YEAR 9

# Science

## STUDENT COMPANION

Pearson | Secondary Teaching Hub

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# Pearson Secondary Teaching Hub Science 9

## Student Companion



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We pay our respects to Elders, past and present.

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# Contents



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# Contents





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# How to use this Student Companion

The Student Companion is a complementary resource that offers a print medium for corresponding lessons in Pearson Secondary Teaching Hub. It is designed to provide learners with a place to create a portfolio of learning to suit their individual needs, whether you are:

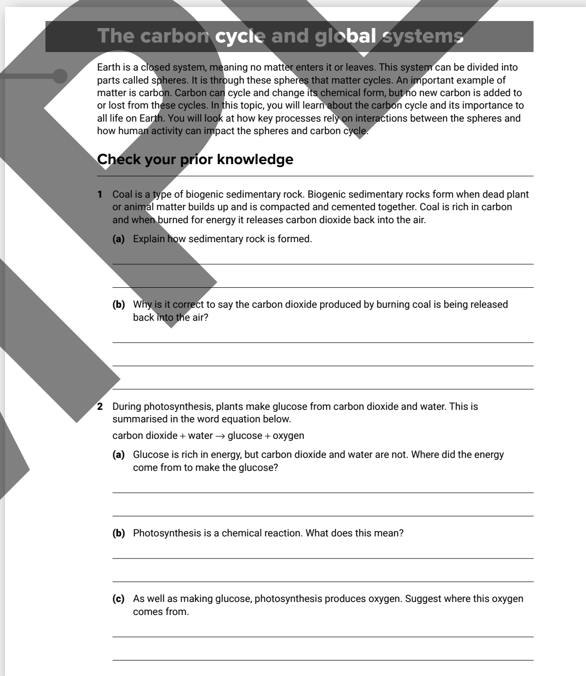
- supporting a blended classroom using the strengths of print and digital
- preparing for exams by creating a study guide or bound reference
- needing a tool to differentiate learning
- looking for meaningful homework tasks.

Learners can develop their portfolio as part of classroom learning or at home as an additional opportunity to engage and re-engage with the knowledge and skills from the lesson.

This could be done as prior learning in a flipped classroom environment or as an additional revision or homework task.

## Check your prior knowledge

Each topic begins with 3–5 questions that test learners' knowledge from previous years or from topics in the Australian Curriculum. These questions provide insight into learners' prior knowledge before they begin a topic, allowing teachers to adapt their teaching and support as needed.



The carbon cycle and global systems

Earth is a closed system, meaning no matter enters it or leaves. This system can be divided into parts called spheres. It is through these spheres that matter cycles. An important example of matter is carbon. Carbon can cycle and change its chemical form, but no new carbon is added to or lost from these cycles. In this topic, you will learn about the carbon cycle and its importance to all life on Earth. You will look at how key processes rely on interactions between the spheres and how human activity can impact the spheres and carbon cycle.

Check your prior knowledge

1 Coal is a type of biogenic sedimentary rock. Biogenic sedimentary rocks form when dead plant or animal matter builds up and is compacted and cemented together. Coal is rich in carbon and when burned for energy it releases carbon dioxide back into the air.

(a) Explain how sedimentary rock is formed.

(b) Why is it correct to say the carbon dioxide produced by burning coal is being released back into the air?

2 During photosynthesis, plants make glucose from carbon dioxide and water. This is summarised in the word equation below.

carbon dioxide + water → glucose + oxygen

(a) Glucose is rich in energy, but carbon dioxide and water are not. Where did the energy come from to make the glucose?

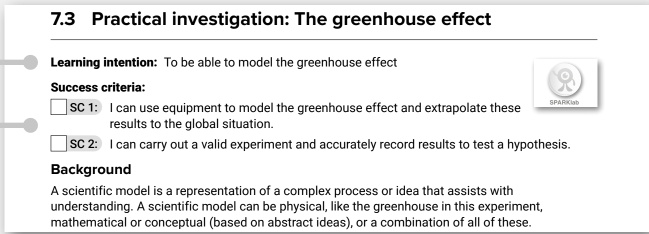
(b) Photosynthesis is a chemical reaction. What does this mean?

(c) As well as making glucose, photosynthesis produces oxygen. Suggest where this oxygen comes from.

## Learning intentions and success criteria

**Learning intentions** are provided for every lesson. The learning intentions are goals or objectives that align to the corresponding digital lesson. They describe what learners should know, understand or be able to do by the end of the lesson.

**Success criteria** clarify expectations and describe what success looks like. The success criteria are specific, concrete and measurable so learners can actively engage with and reflect on their evidence of learning within each lesson.



7.3 Practical investigation: The greenhouse effect

Learning intention: To be able to model the greenhouse effect

Success criteria:

SC 1: I can use equipment to model the greenhouse effect and extrapolate these results to the global situation.

SC 2: I can carry out a valid experiment and accurately record results to test a hypothesis.

Background

A scientific model is a representation of a complex process or idea that assists with understanding. A scientific model can be physical, like the greenhouse in this experiment, mathematical or conceptual (based on abstract ideas), or a combination of all of these.



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## Icons and features

The Teaching Hub icon prompts learners to engage with supporting digital resources to enhance their learning.

**SPARKlab icons** direct learners to alternative, online practical investigations.

**MATERIALS**
- 1 M hydrochloric acid (HCl) solution
- calcium carbonate ($CaCO_3$) powder
- copper(II) oxide (CuO) powder
- sodium hydrogen carbonate ($NaHCO_3$) powder
- 1 cm strip of magnesium (Mg) ribbon
- limewater
- test tubes
- dropping pipette
- rubber stopper
- test-tube rack
- long matches or wooden splints
- one-hold stopper and delivery tube, or sidearm test tube with rubber stopper and delivery tube

**Materials boxes** list all the materials needed to complete a practical investigation. Some include a safety icon that highlights any substances or equipment that require care when preparing or using them.

**Hint boxes** provide hints and tips where relevant in practical investigations and inquiry activities.

**HINT**
Ensure the thermometer bulbs are measuring air temperature only. They should not be touching any objects.

The **safety icon** highlights substances or equipment that may cause harm. Be sure to prepare a risk assessment for these activities and take care when preparing or using these substances and equipment.

**KEY TERMS**
**net** the total, or overall, amount of an effect or quantity
**enhanced greenhouse effect** an increase in the natural greenhouse effect caused by human activity

**Key term boxes** provide learners with definitions for the bolded key terms found throughout the text, supporting the development of their scientific vocabulary and literacy.

**Check-in boxes** prompt learners to check their risk assessment, method or plan with a teacher before proceeding with the practical investigation or inquiry activity.

