatogram

End-of-chapter questions

1 Describe how to obtain the substance in bold from each mixture below.

For each mixture, give the name of the process and state where the named substance would be at the end of the process.

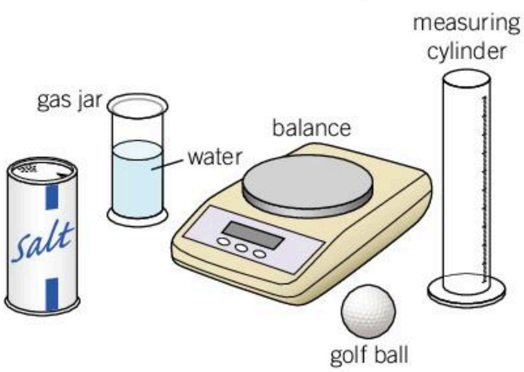
a **sand** from a mixture of sand and water *(2 marks)*

b **salt** from a solution of salt in water *(2 marks)*

c a **dye of one colour** from the mixture of dyes in a felt-tip pen *(2 marks)*

(6 marks)

2 Milly wants to make a golf ball float in water. She has the apparatus in the diagram below.



Milly dissolves different masses of salt in 100 g of water. She records whether or not the ball floats. Her results are in the table below.

Mass of salt dissolved in 100 g of water (g)	Does the golf ball float?
5	no
10	no
15	no
20	yes
25	yes
30	yes

a Name the independent variable in Milly's experiment. *(1 mark)*

b Name the dependent variable. *(1 mark)*

c Name **one** control variable. *(1 mark)*

d Calculate the total mass of solution made when Milly adds 10 g of salt to the water. *(2 marks)*

e Use data in the table to state the smallest mass of salt that Milly adds to the water to make the ball float. *(1 mark)*

f Predict the mass of salt Milly would need to add to 200 g of water to make the ball float. Explain your prediction. *(2 marks)*

(8 marks)

3 The table below shows the solubilities of two substances at different temperatures.

Temperature (°C)	Maximum mass of cerium (III) sulfate that dissolves in 100 g of water (g)	Maximum mass of sodium nitrate that dissolves in 100 g of water (g)
0	21	74
20	9	88
30	7	95
40	6	101
60	4	123
80	–	148
100	–	180

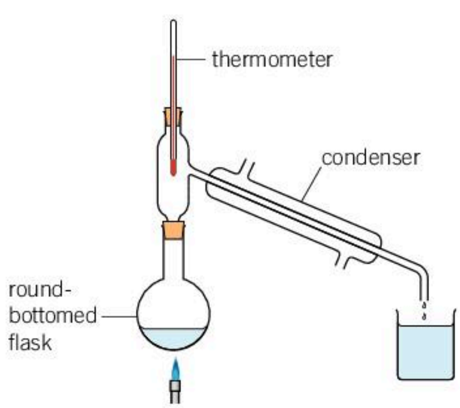
a Plot the data on a line graph. *(5 marks)*

b Draw the line or curve of best fit for each set of data on your graph. *(2 marks)*

c Describe and compare the patterns shown on your graph. *(4 marks)*

(11 marks)

4 Describe and explain how you could extract pure water from inky water using the apparatus below.



(6 marks QWC)

3.1 Acids and metals

Learning objectives

After this topic you will be able to:

- compare the reactions of different metals with dilute acids
- explain the test for hydrogen gas.

Magnesium ribbon in dilute hydrochloric acid.

Key Words

acid, metal

Sulfuric similarities?

Plan an experiment to answer these questions: Do metals that react vigorously with hydrochloric acid also react vigorously with sulfuric acid? Is hydrogen formed as a product?

Foul Fact

In the US, a person died from zinc poisoning after eating 461 pennies. American pennies are mainly zinc.

Zookeepers were worried. A hyena was ill. Its foot was swollen. It refused to eat. What was wrong?

Vets used X-rays to solve the mystery. The hyena had swallowed 20 zinc coins. In the stomach, zinc reacted with hydrochloric **acid**. The reaction made zinc chloride.

zinc + hydrochloric acid → zinc chloride + hydrogen

Zinc chloride dissolves in water. It mixes with blood and travels around the body. This causes zinc poisoning.

How do other metals react with acids?

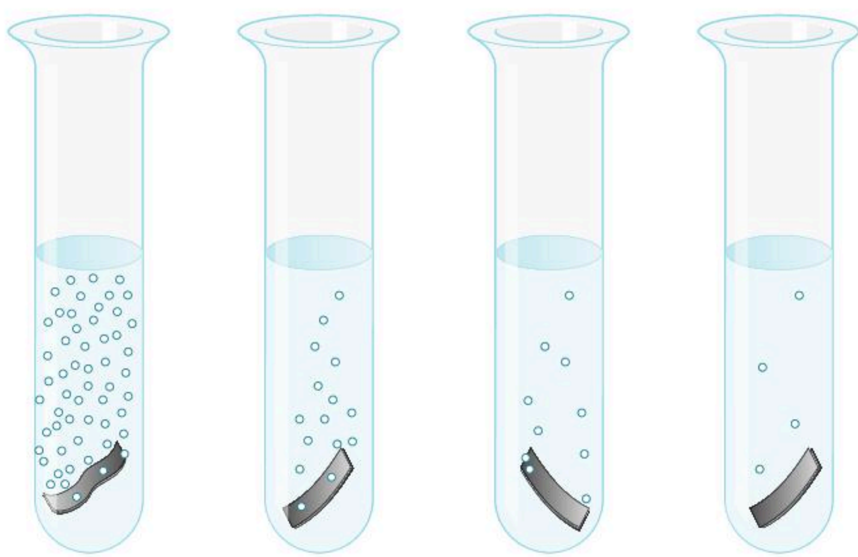
Metals all have similar physical properties. They are shiny. They conduct heat and electricity. Metals have patterns in their chemical properties too.

Anna pours dilute hydrochloric acid into a test tube. She adds magnesium ribbon.

The mixture bubbles vigorously. The magnesium ribbon appears to get smaller, and disappear. A colourless solution remains. There has been a chemical reaction:

magnesium + hydrochloric acid → magnesium chloride + hydrogen

Anna repeats the experiment with different metals. Zinc and iron bubble steadily in acid. Lead reacts more slowly.



All the reactions make a solution of a salt, and hydrogen gas:

zinc + hydrochloric acid → zinc chloride + hydrogen

iron + hydrochloric acid → iron chloride + hydrogen

lead + hydrochloric acid → lead chloride + hydrogen

A Name the products in the reaction of a metal with an acid.

How do you test for hydrogen?

A reaction in a test tube makes bubbles. How can you tell if the bubbles contain hydrogen gas?

1 Collect the gas by holding an empty test tube above the reaction test tube.
2 Light a splint.
3 Hold the splint in the test tube that now contains the gas.
4 Listen. If the splint goes out with a squeaky pop, the gas is hydrogen.

The squeaky pop happens because hydrogen and oxygen react explosively. The product is water.

hydrogen + oxygen → water

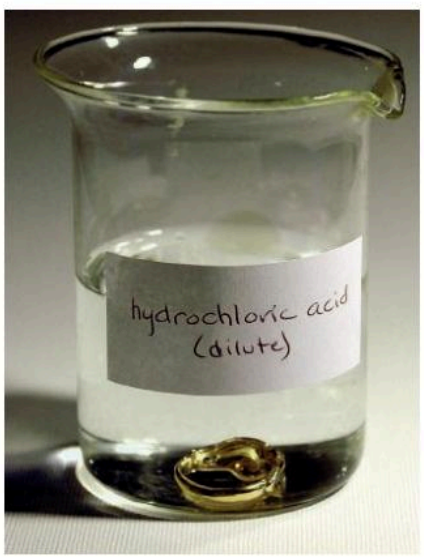
B Describe how you could test for hydrogen gas.

Do all metals react with dilute acids?

Some metals do not react with dilute acids. Nothing happens if you add gold, silver, or copper to dilute hydrochloric acid.

Here is a list of how vigorously different metals react with dilute hydrochloric acid:

magnesium	most reactive
zinc	↓
iron	
lead	
copper, silver and gold	do not react



Gold does not react with dilute acids.

If you hear a squeaky pop then hydrogen is present.

Link

You can learn more about why gold does not react with acid in C2 3.3 The reactivity series

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

Some metals react with hydrochloric acid. The products are **a salt/an alkali** and **oxygen/hydrogen** gas. Iron reacts more vigorously than **magnesium/zinc/lead** and less vigorously than **magnesium/lead/copper**. Some metals, for example, **zinc/silver/magnesium**, do not react with dilute hydrochloric acid.

(5 marks)

2 Some breakfast cereals contain small amounts of iron. Iron is an important mineral.

a Predict the products of the reaction of iron when it reacts with hydrochloric acid in the stomach acid. Explain your prediction. *(3 marks)*

b Describe how you could test if your prediction was correct. *(2 marks)*

3 Draw a visual summary of the reactions of metals and acids, making as many links as possible.

(6 marks)

3.2 Metals and oxygen

Learning objectives

After this topic you will be able to:

- compare the reactions of different metals with oxygen
- use state symbols in balanced formula equations.

State a case

When you write state symbols, use lower case letters – it's (g), not (G).

Have you ever burned magnesium? What did you see? Magnesium burns vigorously. It reacts with oxygen from the air. The product is magnesium oxide.

$$\text{magnesium} + \text{oxygen} \rightarrow \text{magnesium oxide}$$
$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

In the balanced equation above, (s) and (g) are **state symbols**:

- (s) means solid
- (g) means gas

Magnesium reacts with oxygen even when you do not heat it. If you leave magnesium in the air, its surface atoms react with oxygen. This forms a thin layer of magnesium oxide.

▲ The magnesium ribbon on the left has a layer of magnesium oxide on its surface.

A Write the state symbols for a substance in the gas state and in the solid state.

How do other metals react with oxygen?

If you sprinkle zinc powder into a Bunsen flame, you see bright-white sparks. Zinc oxide forms:

$$\text{zinc} + \text{oxygen} \rightarrow \text{zinc oxide}$$
$$2Zn(s) + O_2(g) \rightarrow 2ZnO(s)$$

There is a similar reaction with iron filings. The product is iron oxide.

Copper does not burn in a Bunsen flame. Instead, it forms black copper oxide on its surface.

$$\text{copper} + \text{oxygen} \rightarrow \text{copper oxide}$$
$$2Cu(s) + O_2(g) \rightarrow 2CuO(s)$$

▲ Iron filings burn in air.

Gold is unreactive. It does not burn. Its surface atoms do not react with oxygen. This explains why gold stays shiny.

Gold makes excellent connectors in audio equipment.

B Name two metals that react vigorously with oxygen from the air.

How do reactions with acids and oxygen compare?

Magnesium reacts vigorously with dilute acids. It also burns in oxygen. Magnesium is a **reactive** metal. Gold does not react with dilute acids or with oxygen. It is unreactive.

There is a pattern. Metals that react vigorously with dilute acids also react vigorously with oxygen. Metals that do not react with dilute acids do not react with oxygen.

Metal	Reaction with dilute acid	Reaction with oxygen
magnesium	reacts very vigorously	burns vigorously
zinc	reacts steadily	burns less vigorously
iron	reacts steadily	burns
lead	reacts slowly	do not burn; when heated, form layer of oxide on surface
copper	no reaction	
gold		no reaction

C List the metals in the table in order of how vigorously they react with oxygen, starting with the most reactive.

Fair test?

Jamilla compares the burning reactions of metals. She wants to list four metals in order of how vigorously they react. She has magnesium ribbon, an iron nail, zinc filings, and a piece of copper pipe. She also has a Bunsen burner and tongs. With a partner, discuss how Jamilla can compare the burning reactions. How could she improve her investigation?

Key Words

state symbol, reactive

Fantastic Fact

Magnesium doesn't just react with oxygen from the air; it also reacts with nitrogen, making magnesium nitride.

Summary Questions

1. Copy and complete the sentences below.

   Some metals burn vigorously in air, for example, ______. The products are metal ______. Some metals form an oxide layer on their surface when heated, for example, ______. Some metals, for example ______, do not react with oxygen.

   (4 marks)

2. Write the balanced formula equation for the reaction of calcium with oxygen. Include state symbols.

   (3 marks)

3. Potassium reacts explosively with dilute hydrochloric acid. Predict how vigorously it reacts with oxygen, and the products of the reaction. Explain your answers.

   (4 marks)

4. Create a song or rap to describe patterns in the reactions of metals with acids and oxygen.

   (6 marks)

3.3 Metals and water

Learning objectives

After this topic you will be able to:

- compare the reactions of metals with water
- use the reactivity series to predict reactions.

▲ Calcium reacts vigorously with water.

Tim's tin

Tim wants to know the position of tin in the reactivity series. He does practical tests to collect the data in the table.

Metal	Observations on adding to dilute hydrochloric acid
tin	bubbles slowly
magnesium	bubbles vigorously
copper	no change

Talk about how Tim's data help answer his question. Discuss tests he could do to discover more about the position of tin.

Look at the metals around you. Do they react with water? Stainless steel taps do not. Nor do copper water pipes, nor gold jewellery.

◀ Copper water pipes do not react with water.

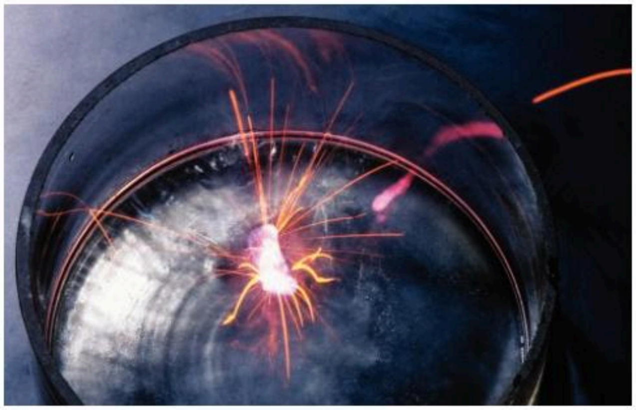
Some metals do react with water. Calcium bubbles vigorously, then seems to disappear. The bubbles are hydrogen gas.

calcium + water → calcium hydroxide + hydrogen

A Name the products of the reaction of calcium with water.

How do other metals react with water?

The Group 1 metals react vigorously with water. There is a flame when potassium reacts with water. Sodium and lithium react slightly less vigorously.



◀ Potassium reacts vigorously with water.

There is a pattern in the Group 1 metal reactions with water. They all make soluble hydroxides and hydrogen gas.

potassium + water → potassium hydroxide + hydrogen

$$2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$$

The state symbols include:

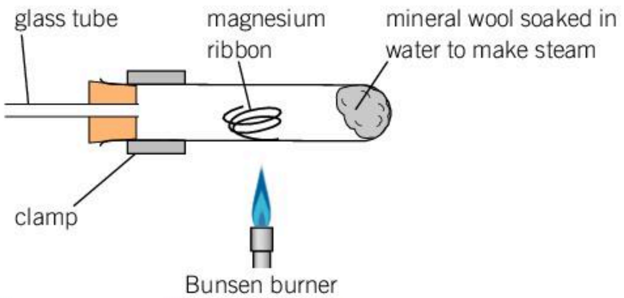
- (l) for the liquid state
- (aq) for a substance dissolved in water.

B Write the state symbols for a substance in the liquid state and dissolved in water.

How do metals react with steam?

Magnesium reacts slowly with cold water. But it reacts quickly with steam.

$$\text{magnesium} + \text{water} \rightarrow \text{magnesium oxide} + \text{hydrogen}$$
$$Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$$



▲ Magnesium reacts with steam in this apparatus.

Zinc and iron also react with steam. The products are hydrogen, and a metal oxide.

Copper and gold are unreactive. They do not react with cold water or steam, just as they do not react with dilute acids and oxygen.

B Name two metals that react with steam but not cold water.

What is the reactivity series?

The patterns of metal reactions with acids, oxygen, and water are similar. The **reactivity series** describes these patterns. It lists the metals in order of how vigorously they react. The metals at the top have very vigorous reactions. Going down the list, the metals get less reactive.

reactive
potassium
sodium
lithium
calcium
magnesium
aluminium
zinc
iron
lead
copper
silver
gold
unreactive

The reactivity series. ▶

Key Words

reactivity series

Summary Questions

1 Write six sentences from the sentence starters and enders below.

Sentence starters	Sentence enders
Sodium…	…is less reactive than copper.
Gold…	…reacts very vigorously with water.
Iron…	…does not react with oxygen, water, or acid.
	…is unreactive.
	…is near the top of the reactivity series.
	…is more reactive than copper.

(6 marks)

2 Write a balanced equation for the reaction of sodium (Na) with water. The products are sodium hydroxide (NaOH) and hydrogen.

(3 marks)

3 Use the evidence in the table below to predict the position of nickel in the reactivity series. Explain your prediction.

Metal	Observations after leaving metal in water and air for one week	Observations on adding dilute sulfuric acid
nickel	no change	bubbles form slowly
iron	makes red-brown flaky substance	bubbles form, more vigorously than nickel
lead	no change	no change

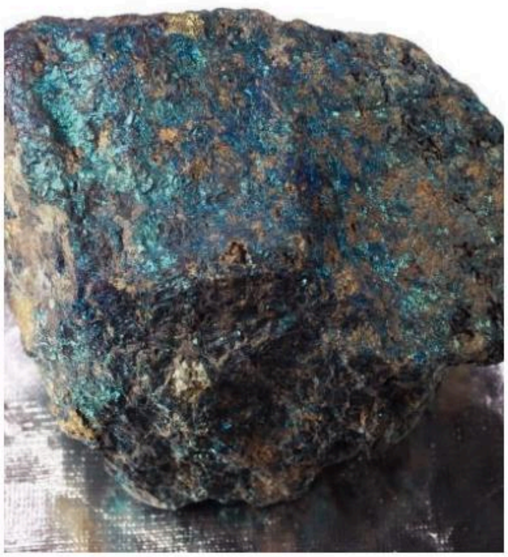
(6 marks QWC)

3.4 Metal displacement reactions

Learning objectives

After this topic you will be able to:

- predict pairs of substances that react in displacement reactions
- use the reactivity series to explain displacement reactions.



▲ This rock contains copper compounds.

What is copper used for? Electric cables, water pipes, and computer parts all include the metal.

Most copper comes from rock that contains copper compounds. Scientists get copper from rock by using chemical reactions. Here's how:

- Add sulfuric acid to the rock. Copper sulfate solution forms.
- Add waste iron to the copper sulfate solution.

There is a chemical reaction. One of the products is copper:

iron + copper sulfate → iron sulfate + copper

$Fe(s) + CuSO_4(aq) \rightarrow FeSO_4(aq) + Cu(s)$

Iron is more reactive than copper. It **displaces** copper from its compound, copper sulfate. The reaction is a **displacement** reaction. In a displacement reaction, a more reactive element displaces, or pushes out, a less reactive element from its compound.

A State what a displacement reaction is.

Other displacement reactions

Elliott adds magnesium to copper sulfate solution. Magnesium is more reactive than copper. So magnesium displaces copper from its compound.

magnesium + copper sulfate → magnesium sulfate + copper

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

▲ Magnesium displaces copper from copper sulfate.

Key Words

displace, displacement, thermite reaction

Link

You can learn more about the displacement reactions of halogens in C2 1.4 The elements of Group 7

If you add copper to magnesium sulfate solution, there is no reaction. Copper is less reactive than magnesium. So copper cannot displace magnesium from its compounds.

B State why copper cannot displace magnesium in magnesium sulfate solution.

Do oxides take part in displacement reactions?

Aluminium is more reactive than iron. It displaces iron from its compounds. For example:

aluminium + iron oxide → aluminium oxide + iron

$$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(l)$$

This is the **thermite reaction**. It involves mixing the two powders, and heating them strongly. The reaction is exothermic. The reaction mixture gets so hot that the iron melts.

The dramatic thermite reaction.

Other metal–metal oxide pairs react. The metal on its own needs to be more reactive than the metal in the compound. For example:

iron + copper oxide → iron oxide + copper

$$2Fe(s) + 3CuO(s) \rightarrow Fe_2O_3(s) + 3Cu(s)$$

Iron has displaced copper from copper oxide.

Copper does not react with iron oxide. This is because copper is less reactive than iron.

Planning paragraphs

Make notes for a piece of writing to explain displacement reactions. Decide how to divide the information into paragraphs. Plan what to include in each paragraph.

Then write your paragraphs. Swap with a friend. Can you suggest improvements?

magnesium
aluminium
zinc
iron
lead
copper
silver
gold

Part of the reactivity series.

Summary Questions

1. Copy the sentences below, correcting the five mistakes.

   In a displacement reaction, a less reactive metal pushes out a more reactive metal from its compound. For example, iron displaces aluminium from aluminium oxide.

   (5 marks)

2. Predict which pairs of substances will react. Give reasons for your decisions.
   - **a** zinc and copper sulfate solution
   - **b** iron and zinc chloride solution
   - **c** aluminium powder and copper oxide powder
   - **d** iron filings and lead oxide powder

   (8 marks)

3. Draw a cartoon that explains how displacement reactions occur.

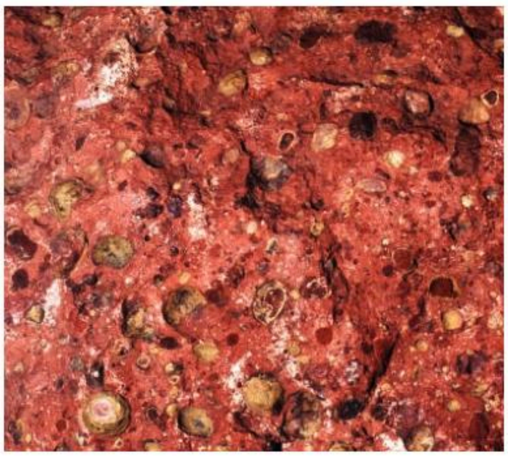
   (6 marks)

3.5 Extracting metals

Learning objectives

After this topic you will be able to:

- use the reactivity series to decide which metals can be extracted from their ores by heating with carbon
- calculate the amounts of metals in ores.



▲ Bauxite aluminium ore is the most commonly mined aluminium ore.

What links the pictures?

The items are made from steel. Steel is mainly iron. But where does iron come from? You cannot find the element on its own in the Earth's crust.

What is an ore?

In the Earth's crust, iron is joined to other elements, in compounds. In many of these compounds iron is joined to oxygen. These are iron oxides.

Most iron oxide is mixed with other compounds in rock. A rock that you can extract a metal from is called an **ore**.

- Iron ore is a mixture of iron oxide and other compounds.
- Aluminium ore is a mixture of aluminium oxide and other compounds.

A State the meaning of the word ore.

How are metals extracted from ores?

There are two main stages in extracting iron from its ore. These are:

1. Separate iron oxide from the compounds it is mixed with.
2. Use chemical reactions to extract iron from iron oxide.

The chemical reactions involve heating iron oxide with charcoal. Charcoal is a form of carbon. It is cheap, and easy to get hold of.

B Describe two stages in extracting a metal from its ore.

magnesium
aluminium
carbon
zinc
iron
lead
copper

▲ Part of the reactivity series, including carbon.

Which metal oxides react with carbon?

Carbon is a non-metal. But we can place it in the reactivity series, between aluminium and zinc.

Any metal that is below carbon in the reactivity series can be displaced from its compounds by carbon. You can heat carbon powder with copper oxide powder. Carbon displaces copper from copper oxide:

carbon + copper oxide → copper + carbon dioxide

$$C(s) + 2CuO(s) \rightarrow 2Cu(s) + CO_2(g)$$

You can also heat carbon with lead oxide.

carbon + lead oxide → lead + carbon dioxide

$$C(s) + 2PbO(s) \rightarrow 2Pb(s) + CO_2(g)$$

c Carbon displaces copper from copper oxide. Write a word equation for this reaction.

Can carbon extract any metal from its compounds?

You cannot use carbon to get aluminium from aluminium oxide. This is because aluminium is more reactive than carbon. It is above carbon in the reactivity series.

Gold always exists as the element itself. It does not form compounds because it is very unreactive. The gold just needs separating from the substances it is mixed with.

Fantastic Fact

We use awesome amounts of ore. In 2010 world iron ore production was 2 400 million tonnes. China dug out 900 million tonnes of this.

Ore waste

Iron ore from different places contains different amounts of iron. Companies extract iron from ores containing between 16% and 70% iron. Calculate the masses of waste from 1 tonne (1000 kg) of each of these ores: an ore that is 50% iron, an ore that is 16% iron, and an ore that is 70% iron.

Key Words

ore

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

An ore is a **substance/rock** that you can extract metal from. Most metals exist in the Earth's crust as **compounds/elements**. These are **joined to/mixed with** other substances in ores.

(3 marks)

2 An ore contains 6% copper. Calculate the mass of copper in 100 kg of this ore. Show your working.

(2 marks)

3 Use the reactivity series to write the balanced symbol equation for the reaction of carbon with zinc oxide. Include state symbols.

(2 marks)

4 Explain why some metals can be extracted from compounds by heating with carbon, and why some cannot. Include examples to illustrate your answer.

(6 marks QWC)

3.6 Ceramics

Learning objectives

After this topic you will be able to:

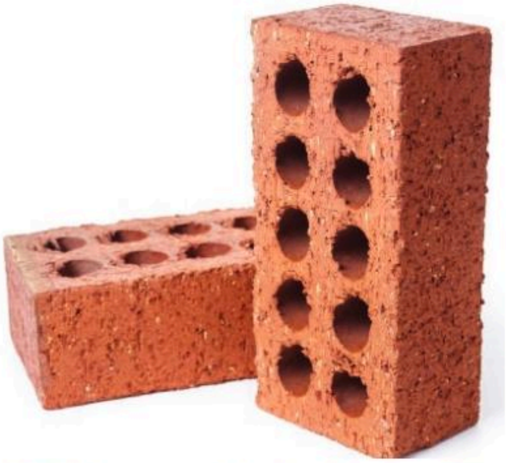
- describe ceramic properties
- explain why the properties of ceramics make them suitable for their uses.