☐ Check in with your teacher to discuss your method and risk assessment.

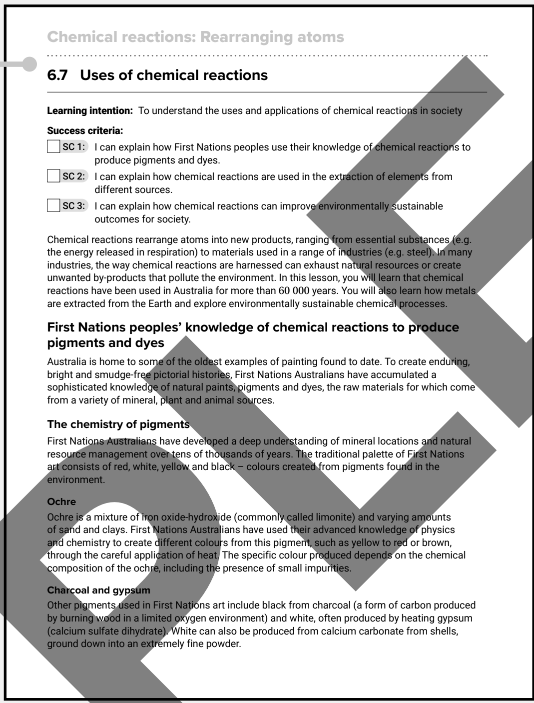
## Rate my learning tool

**Rate my learning tool** Each lesson in the Student Companion contains a space for students to reflect on their understanding. The simple and intuitive design of the lesson reflection tool allows students to scale their confidence, reflect on their learning and identify areas in which they need support.

**RATE MY LEARNING** ○ I need some help ○ I am getting there ○ I get it ○ I am confident

## Theory lessons

**Theory lessons** support the development of science knowledge and understanding by providing content in short, accessible chunks. Questions to check learners' understanding are provided at regular intervals throughout the lesson. Each theory lesson ends with a lesson review that includes 3–6 questions.


Chemical reactions: Rearranging atoms

### 6.7 Uses of chemical reactions

**Learning intention:** To understand the uses and applications of chemical reactions in society

**Success criteria:**

- SC 1: I can explain how First Nations peoples use their knowledge of chemical reactions to produce pigments and dyes.
- SC 2: I can explain how chemical reactions are used in the extraction of elements from different sources.
- SC 3: I can explain how chemical reactions can improve environmentally sustainable outcomes for society.

Chemical reactions rearrange atoms into new products, ranging from essential substances (e.g. the energy released in respiration) to materials used in a range of industries (e.g. steel). In many industries, the way chemical reactions are harnessed can exhaust natural resources or create unwanted by-products that pollute the environment. In this lesson, you will learn that chemical reactions have been used in Australia for more than 60 000 years. You will also learn how metals are extracted from the Earth and explore environmentally sustainable chemical processes.

#### First Nations peoples' knowledge of chemical reactions to produce pigments and dyes

Australia is home to some of the oldest examples of painting found to date. To create enduring, bright and smudge-free pictorial histories, First Nations Australians have accumulated a sophisticated knowledge of natural paints, pigments and dyes, the raw materials for which come from a variety of mineral, plant and animal sources.

**The chemistry of pigments**

First Nations Australians have developed a deep understanding of mineral locations and natural resource management over tens of thousands of years. The traditional palette of First Nations art consists of red, white, yellow and black – colours created from pigments found in the environment.

**Ochre**

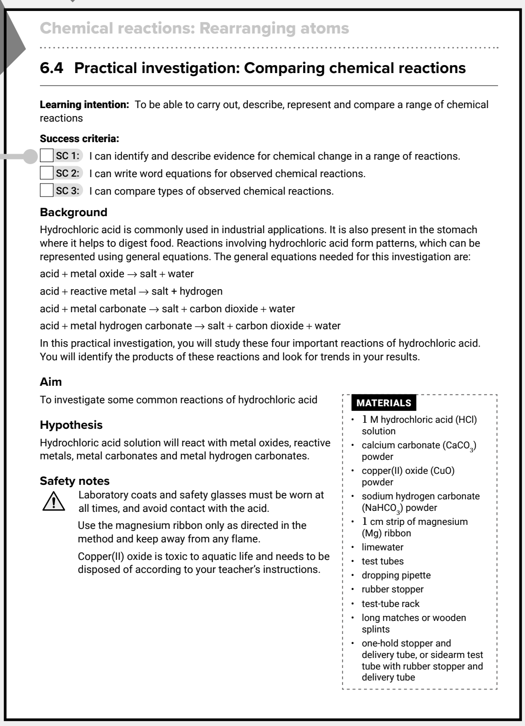
Ochre is a mixture of iron oxide-hydroxide (commonly called limonite) and varying amounts of sand and clays. First Nations Australians have used their advanced knowledge of physics and chemistry to create different colours from this pigment, such as yellow to red or brown, through the careful application of heat. The specific colour produced depends on the chemical composition of the ochre, including the presence of small impurities.

**Charcoal and gypsum**

Other pigments used in First Nations art include black from charcoal (a form of carbon produced by burning wood in a limited oxygen environment) and white, often produced by heating gypsum (calcium sulfate dihydrate). White can also be produced from calcium carbonate from shells, ground down into an extremely fine powder.

## Practical investigations

**Practical investigations** offer learners the chance to complete practical work related to the topics in their Student Companion. They will have the chance to design and conduct experiments, record results, analyse data and prepare evidence-based conclusions. Risk assessments will need to be completed for all practical investigations to ensure learners understand how to conduct investigations safely. SPARKlab icons indicate where an alternative, online practical investigation is available.


Chemical reactions: Rearranging atoms

### 6.4 Practical investigation: Comparing chemical reactions

**Learning intention:** To be able to carry out, describe, represent and compare a range of chemical reactions

**Success criteria:**

- SC 1: I can identify and describe evidence for chemical change in a range of reactions.
- SC 2: I can write word equations for observed chemical reactions.
- SC 3: I can compare types of observed chemical reactions.

#### Background

Hydrochloric acid is commonly used in industrial applications. It is also present in the stomach where it helps to digest food. Reactions involving hydrochloric acid form patterns, which can be represented using general equations. The general equations needed for this investigation are:

acid + metal oxide → salt + water

acid + reactive metal → salt + hydrogen

acid + metal carbonate → salt + carbon dioxide + water

acid + metal hydrogen carbonate → salt + carbon dioxide + water

In this practical investigation, you will study these four important reactions of hydrochloric acid. You will identify the products of these reactions and look for trends in your results.