▲ Ceramics are brittle.

Have you ever wondered what a toilet is made from?

Toilets are made from pottery. Pottery is an example of a **ceramic** material. A brick is a block of a ceramic material. Ceramic materials are compounds. They include metal silicates, metal oxides, metal carbides, and metal nitrides.

▲ Toilets are made from pottery, which is a ceramic.



▲ Bricks are made by heating clay. This hardens the clay. A brick is a block of ceramic material.

A State what a ceramic material is.

What are the properties of ceramics?

All ceramic materials have similar physical properties. They are:

- hard – you can only scratch them with harder materials
- brittle – they break easily
- stiff – they are difficult to bend
- solid at room temperature, with very high melting points
- strong when forces press on them
- break easily when stretched
- electrical insulators.

Ceramics also have similar chemical properties to each other. They do not react with water, acids, or alkalis.

B List four physical properties and one chemical property of ceramics.

Splendid ceramics

You work for a ceramics company. Your boss wants you to write an article for a newspaper, explaining why ceramics are useful. Start by making notes on what to include. Then decide how to organise your ideas into paragraphs. Next, work out how to get readers interested. Finally, write your article.

Why are ceramics useful?

Ceramics have many uses. Their uses depend on their properties.

Bricks are strong when forces press on them. They are also durable and attractive. This makes them suitable for buildings.

Ceramics do not conduct electricity. They are not damaged by water. This makes them useful for electrical power-line insulators.

Ceramics have high melting points. This makes them suitable for jet-engine turbine blades, which get very hot.

Ceramics do not react with water, acids, or alkalis. You can decorate them. This makes them useful for plates, bowls, mugs, and jugs.

▲ Ceramics are used as a building material.

▲ Ceramics are good insulators.

▲ Ceramics have high melting points.

▲ Ceramics do not react with water, acids, or alkalis.

C List three uses of ceramics.

Why do ceramics have these properties?

In ceramic materials, a huge number of atoms join together in one big structure. There are strong forces between the atoms.

This structure explains the properties of ceramic materials.

- You need a great amount of energy to break forces between atoms. This explains why ceramics have high melting points.
- The bonds between atoms are very strong. This is why they are hard. You break some bonds when you scratch ceramic materials.

Key Words

ceramic

Fantastic Fact

The ceramic hafnium carbide has the highest melting point of all known ceramics, at about 3900 °C.

Summary Questions

1 Copy and complete the following sentences using the words below.

insulators silicates compounds high brittle oxides hard

Ceramics are ______. They include metal ______ and metal ______. Ceramics are ______ and ______. They have ______ melting points. They are electrical ______.

(7 marks)

2 Look at the data in the table. Decide which materials could be ceramics. Explain your choices.

Material	Relative hardness	Melting point (°C)
A	2.0	321
B	9.0	3532
C	3.0	825
D	9.0	2930
E	5.8	2800

(4 marks)

3 Summarise the information about ceramics in a table, including how and why they are useful.

(6 marks)

3.7 Polymers

Learning objectives

After this topic you will be able to:

- describe polymer properties
- explain how polymer properties make them suitable for their uses.

▲ Wool is a natural polymer used in clothing.

▲ Cotton is another natural polymer used in clothing.

▲ Rubber is a natural polymer used to make tyres.

Foul Fact

Lobsters, cockroaches, and ants make a polymer – chitin – to form their exoskeletons.

Do you know what umbrellas, beach balls, and carrier bags have in common?

They are made from **polymers**. A polymer is a substance with very long molecules. A polymer molecule has identical groups of atoms, repeated many times.

▲ This is part of a molecule of a polymer called poly(ethene). One molecule has hundreds of $-C_2H_4-$ units, joined in a long chain. The black spheres represent carbon atoms. The white spheres represent hydrogen atoms.

There are many polymers. Different polymers have different properties. Their properties make them suitable for their uses.

A State what a polymer is.

Why are natural polymers useful?

Plants and animals make **natural polymers**, including wool, cotton, and rubber.

Sheep make wool. Wool fibres trap air between them. This means that wool traps heat, making it useful for jumpers and socks.

Cotton plants make cotton fibres. Cotton fabric is strong, durable, and absorbs sweat. It is useful for summer clothing like t-shirts.

Rubber trees produce rubber. Rubber is flexible, waterproof, and durable. These properties make it suitable for tyres.

B Give an example of a polymer, and one of its uses.

Why are synthetic polymers useful?

Synthetic polymers do not occur naturally. They are made in chemical reactions. There are hundreds of synthetic polymers. Scientists work hard to develop new polymers. Each polymer has its own properties.

Poly(ethene)

Poly(ethene) is the scientific name for polythene. There are two types of poly(ethene).

- The molecules in low-density poly(ethene) (LDPE) slide over each other. This makes it flexible. LDPE is also strong. LDPE is used for carrier bags.
- High-density poly(ethene) (HDPE) is also strong and flexible. It is harder than LDPE. Its surfaces can be very smooth. HDPE is used in artificial knee joints. Artificial joints also include metal, such as titanium.

Both types of poly(ethene) do not wear away or break down (decay) naturally. This property is very important for artificial knee joints. But the same property makes it hard to get rid of carrier bags.

Poly(ethene) bags can be dangerous to wildlife.

Poly(vinyl chloride)

Poly(vinyl chloride) (PVC) is waterproof, flexible, and does not conduct electricity. These properties make PVC suitable for waterproof clothes and insulating electric cables.

C State why low-density poly(ethene) makes good carrier bags.

Plotting polymers

Every polymer has its own properties. Plot the density data in the table below on a bar chart. Show your chart to a partner. Ask them to check your scale, labels, and accuracy.

Polymer	Density (g/cm^3)
low-density poly(ethene)	0.92
high-density poly(ethene)	0.96
poly(propene)	0.90
poly(vinyl chloride)	1.30
soft rubber	1.10

Key Words

polymer, natural polymer, synthetic polymer

Summary Questions

1 Copy and complete the sentences below.

A polymer has ______ molecules. Each molecule has identical groups of ______, repeated many times. There are two types of polymer: ______ polymers and ______ polymers. Synthetic polymers include PVC and ______. Poly(ethene) is ______ because its molecules slide over one another.

(6 marks)

2 The list gives some properties of poly(styrene).

Choose properties from the list that explain why polystyrene is suitable for:

a packaging

b disposable cups.

Properties: low density; does not conduct electricity; poor conductor of heat; white colour.

(4 marks)

3 The table gives data about three synthetic polymers. Use the data to compare the polymers.

Polymer	Strength when pulled (N/mm^2)	Relative hardness	Density (g/cm^3)
poly(vinyl chloride)	48	20	1.30
nylon	60	10	1.16
acrylic	74	34	1.19

(6 marks QWC)

3.8 Composites

Learning objectives

After this topic you will be able to:

- describe composite properties
- explain why composite properties make them suitable for their uses.

▲ The builder pours concrete into the gaps between the steel rods. The concrete sets hard.

▲ Part of a carbon-fibre-reinforced plastic bicycle frame.

In constructing a new building, builders use reinforced concrete. What makes this material so strong?

Reinforced concrete consists of steel bars with concrete around it. Concrete is not damaged when forces press on it. But it breaks easily when stretched. Steel is not damaged by stretching forces. Together, steel and concrete put up with strong squashing and stretching forces.

Reinforced concrete is a **composite** material. A composite is a mixture of materials. Each material has different properties. The composite has properties that are a combination of the properties of the materials it is made up of. Scientists experiment with different mixtures. They develop composites with the best properties for particular uses.

A State what a composite material is.

Other composites

Carbon-fibre-reinforced plastic

This bicycle frame is made from **carbon-fibre**-reinforced plastic (CFRP). The composite consists of two materials:

- carbon fibres, which are thin tubes of carbon. The fibres are woven into a fabric.
- a gluelike polymer, which is moulded into different shapes when soft.

Some cyclists prefer CFRP bicycles to steel ones. Reasons for this are:

- CFRP has a lower density, making bicycles lighter
- CFRP does not rust
- CFRP is very strong
- you can mould CFRP into any shape.

CFRP has some disadvantages. Bicycles made from CFRP are expensive. If crashed, they are badly damaged.

B Name two materials in carbon-fibre-reinforced plastic.

Glass-fibre-reinforced aluminium

▲ The world's largest passenger aeroplane, the Airbus A380, is made from composite materials.

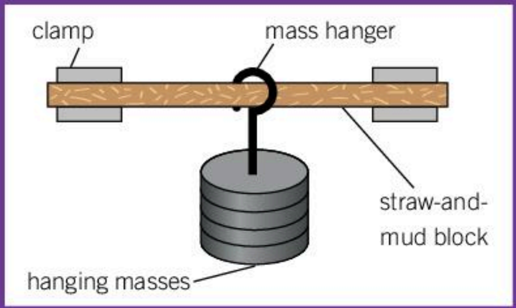
The aeroplane Airbus A380 contains around 20% composite materials. One of these composites is glass-fibre-reinforced aluminium. The materials in this composite include:

- thin layers of aluminium
- layers of glass fibre
- a gluelike polymer to join the layers.

C Name two materials in glass-fibre-reinforced aluminium.

Comparing composites

Callum makes three blocks of a composite material from mud and straw. He puts different amounts of straw in each block. The mud dries. Discuss how Callum could use the apparatus in the diagram to compare the strengths of the blocks. Write down the variables, and suggest how to make the investigation fair.



Key Words

composite, carbon fibre

▲ Woven glass fibre.

Summary Questions

1 Copy the sentences below, choosing the correct bold word.

A composite material is a **mixture/compound** of two or more materials. Each of these materials has **different/the same** properties. The composite material has properties that are **a combination of/exactly the same as** these properties.

(3 marks)

2 Fibreglass is a composite material. It is made from a polymer called polyester resin, and glass fibres. Use the data in the table to explain why fibreglass is a better material for canoes than polyester resin alone.

Material	Density (g/cm^3)	Strength when pulled (MPa)	Strength when squashed (MPa)
polyester resin	1.3	55	140
fibreglass	1.6	250	150

(3 marks)

3 Draw a visual summary of the information on composites.

(6 marks)

C2 Chapter 3 Summary

Key Points

- The reactivity series lists metals in order of how vigorously they react. The most reactive metals are at the top. The table summarises some reactions.

Metal	Reaction with dilute acid	Reaction on heating in air	Reaction with water
potassium	Explode. Products are metal salts and hydrogen.	Burn vigorously. Products are metal oxides.	React vigorously. Products are a metal hydroxide solution and hydrogen.
sodium			
lithium			
calcium	React, making bubbles. Products are metal salts and hydrogen.		
magnesium			React with steam. Products are hydrogen and a metal oxide.
zinc			
iron			
lead		Do not burn. Form oxide layer on surface.	
copper	Do not react.		Do not react.
silver		Do not react.	
gold			

- More reactive metals displace less reactive metals from compounds.
- Zinc, and metals below it in the reactivity series, are extracted by heating their oxides with carbon.
- Ceramic materials include pottery and brick. They are hard and brittle, with high melting points.
- Polymers have long molecules. There are hundreds of polymers. Each has unique properties that make it suitable for particular purposes.
- A composite material is a mixture of materials. It has properties that are a combination of the properties of the materials in the mixture.

Case study

Ranking reactivity

You have three metals, but you don't know what they are. With a partner, discuss what tests to do, to rank them in order of reactivity. How would the results show this? Decide how to make the tests fair.

Task

With your partner, write instructions for the investigation.

Tips

- Include a results table.
- Remember to include all the variables.
- Swap instructions with a partner and suggest improvements.

Key Words

state symbol, reactive, reactivity series, displace, displacement, thermite reaction, ore, ceramic, polymer, natural polymer, synthetic polymer, reinforced concrete, composite, carbon fibre

End-of-chapter questions

1 Anne adds metals to water. Draw lines to match each metal to an observation.

Metal	**Observation**
copper	moves on surface of water
	lilac flame
potassium	bubbles vigorously
calcium	no change

*(**3 marks**)*

2 Lamek compares the reactivity of iron, lead, and zinc with hydrochloric acid.

a Write down **two** things Lamek must do to compare the reactions fairly. *(2 marks)*

b Write down **one** safety precaution Lamek must take. Give a reason for this. *(2 marks)*

c Predict which metal will react most vigorously. Give a reason for your choice. *(1 mark)*

d Name the gas formed when a metal reacts with a dilute acid. *(1 mark)*

*(**6 marks**)*

3 Write down the properties of ceramics, choosing from the list.

hard
soft
brittle
low melting point
electrical insulator
high melting point

*(**4 marks**)*

4 Copy and complete the word equations.

a lithium + water → _______ + _______

b _______ + _______ → magnesium oxide

c zinc + hydrochloric acid → _______ + _______

d magnesium + _______
→ magnesium sulfate + _______

*(**8 marks**)*

5 Katya is investigating displacement reactions. She heats the pairs of substances in the list.

Pair W	iron and aluminium oxide
Pair X	iron and copper oxide
Pair Y	copper and magnesium oxide
Pair Z	iron and lead oxide

a Write down the letters of **two** pairs of substances that react. Explain your choices. *(4 marks)*

b Choose **one** pair of substances that react. Write a word equation for the reaction. *(2 marks)*

*(**6 marks**)*

6 Bob has the salt solutions in the list below. He does not know which is which.

- magnesium chloride
- zinc chloride
- copper chloride

Bob also has pieces of magnesium, iron, zinc, and copper.

Explain how Bob could use his materials to work out which solution is which.

*(**6 marks QWC**)*

4.1 The Earth and its atmosphere

Learning objectives

After this topic you will be able to:

- compare the layers of the Earth
- describe the composition of the atmosphere.

▲ Everything needed to make this packet of crisps comes from the Earth.

What goes into a packet of crisps?

The potatoes come from plants. The plants use water, carbon dioxide from the air, and nutrients from the soil to grow. The salt comes from the sea, or from a mine. Aluminium for the bags comes from bauxite rock. The crisps are packed in nitrogen, which was separated from the air.

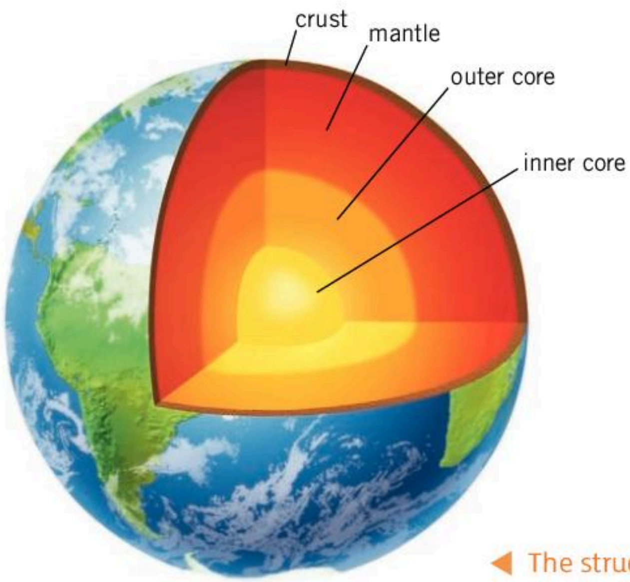
Everything for the packet of crisps – and everything we use – comes from the Earth, the air, or the oceans.

What is the structure of the Earth?

The Earth is made up of four layers.

- The outer layer is the rocky **crust**. It is between 8 km and 40 km thick.
- Beneath the crust is the **mantle**. This is made mostly of solid rock, but it can flow. Very slowly, hotter rock rises and cooler rock sinks.
- About halfway to the centre of the Earth is the **core**. This is mainly iron and nickel. The **outer core** is liquid. The **inner core** is solid.

Of course, no-one has dug to the centre of the Earth. Scientists learn about its structure by studying shock waves from earthquakes. They also examine rocks on the surface and under oceans, and materials that volcanoes bring to the surface.



◀ The structure of the Earth.

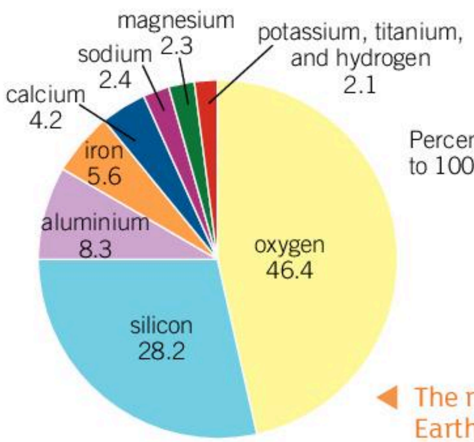
A Name the four layers of the Earth.

Fantastic Fact

For each mile that you drill down into the Earth, the temperature increases by 40 °C.

What's in the crust?

Most rocks are mixtures of compounds. The pie chart shows the elements that make up these compounds.



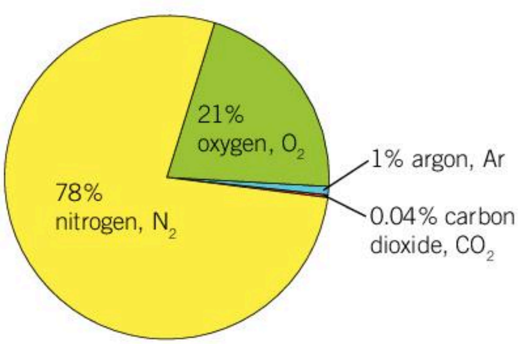
Percentages do not add up to 100% owing to rounding.

◀ The most common elements in the Earth's crust, by mass.

B List the six most common elements in the Earth's crust.

What is the atmosphere?

The **atmosphere** is a mixture of gases that surrounds the Earth. The part of the atmosphere nearest the Earth is the **troposphere**. This layer goes up to about 10 km above the surface of the Earth. The troposphere is mainly a mixture of two elements, oxygen and nitrogen. There are smaller amounts of other substances, including argon and carbon dioxide.



◀ The most common substances in the Earth's atmosphere, by volume.

C State what the atmosphere is.

Questioning the crust

Use the pie charts above to write questions about the composition of the Earth's crust and the atmosphere. Swap with a partner, and answer each other's questions.

Key Words

crust, mantle, core, outer core, inner core, atmosphere, troposphere

Fantastic Fact

The world's deepest hole is in Kola, Russia. It is more than 12 km deep.

Summary Questions

1 Copy and complete the sentences below.

Surrounding the Earth is a mixture of gases called the ______. The Earth itself is made up of four layers. On the outside is the ______. Next is the mantle. The substances of the mantle are mostly in the ______ state. The core consists mainly of two elements – iron and ______. The substances of the outer core are in the ______ state.

(5 marks)

2 The list below gives the names of the four most common substances in the atmosphere. Draw a ring around the name of the most abundant element. Underline the name of the most abundant compound.

argon **nitrogen**
oxygen **carbon dioxide**

(2 marks)

3 Write a paragraph to compare the properties and composition of the Earth's crust, mantle, and core.

(6 marks QWC)

4.2 Sedimentary rocks

Learning objectives

After this topic you will be able to:

- explain two properties of sedimentary rocks
- explain how sedimentary rocks are made.

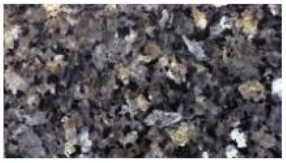
▲ Water soaks into this rock. It is porous.

▲ As they grow, tree roots break up this rock.

▲ Water transports sediments down this stream.

The pictures show three different types of rock. How are they similar and how are they different?

▲ Limestone.



▲ Granite.

▲ Marble.

There are hundreds of rock types. Scientists classify them into three groups:

- **sedimentary** rocks
- **igneous** rocks
- **metamorphic** rocks

A Name the three groups of rock.

What are the properties of sedimentary rocks?

Sedimentary rocks are made up of separate grains. You can see these with a hand lens.

Sedimentary rocks are **porous**. They have gaps between their grains. Air or water can get into these gaps.

Most sedimentary rocks are soft. You can scratch them easily.

B Describe three properties of sedimentary rocks.

How are sedimentary rocks made?

Sedimentary rocks are made up of pieces of older rocks. The process has several stages.

Weathering

Weathering breaks up all types of rock into smaller pieces called **sediments**. There are different types of weathering:

- **Physical weathering** happens because of temperature changes. In **freeze–thaw** weathering, water gets into a crack in a rock. When the temperature is very cold, the water freezes. This forms ice. Ice takes up more space than liquid water. It pushes against the sides of the crack. This happens many times. Eventually, the rock breaks.

- **Chemical weathering** happens when rain falls on rocks. Acids in the rain react with substances in the rock.
- **Biological weathering** happens when plants and animals break up rocks.

Weathering makes sediments but does not move them away from the original rock.

Erosion and transport

Next, sediments move away from their rock. Together, the breaking of rock into sediments and their movement away, is called **erosion**.

Transport processes move sediments far from the original rock. Water, ice, wind, and gravity can all move sediments.

Deposition

Eventually, sediments stop moving. They settle in one place. This is **deposition**. Layers of different types of sediment may settle on top of each other.

Compaction and cementation

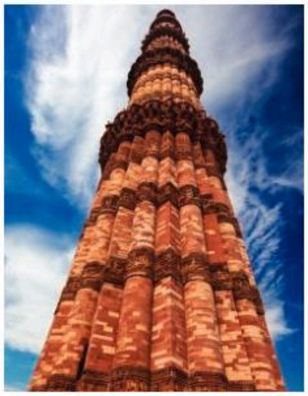
Over many years deposited sediments join together to make new rocks. This happens by:

- **compaction** – the weight of sediments above squashes together the sediments below *or*
- **cementation** – another substance sticks the sediments together.

C List four stages in making sedimentary rocks.

How are sedimentary rocks useful?

There are many types of sedimentary rock. They have different properties and uses.



▲ Sandstone is a good building material.

▲ Limestone is made from shells and skeletons that sank to the bottom of the sea. It is an attractive building material.

Sedimentary sequence

With a partner, plan an exciting talk to explain how sedimentary rocks are formed. Present your talk to another pair. Then listen to their talk. How did they make it interesting?

Key Words

sedimentary, igneous, metamorphic, porous, weathering, sediment, physical weathering, freeze–thaw, chemical weathering, biological weathering, erosion, transport, deposition, compaction, cementation

Summary Questions

1 Write five correct sentences from the sentence starters and enders.

Sentence starters	Sentence enders
Weathering…	…involves the weight of sediment above making sediments below stick together.
Erosion…	…moves sediments far away from the original rock.
Transport…	…breaks rock into smaller pieces.
Deposition…	…breaks rock into smaller pieces and moves them away from the original rock.
Compaction…	…is the settling of sediments.

(5 marks)

2 Describe two properties of sedimentary rocks, and explain why they have these properties. *(4 marks)*

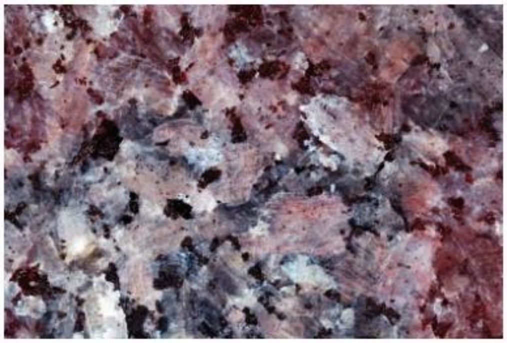
3 Create a flow diagram to explain how sedimentary rocks are formed. *(6 marks)*

4.3 Igneous and metamorphic rocks

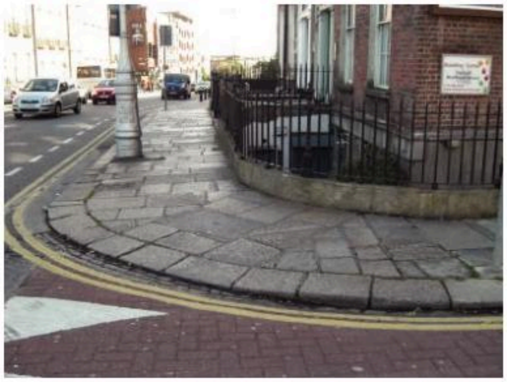
Learning objectives

After this topic you will be able to:

- compare the ways that igneous and metamorphic rocks form
- explain how igneous and metamorphic rocks form.



▲ You can easily see the crystals in this granite. Each crystal is made of one compound. Granite is a mixture of compounds.



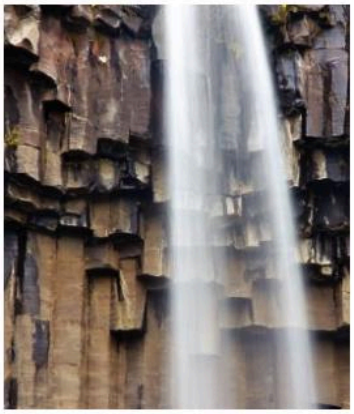
▲ A granite pavement.

▲ Basalt railway ballast.

What type of rock does the picture on the right show?

The rock is basalt. Basalt is an example of an **igneous** rock. Igneous rock forms when liquid rock cools and freezes.

Igneous rock consists of crystals. There are no gaps between the crystals. This explains why igneous rocks are not porous.



▲ Svartifoss, Iceland.

How are igneous rocks useful?

Igneous rocks are hard. They are also **durable**, which means they are difficult to damage. These properties mean that igneous rocks are useful for pavements and underneath railway tracks.

A State three properties of igneous rocks.

Different sized crystals

Underground, liquid rock is called **magma**. Granite forms from magma. Underground, the magma cools and freezes slowly. The particles have time to arrange themselves into big crystals.

Basalt forms when liquid rock cools and freezes quickly. This happens under the sea, or on the surface of the Earth when volcanoes erupt, for example. On the surface, liquid rock is called **lava**. There isn't enough time for large crystals to grow so basalt crystals are smaller than granite crystals. You need a hand lens to see them.

▲ This lava will cool and freeze to form basalt.

What are metamorphic rocks?

The pictures show **metamorphic** rocks.

▲ Marble.

▲ Gneiss.

▲ Slate.