#### Aim

To investigate some common reactions of hydrochloric acid

#### Hypothesis

Hydrochloric acid solution will react with metal oxides, reactive metals, metal carbonates and metal hydrogen carbonates.

#### Safety notes

Laboratory coats and safety glasses must be worn at all times, and avoid contact with the acid.

Use the magnesium ribbon only as directed in the method and keep away from any flame.

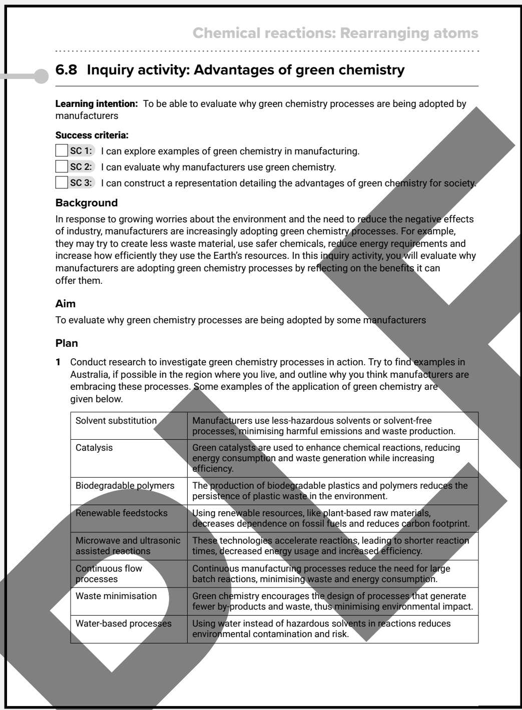
Copper(II) oxide is toxic to aquatic life and needs to be disposed of according to your teacher's instructions.

**MATERIALS**

- 1 M hydrochloric acid (HCl) solution
- calcium carbonate ($CaCO_3$) powder
- copper(II) oxide (CuO) powder
- sodium hydrogen carbonate ($NaHCO_3$) powder
- 1 cm strip of magnesium (Mg) ribbon
- limewater
- test tubes
- dropping pipette
- rubber stopper
- test-tube rack
- long matches or wooden splints
- one-hold stopper and delivery tube, or sidearm test tube with rubber stopper and delivery tube

## Inquiry activities

**Inquiry activities** are open-ended investigations that encourage learners to plan and design solutions to problems. Learners are encouraged to improve and evaluate their ideas, designs or investigations. Inquiry activities require learners to use their understanding of scientific concepts and the science inquiry skills that they have developed throughout each topic in the Student Companion.


Chemical reactions: Rearranging atoms

6.8 Inquiry activity: Advantages of green chemistry

**Learning intention:** To be able to evaluate why green chemistry processes are being adopted by manufacturers

**Success criteria:**

- SC 1: I can explore examples of green chemistry in manufacturing.
- SC 2: I can evaluate why manufacturers use green chemistry.
- SC 3: I can construct a representation detailing the advantages of green chemistry for society.

**Background**

In response to growing worries about the environment and the need to reduce the negative effects of industry, manufacturers are increasingly adopting green chemistry processes. For example, they may try to create less waste material, use safer chemicals, reduce energy requirements and increase how efficiently they use the Earth's resources. In this inquiry activity, you will evaluate why manufacturers are adopting green chemistry processes by reflecting on the benefits it can offer them.

**Aim**

To evaluate why green chemistry processes are being adopted by some manufacturers

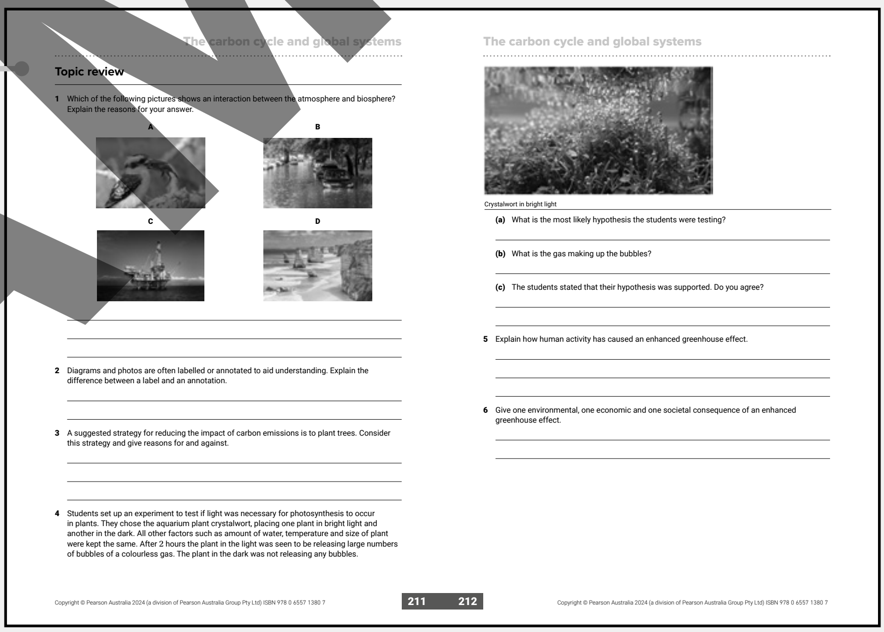
**Plan**

1 Conduct research to investigate green chemistry processes in action. Try to find examples in Australia, if possible in the region where you live, and outline why you think manufacturers are embracing these processes. Some examples of the application of green chemistry are given below.

| | |
|---|---|
| Solvent substitution | Manufacturers use less-hazardous solvents or solvent-free processes, minimising harmful emissions and waste production. |
| Catalysis | Green catalysts are used to enhance chemical reactions, reducing energy consumption and waste generation while increasing efficiency. |
| Biodegradable polymers | The production of biodegradable plastics and polymers reduces the persistence of plastic waste in the environment. |
| Renewable feedstocks | Using renewable resources, like plant-based raw materials, decreases dependence on fossil fuels and reduces carbon footprint. |
| Microwave and ultrasonic assisted reactions | These technologies accelerate reactions, leading to shorter reaction times, decreased energy usage and increased efficiency. |
| Continuous flow processes | Continuous manufacturing processes reduce the need for large batch reactions, minimising waste and energy consumption. |
| Waste minimisation | Green chemistry encourages the design of processes that generate fewer by-products and waste, thus minimising environmental impact. |
| Water-based processes | Using water instead of hazardous solvents in reactions reduces environmental contamination and risk. |

## Topic review

Each topic finishes with a **topic review** that includes 8–15 questions that address every learning intention in the topic. These questions give learners the opportunity to apply the knowledge and skills they have developed throughout the topic.


The carbon cycle and global systems

Topic review

1 Which of the following pictures shows an interaction between the atmosphere and biosphere? Explain the reasons for your answer.

A B C D

2 Diagrams and photos are often labelled or annotated to aid understanding. Explain the difference between a label and an annotation.

3 A suggested strategy for reducing the impact of carbon emissions is to plant trees. Consider this strategy and give reasons for and against.

4 Students set up an experiment to test if light was necessary for photosynthesis to occur in plants. They chose the aquarium plant crystalwort, placing one plant in bright light and another in the dark. All other factors such as amount of water, temperature and size of plant were kept the same. After 2 hours the plant in the light was seen to be releasing large numbers of bubbles of a colourless gas. The plant in the dark was not releasing any bubbles.

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The carbon cycle and global systems

Crystalwort in bright light

(a) What is the most likely hypothesis the students were testing?

(b) What is the gas making up the bubbles?

(c) The students stated that their hypothesis was supported. Do you agree?

5 Explain how human activity has caused an enhanced greenhouse effect.

6 Give one environmental, one economic and one societal consequence of an enhanced greenhouse effect.

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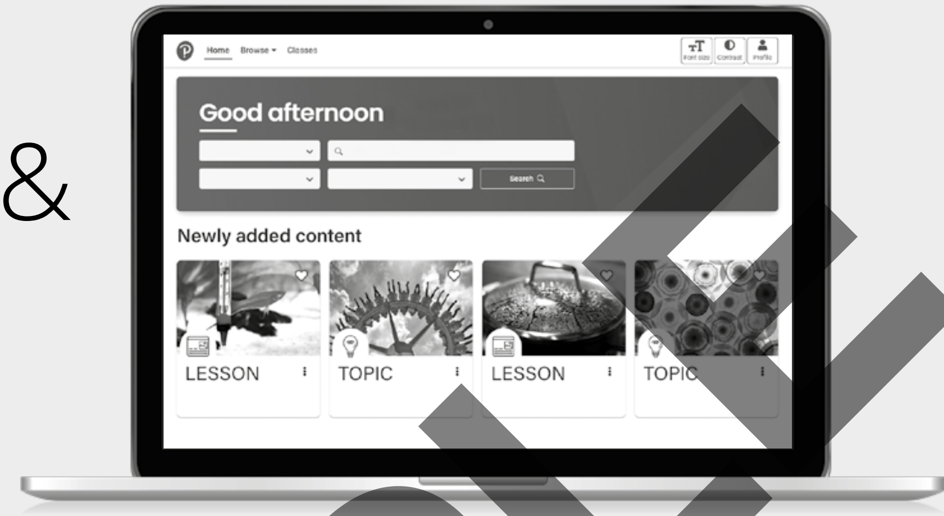


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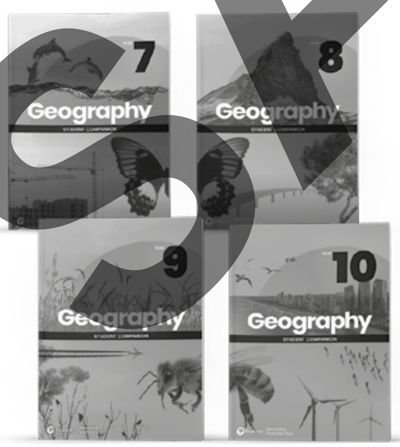
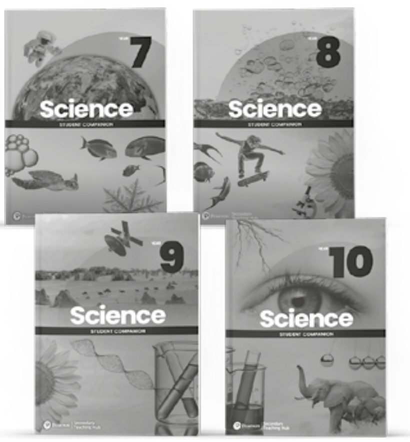



**Mathematics**


**Science**

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# Atomic structure and radioactivity

Atoms are the building blocks that make up everything around us. They are made up of subatomic particles called protons, neutrons and electrons. The protons and neutrons make up the middle of the atom (the nucleus), while the electrons orbit the nucleus. In some atoms, the nucleus can be unstable, causing the atoms to release nuclear radiation. These atoms are 'radioactive'. Radioactive atoms can be used to diagnose and treat diseases, but exposure to too much radiation can be very dangerous.

In this topic you will learn about the structure of atoms. You will use this knowledge to explain and predict the behaviour of substances.

## Check your prior knowledge

**1** List two facts about atoms.

**2** Elements contain only one type of atom and can be represented using an atomic symbol (e.g. C for carbon). List four metallic elements with a two-letter symbol where the first letter is A.

**3** Suggest why the symbol for iron is Fe and not I or Ir.

**4** Methane gas is made up of particles that contain four atoms of hydrogen and one atom of carbon.

**(a)** What name is given to this type of particle?

**(b)** Briefly describe the properties of carbon and oxygen.

**(c)** Explain why the properties of methane are different to the properties of carbon and oxygen.

RATE MY LEARNING | I need some help | I am getting there | I get it | I am confident

## 5.1 Inquiry activity: Contributions to atomic theory

**Learning intention:** To be able to describe discoveries that contributed to the knowledge of the structure of the atom

**Success criteria:**

- [ ] **SC 1:** I can describe the main findings of historical experiments that investigated the structure of the atom.
- [ ] **SC 2:** I can describe how advances in technologies allowed the development of the understanding of atomic structure.
- [ ] **SC 3:** I can compare the contributions of scientists to the development of the understanding of atomic structure.

### Background

Our understanding of atoms today is the result of centuries of observations, hypotheses and scientific discoveries. Each model has built on previous ones to explain observed behaviour more accurately. In this inquiry activity, you will discover the work of some of the scientists who contributed to the modern understanding of atoms, how they used technology to obtain their evidence and how their ideas became accepted.

### Aim

To conduct research to explain how the model of the atom developed over time and consider the contributions of scientists to these discoveries

You will:

- present your findings with diagrams and timelines of the atomic models proposed by each scientist
- describe the technologies used to provide evidence for the models
- explain how the model was accepted by the scientific community.

### Plan

As a team, each student researches a model of the atom as proposed by:

- John Dalton
- J. J. Thomson
- Ernest Rutherford
- Niels Bohr.

Take turns reporting key findings (including an advantage and problem) for each model to the group. Summarise your team's findings in the space below.