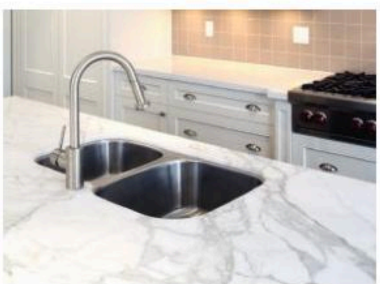
Metamorphic rocks form when heat, high pressure, or both change existing rock. For example:

- Marble starts out as limestone. Marble forms when limestone below the Earth's surface heats up. The limestone does not melt, but its particles are rearranged.
- Slate starts out as a type of sedimentary rock called mudstone. Slate forms when high pressure underground squashes the mudstone. This squeezes out water, and makes layers of new crystals.

B Describe how marble and slate are formed.

How are metamorphic rocks useful?

Metamorphic rocks are made up of crystals. They are not porous.



▲ Marble is not porous. Many people like how it looks. This explains why it is suitable for kitchen worktops.

▲ Slate is not porous. It is made up of layers, so it can be split into thin sheets. This is why it makes good roofing tiles.

C Describe the properties of slate that make it suitable for roofing tiles.

Granite quarry

Rubislaw Quarry, near Aberdeen, is probably the biggest hole in Europe. Between 1740 and 1971 quarry workers dug 6 million tonnes of granite from the quarry. Calculate the mean mass of granite dug out of the quarry each week during this time period.

Link

You can learn more about rocks in C2 4.4 The rock cycle

Key Words

durable, magma, lava

Fantastic Fact

Basalt doesn't only exist on Earth. There is basalt on Mars, Venus, the Moon, and Jupiter's largest moon, Io.

Summary Questions

1 Copy and complete the sentences below, choosing the correct bold words.

High pressure underground may change any rock type into **igneous/metamorphic** rock. When liquid rock cools and freezes, **igneous/metamorphic** rock forms. Granite and basalt are examples of **igneous/metamorphic** rocks. Slate and marble are examples of **igneous/metamorphic** rocks. Igneous and metamorphic rocks are **porous/non-porous** because they are made up of **grains/crystals**. Igneous rocks are **hard/soft**.

(7 marks)

2 Explain why some igneous rocks have small crystals, and others have bigger crystals.

(3 marks)

3 Compare the ways in which igneous and metamorphic rocks form. Include examples in your answer.

(6 marks QWC)

4.4 The rock cycle

Learning objectives

After this topic you will be able to:

- use the rock cycle to explain how the material in rocks is recycled.

▲ An Icelandic volcano.

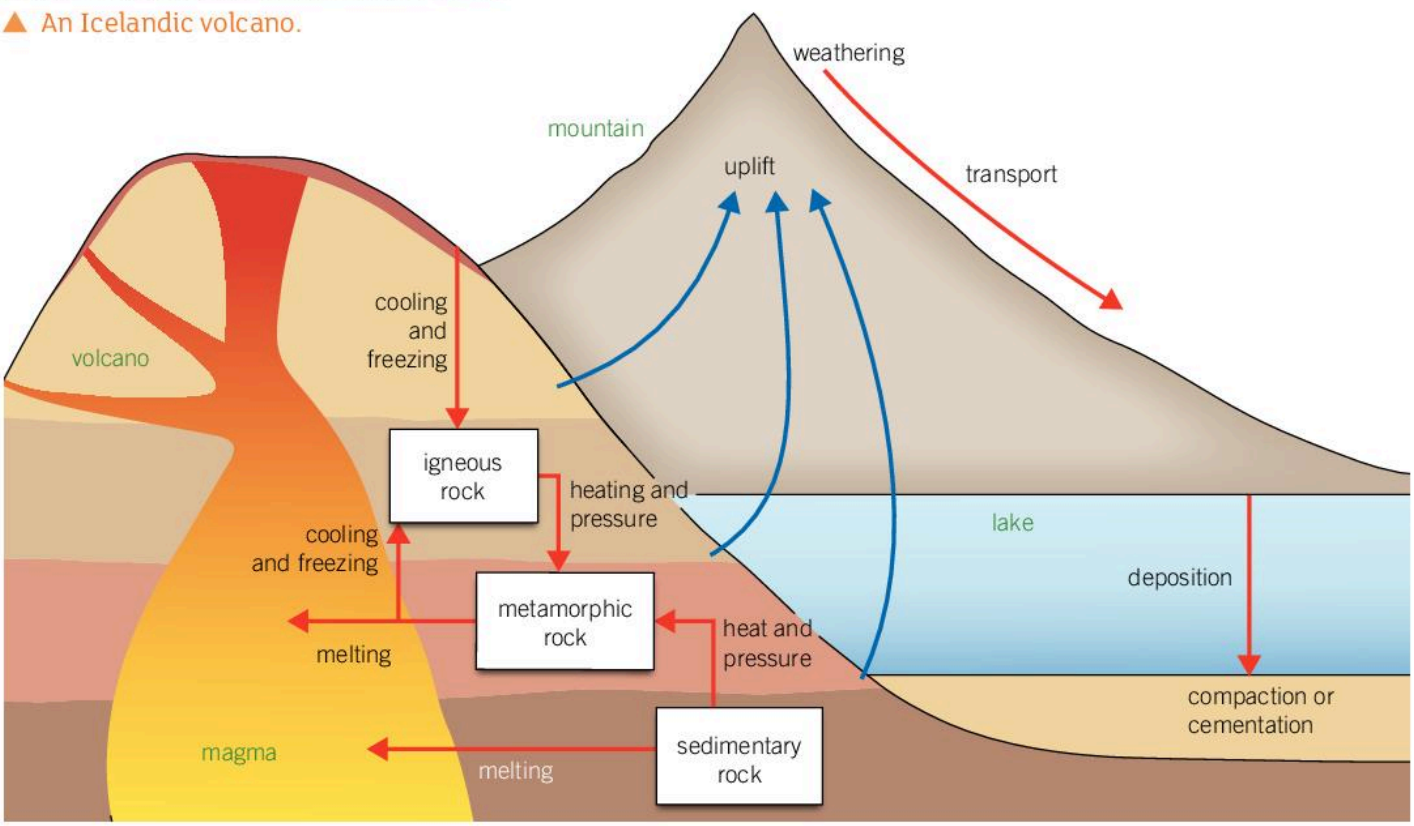
Imagine you came back to Earth a million years after your death. How would the rocks around you be different?

All the time, rocks are changing. Weathering breaks down rock. Sediments make new rock. Volcanoes erupt, and their lava freezes. And, deep within the crust, heating and high pressure change rocks of all types.

A Describe one way that rocks change over time.

What is the rock cycle?

Different rock types, and the processes that change one rock type into another, are linked in the **rock cycle**. The rock cycle shows how rocks change, and how their materials are recycled over millions of years.



▲ The rock cycle.

How does the rock cycle recycle materials?

There are many routes around the rock cycle. Here is one example:

- On the side of a mountain, water pours into a crack. Every night, the water freezes. The ice pushes against the sides of the crack. Sediments break free. Gravity transports them down the mountain.
- A stream flows over the sediments. It transports them to a lake. Sediments settle on the lake bed. Over many years, sediments join together. This makes sedimentary rock.
- Layers of rock build up. The lower layers heat up. Particles in these layers move, forming crystals. Metamorphic rock forms.
- Near the metamorphic rock, hot magma pushes upwards. The magma heats the rock. The rock melts, and becomes part of the magma.
- Magma moves upwards. It forces its way to the surface, and erupts from a volcano. The liquid rock cools and freezes. Igneous rock forms.

What is uplift?

The Earth's crust moves constantly. When continents collide, huge forces from inside the Earth push rocks upwards, and mountains can form. This is called **uplift**. Taiwan, near China, is moving upwards by 1 cm every year. Earthquakes often happen at the same time as uplift.

Uplift provides evidence for the rock cycle. It brings up rocks that were once buried. Mount Everest contains fossils of sea animals because it is made from limestone that formed on the seafloor.

▲ Fossils from Mount Everest.

B State what is meant by uplift.

Rock route

With a partner, talk about different routes around the rock cycle. Make notes about one of these routes. Then write about this route in detail. Organise your writing in paragraphs, and use key words correctly.

Key Words

rock cycle, uplift

Summary Questions

1 Copy and complete the sentences below.

The ______ ______ shows how the materials in rocks are ______, and how different rock types are linked. When forces from inside the Earth push rocks upwards, ______ occurs. This is how ______ are formed. Mount Everest is made from ______ that formed on the seafloor.

(5 marks)

2 Name the processes that changes...

a ...metamorphic rock into magma. *(1 mark)*

b ...magma into igneous rock. *(2 marks)*

c ...layers of sediment into sedimentary rock. *(1 mark)*

3 Write the script for a drama to describe a route around the rock cycle.

(6 marks)

4.5 The carbon cycle

Learning objectives

After this topic you will be able to:

- explain why the concentration of carbon dioxide in the atmosphere did not change for many years
- use the carbon cycle to identify stores of carbon.

Link

You can learn more about how plants use carbon dioxide in B2 2.1 Photosynthesis

Imagine you took 10 000 particles from the air. How many of them would be carbon dioxide molecules?

Fewer than four in 10 000 particles of air are carbon dioxide molecules. But carbon dioxide is vital. Without it, plants cannot make their food. Without carbon dioxide, Earth would be too cold for life as we know it.

A Give two reasons to explain why carbon dioxide is a vital part of the atmosphere.

▲ Burning fossil fuels adds carbon dioxide to the atmosphere.

Carbon dioxide: into and out of the atmosphere

Carbon dioxide is constantly entering and leaving the atmosphere.

These processes *add* carbon dioxide to the atmosphere:

- **Respiration** transfers energy from food in plants and animals. Carbon dioxide is a waste product of respiration.

  glucose + oxygen → carbon dioxide + water

- **Combustion** Fuels such as wood, petrol, and methane produce carbon dioxide on burning.

  methane + oxygen → carbon dioxide + water (+ energy)

Burning fossil fuels adds carbon dioxide to the atmosphere.

B Name two processes that add carbon dioxide to the atmosphere.

These processes *remove* carbon dioxide from the atmosphere:

- **Photosynthesis** Plants use carbon dioxide and water to make glucose.

  $$\text{carbon dioxide + water} \xrightarrow{\text{light}} \text{glucose + oxygen}$$

- **Dissolving** in the oceans.

A question of balance

With a partner, identify four ways that you could reduce the amount of carbon dioxide that you add to the atmosphere in your everyday life. Explain how each method reduces the concentration of carbon dioxide in the atmosphere.

C Name two processes that remove carbon dioxide from the atmosphere.

If carbon dioxide is added to the atmosphere and removed from it at the same rate, its concentration does not change.

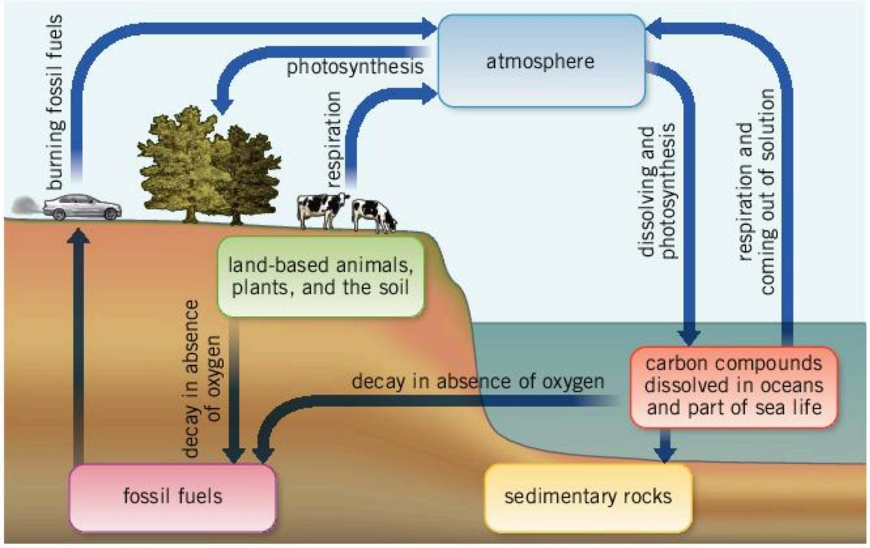
What is the carbon cycle?

The **carbon cycle** shows how carbon dioxide enters and leaves the atmosphere. It also shows how carbon and its compounds enter and leave **carbon stores**. Carbon stores include:

- the atmosphere
- oceans, containing dissolved carbon dioxide
- sedimentary rocks, such as calcium carbonate
- fossil fuels, such as coal, oil, and natural gas
- plants and animals
- soil.

D Name six carbon stores.

This yew tree in Wales has stored carbon compounds in its trunk for over 4000 years.



The carbon cycle.

Key Words

respiration, combustion, photosynthesis, dissolving, carbon cycle, carbon store

Fantastic Fact

Some of the oldest living carbon stores are a group of olive trees in Lebanon, called The Sisters. They are between 6000 and 8000 years old.

Summary Questions

1. Copy and complete the sentences below, choosing the correct bold words.

   Carbon dioxide enters the atmosphere by **photosynthesis/respiration** and **dissolving/combustion**. It leaves the atmosphere by **photosynthesis/respiration** and **dissolving/combustion**. The atmosphere is a store of carbon. Other stores of carbon include **igneous/sedimentary** rocks and fossil fuels such as **oil/sunlight**.

   (6 marks)

2. Describe a route that a carbon atom might take around the carbon cycle. Name four carbon stores the atom passes through and how it moves from one store to another.

   (5 marks)

3. Create a carbon-cycle board game, in which players throw a dice to follow different routes around the carbon cycle.

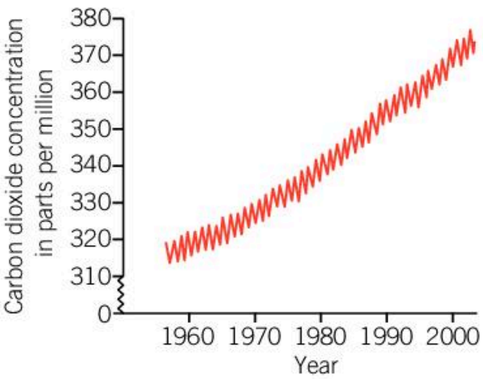
   (6 marks)

4.6 Climate change

Learning objectives

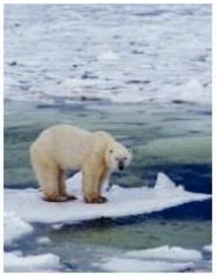
After this topic you will be able to:

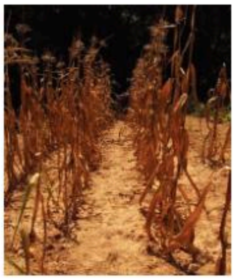
- explain why global warming happens
- explain some impacts of global warming



▲ The changing concentration of carbon dioxide in the atmosphere.

What links the pictures?





The pictures show impacts of climate change. **Climate change** is a long-term change in weather patterns. Increasing amounts of carbon dioxide in the atmosphere cause climate change.

Why more carbon dioxide?

For many years, the concentration of carbon dioxide in the atmosphere stayed the same.

But since 1800 things have changed. Every year, more carbon dioxide enters the atmosphere. The extra carbon dioxide is removed at a slower rate than it enters. The concentration of carbon dioxide increases.

Humans add extra carbon dioxide to the atmosphere by:

- burning fossil fuels to generate electricity, heat homes, and fuel vehicles
- cutting down forests, or burning them, to make space for crops or cattle; this is called **deforestation**. As a result of deforestation there are fewer trees to remove carbon dioxide from the atmosphere.

A Describe two ways that humans add more carbon dioxide to the atmosphere than is removed.

What is the greenhouse effect?

If there were no carbon dioxide in the atmosphere, Earth would be too cold for life.

The Sun heats the Earth's surface. The warm Earth produces radiation. Some of this radiation goes back into space.

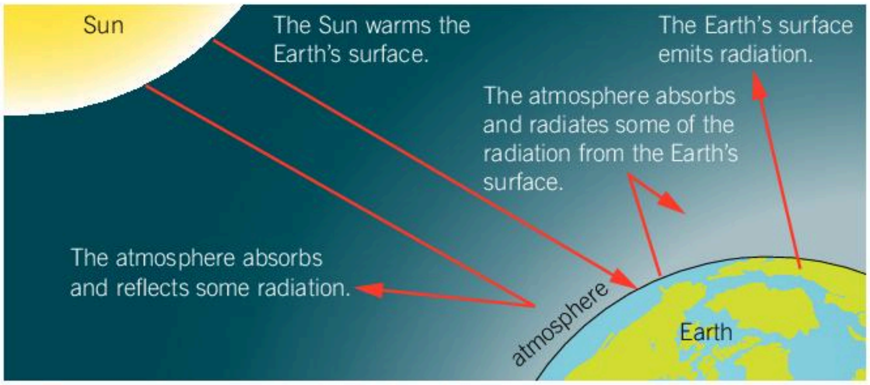
Carbon dioxide in the atmosphere absorbs some of the **radiation** produced by the Earth so it does not go back into space. This keeps the Earth warmer than it would be if the radiation went back into space. This is the **greenhouse effect**. Carbon dioxide is a **greenhouse gas**.

Link

You can learn more about radiation in P2 2.4: Energy transfer: particles

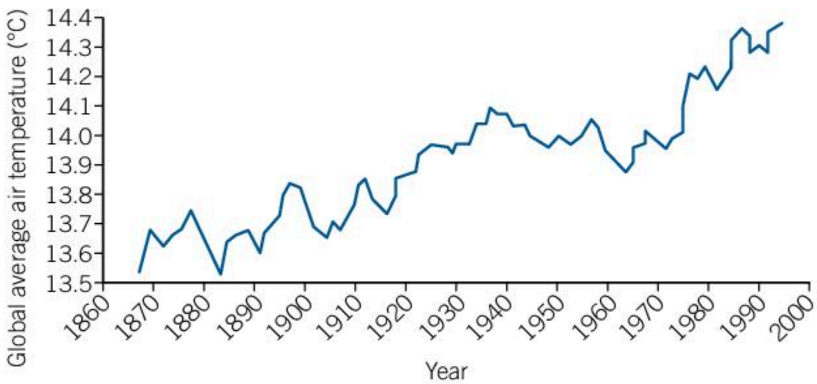
Foul Fact

Carbon dioxide is not the only greenhouse gas. Methane is a greenhouse gas too. One cow burps 280 kg of methane into the air every year.



▲ The greenhouse effect. Not to scale.

Extra carbon dioxide has caused an increase in the global average air temperature. This is **global warming**.



▲ The changing global average air temperature since 1800.

B. Describe the meaning of global warming.

What are the impacts of climate change?

By 2100 scientists predict that the global average air temperature could increase by up to 5 °C. This increase is already causing problems. For example:

- melting polar ice is making sea levels rise, causing flooding on low-lying coasts
- more droughts, heavier rainfall, and heatwaves.

These changes may cause some species to become extinct. More frequent droughts will make it harder to grow enough food.

Key Words

climate change, deforestation, radiation, greenhouse effect, greenhouse gas, global warming

Global graphs

With a partner, discuss the two graphs on this spread. What do they show? How do their shapes compare? Then think about the data. What apparatus might scientists use to collect temperature data? How might they collect carbon dioxide concentration data that is fair to compare? Now write up your findings.

Link

You can learn more about extinction in B2 3.7 Extinction

Summary Questions

1 Choose one bold phrase to write next to each definition.

global warming **climate change** **greenhouse effect** **deforestation**

Definitions

- gases in the atmosphere increasing the global average air temperature
- the increase in the global average air temperature
- cutting down or burning forests
- changes to long-term weather patterns

(4 marks)

2 Draw a labelled diagram to explain the greenhouse effect and global warming.

(4 marks)

3 Explain in detail the causes and effects of climate change.

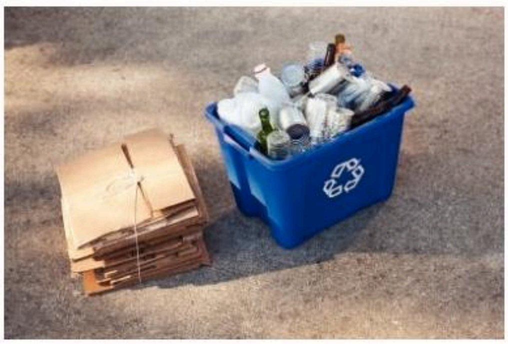
(6 marks QWC)

4.7 Recycling

Learning objectives

After this topic you will be able to:

- explain how aluminium is recycled
- analyse the advantages and disadvantages of recycling.



▲ Lots of different materials can be recycled.

▲ If we continue to use tin as we do now, tin ore might run out by 2030.

What do you recycle?

You can recycle many types of material, including paper, metals, and plastics. But is it worth the effort?

Where do resources come from?

The materials that make everything we use come originally from the Earth's crust, atmosphere, or oceans. These resources will not last forever.

The table shows an estimate of when the materials we get four elements from might run out.

Element	Uses of element	When the source of the element will run out (estimated year)
phosphorus	making fertilisers	between 2060 and 2110
gold	jewellery, electrical connections	2040
tin	food containers, solder	2030
aluminium	aeroplanes, overhead power cables, kitchen foil	2500

A State where all the materials we use originally come from.

What is recycling?

Recycling means collecting and processing materials that have been used so that the materials can be used again. Examples of recycling include:

- recycling paper to make new paper
- recycling plastic bottles to make fleeces
- recycling aluminium cans to make aluminium sheets to make more cans.

How is aluminium recycled?

Alex puts out an aluminium can for recycling. A lorry takes it to a factory. At the factory, machines shred the can and remove its decoration.

A furnace melts the aluminium shreds. The liquid cools and freezes in a mould. This is an aluminium ingot.

▲ An aluminium ingot.

The ingot is heated to 600 °C to soften it. Huge rollers roll it into thin sheets. The sheets are made into new cans.

B Describe what recycling is.

Advantages and disadvantages

There are many advantages of recycling. For example:

- Recycling means resources will last longer.
- Recycling uses less energy than using new materials. Around 255 MJ of energy is needed to extract 1 kg of aluminium from its ore. Only 15 MJ is needed to make 1 kg of recycled aluminium.
- Recycling reduces waste and pollution. Extracting aluminium from its ore creates huge amounts of dangerous 'red mud' waste.

C List three advantages of recycling.

Recycle and remake

Calculate how many kilograms of recycled aluminium you could make using the same amount of energy it takes to extract 1 kg of aluminium from its ore.

There are some disadvantages to recycling. Some people think that separating rubbish is a nuisance. The lorries that collect recycling use fuel and create pollution.

D State two disadvantages of recycling.

Can you recycle everything?

Some materials are easier to recycle than others. Companies that recycle plastic waste need to separate different sorts of plastic from each other. This is often done by hand, and takes a long time.

This girl is wearing a fleece made from recycled bottles.

Bottled fleeces

A company states that it needs 25 two-litre plastic bottles to make one fleece. Estimate the number of bottles needed to make a fleece for everyone in your school.

Link

You can learn more about metal ores in C2 3.5 Extracting metals

Key Words

recycling

Summary Questions

1 Write down the two statements below that are examples of recycling.

- collecting old glass bottles, melting the glass, and making new bottles
- using a plastic bag from the supermarket to wrap your packed lunch in
- collecting and melting poly(propene) bottle tops, and using them to make poly(propene) rope

(2 marks)

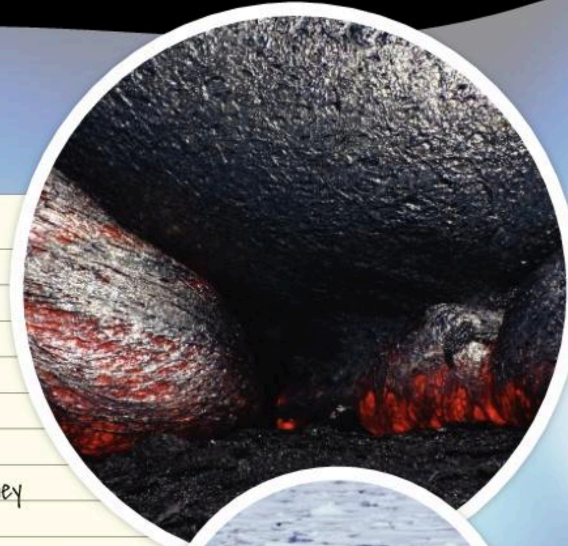
2 Describe how aluminium is recycled.

(4 marks)

3 Evaluate the advantages and disadvantages of recycling.

(6 marks QWC)

C2 Chapter 4 Summary



Key Points

- Everything we use comes from the Earth's crust, atmosphere, or oceans.
- The Earth consists of the crust, mantle, outer core, and inner core.
- The atmosphere is the mixture of gases around the Earth. It is mainly nitrogen and oxygen, with smaller amounts of argon and carbon dioxide.
- Sedimentary rocks form as a result of weathering, erosion, transport, deposition, and compaction or cementation.
- Sedimentary rocks have separate grains. They are porous. Most are soft.
- Igneous rocks forms when liquid rock freezes. They consist of crystals. They are non-porous, hard, and durable.
- Metamorphic rocks form when heating, high pressure, or both change existing rock. They consist of crystals. They are non-porous.
- The rock cycle shows how materials in rock are recycled over millions of years.
- Huge forces inside the Earth push rocks upwards to form mountains. This is called uplift.
- Carbon stores include the atmosphere, oceans, sedimentary rocks, fossil fuels, and organisms.
- The carbon cycle shows how carbon compounds enter and leave carbon stores.
- The concentration of carbon dioxide in the atmosphere is increasing because of deforestation and burning fossil fuels.
- Extra carbon dioxide in the atmosphere causes climate change.
- Recycling involves collecting and processing materials that have been used to make new objects.

Key Words

crust, mantle, core, outer core, inner core, atmosphere, troposphere, sedimentary, igneous, metamorphic, porous, weathering, sediment, physical weathering, freeze-thaw, chemical weathering, biological weathering, erosion, transport, deposition, compaction, cementation, durable, magma, lava, rock cycle, uplift, respiration, combustion, photosynthesis, dissolving, carbon cycle, carbon store, climate change, deforestation, radiation, greenhouse effect, greenhouse gas, global warming, recycling.

Maths challenge

Ranking recycling

Imagine that you work for a recycling company and that your job is to design the website. Your boss has given you the data below.

Task

Design the homepage of the website. Include a chart or graph of the information in the table. In your chart, show the changes in the percentages of waste recycled in each country between 2001 and 2010.

Tips

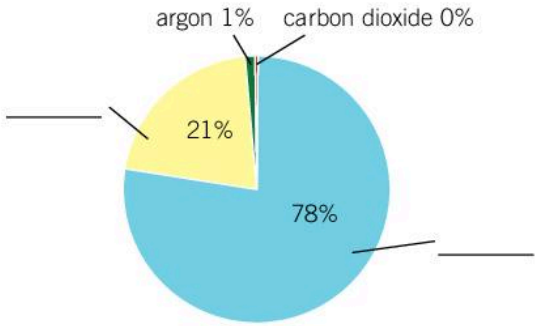
Provide information about where our resources come from and how we can recycle them.

Country	% of waste recycled in 2001	% of waste recycled in 2010
Austria	57.3	62.8
Portugal	15.5	18.8
Iceland	17.3	23.4
Ireland	11.3	35.7
Norway	44.3	42.1
UK	12.4	38.8

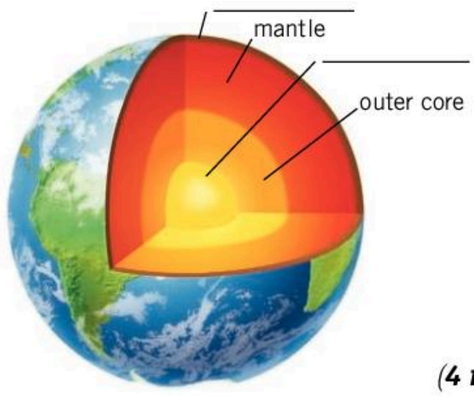
Data: European Environment Agency

End-of-chapter questions

1 Write the missing labels on the diagrams.

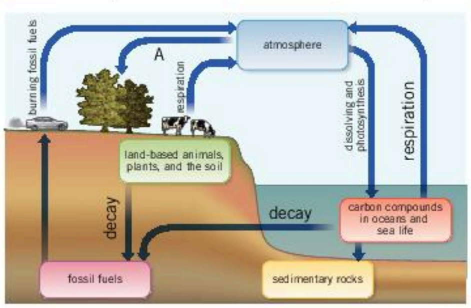


gases in the atmosphere of the Earth



(4 marks)

2 The diagram shows the carbon cycle.



a Name **three** stores of carbon shown on the carbon cycle. *(3 marks)*

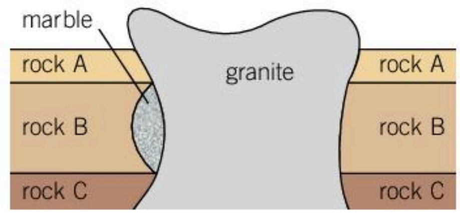
b Name the process represented by arrow A. *(1 mark)*

c Name **two** processes that add carbon dioxide to the atmosphere. *(2 marks)*

d Give **two** reasons to explain why the amount of carbon dioxide in the atmosphere has increased since the year 1800. *(2 marks)*

(8 marks)

3 The diagram shows the rocks on a cliff face.



a Rocks A, B, and C are sedimentary rocks. Write the letter of the layer of sedimentary rock that formed first. *(1 mark)*

b Write the letter of the youngest sedimentary rock. *(1 mark)*

c Granite is an igneous rock. Explain how the granite in the diagram was formed. *(3 marks)*

d Suggest why the granite sticks up above rock A. *(2 marks)*

e Marble is a metamorphic rock. Suggest **two** reasons why it formed only in the position shown on the diagram. *(2 marks)*

(9 marks)

4 Harry investigates the speed of cooling on crystal size. He places drops of liquid salol onto microscope slides. Once the salol freezes he observes the crystals.

Harry lists the variables in his investigation:

X temperature of microscope slide
Y number of drops of salol
Z size of crystals

a Name the independent variable. *(1 mark)*

b Name the dependent variable. *(1 mark)*

c Explain why Harry must control the other variable. *(1 mark)*

d Describe what Harry would observe if the crystals formed quickly and if they formed slowly. *(2 marks)*

(5 marks)

5 Explain how the materials that rocks are made from are recycled in the rock cycle.

(6 marks QWC)

Chemistry 3

In this unit you will learn about nanoparticles. Nanoparticles make exciting new materials, with properties that make them perfect for strengthening sports equipment, protecting electronic devices, and treating disease. You will also learn about vital turning points in chemistry. How did scientists find out what's in an atom, and what fossils tell us about the history of life on Earth? You will also discover how chemistry helps to solve crimes.

You already know

- The properties of a substance are determined by the structure and behaviour of its particles.
- The properties of a substance determine its uses.
- Polymers have long particles.
- All substances are made up of atoms.
- Every element has its own type of atom.
- All the elements are listed in the Periodic Table.
- The pH scale shows whether a solution is acidic, alkaline, or neutral.
- Techniques for separating mixtures include filtration and chromatography.

Q

Give the pH of a neutral solution, and the pH ranges of acidic and alkaline solutions.

BIG Questions

- What gives nanoparticles their properties, and how do these properties make them useful?
- How did chemists find out what atoms are made of?
- How does chemistry help solve crimes?

Picture Puzzler
Key Words

Can you solve this Picture Puzzler?

The first letter of each of these images spells out a science word that you will come across in this unit.

Picture Puzzler
Close Up

Can you tell what this zoomed-in picture is?

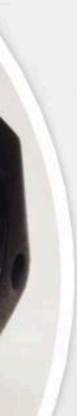
***Clue**: It's millions of years old.*

Making connections

In **C1** you learnt how to distinguish if a reaction has occured.

In **C2** you learnt about different types of reactions.

In **C3** you will apply these reactions to atmospheric chemistry and detection techniques.



1.1 Nanoparticles

Learning objectives

After this lesson you will be able to:

- explain what nanoparticles are
- describe the properties of nanoparticles.

▲ Sebastien Zamith is studying nanoparticles to discover how water droplets form in clouds.

▲ A gold ring.

Bandages that kill bacteria. Lightweight bullet-proof vests. Materials that capture carbon dioxide. What do these things have in common? They all include nanoparticles, or might in future.

All over the world, scientists are studying nanoparticles. They use what they learn to create exciting new materials.

A List three things that include nanoparticles, or might in future.

What are nanoparticles?

Nanoparticles are tiny pieces of a substance. A nanoparticle is made up of just a few hundred atoms. The diameter of a nanoparticle is between 1 nanometre and 100 nanometres. You cannot see it with a normal microscope.

A **nanometre** is a unit of length. Its symbol is nm. One nanometre is one billionth of a metre, or 0.000 000 001 m. The length of 1 nm compared to 1 m is the same as the diameter of a marble compared to the diameter of the Earth.

When we talk about nanoparticles, "particle" means a piece of a substance.

B State what a nanoparticle is.

Why are nanoparticles special?

A substance that exists as nanoparticles has different properties to normal-sized pieces of the same substance. Why is this?

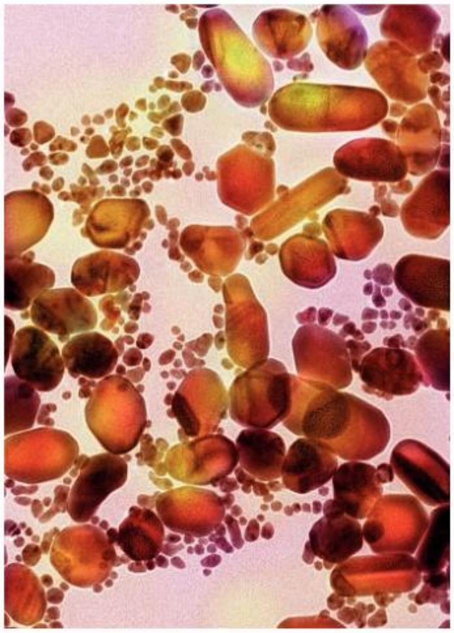
Imagine a gold ring. It has a mass of 4 g. Most of its atoms are inside the gold. Very few are on the surface.

Now imagine you have 4 g of gold nanoparticles. There is the same number of atoms in the ring and in the nanoparticles. But there are many more atoms on the surface of the nanoparticles.

The huge number of surface atoms gives a substance special properties when it is in the form of nanoparticles.

Normal-sized pieces of gold are yellow in colour. If you mix nanoparticles with water, the water looks reddish in colour. In its normal form, gold cannot mix with water.

The bottle contains gold nanoparticles mixed with water.



Gold nanoparticles. The picture was taken with a scanning electron microscope, and then coloured. Magnified × 215 000.

c State which has the greater number of atoms on its surface, 1 g of a gold ring or 1 g of gold nanoparticles.

How small?

A human hair has a diameter of between 20 and 100 μm. Calculate the mean diameter of a human hair. Then calculate how many nanoparticles of diameter 30 nm fit across an average human hair.

1 nm = 0.000 000 001 m and 1 μm = 0.000 001 m

Fantastic Fact

Some socks contain silver nanoparticles to kill bacteria and help stop feet smelling.

Key Words

nanoparticle, nanometre

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

A nanoparticle is a tiny piece of a substance. It is made up a few **hundred/million** atoms. The diameter of a nanoparticle is between 1 and **100/1000** nanometres. One nanometre is **0.000 000 001/ 0.000 001** metres. A substance has **the same/ different** properties when it exists as nanoparticles compared to when it exists in normal-sized pieces. This is because the nanoparticles have a **smaller/ bigger** surface area.

(5 marks)

2 A scientist has 1 g of silver nanoparticles, and a 1 g lump of silver. Which has the greater number of surface atoms? Explain your answer.

(2 marks)

3 Compare the properties of gold nanoparticles with those of gold in normal-sized pieces. Explain any differences.

(6 marks QWC)

1.2 Using nanoparticles

Learning objectives

After this lesson you will be able to:

- explain how the properties of nanoparticles make them suitable for their uses.

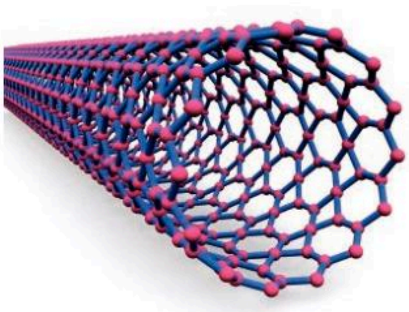
Imagine a phone that survives being dropped in the toilet. Imagine clothes that never get dirty. Imagine sports equipment that never breaks. Thanks to nanoparticles, these dreams may soon come true.

▲ Nanoparticles may soon mean that your phone could survive being dropped in the toilet.

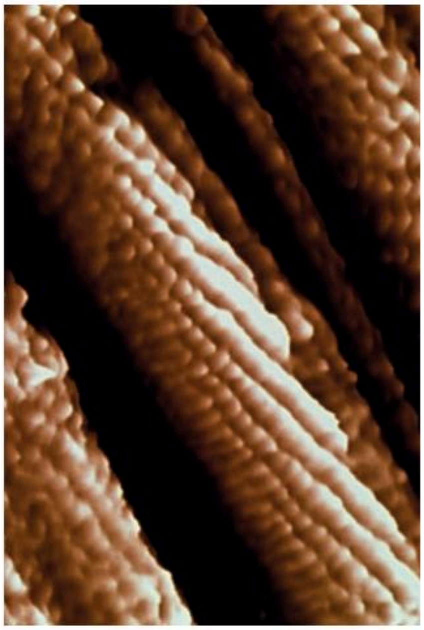
Substances in the form of nanoparticles are already useful. Scientists keep thinking of new ways to use their special properties.

What are carbon nanotubes?

Scientists first made **carbon nanotubes** in the 1990s. Carbon nanotubes are cylinders of carbon atoms. Their walls can be just one atom thick. The diameter of a carbon nanotube is about 1 nm.



▲ A model showing the atoms in one nanotube.



▲ A cluster of nanotubes.

A State what a carbon nanotube is.

Carbon nanotubes have amazing properties. They are some of the strongest and stiffest materials that exist. They have low densities. These properties make them ideal for many uses, including:

- strengthening tennis-racquet frames
- strengthening bicycle parts
- making lightweight bullet-proof vests.

▲ Composite materials that include carbon nanotubes are used in wind turbines.

Mixing carbon nanotubes with polymers makes strong composite materials. These materials are used in wind turbines.

Carbon nanotubes are excellent conductors of heat. Scientists think they could be used in future to heat aircraft wings to stop them going icy. The table shows how well carbon nanotubes conduct heat, compared to other materials.

Material	Thermal conductivity (W/m/K) (how well the material conducts heat)
brick	1.4
carbon nanotubes (along the tube)	3500
carbon nanotubes (across the tube)	1.52
copper	401

B Write down three properties of carbon nanotubes.

Can nanoparticles protect phones and fabrics?

In 2013, scientists announced an exciting invention. They had created a nanoparticle coating for phones and other electronic devices. The coating means there is nowhere for liquids to get in.

The coating consists of polymer nanoparticles. It is 1000 times thinner than a human hair. You cannot see it, and it does not affect how the phone works. When a raindrop (or spilt coffee) falls on the phone, it does not spread out. It stays as a drop, and rolls away.

Other groups of scientists are experimenting with clothing. Can they add nanoparticle coatings to clothes to stop them getting dirty?

C State one use of a nanoparticle coating.

Nanoparticles in the news

Write an exciting news article about one of the new uses of nanoparticles described on these two pages. Start by describing the innovation. Then use simple language to explain why the properties of the nanoparticle material make it perfect for this use.

Fantastic Fact

The longest carbon nanotube ever made was 18.5 cm long.

Key Words

carbon nanotube

Summary Questions

1 Copy and complete the sentences below.

Carbon nanotubes are __________ of carbon atoms. Their walls are often one __________ thick. The diameter of a carbon nanotube is about one __________. Carbon nanotubes are strong, __________, and they are good conductors of __________.

(5 marks)

2 Carbon nanotubes have been used to make ice-hockey sticks and baseball bats. Identify the property of carbon-nanotube materials that makes them suitable for these purposes.

(1 mark)

3 Use the data in the table on this page to write a few sentences to compare the thermal conductivity of the materials in the table. Include an explanation of the term *thermal conductivity* in your answer.

(6 marks QWC)

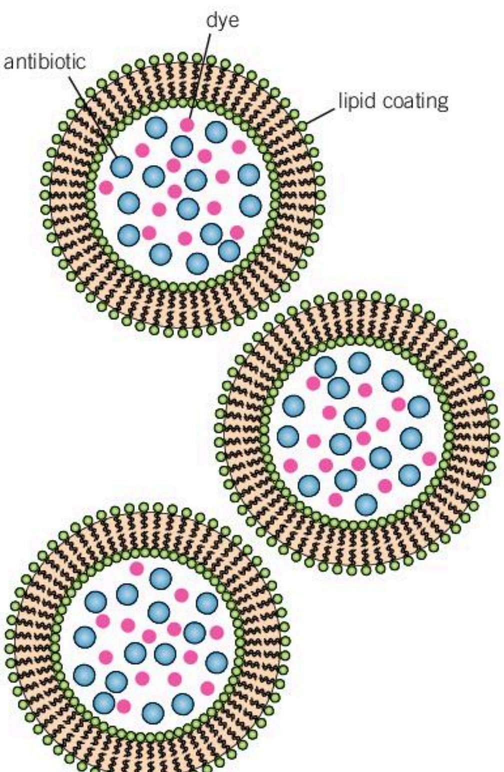
1.3 Nanoparticles in medicine

Learning objectives

After this lesson you will be able to:

- describe how nanoparticles are used in medical treatments.

▲ An infected burn.



▲ Spheres of nanoparticles like these are used in bandages.

Which of these medical innovations use nanoparticles?

- cancer drugs with no side effects
- bandages that detect infections
- magnetic treatments that destroy tumours

All these innovations use nanoparticles. Scientists think creatively to come up with ideas for new treatments. They test out their ideas by collecting evidence. They tell others about their discoveries. The use of nanoparticles to treat disease is called **nanomedicine**.

A State what is meant by nanomedicine.

How do nanoparticles improve bandages?

Scientists are working on a new type of bandage. The bandage detects and treats burns that get infected by harmful bacteria. Scientists hope that it will prevent deaths caused by infections.

The bandage includes nanoparticles arranged in spheres. Inside each sphere is some dye and an antibiotic.

A nurse bandages a burn wound on a patient. Later, bacteria get into the wound. The bacteria give out poisons. The poisons break into the spheres of nanoparticles. As a sphere breaks, its dye comes out. The dye stains the bandage. The nurse knows that the wound is infected. Next the spheres release their antibiotics, which destroy the bacteria.

Scientists expect the bandages to have many advantages, including:

- detecting and treating infections immediately
- not needing to remove bandages – removing them can be painful, and slow down healing.

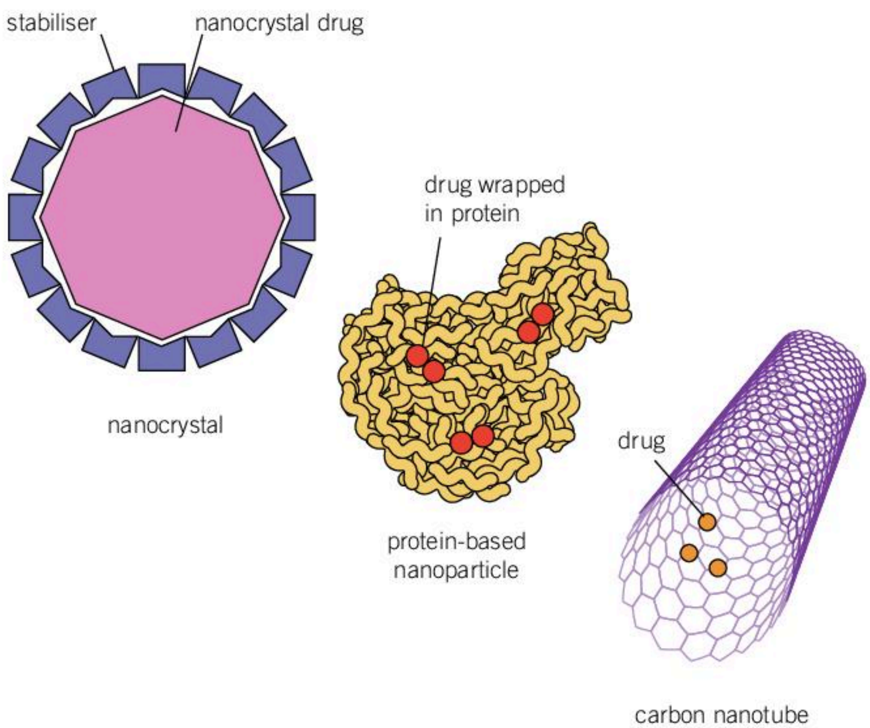
B Describe two advantages of using nanoparticles in bandages.

How can nanoparticles deliver drugs to cancer cells?

Some cancer drugs have very unpleasant side effects. How can we prevent these side effects? Can we use nanoparticles to deliver drugs to cancer cells?

Scientists are creating nanoparticles with cancer-fighting drugs inside them. The nanoparticles travel through the body. They reach a cancer cell. The cancer cell recognises the nanoparticles, and absorbs them. Inside the cell, the nanoparticles break up. They release their medicine.

This type of drug-delivery system has many advantages. The drug only gets into cancer cells. This reduces side effects, and does not waste medicine.



▲ Three types of nanoparticle that deliver drugs.

C Describe how nanoparticles deliver drugs to cancer cells.

How do magnetic nanoparticles destroy tumours?

Scientists are working on other cancer treatments. One possible treatment involves injecting iron oxide nanoparticles into a tumour. The nanoparticles are magnetic.

Doctors will apply a magnetic field near the tumour, and keep changing its direction. This heats the nanoparticles and warms up the tumour. At 5 °C above normal body temperature, tumour cells die. Healthy cells nearby are not harmed.

Scientists are testing this technique on mice with lung cancer.

Your treatment explained...

Choose one of the treatments described on these two pages. Write a leaflet for a patient who is about to have the treatment. Include a description of what will happen to the patient, and an explanation of how it works.

Key Words

nanomedicine

Summary Questions

1 Copy and complete the sentences below.

The use of nanoparticles to treat disease is called __________. Scientists are developing many new treatments based on nanoparticles, including bandages that __________ and __________ infection, nanoparticles that __________ drugs to cancer cells, and magnetic nanoparticles that __________ and __________ tumours when an alternating magnetic field is applied.

(6 marks)

2 Describe how magnetic nanoparticles might one day destroy tumours.

(3 marks)

3 Make a poster to explain in detail six uses of nanoparticles.

(6 marks)

1.4 Nanoparticle safety

Learning objectives

After this lesson you will be able to:

- describe an example of how scientists are investigating nanoparticle safety.

▲ Sunscreen with normal zinc oxide is white.

Scientists are finding more and more uses for nanoparticles. But are they safe? Do they cause more health problems than they solve? Scientists are investigating.

Investigating sunscreen

Some sunscreens contain zinc oxide nanoparticles. Zinc oxide stops harmful ultraviolet light reaching the skin. Normal zinc oxide is white. It can be visible on your skin, so is not popular. Zinc oxide nanoparticles have diameters of between 20 and 30 nm. They are invisible.

A Write down the range of diameters of zinc oxide nanoparticles.

Scientists in Australia read about research that others had done. They learnt that nanoparticles could be damaging if they get into cells in the human body. The Australians asked a question about **safety** – *Can zinc oxide nanoparticles get through the skin and into the blood?* They devised an investigation to find out.

The scientists made two types of sunscreen.

- Sunscreen A contained zinc oxide nanoparticles.
- Sunscreen B had bigger pieces of zinc oxide.

B State the question the scientists were investigating.

The scientists asked for volunteers. They took blood and urine samples from the volunteers. They measured the concentration of zinc in their blood.

Half of the volunteers applied sunscreen A twice a day. Half of the volunteers applied sunscreen B twice a day.

After a few days, the scientists took blood and urine samples from the volunteers. There was extra zinc in all the blood samples, but the amounts were tiny. It did not seem to matter which sunscreen the volunteers had used.

The scientists could not detect which form the zinc was in. Was it zinc oxide nanoparticles, which might damage cells? Or was it normal dissolved zinc, which is vital for health? The scientists want to do more research to find out.

▲ Taking a blood sample.

The Australian scientists considered the benefits and risks of using sunscreen. They suggest that people should continue to use nanoparticle-containing sunscreen. Not using sunscreen can lead to cancers.

Investigating the effects of diesel exhaust fumes

Scientists have been investigating the effect on health of nanoparticles in diesel exhaust fumes.

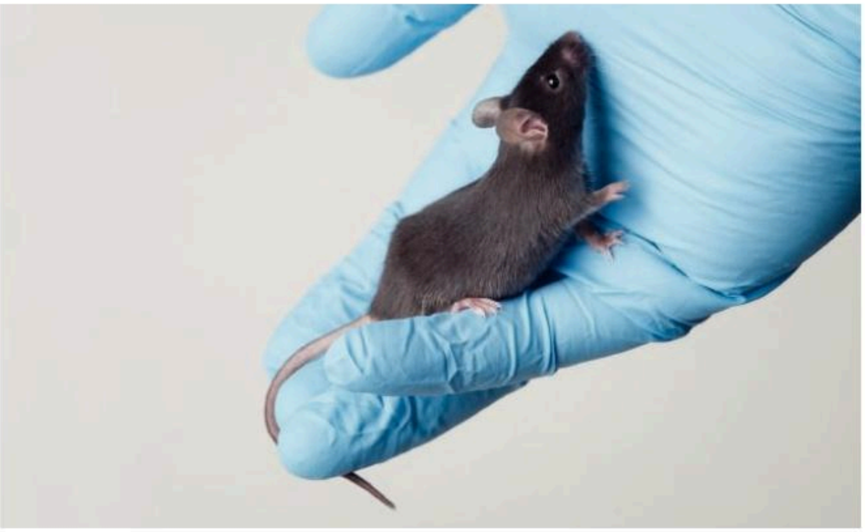
They did experiments with mice. They bred some mice with high cholesterol. They divided the mice into two groups.

- Group A was exposed to traffic pollution, which includes diesel exhaust fumes.
- Group B breathed clean air.

Five weeks later, the scientists examined arteries in the mice. The arteries of the mice in group A had 55% more fat than the arteries of the mice in group B.

The scientists concluded that diesel exhaust fumes might cause a build-up of fatty deposits in arteries. These can lead to heart disease.

C Describe what the scientists found in their investigation of diesel exhaust fumes.



▲ A laboratory mouse.

Spotting variables

With a partner, identify the dependent and independent variables in the sunscreen investigation. Which other variables do you think the scientists would need to consider in their investigation?

▲ Exhaust fumes can be harmful to health.

Key Words

safety

Summary Questions

1 Suggest why scientists are investigating nanoparticle safety. *(1 mark)*

2 **a** Write down the independent and dependent variables in the mouse experiment. *(2 marks)*

b List two other variables that scientists would need to consider in the mouse experiment. *(2 marks)*

3 Describe how scientists have investigated the impact of nanoparticles in diesel exhaust fumes on human health. *(3 marks)*

4 Design an experiment to investigate whether zinc oxide nanoparticles from sunscreen get into mouse urine. Identify the variables and consider how you would make sure the experiment is fair. *(6 marks)*

1.5 Cars: pros and cons

Learning objectives

After this lesson you will be able to:

- explain how combustion reactions in car engines produce exhaust gases
- describe some advantages and disadvantages of cars.

Link

You can learn more about greenhouse gases in C2 4.6 Climate change

Key Words

hydrocarbon, particulate

Imagine a world without cars. Would it be a better or worse place to live? Cars are convenient, making it easier for you to get wherever you want, whenever you want.

But cars are not all good news. In 2011 nearly 2000 people died in road accidents in the UK. Car drivers tend to walk less than non-car drivers, and are more likely to become obese. And, of course, cars cause pollution.