## Conduct

Using the information from your team, create diagrams and a timeline that summarises the four models of the atom. Highlight key differences between each model.

## Improve

After receiving constructive feedback on your timeline, suggest one improvement to your representation that would improve how it communicates the development of the atomic model.

## Evaluate

1 With one of the models, describe in detail how advances in technologies allowed the development of that model.

2 Neutrons were discovered by English scientist James Chadwick in 1932. Suggest why the neutron was the last of the three main subatomic particles to be discovered. Compare the importance of this discovery and its impact on one of the four models described in your timeline.

RATE MY LEARNING — I need some help — I am getting there — I get it — I am confident

# 5.2 Elements and atoms

**Learning intention:** To understand that different atoms have different numbers of subatomic particles

**Success criteria:**

- [ ] **SC 1:** I can draw a two- or three-dimensional representation of a specific atom given the number of protons, electrons and neutrons present in the atom.
- [ ] **SC 2:** I can calculate the mass of atoms based on the number of protons and neutrons they contain.
- [ ] **SC 3:** I can calculate the number of neutrons an atom contains from its mass number and atomic number.

The writer Bill Bryson describes atoms in the following way: 'Protons give an atom its identity and electrons its personality'. This is a great way to think about atoms. In this lesson, you will learn about the different numbers of subatomic particles in atoms.

## Drawing two- or three-dimensional representations of an atom

A periodic table gives the name and symbol of an element and the number for that atom (its **atomic number**, which is the number of **protons** in that atom). The periodic table groups elements based on their properties. All atoms have the same number of **electrons** as protons. An atom of carbon, for example, has six protons and six electrons. The number of **neutrons** can vary.

To identify an atom from a representation, count the number of protons and then look up that number in a periodic table.

When drawing an atom, refer to the periodic table and draw the correct number of protons in the nucleus. Then put the same number of electrons around the nucleus. (This is sometimes called the **electron cloud**.) If you know the number of neutrons, these can be added to the protons.

### KEY TERMS

**atomic number** the number of protons in the nucleus of an atom, indicated in the periodic table

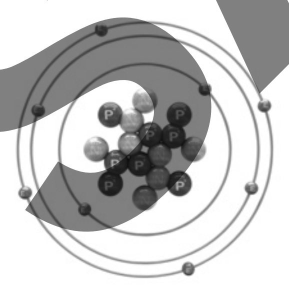
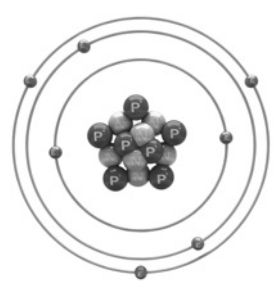
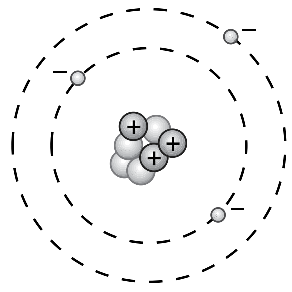
**proton** a subatomic particle with a positive electric charge

**electron** a subatomic particle with a negative electric charge

**neutron** a subatomic particle with no electric charge

**electron cloud** the region of negative charge surrounding the nucleus, containing the electrons

Some example two-dimensional representations of atoms are shown in the table below.

| Oxygen | Nitrogen | Lithium |
|---|---|---|
|  |  |  |
| 8 protons | 7 protons | 3 protons |
| 8 neutrons | 7 neutrons | 4 neutrons |
| 8 electrons | 7 electrons | 3 electrons |

**1** Draw a labelled diagram of an atom of helium. Assume the number of neutrons is the same as the number of protons.

## Calculating the mass of atoms

Electrons are much smaller than protons and neutrons. Protons and neutrons are approximately the same size and mass, while electrons have only about $\frac{1}{1800}$ the mass of a proton. Therefore, most of the mass of an atom is located in the nucleus, which is made up of protons and neutrons. The table below summarises the charge and mass for the subatomic particles.

| | Proton | Electron | Neutron |
|---|---|---|---|
| **Location** | nucleus | electron cloud surrounding nucleus | nucleus |
| **Relative charge** | +1 | –1 | 0 |
| **Relative mass** | 1 | $\frac{1}{1800}$ | 1 |

atomic number (*Z*) = number of protons

mass number (*A*) = number of protons + number of neutrons

Note that the mass number will always be bigger than the atomic number.

### Identifying atomic number and mass number

| | $^{24}_{12}Mg$ | $^{71}_{35}Cl$ | $^{48}_{22}Ti$ |
|---|---|---|---|
| **Element** | magnesium | chlorine | titanium |
| **Atomic number (*Z*)** | 12 | 35 | 22 |
| **Mass number (*A*)** | 24 | 71 | 48 |

**2** Complete the following table. Use a periodic table to find the number of protons in each element.

| Element | Number of protons | Number of neutrons | Mass number |
|---|---|---|---|
| manganese | | 30 | |
| tin | | 70 | |
| sulfur | | 17 | |

## Calculating the number of neutrons in an atom

Because we know that: atomic number (*Z*) = number of protons

mass number (*A*) = number of protons + number of neutrons

Therefore, number of neutrons = mass number – atomic number (*A* – *Z*).

If we know the mass number and atomic number, we can calculate the number of neutrons.

| | $^{56}_{26}Fe$ | $^{64}_{29}Cu$ | $^{133}_{55}Cs$ |
|---|---|---|---|
| **Element** | iron | copper | caesium |
| **Mass number (*A*)** | 56 | 64 | 133 |
| **Atomic number (*Z*)** | 26 | 29 | 55 |
| **Number of neutrons = *A* – *Z*** | 56 – 26 = 30 | 64 – 29 = 35 | 133 – 55 = 78 |

**3** Complete the following table using the element symbols and mass numbers shown in the first column. You will also need to refer to a periodic table.

| Element and mass number | Name | Atomic number | Mass number | Number of protons | Number of neutrons | Number of electrons |
|---|---|---|---|---|---|---|
| $^{23}Na$ | | | | | | |
| $^{208}Pb$ | | | | | | |

## Lesson review

**1** An atom has 9 protons, 11 neutrons and 9 electrons.

**(a)** Draw a diagram of this atom.

**(b)** Identify this atom.

**2** An atom has 18 protons and 22 neutrons.

**(a)** Identify this atom.

**(b)** Calculate its mass number.

**3** An atom has 15 protons and its mass number is 31. How many neutrons does it have?

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# 5.3 Isotopes

**Learning intention:** To understand how different isotopes of atoms exist

**Success criteria:**

- [ ] **SC 1:** I can describe, with examples, what an isotope is.
- [ ] **SC 2:** I can identify isotopes of atoms based on the number of protons and neutrons they contain.
- [ ] **SC 3:** I can explain, using an example, the different characteristics of isotopes of the same atom.