What's in car exhaust fumes?

Carbon dioxide

Petrol and diesel are mixtures of compounds. Most of the compounds are **hydrocarbons**. This means they are made up of atoms of carbon and hydrogen only. Octane is one hydrocarbon in petrol. When it burns, it reacts with oxygen to make carbon dioxide and water:

octane + oxygen → carbon dioxide + water

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

A Name the two products of the combustion reaction of octane.

On a cold day, you can often see water dripping out of car exhaust pipes. Carbon dioxide gas escapes to the atmosphere. It is a greenhouse gas, and contributes to climate change. Scientists estimate that carbon dioxide from cars accounts for 13% of the UK's total carbon dioxide emissions.

Oxides of nitrogen

Car engines get very hot. At high temperatures, nitrogen and oxygen from the air react together. In petrol engines, the main product of this reaction is nitrogen monoxide:

nitrogen + oxygen → nitrogen monoxide

$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$

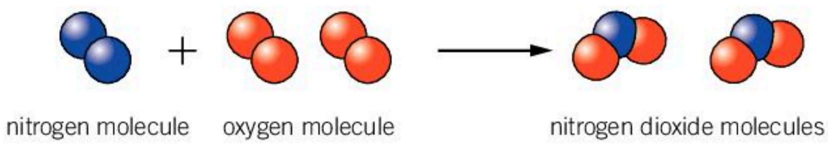
In diesel engines, the main product is nitrogen dioxide:

nitrogen + oxygen → nitrogen dioxide

$$N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)$$

Fantastic Fact

On average, car drivers walk for one hour less per week than people without cars. Over 10 years, car drivers could gain 13 kg in body mass compared to non-drivers.



▲ When nitrogen reacts with oxygen to make nitrogen dioxide, atoms are re-arranged.

If you have asthma, breathing in nitrogen dioxide can make it worse. Nitrogen dioxide in the air dissolves in rainwater to make an acidic solution. This causes acid rain. Acid rain damages trees and lake life, as well as limestone buildings.

B Name the oxides of nitrogen produced when nitrogen and oxygen react together in petrol and diesel engines.

Particulates

Burning diesel also makes another type of product: **particulates**. Particulates are tiny bits of solid, about 100 nm across. They mix with the air. Particulates are easy to breathe in because they are so small. They quickly reach the lungs. They make asthma and chest infections worse.

A group of scientists studied data on the causes of heart attacks. They found that air pollution, including particulates, can lead to heart attacks.

C Identify three health problems caused by diesel particulates.

Calculating CO_2

In 1975 the mass of carbon dioxide emitted by UK cars was 46 million tonnes. The mass of carbon dioxide increased by 57% between 1975 and 2005. Calculate the mass of carbon dioxide emitted by UK cars in 2005.

▲ Acid rain damages trees.

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

Most cars burn petrol or **diesel/oil**. These fuels are mixtures of **acids/hydrocarbons**. Their molecules consist of atoms of hydrogen and **oxygen/carbon** only. When they burn, they make two products – carbon dioxide and **water/oxygen**. *(4 marks)*

2 One of the hydrocarbons in petrol is heptane, C_7H_{16}. Write a word equation for its combustion reaction. *(4 marks)*

3 Evaluate the advantages and disadvantages of cars. *(6 marks QWC)*

1.6 New fuels

Learning objectives

After this lesson you will be able to:

- describe the advantages and disadvantages of new vehicle fuels.

▲ Crude oil is extracted from oil wells under the ground or sea.

Petrol and diesel are fossil fuels. They are separated from crude oil. Will they last forever?

Crude oil is non-renewable. It is used up more quickly than it is replaced. And, of course, burning petrol and diesel produces harmful gases. This is why scientists are developing replacement fuels.

A State what is meant by non-renewable.

What are the pros and cons of hydrogen fuel?

There are two ways of using hydrogen fuel. Some cars burn hydrogen in their engines instead of petrol. Another type of car has a **hydrogen fuel cell**. Hydrogen flows into the cell from a tank. It reacts with oxygen from the air and generates electricity. The electricity powers a motor. This makes the wheels turn.

Hydrogen fuel makes one harmless waste product, water. But it does have disadvantages:

- Hydrogen is difficult to store, since mixtures of hydrogen and oxygen are explosive.
- There are few hydrogen filling stations.

Hydrogen does not occur naturally on Earth. It is manufactured from methane in two steps. The process makes waste carbon dioxide.

Step 1: methane + water → carbon monoxide + hydrogen

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

Step 2: carbon monoxide + water → carbon dioxide + hydrogen

$$CO + H_2O \rightarrow CO_2 + H_2$$

B Describe one advantage and one disadvantage of hydrogen fuel.

▲ Hydrogen fuels this London bus.

▲ Hydrogen fuels this Bristol ferry.

Fantastic Fact

Swedish scientists have discovered how to make methane from dead cow waste. The methane fuels trains.

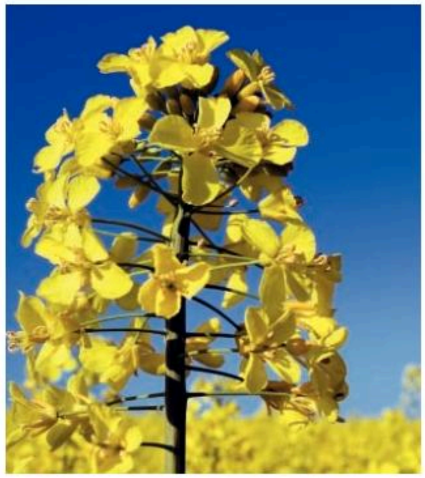
Key Words

hydrogen fuel cell, biofuel, renewable, carbon neutral

What are biofuels?

If you lived in Brazil, you would travel in vehicles fuelled by **biofuels**. Biofuels are made from plants, or animal waste. They are **renewable**, meaning they are easily replaced.

▲ Brazil makes ethanol from sugar cane. Ethanol burns in car engines.



▲ Oilseed rape seeds contain oil. The oil makes biodiesel.

All biofuels are mixtures of compounds. The compounds consist mainly of carbon, hydrogen, and oxygen atoms. They burn to make carbon dioxide and water. Carbon dioxide is a greenhouse gas.

Some people say that biofuels are **carbon neutral**. This means that the plants they are made from remove the same amount of carbon dioxide from the atmosphere when they grow as the fuels put into the atmosphere when they burn.

However, farmers use fossil-fuel-burning tractors when growing crops. They add fertilisers. This means that biofuels are not really carbon neutral.

C State what a biofuel is.

Fuel chart

The table shows the energy released on burning different fuels. Plot the data on a suitable graph or chart to show how the values compare.

Fuel	Energy released on burning (kJ/g)
diesel	45
hydrogen	143
ethanol	30
sunflower oil	38
peanut oil	40
rapeseed oil	37

▲ A few vehicles burn waste cooking oil.

Summary Questions

1. Copy and complete the sentences below.

   Petrol and diesel are __________ fuels. They are non-__________. Some vehicles use hydrogen fuel. This produces electricity when it reacts with oxygen in a fuel __________. There is one waste product, __________. Fuels produced from __________ or animal __________ are called __________.

   (7 marks)

2. Use the data in the table on this page to calculate the amount of energy transferred on burning 5 kg of sunflower oil.

   (2 marks)

3. Describe the advantages and disadvantages of biofuels.

   (2 marks)

4. Some people say that alternative fuels are carbon neutral. Discuss whether or not you agree with this statement.

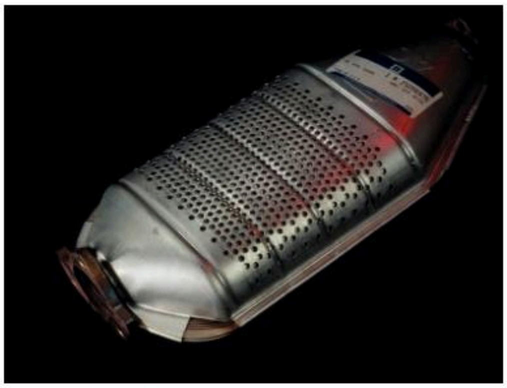
   (6 marks QWC)

1.7 Cleaning up exhausts

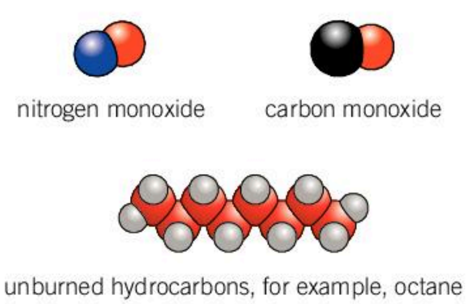
Learning objectives

After this lesson you will be able to:

- explain using word equations how catalytic converters clean up exhaust gases.



▲ A catalytic converter.



▲ Petrol engines produce these harmful substances.

Catalyst calculations

Imagine that a company extracted 15 g of platinum, and no other substances, from 3 tonnes of rock. Calculate the mass of waste material produced. 1 tonne = 1000 kg.

Car exhaust fumes were much more dangerous 50 years ago. What has made them safer?

A modern car has a **catalytic converter** between its engine and exhaust pipe. This converts harmful substances made in the engine to less harmful ones.

A State the purpose of a catalytic converter.

Waste substances

Petrol is a mixture of hydrocarbons. Hydrocarbons burn to make carbon dioxide and water. These are not the only products of combustion. Small amounts of carbon monoxide and nitrogen monoxide are also made.

Some hydrocarbon molecules do not burn. They mix with the combustion products.

It is not safe to release large amounts of these substances into the air.

- Carbon monoxide is poisonous.
- Nitrogen monoxide is a greenhouse gas.
- Some hydrocarbons increase the chance of getting cancer.

B Name three harmful substances made in petrol engines.

How do catalytic converters work?

Reactions to remove harmful substances

Carbon monoxide and hydrocarbons react with oxygen. The reactions make less harmful substances:

carbon monoxide + oxygen → carbon dioxide

$$2CO + O_2 \rightarrow 2CO_2$$

octane + oxygen → carbon dioxide + water

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

On their own, these reactions are very slow. Catalysts in catalytic converters speed them up.

Inside a catalytic converter

Many catalytic converters are made from a ceramic, with a honeycomb structure. This has a big surface area. There is plenty of space for reactions.

C State why catalytic converters have a large surface area.

On the surface of the honeycomb is the catalyst. This may include platinum, rhodium, and palladium.

▲ The honeycomb structure of a catalytic converter.

Oxidation reactions take place on the surface of the catalyst:

- Carbon monoxide makes carbon dioxide.
- Unburned hydrocarbons make carbon dioxide and water.

At the same time, nitrogen monoxide decomposes on the catalyst surface:

nitrogen monoxide → nitrogen + oxygen

$$2NO \rightarrow N_2 + O_2$$

D Name three metals in catalytic converters.

Where do the catalysts come from?

Platinum and palladium are unreactive. They are near the bottom of the reactivity series. This explains why they can occur naturally as elements.

Some platinum comes from Canada, where it exists as platinum arsenide ($PtAs_2$). This is mixed with other chemicals in an ore. There is 5 g of platinum in one tonne of rock.

Some metals used in catalytic converters are recycled from old catalytic converters. Every year, around 2 tonnes of rhodium are obtained from this source. About 16 tonnes of rhodium are extracted from rock each year.

Key Words

catalytic converter

▲ Platinum.

Summary Questions

1 Copy and complete the sentences below, choosing the correct bold words.

The main products of hydrocarbon combustion are **carbon dioxide/nitrogen dioxide** and water. Reactions in car engines also make carbon **monoxide/trioxide** and nitrogen **monoxide/trioxide**. Catalytic converters remove the unwanted carbon compound in **an oxidation/a decomposition** reaction.

(4 marks)

2 Use data on this page to calculate:

a the total mass of rhodium obtained each year *(1 mark)*

b the fraction and the percentage of this mass that is recycled rhodium. *(4 marks)*

3 Write word equations to summarise the reactions that occur in the catalytic converter.

(3 marks)

4 Draw a large diagram of a catalytic converter. Add labels and notes to your diagram to show how it removes harmful substances from exhaust gases. Add balanced formula equations to your diagram and include state symbols.

(6 marks)

1.8 Hybrid electric cars

Learning objectives

After this lesson you will be able to:

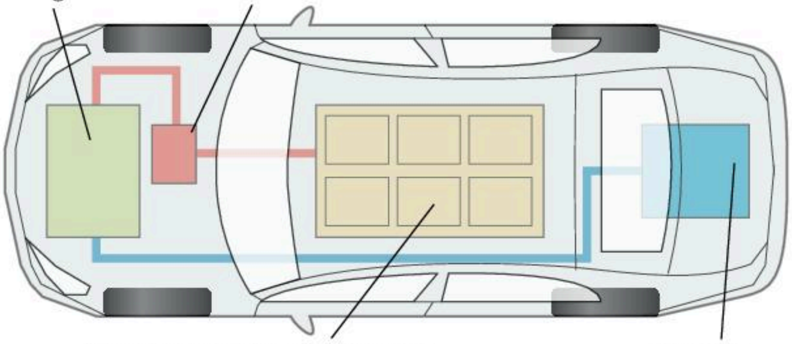
- explain why hybrid electric cars use less fuel than cars fuelled by petrol alone
- compare the advantages and disadvantages of different types of car.

▲ A hybrid electric bus.

Have you ever travelled in a hybrid electric car or bus?

Engineers developed hybrid electric vehicles to save fuel and money, and to reduce greenhouse gases.

A **hybrid electric car** includes an internal combustion engine (like a normal car) and a big battery. At higher speeds, the engine propels the car. At lower speeds, the battery takes over.



▲ A hybrid electric car viewed from above.

A State what a hybrid electric car is.

Pros and cons of different car types

In a petrol car, fuel burns in the engine. The engine turns a transmission. This turns the wheels. In an electric vehicle, a battery provides electricity to an electric motor. The motor turns the transmission. This turns the wheels.

The table shows some advantages and disadvantages of petrol and electric cars.

Petrol car	Electric car
Travels a long distance on one tank of fuel.	Travels only 150 miles between charges.
Quick to refill.	Slow to charge.
Makes pollution as it moves.	Does not make pollution as it moves.
	The electricity used to charge the battery may have been produced from fossil fuels. This produces pollution.
Noisy.	Quiet.

B Describe one advantage and one disadvantage of an electric car.

How do hybrid electric cars work?

Hybrid electric cars combine the best features of petrol and electric cars. There are two main types:

- In a parallel hybrid, a fuel tank supplies fuel to the engine. Batteries supply chemical energy to the electric motor. The engine and motor can turn the transmission at the same time.
- In a series hybrid, petrol provides energy to turn a generator. Sometimes, the generator charges the batteries. The rest of the time, the generator provides electricity to a motor. The motor turns the transmission.

C Name one component that is in a series hybrid car but not in a parallel hybrid car.

Why do hybrid cars use less fuel?

Hybrid electric cars use less fuel than petrol cars. This means they create less pollution. There are several reasons for this, including:

- A hybrid car does not need the engine to turn all the time because it has an electric motor. The car may automatically turn off the petrol engine at a red light.
- Hybrid cars use regenerative braking. Normally, when a car brakes, kinetic energy is dissipated and heats the surroundings. In a hybrid car, this energy recharges the battery.

What's in a battery?

Most hybrid car batteries are nickel–metal hydride batteries. Nickel may cause cancer. Scientists are working on making lithium-ion batteries for cars, like the batteries in your phone or laptop.

▲ A nickel–metal hydride car battery.

Comparing cars

Write the text and draw pictures for a webpage to help people decide whether to buy a hybrid electric car or an electric car.

Key Words

hybrid electric car

Summary Questions

1 Copy and complete the sentences below.

A petrol car has an internal __________ engine. An electric car has a rechargeable __________. A __________ electric car has both of these. A hybrid car burns __________ fuel than a petrol car and produces __________ exhaust gas.

(5 marks)

2 Describe two advantages and two disadvantages of petrol-driven cars and of electric cars.

(4 marks)

3 Draw a visual summary that explains the differences between petrol-driven cars and hybrid cars.

(6 marks)

C3 Chapter 1 Summary

Key Points

- Nanoparticles are tiny pieces of a substance with a diameter of between 1 nm and 100 nm.
- 1 g of a nanoparticle substance has more atoms on its surface than 1 g of the same substance existing in normal-sized pieces.
- Carbon nanotubes are cylinders of carbon atoms.
- Carbon nanotubes are strong, stiff, and have low densities. They make items strong, stiff, and lightweight.
- Nanoparticles can be used to protect items from water and stains. Nanomedicine is the use of nanoparticles to treat disease. Scientists are developing the use of nanoparticles to release antibiotics in bandages, to deliver drugs to tumours, and to destroy tumours.
- Scientists are investigating the risks of using nanoparticles.
- Most cars burn petrol or diesel. These fuels are mixtures of hydrocarbon compounds.
- Burning petrol or diesel produces two main products – carbon dioxide and water.
- Other substances are produced by chemical reactions in car engines, including nitrogen oxides, carbon monoxide, particulates, and unburned hydrocarbons.
- Chemical reactions in catalytic converters remove carbon monoxide, nitrogen monoxide, and unburned hydrocarbons from vehicle exhausts.
- Hydrogen can be used as a vehicle fuel. It produces one combustion product – water.
- Hydrogen is difficult to store and transport safely.
- Hybrid electric cars include an internal combustion engine, fuelled by petrol or diesel, and a battery.
- A hybrid electric car uses less fuel than a petrol or diesel car.

Key Words

nanoparticle, nanometre, carbon nanotube, nanomedicine, safety, hydrocarbon, particulate, hydrogen fuel cell, biofuel, renewable, carbon neutral, catalytic converter, hybrid electric car

Maths challenge

Best way to travel?

A family of four is travelling from Exeter to Newcastle – a distance of 420 km and back again. They can travel by air, coach, train, petrol car, or hybrid car. The aeroplane, coach, and train will make the journey even if the family decide on another method of travel.

Task

Write a letter to the family recommending which method of travel they should use from an environmental point of view.

Method of transport	Mass of carbon dioxide produced (g/km)
air	170 (per person)
rail	53 (per person)
coach	30 (per person)
petrol car	150 (per car)
hybrid car	49 (per car)

Tips

- Use the data in the table to estimate the mass of carbon dioxide produced for each travel option.
- Calculate the total for the whole family.
- Remember to include the return journey.

End-of-chapter questions

1 Copy the table. Then tick one or more boxes to show which statement or statements are true of nanoparticles.

Statement	Is the statement true of nanoparticles?
Their diameter is between 1 nm and 1000 nm.	
100 g of a nanoparticle substance has a greater surface area than 100 g of the same substance as normal-sized pieces.	
A nanoparticle is made up of a few hundred atoms.	

(**3 marks**)

2 Copy and complete the sentences below. Use the words and phrases in the box once, more than once, or not at all.

> biofuel, carbon dioxide, maize, water, sugar cane, oxygen

Ethanol is an example of a _______. It is produced from crops such as _______ and _______. As these crops grow, they take in _______ gas from the air. An ethanol molecule is made up of atoms of carbon, hydrogen, and oxygen. This means that ethanol produces two main products when it burns: _______ and _______.

(**6 marks**)

3 Read the passage in the box, then answer the questions that follow.

> Medical staff use cotton gauze to help stop wounds bleeding. Medical gauze did not change much during the last century. In the early 2000s scientists developed a better gauze. First they added a substance called QuickClot to medical gauze. It stopped the bleeding but it became hot when in contact with blood or water. This caused burns. The scientists tried adding a different material to medical gauze – kaolin clay. The clay is rich in aluminosilicate nanoparticles. These help blood to clot, and so stop bleeding. The nanoparticles do not enter the body, since they get trapped at the injury site.

a Describe and explain the hazard linked to adding QuickClot to medical gauze. *(2 marks)*

b Name the substance in kaolin clay that helps blood to clot. *(1 mark)*

c Suggest why scientists working on the project claim that adding kaolin clay to medical gauze is unlikely to be hazardous to health. *(1 mark)*

(**4 marks**)

4 Hexadecane is one of the compounds in diesel.

a Hexadecane is a hydrocarbon. State what is meant by a hydrocarbon. *(1 mark)*

b Write the names of the two main products formed when hexadecane burns. *(2 marks)*

c Write a word equation for the combustion reaction of hexadecane. *(2 marks)*

d The formula of hexadecane is $C_{16}H_{34}$. Give the number of atoms of the two elements that make up a molecule of hexadecane. *(2 marks)*

e Burning 1 kg of hexadecane releases 47 MJ of energy. Calculate the energy released on burning 3 kg of hexadecane. *(2 marks)*

(**9 marks**)

5 Explain in detail how catalytic converters make car exhaust fumes less harmful.

(**6 marks QWC**)

2.1 Evidence for atoms

Learning objectives

After this lesson you will be able to:

- describe evidence for Dalton's atomic model
- explain one way of developing a scientific explanation.

▲ How many pieces could you cut this chocolate into?

▲ Dalton collected gas from marshes to use in his experiments.

Imagine a bar of chocolate. How many pieces can you divide it into? Can you go on cutting it up forever?

People wondered about questions like this more than 2500 years ago. Some argued that matter completely fills its space. You can divide it into smaller pieces for ever.

But Indian and Greek philosophers had a different idea. They said that everything is made up of tiny particles, with empty space between. You cannot see the particles, or cut them up. The Greeks called these particles **atoms**.

The philosophers did not do experiments. They worked out their answers using creative thought.

▲ The Greek philosophers Leucippus and Democritus said that atoms are the smallest pieces of matter that exist.

A How did Indian and Greek philosophers work out that everything is made from atoms?

How did Dalton develop his atomic model?

For many years, there was no experimental evidence for atoms. Then John Dalton came along. He found evidence for atoms. His work marks a turning point in chemistry.

Dalton taught chemistry in Manchester. He was also interested in the weather. In 1787 he made the first of 200 000 entries in his weather diary. Dalton thought carefully about his observations.

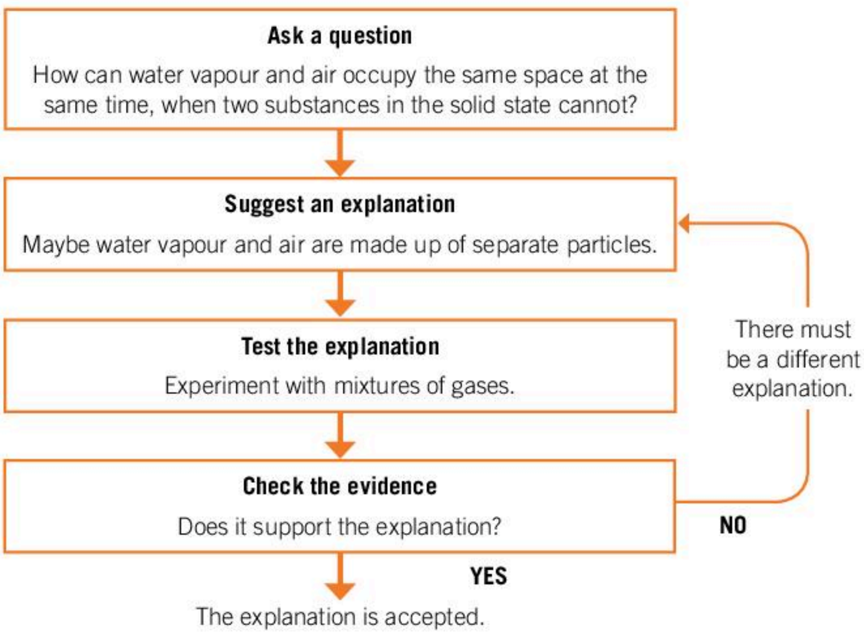
He read about the work of a French chemist, Antoine Lavoisier. Lavoisier had discovered that the air included at least two gases.

Dalton worked out that water exists in the air as a gas, separate from other gases. He asked a question:

How can water vapour and air occupy the same space at the same time, when two substances in the solid state cannot?

Dalton suggested an explanation to answer his question. He said that water vapour and air are made up of separate particles. When water evaporates, its particles mix with air particles.

Dalton wanted to test his explanation. He designed and carried out experiments on mixtures of gases. The evidence supported his explanation. Dalton made a conclusion. In any mixture of gases, the particles of the different gases are not joined together. They are just mixed up.



▲ Dalton found evidence for particles by asking a question and testing an explanation.

Dalton continued to experiment with gases. He extended his original explanation to develop an atomic model. His model includes these ideas:

- Each **element** has its own type of atom.
- The atoms of different elements have different masses.
- **Compounds** form when atoms of different elements join together.
- Atoms are re-arranged in chemical reactions.

B List the four ideas in Dalton's atomic model.

Atoms and evidence

Imagine that Dalton and Democritus could meet to discuss their ideas about atoms. Write the script for a conversation they might have. Then perform the conversation with a partner.

Link

You can learn more about solids, liquids, and gases in C1 1.2 States of matter

Key Words

atom, element, compound

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

Everything is made up of **big/small** particles. There is **empty space/air** between the particles. Two gases can occupy the same space because their particles are **joined together/mixed up**.

(3 marks)

2 Explain how Dalton used evidence from another scientist to help him develop his atomic model.

(2 marks)

3 Compare the ideas of Democritus and Dalton, and the ways in which they developed their ideas.

(6 marks QWC)

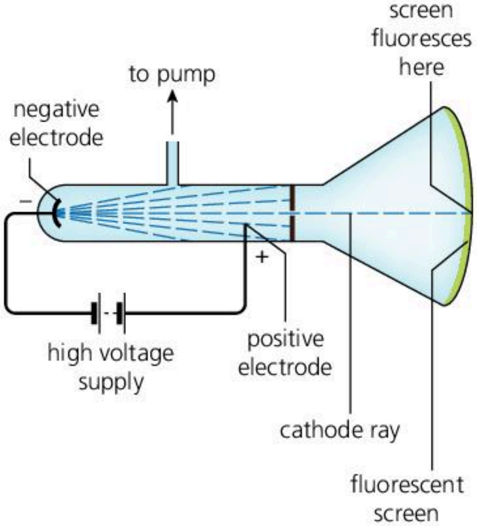
2.2 Looking into atoms

Learning objectives

After this lesson you will be able to:

- explain how scientists discovered electrons and the nucleus.

▲ Dalton imagined atoms as tiny billiard balls.



▲ Scientists used this apparatus to investigate the effect of electricity on gases.

Link

You can learn more about electric charge in P2 1.1 Charging up

Is there anything inside an atom? Is it a solid sphere? Or is it made up of even tinier particles?

Dalton imagined an atom as a billiard ball. You cannot break it up. It is the same all the way through. Other scientists questioned this idea. By 1904, they had some answers.

A State how Dalton imagined an atom.

What's in an atom?

Scientists were investigating gases. They put a tiny amount of gas in a sealed tube with a screen. They built an electric circuit, and supplied a big voltage. Part of the screen glowed green. Why? Scientists suggested that rays from the negative electrode caused the green glow. The rays travelled through the gas and hit the screen.

Scientist J. J. Thomson asked a question about the rays:

What are the rays made of?

He wondered if the rays were electrically charged. He decided to test his explanation.

Thomson passed the rays between two pieces of metal with electrical charges. The rays bent towards the positively charged metal. Thomson's explanation was correct. The rays are negatively charged.

Thomson did more experiments. He thought about the evidence. He realised that the negative rays are made up of tiny particles. He called the particles **electrons**. Every electron has the same negative charge and tiny mass.

Thomson wondered where the electrons came from. He realised that, since everything is made up of atoms, electrons must be part of atoms.

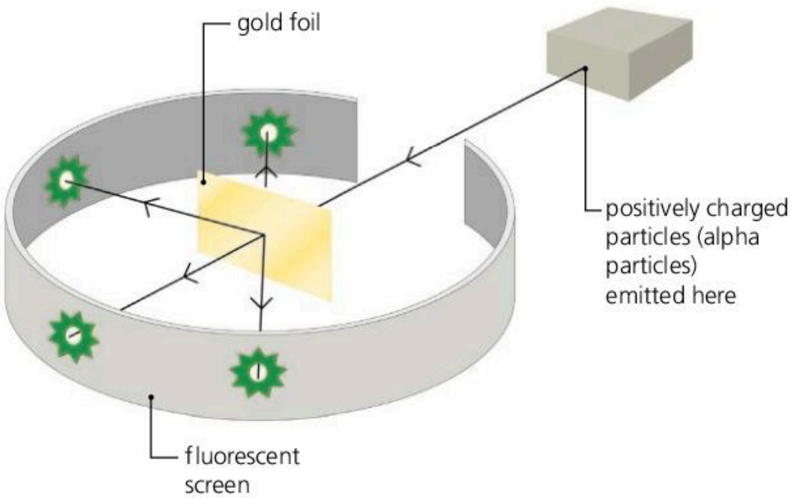
B State what an electron is.

In 1904 Thomson suggested a new atomic model. He said that an atom has negative electrons moving around in a positively charged sphere. Some people called Thomson's idea the plum-pudding model. It reminded them of plums in a pudding.

C Describe the plum-pudding model of an atom.

Is the plum-pudding model correct?

Ernest Rutherford wondered if the plum-pudding model was correct. He worked with other scientists to find out. The scientists set up the apparatus below.



▲ Rutherford, Geiger, and Marsden used this apparatus to test the plum-pudding model.

The scientists planned to fire positive particles at the gold foil. They predicted that most would go straight through. A few would pass close to negative electrons and be attracted towards the electrons; they would change direction slightly.

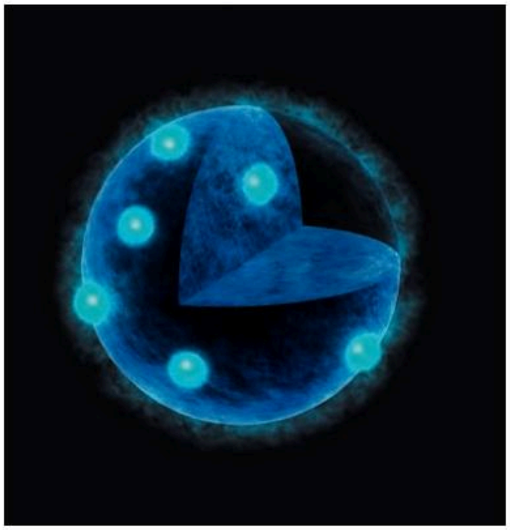
The scientists carried out their plan. The results were bizarre. Some positive particles bounced back off the foil.

Rutherford thought about the strange results. How could he explain them? By 1911, he had a new model:

- Atoms have a central nucleus with a positive charge. Most of the mass of the atom is here.
- There is a big empty space around the nucleus. Electrons move around here.

How massive?

The nucleus of an oxygen atom has a relative mass of 16. An electron has a relative mass of 0.0005. How many times more massive is an oxygen atom nucleus than an electron?



▲ Thomson's plum-pudding model.

Key Words

electron

Summary Questions

1 Copy and complete the sentences below.

Dalton imagined an atom as a billiard __________. J. J. Thomson created the plum-__________ model of an atom. It had __________ electrons moving around a positively charged sphere. Rutherford discovered that an atom has a central __________ with a __________ charge.

(5 marks)

2 Explain how Rutherford discovered that an atom has a positively charged nucleus.

(4 marks)

3 Make a chart to summarise the models described on these two pages, and the evidence for them.

(6 marks)

2.3 Discovering the Periodic Table

Learning objectives

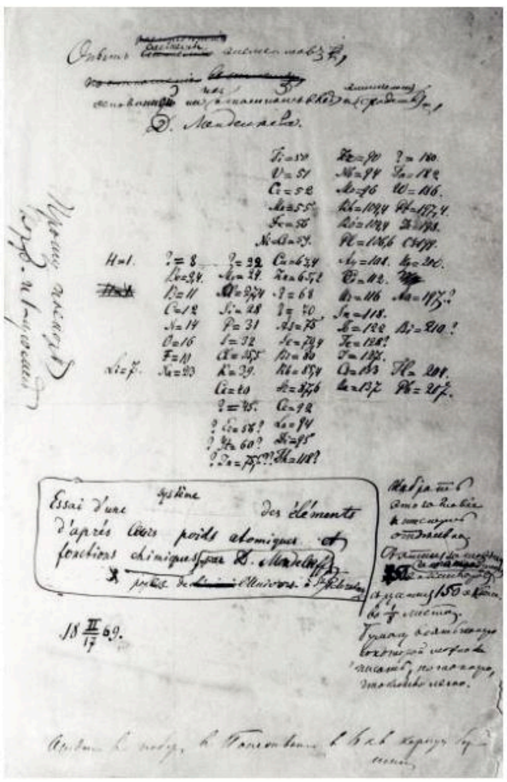
After this lesson you will be able to:

- describe how Mendeleev devised the Periodic Table
- describe how Tacke and Noddack discovered rhenium.

By 1860 scientists knew of around 60 elements. They knew a great deal about their properties. But much of this knowledge was a jumble of facts.

Russian chemist Dmitri Mendeleev sparked another turning point in chemistry. He devised the **Periodic Table**. The Periodic Table is a vital tool in chemistry. It shows patterns in properties, and helps us to make predictions.

A Name the scientist who devised the Periodic Table.



▲ Mendeleev's first Periodic Table.

Organising elements

In 1860 Mendeleev went to a conference in Germany. He heard a talk by an Italian, Stanislao Cannizzaro. Cannizzaro had worked out the masses of the atoms of the elements known at the time. He gave out copies of his data. Mendeleev picked up a copy.

Several chemists tried using atomic mass data to organise the elements, and show patterns in properties. No-one came up with the perfect arrangement.

One day Mendeleev was at home, writing a textbook. He was trying to organise information about elements' properties. Mendeleev cut out some cards. On each card he wrote the name of an element and some data for the element, including:

- its atomic mass
- its physical properties
- the formulae of its compounds with hydrogen and oxygen.

Mendeleev tried sorting the cards in different ways. Eventually, he came up with an arrangement that worked. The elements were in atomic mass order. Elements with similar properties were grouped together. Mendeleev wrote his arrangement on the back of an envelope. This was the first Periodic Table.

Mendeleev was confident in his arrangement. He left gaps for elements that he predicted should exist but that had not yet been discovered. He predicted the properties of these elements. Later, chemists discovered the missing elements, including gallium, scandium, and germanium.

Key Words

Periodic Table, catalyst

B State why Mendeleev left gaps in his Periodic Table.

Who discovered rhenium?

By 1925 most of the gaps in the Periodic Table had been filled. But there were spaces beneath manganese for two undiscovered elements.

Two German chemists, Ida Tacke and Walter Noddack, extracted 1 g of a new substance from 660 kg of an ore. The chemists thought the substance might be one of the missing elements.

Tacke and Noddack asked Otto Berg to do some tests on the substance. He confirmed that the substance was one of the missing elements. They called the element rhenium.

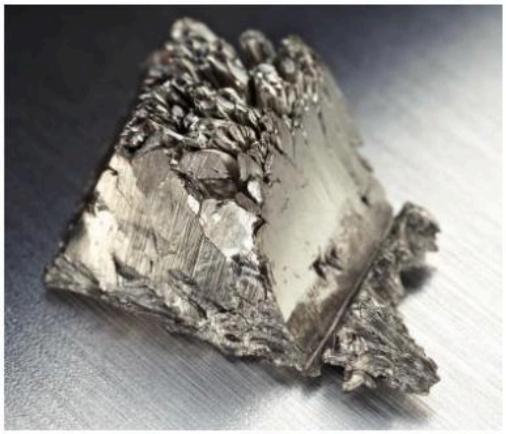
Rhenium speeds up chemical reactions – it is an excellent **catalyst**. It is also included in alloys for jet engine parts.

◀ Ida Tacke was one of the discoverers of the element rhenium.

C Name the three scientists involved in the discovery of the element rhenium.

Mendeleev's musings

Imagine what Mendeleev might have said when he first devised the Periodic Table. Write a script, and perform it to a partner.



▲ Mendeleev predicted the existence of scandium, and its properties.

Fantastic Fact

Ida Tacke was nominated three times for the Nobel Prize in Chemistry but never won it.

Summary Questions

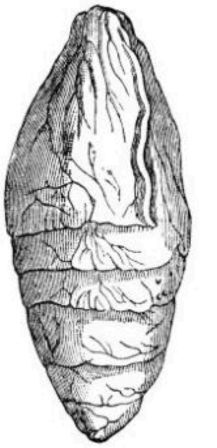
1. Copy the sentences below, choosing the correct bold words.
   Mendeleev collected data about the **masses/sizes** of atoms of elements, their **physical/chemical** properties, and the formulae of their compounds with **nitrogen/oxygen** and hydrogen. He arranged the elements in order of increasing atomic **size/mass**. Elements with **similar/different** properties were grouped together. *(5 marks)*
2. Describe how Tacke and Noddack discovered a missing element, and why they asked another scientist for help. *(3 marks)*
3. Explain how Mendeleev devised the Periodic Table. Include an explanation of how he used data from another scientist. *(6 marks QWC)*

2.4 Lessons from fossils

Learning objectives

After this lesson you will be able to:

- describe how fossils are formed
- explain what fossils tell us about the ages of rocks.



▲ Mary Anning investigated fossilised feces from ichthyosaurs. She broke them open and found fossilised fish bones. This shows what the dinosaurs ate.

What secrets do fossils hold?

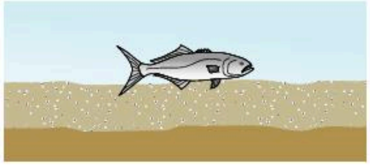
◀ This is a 3.7-million-year-old fossil of human footprints at Laetoli, Tanzania. This shows that humans began walking much earlier than previously believed.

How do fossils form?

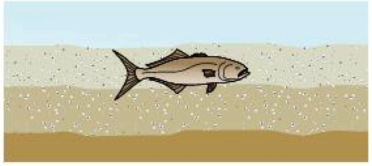
Fossils are the remains, or traces, of plants or animals that lived many years ago. They have been preserved by natural processes.

Most plants and animals do not form fossils when they die. An animal eats them, or they rot away. But occasionally a dead animal or plant (or its feces or footprints) is quickly covered in sand, mud, or dust – perhaps when a river floods or a volcano erupts. Then a fossil may form. The diagrams below show one way of forming fossils.

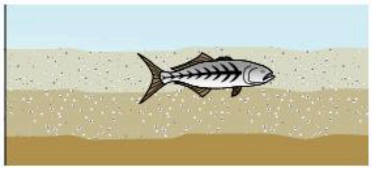
A Write down what a fossil is.



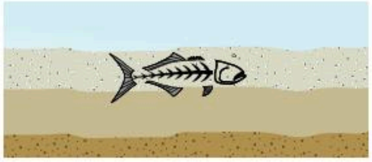
▲ An animal dies. It falls onto mud or sand.



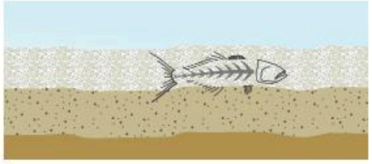
▲ More mud or sand quickly buries the body.



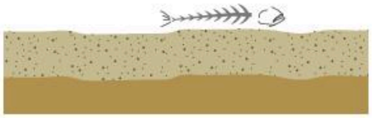
▲ Bacteria slowly break down the soft parts of the body. Its skeleton remains.



▲ The mud or sand above and around the skeleton starts to become rock.



▲ As rock forms, underground water that is rich in dissolved minerals seeps into tiny spaces in the skeleton. These minerals gradually replace the original minerals of the skeleton. A hard copy of the original skeleton is formed.



▲ Many years later, soft rock around the fossil is eroded. The fossil is exposed.

What do fossils tell us about their rocks?

Fossils are found in sedimentary rocks. Sedimentary rocks are formed in layers, over millions of years. The oldest layers are on the bottom. The layers are called **strata**.

Two hundred years ago a miner, William Smith, noticed that different strata contained fossils of different species. He asked a scientific question, and suggested an explanation:

Why do different rock strata contain different fossils? Perhaps rock strata of the same age always contain fossils of the same species…

Smith travelled widely looking for evidence. He published his findings so that other scientists could help collect evidence. Eventually he came up with an explanation:

Rock strata of the same age contain fossils of the same species. You can only find certain fossils in rock strata of a certain age.

Other scientists used Smith's explanation to classify rock strata by the fossils they contained. By 1850 they had divided the Earth's history into geological time periods. Each time period had its own **index fossil**. The index fossil shows the relative age of the rock.

Geological time period	Index fossil	Approximate date for start of time period (million years ago)
Quaternary		2.6
Tertiary		66
Cretaceous		146
Jurassic		200
Triassic		251

▲ Index fossils for the five most recent geological time periods.

B State what an index fossil shows.

Explaining explanations

Draw a flow diagram to show the stages William Smith went through to develop his explanation.

Link

You can learn more about rocks in C2 4.4 The rock cycle

Key Words

fossil, strata, index fossil

Foul Fact

Mary Anning was famous for her work on fossils. However, she was not allowed to join the Geological Society of London because she was female.

Summary Questions

1 Copy and complete the sentences below.

Fossils are the remains, or __________, of animals or __________ that lived many years ago. They have been preserved by __________ processes. Fossils form in __________ rock. Layers of rock are called __________.

(5 marks)

2 Describe one way in which a fossil is formed.

(4 marks)

3 Make a poster to display some important lessons we have learned from fossils.

(6 marks)

2.5 The oldest primate

Learning objectives

After this lesson you will be able to:

- explain how a recent fossil find makes scientists question earlier explanations about evolution
- describe the process of peer review.

▲ The 55-million-year-old fossil.

▲ Scientists think *Archicebus* looked like this.

In 2013 scientists announced an exciting find – a 55-million-year-old fossil.

It is the oldest **primate** fossil ever discovered. Primates are a group of mammals that includes monkeys, apes, tarsiers, and humans.

The team announced their discovery in a **scientific journal**. A scientific journal is a collection of articles written by scientists about their research. The articles are **peer reviewed**. This means that they are checked by other scientists who were not involved in the work but who are experts in that particular area of research. Scientists publish their work in journals to tell others about their research.

A State what a scientific journal is.

How did scientists study the fossil?

A Chinese farmer found a tiny fossilised skeleton in 2003. The farmer showed his find to a scientist, Dr Ni Xijun. A 10-year quest then began to solve the mysteries locked within the remains.

Dr Ni got together a team of experts from China and the USA. The scientists split apart the layers of rock that contained the fossil. They took accurate measurements and made detailed observations. Then they took the fossil to France. Another scientist used a new technique to study the fossil.

B State why the scientists took the fossil to France.

What can we learn from the fossil?

The life of *Archicebus*

Measurements show that the animal was just 71 mm long. Its mass was about 30 g. It would fit into the palm of your hand.

Scientists realised that the skeleton belongs to a species never seen before. They called the species *Archicebus achilles*. *Archicebus* had feet like a small monkey. Its skull had small eye sockets, suggesting it was active in daylight.

At the time *Archicebus* lived on Earth the planet was covered in tropical rainforests. *Archicebus*'s skeleton shows that it was active and agile. It leapt through the treetops. *Archicebus* had small, pointy teeth, perfect for eating insects.

C Explain why scientists think the animal was active in daylight.

Human evolution

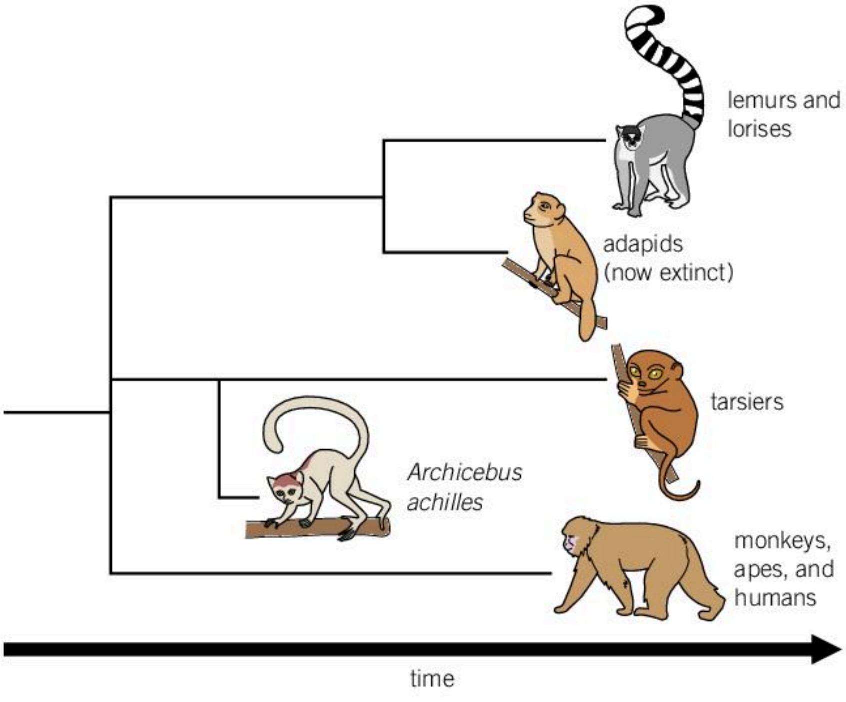
At the moment, no-one knows whether the discovery will mark a turning point in the understanding of human evolution. But it seems likely that it will.

The scientists say that *Archicebus* is an ancestor of today's tarsiers. These are small, nocturnal primates. They live in Asian forests.

The scientists say that *Archicebus* changes earlier ideas that the first primates were the size of modern monkeys. Instead, they were probably small mammals, scurrying through rainforest canopies.

The scientists also point out that the new find may show that the first humans did not evolve in Africa – as scientists previously believed – but in Asia.

Finally, the scientists say that *Archicebus* shows that primates separated into two groups (tarsiers, and the group including monkeys, apes, and humans) up to 10 million years earlier than previously thought.



▲ *Archicebus* in the primate family tree.

Family tree

Look carefully at the family-tree diagram. With a partner, discuss what it shows. Then write an explanation of the diagram.

▲ A modern tarsier.

Key Words

primate, scientific journal, peer review

Summary Questions

1 Copy and complete the sentences below.
Scientists found the fossilised skeleton of a 55-million-year-old primate. Primates include monkeys, apes, tarsiers, and __________. The scientists published their findings in a scientific __________. Their article was peer __________.
(3 marks)

2 Explain why scientists think *Archicebus achilles* ate insects.
(2 marks)

3 Explain what scientists have learned from *Archicebus achilles*.
(6 marks QWC)

C3 Chapter 2 Summary

Key Points

- In the 1790s John Dalton found experimental evidence for the existence of atoms.
- John Dalton developed an atomic model. He imagined atoms as billiard balls.
- Dalton's model states that every element has its own type of atom, and the atoms of different elements have different masses. Compounds form when atoms of different elements join together. Atoms are re-arranged in chemical reactions.
- J. J. Thomson discovered that atoms are made up of even smaller particles, including electrons. An electron has a negative charge.
- Ernest Rutherford fired positive particles at gold foil. A few particles bounced back. Rutherford explained his observations by stating that most of the mass of an atom is in a central, positively charged nucleus.
- Stanislao Cannizzaro published a list of the masses of atoms of the 60 elements known in 1860.
- Dmitri Mendeleev used atomic masses and data on the properties of elements to arrange elements in the Periodic Table.
- The Periodic Table shows patterns in properties, and enables us to make predictions.
- Mendeleev left gaps for elements he expected would be discovered later. Ida Tacke and Walter Noddack discovered rhenium in 1925.
- Fossils are the remains, or traces, of plants and animals that lived many years ago. They have been preserved by natural processes.
- Fossils form in sedimentary rocks. The layers in sedimentary rocks are called strata. Rock strata of different ages contain fossils of different species.
- Scientists report their findings in scientific journals. Articles in scientific journals are peer reviewed.

Key Words

atom, element, compound, electron, Periodic Table, catalyst, fossil, strata, index fossil, primate, scientific journal, peer review

Case study

Exposing explanations

Scientists use evidence and their scientific knowledge to develop explanations.

Task

Write a plan for a lesson that will teach students in Year 7 how scientists develop scientific explanations.

Tips

- Create a table to show each of the stages below for every explanation that is described:
  - asking a question
  - suggesting an explanation
  - testing the explanation.

End-of-chapter questions

1 Fossils provide clues about life on Earth in earlier times. Copy the descriptions of fossil discoveries. Then write the letter of one explanation next to each description.

(4 marks)

Description of discovery	Explanation
bones from smaller ichthyosaurs in fossilised ichthyosaur feces	
spiral markings on fossilised ichthyosaur feces	
fossilised fish bones in fossilised ichthyosaur feces	
fossilised ichthyosaur feces that are black in colour	

Explanations:

A Ichthyosaurs ate sea animals.

B Ichthyosaurs ate other ichthyosaurs.

C Ichthyosaurs had ridges in their intestines.

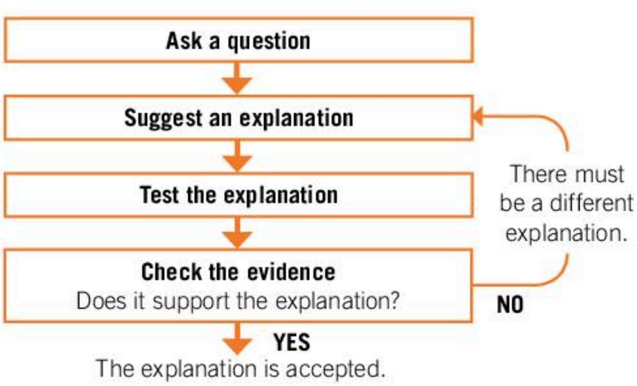
D Ichthyosaurs ate animals that contained ink sacs, like modern squid.

2 Copy and complete the sentences below.

Everything is made up of tiny particles called _______. Each of these particles has a _______ in its centre. This is _______ charged. There is an empty space around the centre of the atom. Tiny particles that are _______ charged move around here.

(4 marks)

3 Copy the diagram below, which outlines how scientists may develop a scientific explanation.



Then write each of the three statements below in the correct box of the diagram to outline how Mendeleev discovered the Periodic Table.

(3 marks)

Statements

X Write the elements in order of the mass of their atoms. Look for patterns in the elements' properties.

Y What are the patterns in the properties of elements?

Z When atoms are arranged in order of the mass of their atoms, there is a repeating pattern of properties.

4 Read the passage in the box.

> John Dalton knew that the air included at least two gases. If you had 1 m^3 of each gas, they would each have a different mass. Dalton asked a question:
>
> *Why does gravity not separate the heavier gas from the lighter gas?*
>
> Dalton suggested a possible explanation to answer his question. The gas particles, he said, were surrounded by heat. Heat keeps the particles apart, and prevents them from settling down into separate groups. He extended his idea by assuming that each gas had its own type of atoms. The greater the mass of 1 m^3 of a gas, the heavier its atoms.

Write a critical review of Dalton's ideas described in the passage above. In your answer, state which parts of the explanation are correct, and improve any parts of the explanation that are not correct.

(6 marks QWC)

3.1 Break-in!

Learning objectives

After this lesson you will be able to:

- explain how to separate mixtures by filtration and evaporation.

There has been a break-in at Sava Shop. The window is broken. Outside, there is blood on the sandy path. Inside is a horrible stink. Has someone been sick?

▲ The driver's hand.

▲ The crime scene.

Along the road, police stop a swerving car. The driver has blood on his hands and damp patches on his coat. His breath smells of cider. More noticeable is another, stronger smell. Could it be vomit, or rancid sweat?

A Name the sense the police officers use to detect cider.

Key Words

DNA, filtration, filtrate, evaporate

What evidence do the police collect?

From the driver

At the car, police officers breathalyse the driver. The test is positive. He has drunk too much alcohol to legally drive. The officers take the driver to the police station. Here, he gives his name – Ryan. Ryan takes off his coat. An officer places the coat in a bag, and seals it up. The foul smell is less strong.

The officer notices cuts on Ryan's hands. She uses a damp cotton-wool swab to collect some dried blood. She places the swab in pure water, seals the container, and puts it in a freezer. Once frozen, she will send the sample for **DNA** analysis. Does the blood belong to Ryan or to someone else?