Unlike protons, the number of neutrons in atoms of an element can vary. A carbon atom (which always has six protons) might have six neutrons, or might have seven or eight neutrons. Atoms of the same element that have different numbers of neutrons are called **isotopes**, and there are lots of them! In this lesson, you will learn what an isotope is, see some common examples of isotopes and discover how the number of neutrons affects the properties of the atom, including its mass.

**KEY TERM**

**isotope** a group of atoms with the same number of protons but different numbers of neutrons

## Isotopes

Isotopes are different 'versions' of atoms. Neon, for example, has the atomic number of 10, so every neon atom in the universe has 10 protons. However, in nature, if you had 10 000 neon atoms, around 9048 of them would contain 10 neutrons, 27 would contain 11 neutrons and 925 would contain 12 neutrons. These three neon isotopes all have the same chemical properties, but their masses are different.

### The masses of isotopes

The masses of atoms can be compared using the mass number. Recall that:

mass number = number of protons + number of neutrons

For a neon atom with 12 neutrons, the mass number is 10 (the atomic number) plus 12, which equals 22. Therefore, this isotope of neon is called neon-22, or Ne-22.

**1** Using an example of your choice, explain the meaning of the term isotope.

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## Identifying isotopes of atoms

Nearly all elements have atoms that are isotopes of each other. For some elements, nearly all atoms present in a natural sample are the same isotope. For example, 99.6% of nitrogen atoms are nitrogen-14, and only 0.4% are nitrogen-15. However, for other elements, there is a more even spread of isotopes. For example, around 51% of bromine atoms are bromine-79, while 49% are bromine-81.

The table below shows examples of isotopes, their composition and their relative abundance.

| Element | Atomic number | Isotope | Neutrons | Relative abundance (approximate) |
|---|---|---|---|---|
| chlorine (Cl) | 17 | chlorine-35 | 18 | 76% |
| | | chlorine-37 | 20 | 24% |
| barium (Ba) | 56 | barium-134 | 78 | 2.4% |
| | | barium-135 | 79 | 6.6% |
| | | barium-136 | 80 | 7.9% |
| | | barium-137 | 81 | 1.1% |
| | | barium-138 | 82 | 71.7% |
| copper (Cu) | 29 | copper-63 | 34 | 69% |
| | | copper-65 | 36 | 31% |
| uranium (U) | 92 | uranium-235 | 143 | 0.7% |
| | | uranium-238 | 146 | 99.3% |

The names of isotopes can be written out in full (e.g. barium-136), abbreviated with the chemical symbol of the element (Ba-136), or with the mass number as a superscript before the chemical symbol ($^{136}Ba$).

**2** Complete the table below. You will need a periodic table to locate the atomic numbers of the elements.

| Element symbol | Atomic number | Isotope | Neutrons |
|---|---|---|---|
| | 47 | | 60 |
| | | | 62 |
| | | carbon-12 | 6 |
| | | | 8 |
| | 18 | | 20 |
| K | | | 20 |

## Characteristics of isotopes of the same atom

### Chemical properties

The chemical properties of an atom are determined by its electrons. In a **neutral** atom, the number of electrons is the same as the number of protons. Therefore, since isotopes of the same element have the same number and arrangement of protons and electrons, their chemical properties are the same.

> **KEY TERM**
> **neutral** having no overall electrical charge

### Physical properties

The physical properties of an atom, such as boiling point, melting point and density, are related to its mass. The isotopes of an element have different masses because they have different numbers of neutrons. Therefore, the isotopes of an element may have different physical properties.

For example, the boiling point of hydrogen-1 is –253°C, but the boiling point of hydrogen-2 is –249°C. Because the atoms of hydrogen-2 are twice as heavy as the atoms of hydrogen-1, more energy is required to separate them, making the boiling point slightly higher.

### Stability of atoms and radioactive decay

If the nuclei of an atom contains significantly more neutrons than protons, this can make the nucleus unstable. This can result in nuclear decay, where the nucleus splits into two or more particles, causing **radiation** from the atom. Isotopes with unstable nuclei are called 'radioisotopes'. The amount of radiation is described as **radioactivity**.

Different isotopes of an element can be stable or radioactive. For example, the nuclei in carbon-12 atoms (six protons and six neutrons) are stable, but the nuclei in carbon-14 atoms (six protons and eight neutrons) are unstable. Therefore, carbon-14 is a radioisotope.

**KEY TERMS**

**radiation** the emission of energy in the form of electromagnetic waves or subatomic particles

**radioactivity** amount of radiation emitted from a nucleus undergoing nuclear decay

**3** Zirconium has an atomic number of 40. Its most common isotope (zirconium-90) is stable, and its least common isotope (zirconium-95) is radioactive. Explain why zirconium-95 is radioactive but zirconium-90 is not.

## Lesson review

**1** Consider the table of atoms below and identify any atoms that are isotopes of each other. Explain your reasoning.

| Atom | Neutrons | Protons | Atomic number | Mass number |
|---|---|---|---|---|
| a | 1 | 2 | | |
| b | 1 | 1 | | |
| c | | | 16 | 32 |
| d | | 2 | | 4 |
| e | | | 8 | 16 |
| f | 17 | 16 | | |

2 Complete the table below. You will need to refer to a periodic table.

| Protons | Neutrons | Isotope |
|---|---|---|
| 1 | 0 | |
| 55 | 78 | |
| 27 | 32 | |
| | | xenon-132 |

3 Using an example, explain why the chemical properties of two isotopes of the same element are identical but the physical properties may be different.



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## 5.4 Radioactivity and nuclear decay

**Learning intention:** To understand that radioactivity is caused by the decay of atomic nuclei

**Success criteria:**

- [ ] **SC 1:** I can identify atoms that are likely to be unstable based on the number of protons and neutrons they contain.
- [ ] **SC 2:** I can compare alpha, beta and gamma radiation in terms of the properties of the radiation.
- [ ] **SC 3:** I can compare alpha, beta and gamma radiation in terms of the nuclear processes that cause them.

There are three main types of radiation emitted by radioactive atoms: alpha particles, beta particles and gamma rays. In this lesson, you will learn about alpha, beta and gamma nuclear decay, including how they occur and their potential effects.

### Identifying unstable atoms

The nuclei of some atoms are unstable and undergo nuclear decay. These atoms are called radioisotopes. Radioisotopes tend to have more neutrons than protons. For example, of the isotopes carbon-12, carbon-13 and carbon-14, only carbon-14 is a radioisotope. The nucleus of carbon-14 is unstable due to its two extra neutrons.