Later, a doctor comes to the police station. She takes 10 cm^3 of blood from a vein in Ryan's arm, and separates it into two parts. This blood will be tested for alcohol.

▲ Taking the blood sample.

From the shop

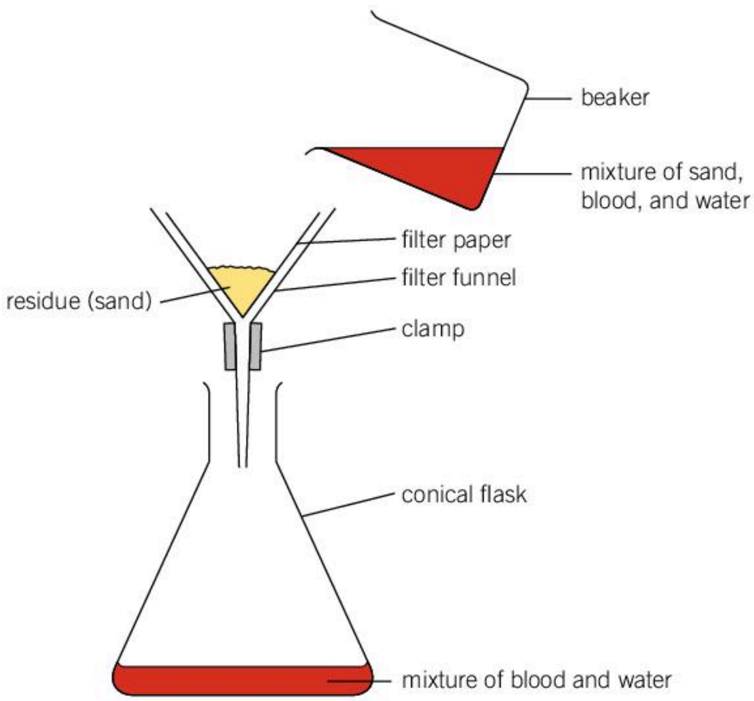
Scene-of-crime officers arrive at the shop. They take samples of bloody sand from the path. They look for fingerprints and hairs.

The smell inside the shop is overpowering. The police call the fire brigade. Is it safe to enter? Can they find out what is causing the smell?

How can you separate blood from sand?

The crime-scene investigators send the bloody sand to a laboratory. They hope to use the blood to help identify the criminal.

Scientists use **filtration** to separate the sand and blood. They add pure water to the bloody sand. The blood mixes with the water. They filter the mixture.



▲ Filtering the mixture.

When the mixture is filtered, sand remains in the filter paper. The grains of sand are too big to get through the tiny holes in the filter paper. The particles in the water and in the blood mixture are much smaller than the grains of sand. They go through the tiny holes in the filter paper, into the flask beneath.

The scientists keep the **filtrate**. They allow the water to **evaporate**. They plan to do a DNA test on the blood. Will the sample be good enough to help identify the criminal?

B Name the two processes used to separate sand from bloody water.

Link

You can learn more about separation techniques in C2 2.4 Filtration

Media briefing

You are a senior police officer. You need to brief the media about the crime. Plan what to say, then deliver your briefing. Speak calmly and clearly.

Summary Questions

1 Copy the sentences below, choosing the correct bold words.

You can use **filtration/ evaporation** to separate sand from a solution. You can then use **filtration/evaporation** to remove water from the solution.

(2 marks)

2 Explain how filtration works.

(3 marks)

3 Suggest why the smell from Ryan's coat is less strong when sealed in a bag.

(2 marks)

4 Draw and annotate a visual summary of the evidence collected so far. In a different colour, write down what the police might find out from each piece of evidence.

(6 marks)

3.2 Smelly problem

Learning objectives

After this lesson you will be able to:

- explain how to identify acids and alkalis
- give examples of neutralisation reactions.

Specially trained fire-fighters arrive at the shop. The smell is less strong, since some particles of the smelly substance have diffused through the broken window. Two fire-fighters put on gas-tight suits, gloves, and breathing apparatus. They enter the shop.

A State why the smell has become less strong.

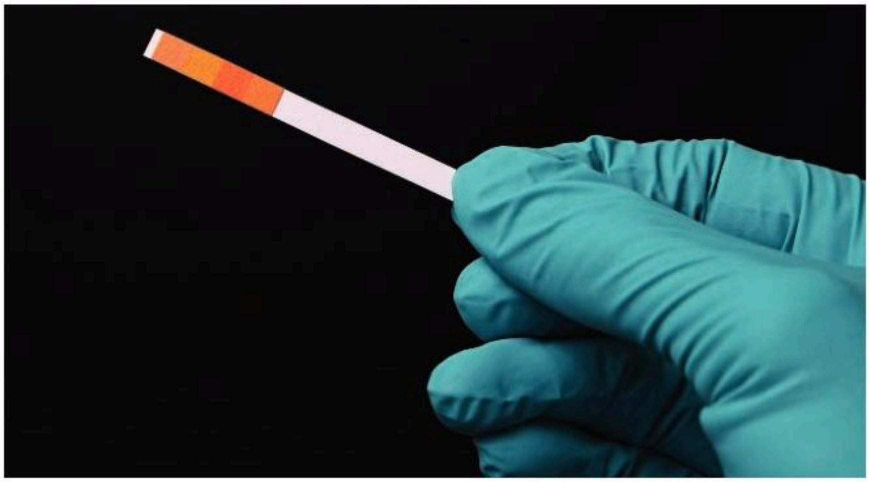
▲ This fire-fighter is wearing breathing apparatus.

Is the smelly liquid acidic?

Behind the window is a puddle of liquid. It looks oily, unlike water. Is this the source of the smell?

The fire-fighters dip red **litmus** paper into the liquid. There is no change. They do the same with blue litmus paper. The paper turns red. This tells them that the liquid is acidic.

They check the liquid with **universal indicator** paper. Its colour shows that the liquid pH is 3.



▲ The liquid is acidic.

B State how the fire-fighters know the liquid is acidic.

Crime report

Write a newspaper report on the crime so far. Plan your work carefully. Decide what to include in each paragraph, and choose the best order for your paragraphs.

Key Words

litmus, universal indicator, hazard

What is the liquid?

The fire-fighters collect a sample of the liquid. They will use instruments in their vehicle to identify it.

At that moment, a police inspector arrives. He thinks he recognises the smell from a previous incident. Is it butanoic acid? A colleague looks it up on the Internet. She reports that butanoic acid has a foul smell – like vomit or rancid butter. Its melting point is −8 °C and its boiling point is 164 °C, so it is liquid at room temperature (22 °C). Its formula is $C_4H_8O_2$.

Butanoic acid has been used in acid attacks, says the colleague. A man threw the substance into a victim's face, blinding him. Protestors have used butanoic acid to attack whaling ships.

The fire-fighters get their results. The substance is butanoic acid.

C Write down the state of butanoic acid at room temperature.

How can they dispose of the liquid?

Butanoic acid has this **hazard** symbol. It is corrosive.

Safety guidance for butanoic acid includes:

- Avoid contact with skin and eyes.
- Wear eye protection and gloves.
- Do not inhale the substance.
- Do not empty it into drains.

The fire-fighters look up how to deal with spilt butanoic acid. There are two options:

- For large amounts, add sand or soil to absorb the liquid. Then call in a specialist waste-disposal company to remove the mixture.
- For small amounts, add sodium hydroxide solution to neutralise the acid:

  butanoic acid + sodium hydroxide → sodium butanoate + water

  The salt produced in the reaction, sodium butanoate, is much less harmful than butanoic acid.

The puddle of liquid is quite big so the fire-fighters decide to cover it with sand.

D Name the products of the neutralisation reaction between butanoic acid and sodium hydroxide.

▲ Protesters have used butanoic acid to attack whaling ships.

Summary Questions

1 Copy and complete the sentences below.

If you dip blue litmus paper into an acid, the paper changes colour to ________. You can use universal indicator to find out the ________ of the acid. When an acid reacts with an alkaline solution, the products are a ________ and ________.

(4 marks)

2 Copy and complete the word equations below.

a ethanoic acid + ______ hydroxide → potassium ethanoate + ______ *(2 marks)*

b propanoic acid + sodium hydroxide → ______ propanoate + ______ *(2 marks)*

c butanoic acid + potassium hydroxide → ______ ______ + water *(1 mark)*

3 Explain how neutralisation reactions produce substances that are safer than the starting materials. Illustrate your answer with examples.

(6 marks QWC)

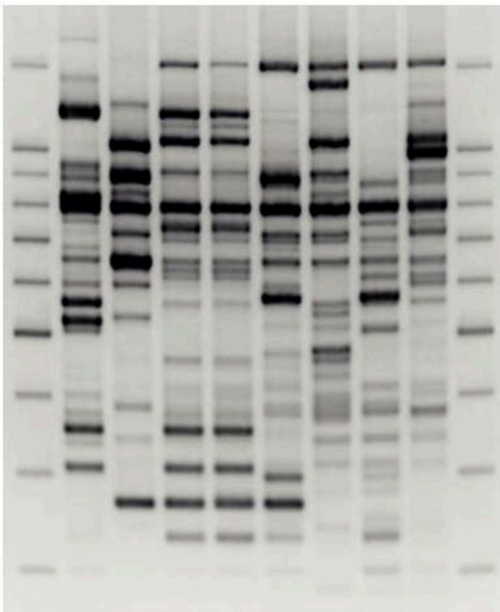
3.3 Message in a bottle

Learning objectives

After this lesson you will be able to:

- describe how chromatography separates dyes in ink.

The DNA analysis of the blood from Ryan's hand has been returned to the police station. It turns out that the DNA is not new to the police. It matches a sample analysed 10 years ago, found on a blood-stained note posted to the police. The note was written in fountain pen.



▲ DNA test results.

The police never found the writer, or the garden. What secrets might it hold? The police get permission to search Ryan's house. Is something buried in the garden? Will they find the ink used to write the note?

How did they analyse the ink?

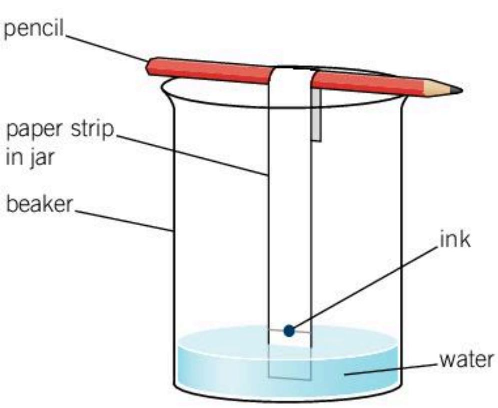
At Ryan's house, the police do a careful search. At the back of a kitchen cupboard, they find an old bottle of ink.

▲ The ink.

The police officers know they must send the ink to the forensic laboratory. But they do their own test first, using a technique called **chromatography**.

The officers take a piece of chromatography paper. They draw a line on the paper, in pencil. They drip a drop of the ink onto the line. They place the bottom of the paper in a beaker of water. The officers wait. As soon as the first spot reaches the top of the paper, they remove the chromatogram.

A Name the technique used to analyse the ink.



▲ The officers' chromatography apparatus.

How chromatography works

Water moves up the paper. It reaches the ink. Ink is a mixture of dyes. Some dyes mix well with water. Others mix less well. Some dyes are attracted to the paper more strongly than others.

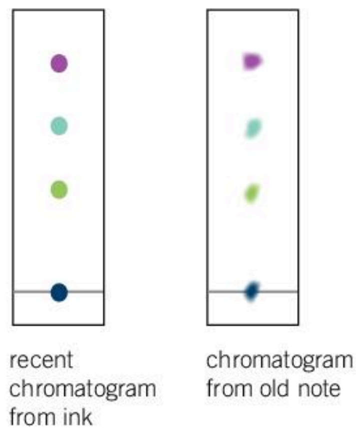
The dyes travel up the paper at different speeds. The dye that travels fastest reaches the top of the paper. This dye mixes well with water, and is not strongly attracted to the paper.

In paper chromatography, the paper is the **stationary phase**. The water is the **mobile phase**.

B Name the mobile phase and the stationary phase in paper chromatography.

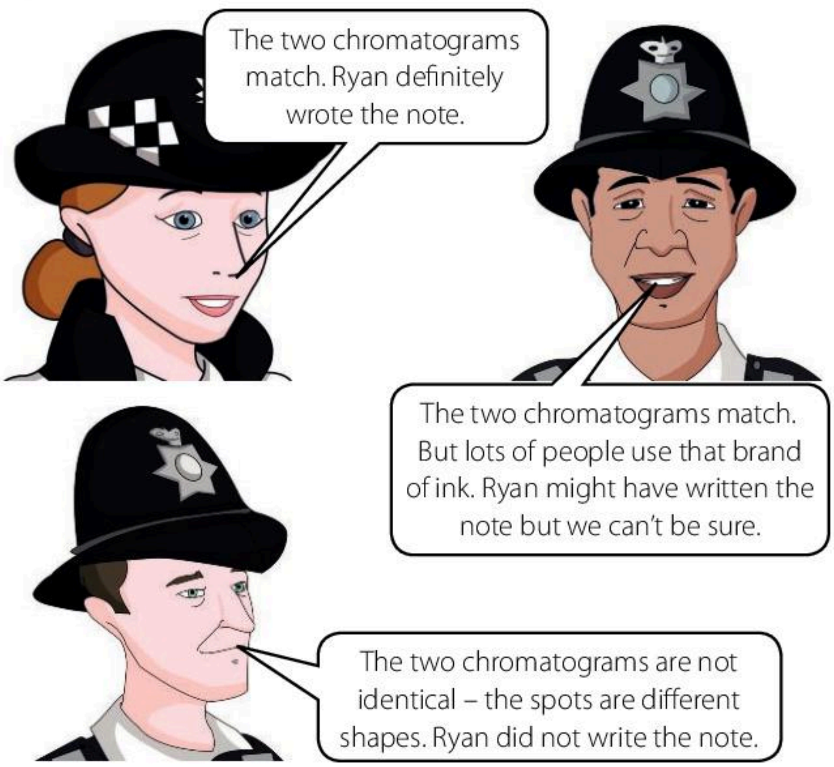
What the chromatogram shows

The officers look back at the records from 10 years ago. They find an old chromatogram, made from ink extracted from the note. They compare this chromatogram with their own.



▲ The two chromatograms.

The police officers have different opinions about what conclusion they can make from the chromatograms.



Key Words

chromatography, stationary phase, mobile phase

Repeatable results?

The police officers want to check that their results are repeatable. They make some more chromatograms with the ink. Is this is a good idea? Can it help them decide whose conclusion is correct? Explain your answers.

Summary Questions

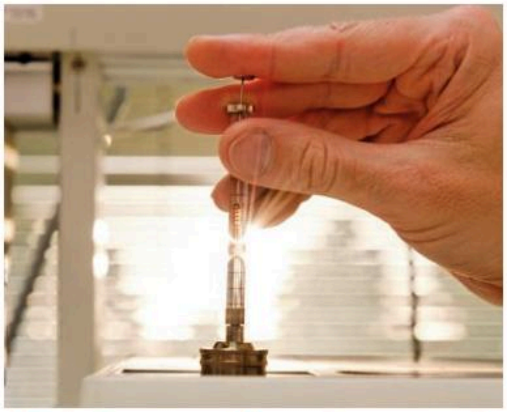
1. Copy and complete the sentences below, choosing the correct bold words.
   Paper chromatography separates substances in **compounds/mixtures**. The **paper/water** is the stationary phase and the **paper/water** is the mobile phase. The dye that mixes **best/least well** with the water and that is attracted **best/least well** to the paper travels fastest up the paper. *(5 marks)*
2. Read the police officers' different conclusions. Write down which conclusion you think is best, and give a reason for your choice. *(3 marks)*
3. Draw and annotate a diagram to explain how paper chromatography works. *(6 marks)*

3.4 Blood alcohol

Learning objectives

After this lesson you will be able to:

- describe how gas chromatography separates alcohol from blood.



▲ Injecting a sample for gas chromatography.

Legal limits

The table shows the maximum legal blood–alcohol levels for driving in different countries (June 2013). Plot the data on a bar chart, and write a paragraph to compare the values.

Country	Maximum legal blood–alcohol concentration for drivers (mg of alcohol in 100 cm^3 of blood)
Australia	50
Denmark	50
France	50
Hungary	0
India	30
Netherlands	50 (new drivers 20)
Poland	20
Sweden	20
UK	80
US	80

On the day the crime was discovered, a doctor used a syringe to remove 10 cm^3 of blood from Ryan's arm. She divided the blood into two, and sealed and labelled each sample. She gave one sample to a police officer, and one to Ryan. The police officer sent his sample to a laboratory. Ryan gave his sample to a solicitor, who put it in the fridge.

How do scientists analyse blood?

At the laboratory, a chemist looks carefully at the labels and seals on the container. She must be sure they have not been tampered with. She injects some blood into a **gas chromatography** instrument. Gas chromatography separates and identifies substances in mixtures and measures their amounts.

In the gas chromatography instrument, the blood sample is heated. Any alcohol in the blood becomes a gas. Other substances in the sample also turn to gas.

Helium gas is added to the mixture of gases. Helium is the mobile phase, like water in paper chromatography. The mixture flows through a tube. In the tube is a polymer column. The polymer is the stationary phase.

Different substances move through the column at different speeds. The speed at which a substance travels depends on how strongly it is attracted to the polymer.

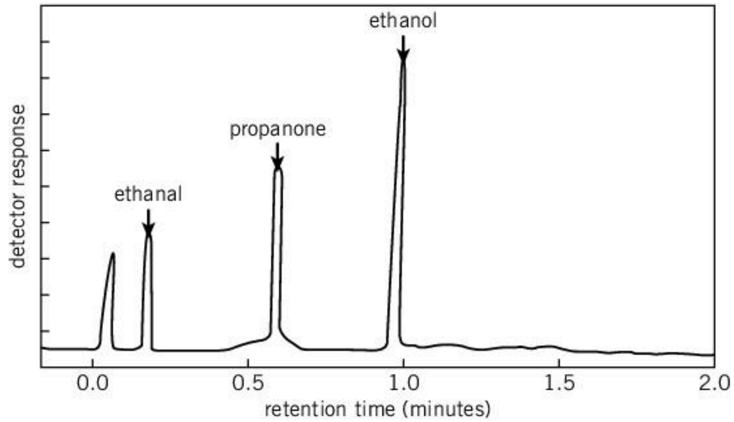
A Name the stationary phase and the mobile phase in gas chromatography.

Foul Fact

If a driver has had any alcohol at all there is an increased chance of having an accident, even if they are not over the UK blood–alcohol limit.

How do scientists interpret the chromatogram?

Coloured spots show separate substances in paper chromatography. Gas chromatography produces a different record, called a gas chromatogram. This has a peak for each substance the instrument detects.



▲ Gas chromatogram of Ryan's blood.

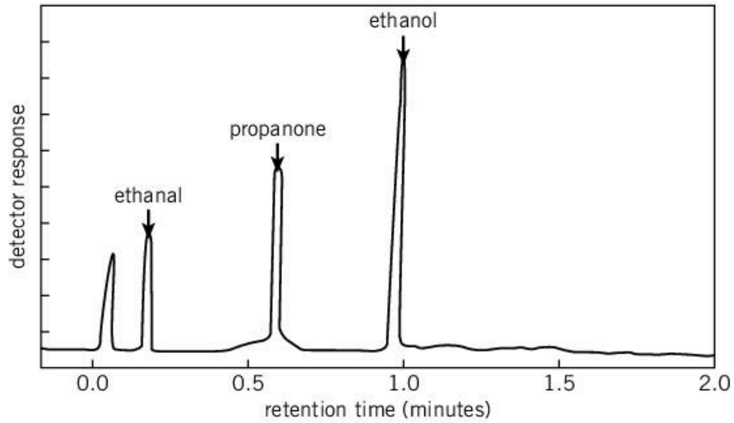
B State what a gas chromatogram is.

The chromatogram shows that there is ethanol in Ryan's blood. Ethanol is the drug in alcohol. The chemist looks at the height of the ethanol peak and at the vertical scale. There is a high concentration of ethanol in Ryan's blood. It is higher than the concentration allowed for driving legally.

How did Ryan respond?

The chemist sends the test result to the police station. Ryan is not happy. "The result is wrong," he says. "My sample was muddled with someone else's."

Ryan sends his sample to a different laboratory. A chemist obtains the chromatogram below.



Key Words

gas chromatography

Summary Questions

1 Copy and complete the sentences below.

A technique called __________ chromatography is used to identify alcohol in blood. In this type of chromatography, helium gas is the __________ phase, and a __________ column is the stationary phase. A gas chromatogram shows a __________ for each substance the instrument detects.

(4 marks)

2 Describe how different substances are separated from blood in gas chromatography.

(4 marks)

3 Compare the chromatograms from the two laboratories. What conclusion can you make? Explain your answer.

(4 marks)

4 Write a paragraph to compare paper chromatography and gas chromatography.

(6 marks, QWC)

3.5 Body!

Learning objectives

After this lesson you will be able to:

- use the reactivity series to predict whether metals will react with oxygen and water vapour in the air or soil.

▲ Police officers dig up Ryan's garden after discovering the note.

The police officers look back at the note. "Buried in my garden," it says. The police officers find out Ryan's addresses of the past 15 years. They get permission to dig up all three gardens. What will they find?

What's under the flowers?

The police officers go to Ryan's current address. They dig up the garden. They find nothing odd.

Next, the officers go to a previous address. They dig carefully. Under a flowerbed, they find a small bone. Is it from a dead cat or dog? Or might it be something more sinister?

The officers continue digging. They find more bones, wrapped in what might once have been carpet. They look more closely. The bones are human.

The flesh has decayed. No-one could recognise the person. But around one finger is a shiny gold-coloured ring. Around the neck is a blackened necklace. Around a wrist is a rusty watch. Can these **metal** clues identify the body?

What does Ryan say?

The police officers question Ryan about their new finds. Does he know anything about the skeleton in his old garden?

Ryan keeps quiet, until the officers show him photos of the jewellery. "That proves it wasn't me," he says. "I moved away from that house 10 years ago. There is no way the ring could still be that shiny!"

Key Words

metal, reactivity series, rust

▲ The rusty watch.

▲ The ring.

What do the metals tell us?

Gold is near the bottom of the **reactivity series**. It does not react with oxygen or water. A gold object remains shiny for many years, even when buried in damp soil.

potassium
sodium
magnesium
zinc
iron
lead
copper
silver
gold
platinum

▲ The reactivity series.

A Name one metal that does not react with oxygen or water.

The police officers show the other metal objects to a forensic chemist. The necklace is silver. Silver is near the bottom of the reactivity series but it does react with sulfur compounds in the air. The product is black silver sulfide.

The watch, says the forensic chemist, is mainly iron. It has rusted. **Rust** forms when iron reacts with oxygen and water. Rust is hydrated iron oxide, which is an orange-brown colour.

iron + water + oxygen → hydrated iron oxide

The officers consider the evidence. The metals found with the body could have been buried 10 years ago…exactly when Ryan lived at the house where the body was found. Has the shop break-in led them to find a murderer?

B Use the reactivity series to predict two metals that react easily with oxygen and water.

Link

You can learn more about the reactivity series in C2 3.4 Metal displacement reactions

Summary Questions

1 Copy and complete the sentences below, choosing the correct bold words.

The reactivity series shows how vigorously metals react. Gold is near the **top/bottom** of the reactivity series. It **reacts vigorously/does not react** with oxygen and water. Iron is **higher/lower** in the reactivity series. It reacts with oxygen and **water/nitrogen** to make rust. The scientific name for rust is **hydroxide/hydrated** iron oxide. *(5 marks)*

2

- **a** Name the most reactive metal in the reactivity series on this page. *(1 mark)*
- **b** Use the reactivity series to name two metals that do not react with water or oxygen. *(1 mark)*
- **c** Name the product formed when zinc reacts with oxygen. *(1 mark)*

3 Ryan will soon have to face a courtroom trial. Write a paragraph for the jury about the metal objects found with the body. Explain in detail how their condition suggests that they were buried 10 years ago. *(6 marks)*

3.6 Clues in the carpet

Learning objectives

After this lesson you will be able to:

- describe the difference between biodegradable and non-biodegradable materials
- explain why the properties of sisal, wool, and poly(propene) make them suitable for carpets.

▲ Was this carpet buried 10 years ago?

▲ Wool is a natural product.

▲ A warm-feeling and soft wool carpet.

The crime-scene investigators investigate the carpet that was wrapped around the bones found in Ryan's garden. Could it have been buried 10 years ago?

What's in a carpet?

Different materials are used to make carpets. Some carpets have a woven sisal base. Wool tufts are joined to this base.

- Sisal is a **natural** product, obtained from a plant. Each leaf contains many fibres. They are extracted and made into strong threads. Sisal is an insulator. It does not catch fire easily.
- Wool is also a natural product, obtained from sheep. Like sisal, it is an insulator. It feels soft. It does not catch fire easily.

▲ A sisal plant.

A Describe two properties that make wool suitable for making carpets.

Some carpets include poly(propene) tufts. Poly(propene) is a **synthetic** polymer. It is made from substances obtained from crude oil. It is hard-wearing and easy to clean.

▲ Poly(propene) carpets can be dyed with many colours.

B Describe two properties that make poly(propene) suitable for making carpets.

Which carpet materials are biodegradable?

Some materials are **biodegradable**. This means that they can be broken down by natural processes. In the soil, bacteria or fungi will help them to rot away. Wool and sisal are biodegradable.

Poly(propene) is not biodegradable. It does not rot away naturally. It may remain unchanged in the environment for many years.

If the body was wrapped in a poly(propene) carpet, the carpet would not have changed much over time. Wool carpet, however, would have partly rotted away.

C State what the word biodegradable means.

What does the carpet tell us about the crime?

Forensic scientists look carefully at the carpet around the body. It has partly rotted away. Its base appears to be made of woven sisal, and tufts of wool. The scientists conclude that their observations agree with the idea that the carpet was buried 10 years ago, at the time the police received the note.

The evidence is fitting together…

Crime report

In C3.2 you began to write a crime report for a newspaper. Continue the report now, adding information about the new evidence on these two pages, and explaining what it shows. Include scientific ideas in your report, and make sure you organise your report logically.

Key Words

natural, synthetic, biodegradable

Summary Questions

1 Copy and complete the sentences below.

Sisal is a suitable material for making carpets because it is a good __________. It does not catch __________ easily. Wool also has __________ that make it suitable for carpets. It feels __________. Poly(propene) is a synthetic __________ that also has properties that make it suitable for carpets. *(5 marks)*

2 Describe the difference between biodegradable and non-biodegradable materials and give examples of each. *(4 marks)*

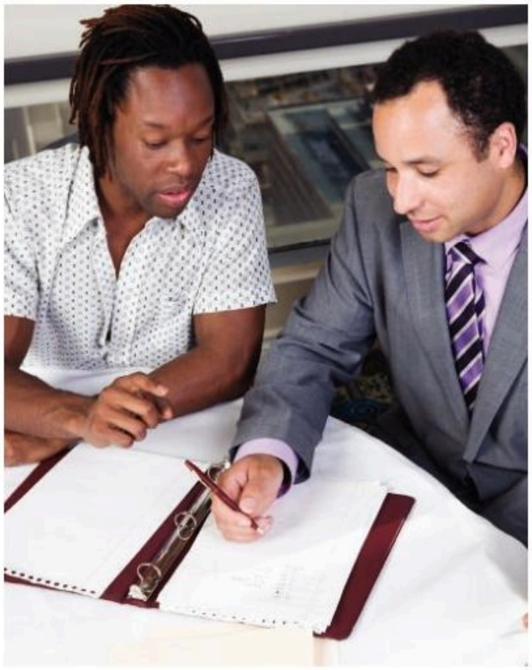
3 Suggest some advantages and disadvantages of making carpet from a non-biodegradable material. *(6 marks QWC)*

3.7 A week in court

Learning objectives

After this lesson you will be able to:

- describe how scientific evidence can help solve crimes.



▲ The detectives gather all of the evidence and prepare their court case.

Key Words

dental record

Science solves crimes

Design a poster to show how the police officers, forensic scientists, and crime-scene investigators worked scientifically to solve the crime.

The police officers look back at their missing-person records. Two people went missing 10 years ago, at the time the police received the note and the body was buried. Their names were Angela Scott and Shannon Smith. Might the body be one of theirs?

The officers call in Angela's relatives. They look at the ring. It had belonged to Angela. A dentist studies Angela's **dental records**, and examines the teeth in the buried skull. The records match the teeth. The body is Angela's.

▲ Dental X-ray.

A State two methods the police used to identify Angela's body.

Preparing for court

The detectives have a great deal of evidence linking Ryan to the body:

- The DNA from the blood on the note matches the DNA in Ryan's blood sample and from his hands.
- The ink on the note matches the ink in Ryan's cupboard.
- The body was found in the garden of the house that Ryan was living in 10 years ago.

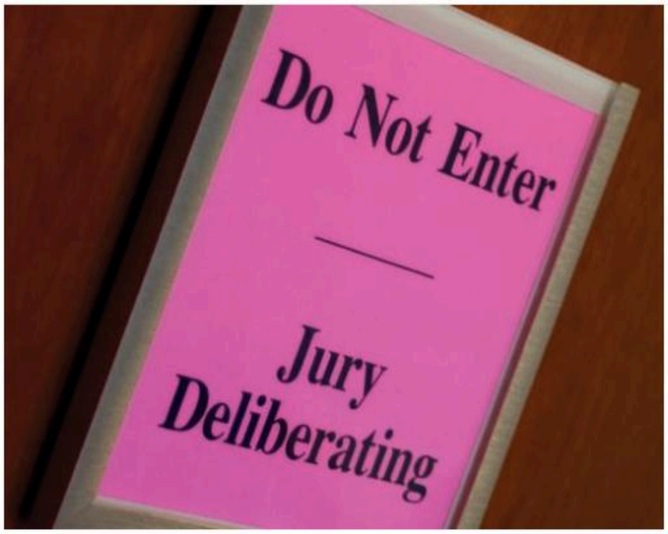
But is Ryan guilty of murder? Only a court can decide.

The detectives prepare their case carefully. Weeks later, the case comes to court. Ryan is charged with criminal damage to the shop, drink-driving, and the murder of Angela Scott.

B Name the three offences that Ryan has been charged with.

The court room.

Lawyers and police officers present evidence to the courtroom.



The jury considers all the evidence they have heard. They use this to decide whether Ryan is innocent or guilty of the charges.

In court

The police officers give evidence in court. So does Ryan. The lawyers ask questions. They show that Ryan does not always tell the truth.

The officers tell the court that Angela and Ryan had been school friends. They saw each other regularly as friends after leaving school. 10 years ago, when they were both 19, they started dating. After a while, Angela decided to end the relationship. Ryan was very, very angry – angry enough to kill Angela.

Outside the courtroom, having heard all the evidence, the jurors discuss the evidence. They decide that the evidence is enough to convict Ryan of all three crimes. He is guilty, they say, beyond all reasonable doubt.

Summary Questions

1 Copy and complete the sentences below.

There was a lot of __________ linking Ryan to the crime. The __________ from the blood on the note matched the DNA in Ryan's blood sample. The ink on the __________ matched the ink in Ryan's cupboard. The __________ was found in the garden of the house that Ryan was living in 10 years ago.

(4 marks)

2 Describe the scientific evidence on this page that links Ryan to the murder of Angela Scott.

(3 marks)

3 Describe two techniques used by detectives to obtain evidence used in Ryan's conviction.

(6 marks)

4 Suggest why a jury might consider evidence from the buried skull and dental records to be more reliable than evidence from the ring buried with the body.

(6 marks QWC)

C3 Chapter 3 Summary

Key Points

- Filtration separates an insoluble solid from a liquid, or from a solution of another substance.
- In filtration, pieces of solid do not go through the holes in filter paper. Particles of the liquid are small enough to pass through the holes.
- Red litmus paper becomes blue in an acidic solution.
- Blue litmus paper becomes red in an alkaline solution.
- The colour of universal indicator gives the pH of a solution.
- When an acid is neutralised by an alkali, the products are a salt and water.
- Paper chromatography separates the dyes in ink. The stationary phase is paper. The mobile phase is water or another solvent.
- In gas chromatography, the stationary phase is a polymer. The mobile phase is helium.
- A gas chromatogram has a peak for each substance the instrument detects. It shows the relative amounts of the substances in a mixture.
- The reactivity series lists metals in order of the vigour of their reactions.
- Potassium, sodium, and magnesium are near the top of the reactivity series. Copper, silver, and gold are at the bottom.
- Iron reacts slowly with oxygen and water to form hydrated iron oxide. This is rust.
- A biodegradable material is made harmless by natural processes. Bacteria or fungi may help the material to rot away. Biodegradable materials include wool and sisal.
- Poly(propene) is made from substances separated from crude oil. It is not biodegradable.

Key Words

DNA, filtration, filtrate, evaporate, litmus, universal indicator, hazard, chromatography, stationary phase, mobile phase, gas chromatography, gas chromatogram, biodegradable, metal, reactivity series, rust, dental record

Case Study

Biodegradable or not?

Some materials are biodegradable and some are not. How can you find out if a material will biodegrade?

Task

Plan an investigation to find out which of these materials are biodegradable and which are not: cotton, poly(ethene), polystryrene, paper, silk, wood.

Tips

In your plan:

- list the independent, dependent, and control variables
- draw a labelled diagram to show what to do
- make a results table to fill in
- state how you will know which materials are biodegradable, and which are not.

End-of-chapter questions

1 Write down the letter of the mixtures below that you could separate by filtration.

a sand from a mixture of sand and water
b copper sulfate from a solution of copper sulfate in water
c sand from a mixture of sand and salt solution
d salt from a mixture of sand and salt solution
e iron filings from a mixture of iron filings and water

(**5 marks**)

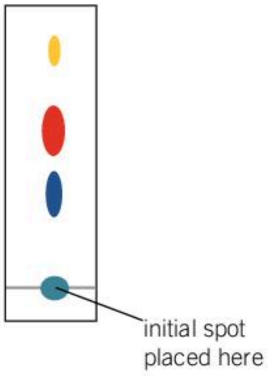
2 A biodegradable material is one that it decays naturally. Three of the materials in the list below are biodegradable. Write down their names.

wool gold flour paper, poly(propene)

(**3 marks**)

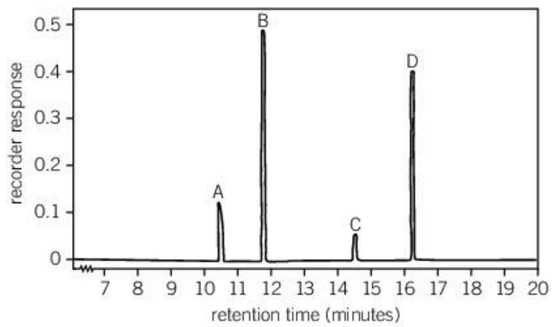
3 The paper chromatogram below was obtained from a felt-tip pen.

a Name the stationary phase in paper chromatography. *(1 mark)*
b Look at the paper chromatogram below. Give the number of substances that were mixed to make the ink in the felt-tip pen. Explain your answer. *(2 marks)*



(**3 marks**)

4 The gas chromatogram below was obtained from a mixture of substances.



a Give the number of substances shown on the chromatogram. *(1 mark)*
b Give the letter of the substance present in the mixture in the greatest amount. *(1 mark)*
c Name the mobile phase in gas chromatography. *(1 mark)*

(**3 marks**)

5

a Name the three least reactive metals in the reactivity series. *(3 marks)*
b Name the most reactive metal in the reactivity series. *(1 mark)*
c Write a word summary for the reaction of iron with oxygen and water. *(2 marks)*

(**6 marks**)

6 The equations below show some reactions of metals. Rewrite the equations so that they are balanced.

a $Cu + O_2 \rightarrow CuO$ *(2 marks)*
b $Ag + H_2S \rightarrow Ag_2S + H_2$ *(2 marks)*
c $Fe + O_2 \rightarrow Fe_2O_3$ *(2 marks)*
d $Na + H_2O \rightarrow NaOH + H_2$ *(2 marks)*

(**8 marks**)

7 Compare the advantages and disadvantages of the techniques of filtration and gas chromatography to separate mixtures.

(**6 marks QWC**)

Glossary

accurate Close to the true value of what you are measuring.

acid An acid is a solution with a pH value less than 7.

acid rain Rain that has a non-metal dissolved in it.

acidic solution An acidic solution has a pH less than 7.

alkali An alkali is a soluble base.

alkaline solution An alkaline solution has a pH greater than 7.

analyse The process of looking at data and writing about what you have found out.

atmosphere The mixture of gases surrounding the Earth.

atmospheric pressure Pressure caused by the collisions of air molecules that produce a force on an area.

atom A neutral particle; everything is made of atoms.

balanced symbol equation In a balanced symbol equation, chemical formulae represent the reactants and products. The equation shows how atoms are rearranged, and gives the relative amounts of reactants and products.

bar chart A way of presenting data when one variable is discrete or categoric and the other is continuous.

base A base is a substance that neutralises an acid.

biodegradable A substance is biodegradable if it can be broken down by natural processes.

biological weathering The breaking up or wearing down of rocks by the action of living things.

boiling The change of state from liquid to gas that occurs when bubbles of the substance in its gas state form throughout the liquid.

boiling point The temperature at which a substance boils.

carbon cycle The carbon cycle shows stores of carbon, and summarises how carbon and its compounds enter and leave these stores.

carbon fibre A material made of thin tubes of carbon.

carbon nanotube A cylinder of carbon atoms, often with walls just one atom thick.

carbon neutral A fuel is said to be carbon neutral if the amount of carbon dioxide it takes in when it grows is equal to the amount of carbon dioxide produced when it burns.

carbon store A place where carbon and its compounds may remain for a long time. Carbon stores include the atmosphere, oceans, sedimentary rocks, fossil fuels, the soil, and living organisms.

catalyst Substance that speeds up a reaction without being used up.

catalytic converter A part of a car between the engine and exhaust pipe that converts harmful sustances made in the engine into less harmful ones.

categoric A variable that has values that are words.

cementation The 'gluing together' of sediments by different chemicals to make sedimentary rocks.

ceramic A compound such as a metal silicate or oxide that is hard, strong, and has a high melting point.

change of state The process by which a substance changes from one state to another.

chemical formula A formula that shows the relative number of atoms of each element in a compound.

chemical property How a substance behaves in its chemical reactions.

chemical reaction A change in which atoms are rearranged to create new substances.

chemical symbol A one- or two-letter code for an element that is used by scientists in all countries.

chemical weathering The breaking up or wearing down of rocks by the action of chemicals such as those in rainwater.

chromatogram An image obtained from chromatography.

chromatography A technique to separate mixtures of liquids that are soluble in the same solvent.

climate change A long-term change in weather patterns.

combustion A chemical reaction in which a subsance reacts quickly with oxygen and gives out light and heat. Also called burning.

compaction The process of squashing sediments together to make new rocks by the weight of layers above.

composite A mixture of materials with properties that are a combination of those of the materials in it.

compound A substance made up of atoms of two or more elements, strongly joined together.

concentrated A solution is concentrated if it has a large number of solute particles per unit volume (litre or cubic metre).

concentration A measure of the number of particles of a substance in a given volume.

conclusion What you write down to say what you have found out during an investigation.

condense The change of state from gas to liquid.

confidence (in a conclusion) How sure you are of your conclusion based on the data.

conservation of mass In a chemical reaction, the total mass of reactants is equal to the total mass of products. This is conservation of mass. Mass is conserved in chemical reactions and in physical changes.

continuous A variable that has values that can be any number.

control variable A variable that you have to keep the same in an investigation.

corrosive A substance is corrosive if it can burn your skin or eyes.

crust The rocky outer layer of the Earth.

data Words or numbers that you obtain when you make observations or measurements.

decomposition A chemical reaction in which a compound breaks down to form simpler compounds and/or elements.

deforestation The cutting down or burning of trees in forests.

dental record A person's dental history used for identification.

density The mass of a material in a certain volume.

dependent variable A variable that changes when you change the independent variable.

deposition The settling of sediments that have moved away from their original rock.

dilute A solution is dilute if it has a small number of solute particles per unit volume (litre or cubic metre).

discrete A variable that can only have whole-number values.

displace A more reactive metal displaces – or pushes out – a less reactive metal from its compound.

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

dissolve The mixing of a substance (the solute) with a liquid (the solvent) to make a solution.

distillation A technique that uses evaporation and condensation to obtain a solvent from a solution.

durable A property of a material meaning that it is difficult to damage.

element A substance that cannot be broken down into other substances.

electron A tiny particle with a negative charge that is part of an atom.

element A substance that cannot be broken down into other substances.

endothermic change An endothermic change transfers energy from the surroundings.

energy Energy is needed to make things happen.

erosion The breaking of a rock into sediments, and their movement away from the original rock.

ethanol The drug found in alcoholic drinks.

evaluate To discuss the quality of data collected during an investigation and suggest improvements to the method.

evaporate The change of state from liquid to gas that occurs when particles leave the surface of the liquid only. It can happen at any temperature.

evidence measurements or observations that scientists use to develop or check theories.

exothermic change An exothermic change transfers energy to the surroundings.

filtering A way of separating pieces of solid that are mixed with a liquid or solution by pouring through filter paper.

filtrate The liquid or solution that collects in the container after the mixture has passed through the filter paper.

filtration A way of separating pieces of solid that are mixed with a liquid or solution by pouring through filter paper.

forensic science Study of evidence and objects that relate to a crime.

fossil The remains, or traces, of an animal or plant that lived many years ago. Fossils are preserved by natural processes.

fossil fuel A fuel made from the remains of animals and plants that died millions of years ago. Fossil fuels include coal, oil, and natural gas.

freezing The change of state from liquid to solid.

freeze–thaw Weathering of rocks that happens as a result of water repeatedly freezing and thawing.

fuel A material that burns to transfer useful energy.

gas In the gas state, a substance can flow and can also be compressed.

gas chromatogram An image obtained from gas chromatography.

gas chromatography A technique to separate and identify substances in mixtures, and measure their amounts. In gas chromatography the stationary phase is a polymer, and the mobile phase is helium gas.

global warming The gradual increase in the Earth's mean air temperature.

greenhouse effect The absorbing of energy by gases in the atmosphere, such as carbon dioxide, which keeps the Earth warmer than it would otherwise be.

greenhouse gas A gas that contributes to climate change, such as carbon dioxide.

group A vertical column of the Periodic Table. The elements in a group have similar properties.

Group 0 Group 0 is on the right of the Periodic Table. Group 0 elements include helium, neon, argon, and krypton.

Group 1 The elements in the left column of the Periodic Table, including lithium, sodium, and potassium.

Group 7 Group 7, is second from the right of the Periodic Table. Group 7 elements include fluorine, chlorine, bromine, and iodine.

halogen Another name for the Group 7 elements.

hazard A possible source of danger.

hybrid electric car A hybrid electric car includes an internal combustion engine and a big battery.

hydrocarbon A compound whose molecules are made up of atoms of carbon and hydrogen only.

hydrogen fuel cell An electric cell that generates electricity when hydrogen and oxygen react together.

hypothesis An idea that is a way of explaining scientists' observations.

igneous (rock) Rock made when liquid rock (magma or lava) cools and freezes.

impure A subsatnce is impure if it has different substances mixed with it.

independent variable A variable you change that changes the dependent variable.

index fossil A fossil type that indentifies the geological time period in which a rock was formed.

indicator A substance that changes colour to show whether a solution is acidic or alkaline.

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

insoluble A substance that cannot dissolve in a certain solvent is insoluble in that solvent.

investigation An experiment or set of experiments designed to produce data to answer a scientific question or test a theory.

lava Liquid rock that is above the Earth's surface.

line graph A way of presenting results when there are two numerical variables.

line of best fit A smooth line on a graph that travels through or very close to as many of the points plotted as possible.

liquid In the liquid state, a substance can flow but cannot be compressed.

litmus An indicator. Blue litmus paper goes red on adding acid. Red litmus goes blue on adding alkali.

mantle The layer of Earth that is below the crust. It is solid but can flow very slowly.

material The different types of stuff that things are made from.

mean An average of a set of data, found by adding together all the values in the set and dividing by the number of values in the set.

melting The change of state from solid to liquid.

melting point The temperature at which a substance melts.

metal Elements on the left of the stepped line of the Periodic Table. Most elements are metals. They are good conductors of energy and electricity.

metalloid Elements near the stepped line of the Periodic Table are metalloids.

metamorphic (rock) Rock fomed by the action of heating and/or pressure on sedimentary or igneous rock.

mixture A mixture is made up of substances that are not chemically joined together.

mobile phase The solvent that carries substances up a piece of chromatography paper, or the gas that carries substances through a gas chromatography column.

molecule A group of two or more atoms, strongly joined together.

natural polymer Polymers made by plants and animals, including wool, cotton, and rubber.

nanomedicine The use of nanoparticles to treat disease.

nanometre A unit of length, which is one billionth of a metre (0.000 000 001 m). Its symbol is nm.

nanoparticle Tiny pieces of a substance, with a diamater of between 1 nanometre and 100 nanometres.

neutral A solution that is neither alkaline nor acidic. Its pH is 7.

neutralisation In a neutralisation reaction, an acid cancels out a base or a base cancels out an acid.

noble gas Another name for the Group 0 elements.

non-metal Elements on the right of the stepped line of the Periodic Table. They are poor conductors of energy and electricity.

non-renewable Energy resources that have a limited supply.

observation Carefully looking at an object or process.

ore A rock that you can extract a metal from.

outlier A result that is very different from the other measurements in a data set.

outer core The liquid iron and nickel between the Earth's mantle and inner core.

oxidation A chemical reaction in which substances react with oxygen to form oxides.

particle The tiny things that materials are made from.

particulate Tiny pieces of solid, about 100 nm across. Particulates form when diesel burns.

peer review The evaluation of a scientist's work by another scientist.

period A horizontal row of the Periodic Table. There are trends in the properties of the elements across a period.

Periodic Table A table of all the elements, in which elements with similar properties are grouped together.

pH scale The pH scale shows whether a substance is acidic, alkaline, or neutral. An acid has a pH below 7. An alkaline solution has a pH above 7. A solution of pH 7 is neutral.

physical change A change that is reversible, in which new substances are not made. Examples of physical changes include changes of state, and dissolving.

physical property A property of a material that you can observe or measure.

physical weathering The breaking up or wearing down of rocks by the effects of changing temperature.

pie chart A way of presenting data when one variable is discrete or categoric and the other is continuous.

plan A description of how you will use equipment to collect valid data to answer a scientific question.

polymer A substance made up of very long molecules.

porous A porous material has small gaps that may contain substances in their liquid or gas states. Water can soak into a porous material.

precise This describes a set of repeat measurements that are close together.

prediction A statement that says what you think will happen.

primate A group of mammals including monkeys, apes, tarsiers, and humans.

product A substance that is made in a chemical reaction.

property A quality of a substance or material that describes its appearance, or how it behaves.

pure A substance is pure if it has no other substances mixed with it.

random (error) A error that causes there to be a random difference between a measurement and the true value each time you measure it.

range The difference between the lowest and highest values a variable can have.

reactant A starting substance in a chemical reaction.

reaction The support force provided by a solid surface like a floor.

reactive A substance is reactive if it reacts vigorously with substances such as dilute acids and water.

reactivity series A list of metals in order of how vigorously they react.

recycling Collecting and processing materials that have been used, to make new objects.

reinforced concrete A composite material consisting of steel bars surrounded by concrete.

renewable A fuel that is easily replaced.

repeatable (results) When you repeat measurements in an investigation and get similar results they are repeatable.

reproducible (results) When other people carry out an investigation and get similar results to the orginal investigation the results are repeatable.

residue The solid that collects in the filter paper.

risk the probability of something happening that could cause damage or injury.

risk assessment A description of how you will make it less likely that people will be injured, or equipment damaged, and what to do if this happens.

rock cycle The rock cycle explains how rocks change and are recycled into new rocks over millions of years.

rust Hydrated iron oxide, which forms when iron reacts with oxygen and water.

safety Making sure that something is safe and that hazards and risks are minimal.

salt A salt is a compound in which the hydrogen atoms of an acid are replaced by atoms of a
metal element.

saturated solution A solution in which no more solute can dissolve.

scientific journal A collection of articles written by scientists about their research.

sediment Pieces of rock that have broken away from their original rock.

sedimentary (rock) Rock made from sediments.

solid In the solid state, a substance cannot be compressed and it cannot flow.

solubility The solubility of a substance is the mass that dissolves in 100 g of water.

solute The solid or gas that dissolves in a liquid.

solution A mixture of a liquid with a solid or a gas. All parts of the mixture are the same.

solvent The liquid in which a solid or gas dissolves.

spread The difference between the highest and lowest measurements of a set of repeat measurements.

states of matter The three forms in which a substance can exist – solid, liquid, and gas.

state symbol A state symbol gives the state of a substance in a chemical equation. (s) means solid, (l) means liquid, (g) means gas, and (aq) means dissolved in water.

stationary phase The medium that the mobile phase passes through in chromatography. In paper chromatography, the stationary phase is the paper.

strata Layers of sedimentary rock.

sublime The change of state from solid to gas.

substance A material that is not a mixture. It has the same properties all the way through.

synthetic polymer A substance made up of very long molecules that does not occur naturally.

systematic (error) An error that causes there to be the same difference between a measurement and the true value each time you measure it.

thermite reaction Reaction of aluminium with iron oxide to make aluminium oxide and iron.

transport Movement of sediments far from their original rock.

troposphere The part of the atmosphere nearest the Earth.

uncertainty the amount by which you cannot be sure of the value of your measurement because of your measuring instruments or methods.

universal indicator An indicator that changes colour to show the pH of a solution. It is a mixture of dyes.

weathering Weathering breaks up all types of rock into smaller pieces, called sediments.

unreactive Elements that take part in few chemical reactions are unreactive.

variable A quantity that can change, for example, time, temperature, length, mass.

word equation A way of representing a chemical reaction simply. The reactants are on the left of an arrow, and the products are on the right. The arrow means *reacts to make*.

Index

The Periodic Table

Times of discovery

- before 1800
- 1800–1849
- 1849–1899
- 1900–1949
- 1949–1999

Key: relative atomic mass / chemical symbol / name / atomic (proton) number

Period	Group 1	2											3	4	5	6	7	8
								1.0 H hydrogen 1										4 He helium 2
2	7 Li lithium 3	9 Be beryllium 4											11 B boron 5	12 C carbon 6	14 N nitrogen 7	16 O oxygen 8	19 F fluorine 9	20 Ne neon 10
3	23 Na sodium 11	24 Mg magnesium 12											27 Al aluminium 13	28 Si silicon 14	31 P phosphorus 15	32 S sulfur 16	35.5 Cl chlorine 17	40 Ar argon 18
4	39 K potassium 19	40 Ca calcium 20	45 Sc scandium 21	48 Ti titanium 22	51 V vanadium 23	52 Cr chromium 24	55 Mn manganese 25	56 Fe iron 26	59 Co cobalt 27	59 Ni nickel 28	63.5 Cu copper 29	65 Zn zinc 30	70 Ga gallium 31	73 Ge germanium 32	75 As arsenic 33	79 Se selenium 34	80 Br bromine 35	84 Kr krypton 36
5	85.5 Rb rubidium 37	88 Sr strontium 38	89 Y yttrium 39	91 Zr zirconium 40	93 Nb niobium 41	96 Mo molybdenum 42	(98) Tc technetium 43	101 Ru ruthenium 44	103 Rh rhodium 45	106 Pd palladium 46	108 Ag silver 47	112 Cd cadmium 48	115 In indium 49	119 Sn tin 50	122 Sb antimony 51	128 Te tellurium 52	127 I iodine 53	131 Xe xenon 54
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