The following table gives some examples of radioisotopes, including their composition and uses or effects.

| Radioisotope | Number of protons and neutrons | Uses / effects |
|---|---|---|
| cobalt-60 | 27 protons, 33 neutrons | Used in radiotherapy for the treatment of cancer. |
| iodine-131 | 53 protons, 78 neutrons | Can be added as a tracer to water to monitor leaks in water systems. |
| radon-222 | 86 protons, 136 neutrons | Exposure to excessive amounts greatly increases the risk of lung cancer in both smokers and non-smokers. |
| americium-241 | 95 protons, 146 neutrons | Used in household smoke detectors. |
| uranium-235 | 92 protons, 143 neutrons | Used as a fuel in nuclear power stations. Uranium is slightly unusual because uranium-238 is more stable than uranium-235, despite having more neutrons. Both isotopes are radioactive. |

**1** The most common isotope of krypton is Kr-84. The radioisotope Kr-85 is produced as a by-product of nuclear power stations. Explain why Kr-84 is stable but Kr-85 is a radioisotope.

## Comparing alpha, beta and gamma radiation

The three types of radiation caused by nuclear decay are alpha particles, beta particles and gamma rays.

### Alpha (α) radiation

Alpha particles are made up of two protons and two neutrons, the same as the nucleus of a helium atom, and are given the symbol α. They have a positive charge of +2. (Remember that protons have a positive charge and neutrons are neutral.)

Compared with other forms of radiation, alpha particles are large. They can be stopped by a single sheet of paper or the skin. Although they are only able to travel a few centimetres through the air, alpha radiation can damage living cells. This is especially a problem if the materials giving off the alpha radiation enter the body through breathing or digestion.

### Beta (β) radiation

Beta particles are small negatively charged particles emitted from the nucleus of an atom. They are given the symbol β.

Beta particles have the same mass and charge as electrons. Beta particles are much smaller and lighter than alpha particles, which means that they can penetrate further into materials and have a range of up to six metres in air. They can be stopped by a few millimetres of plastic or a thin sheet of aluminium.

### Gamma (γ) radiation

Unlike alpha and beta radiation, gamma rays have no charge or mass. Instead, they are a form of electromagnetic radiation. They are similar to X-rays or microwaves but with much higher energy.

Gamma rays can travel through most materials and over huge distances, including through the vacuum of space. Because of this they are potentially the most harmful type of nuclear radiation. Gamma rays can be stopped by several centimetres of lead or several metres of concrete.

**2** Use the information about the size and the speed of particles to suggest why beta radiation can travel much further in air than alpha particles.

## Nuclear processes that cause alpha, beta and gamma radiation

When nuclear decay happens and an alpha or beta particle is released, the numbers of protons and neutrons in the nucleus of the atom change. This is called a nuclear reaction. It changes the properties of the atom, and may even change the atom into an atom of a different element.

### Alpha decay

An alpha particle contains two protons and two neutrons. Therefore, when an atom undergoes alpha decay, its number of protons drops by two, the number of neutrons drops by two and the mass number drops by four. Because the number of protons has changed, the atom is now a different element, with a different atomic number. For example, when a uranium-238 nucleus (atomic number = 92) undergoes alpha decay, it becomes a thorium-234 atom, with an atomic number of 90.

### Equation for alpha decay

Nuclear reactions can be summarised using nuclear equations. The atoms are labelled with the mass number (above) and the atomic number (below).

The alpha decay of uranium-238 can be represented like this:

$^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$

Or the symbol for the alpha particle can be used:

$^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\alpha$

Notice how the atomic number drops by 2 and the mass number drops by 4.

## Beta decay

The best way to understand beta decay is to consider that a neutron is actually a proton combined with an electron. The opposite charges of the positive proton and the negative electron cancel each other out and make the neutron neutral. During beta decay, the neutron splits into the electron and the proton. The proton stays in the nucleus of the atom and the electron is released, with high energy, as a beta particle.

The atom now has one less neutron, but one more proton. This changes the atomic number of the atom, making it an atom of a different element. The mass of the atom is unchanged.

### Equation for beta decay

The beta decay of carbon-14 can be represented like this:

$^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}\beta$

Because the beta particle (electron) is negatively charged, it has −1 where the atomic number is normally written.

Notice that in beta decay, the atomic number increases by 1 and the mass number stays the same.

## Gamma decay

Gamma decay involves the release of energy, but no particles are released from the atom. Therefore, the number of neutrons and protons in the nucleus remain the same.

**3** During alpha decay, the atomic number of an atom drops by 2; in beta decay, the atomic number increases by 1; and in gamma decay, the atomic number does not change. Explain why.

## Lesson review

**1** Hydrogen-3 (also called tritium) is a radioisotope.

**(a)** Explain why the nucleus of tritium is unstable.

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**(b)** Tritium undergoes beta decay. State the name of the isotope formed as a result. Explain the reasons for your answer.

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**2** Some nuclear reactions produce a type of energy called neutron radiation. This is a high-energy stream of neutrons that can pass through lead, can travel more than $100\ \mathrm{m}$ in air but can be stopped by very thick concrete or large amounts of water.

Develop a table that compares the properties of neutron radiation to the properties of beta radiation. Include any similarities and differences.

**3** Using the example of the decay of fluorine-20, explain how beta decay can cause the formation of an atom of a different element. You do not need to use nuclear equations in your answer.

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**4** Below are a range of equations showing examples of nuclear decay. For each one, complete the equation and state the type of decay occurring.

**(a)** $^{210}_{84}\mathrm{PO} \rightarrow {}^{206}_{82}\mathrm{Pb} +$ ______________ Type of decay: ______________

**(b)** $^{32}_{15}\mathrm{P} \rightarrow$ ______________ $+ {}^{0}_{-1}\beta$ Type of decay: ______________

**(c)** ______________ $\rightarrow {}^{211}_{85}\mathrm{At} + {}^{4}_{2}\mathrm{He}$ Type of decay: ______________

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## 5.5 Half-lives

**Learning intention:** To understand the concept of radioactive half-life

**Success criteria:**

- [ ] **SC 1:** I can describe radioactive decay in terms of half-lives.
- [ ] **SC 2:** I can use half-lives to predict change in levels of radioactivity over time.

By studying the decay rates of radioisotopes, scientists can calculate the **half-lives** of these atoms. While this information cannot predict when an individual atom will decay, it can predict how many atoms will decay in a given length of time. In this lesson, you will learn how half-life can be applied to the science of radioactive decay to better understand radioactivity.

**KEY TERM**
**half-life** the time it takes for half of a radioactive sample to decay

### Radioactive decay and half-lives

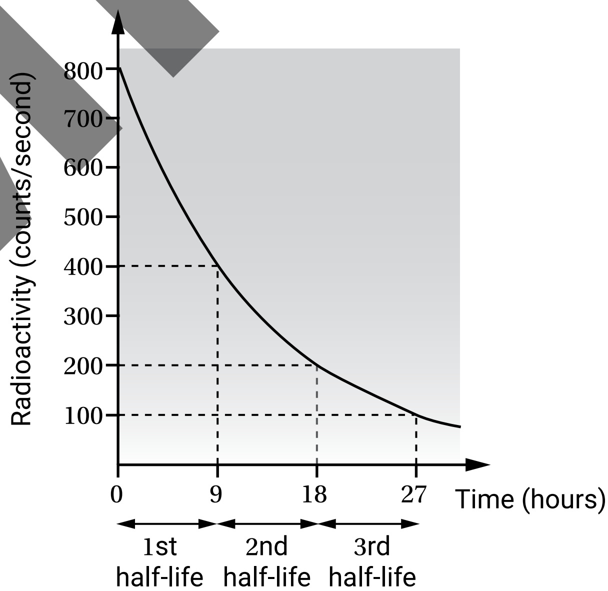
Imagine you have 80 atoms of a radioisotope. After 10 minutes, half of the atoms (40) decay into a different atom. In this case, the half-life of the decay is 10 minutes. Because the chance of a single atom decaying has not changed, over the next 10 minutes, another half (40) of the remaining 40 radioactive atoms will decay, leaving 20 radioactive atoms. This is how the idea of half-life works.

Different isotopes have different half-lives. For example, carbon-14 always has a half-life of 5730 years, and radon-222 always has a half-life of 3.8 days. Half-life can be written as $t_{½}$.

#### Measuring half-life

By measuring radioactivity, we can work out the rate at which radioisotopes decay. This is done using a Geiger counter. A Geiger counter indicates the level of radioactivity in counts per second (written 'cps') or counts per minute, with each count being one particle or burst of gamma radiation.

The graph shows the radioactivity in counts per second for a radioisotope with a half-life of 9 hours. The decay curve shows this is exponential decay, with the radioactivity decreasing by half in a constant amount of time.




**1** A Geiger counter measures the level of radioactivity of a sample of a substance.

**(a)** Explain why this helps scientists to monitor how much of a radioactive sample has decayed.

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**(b)** If the reading from a sample on a Geiger counter is 400 counts per second (cps), and the half-life of the radioisotope is 7 years, determine how long it will take for the reading to drop to 100 cps.

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## Using half-lives to predict change in radioactivity over time

The half-life of a radioisotope can be used to predict how the levels of radioactivity will change over time.

Consider a situation in which radioactivity drops from 120 cps to 60 cps in four hours, and then from 60 cps to 30 cps in the next four hours. It can be predicted that the radioactivity will halve again in the next four hours to be 15 cps.

### Isotopes with long half-lives

In general, if a radioisotope has a long half-life, the levels of radioactivity will change slowly. Americium-241, the radioactive source used in household smoke detectors, has a half-life of 432 years. This long half-life means the smoke alarm will keep working for a long time.

Plutonium-239, used in nuclear power plants and nuclear weapons, has a half-life of 24 110 years. This makes the management of waste plutonium-239 very challenging.

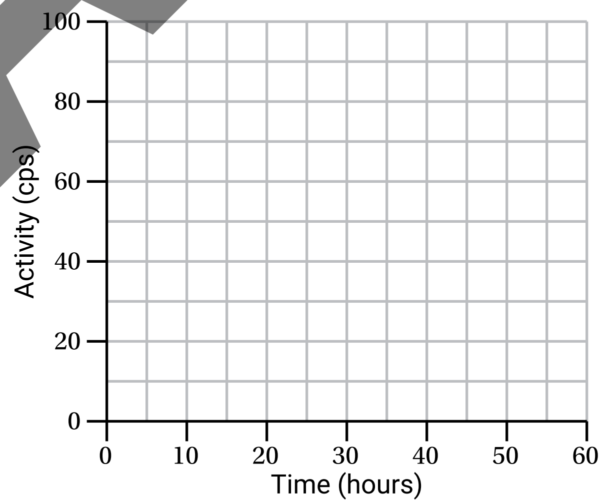
### Isotopes with short half-lives

Iodine-123, used in medical imaging, has a half-life of just over 13 hours. This short half-life means that, after only a few days, there is very little radioactivity from the iodine remaining in the body.

**2** Explain why the radioactivity of an isotope with a half-life of 30 minutes will drop significantly within a few hours.

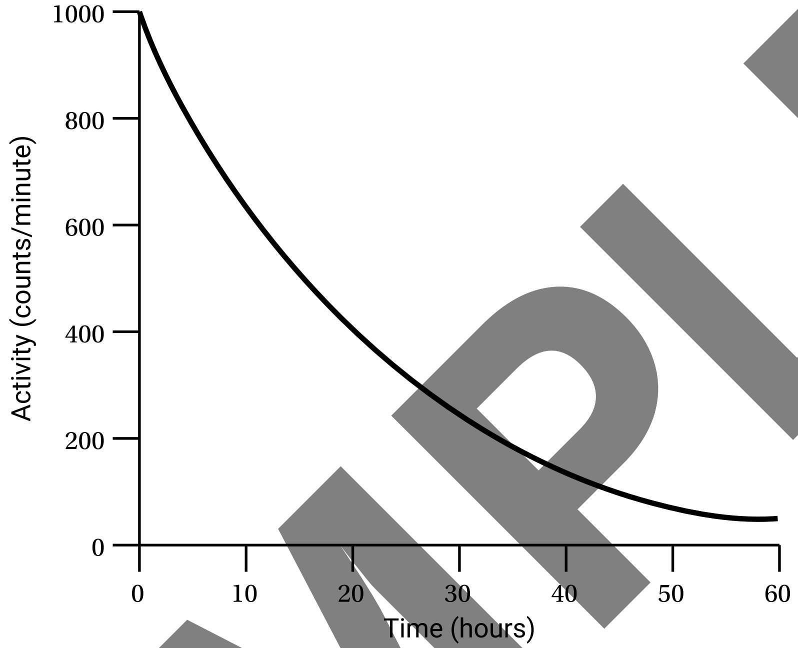
## Lesson review

**1** The radiation emitted from a radioactive sample was monitored using a Geiger counter. The radioisotope in the sample was known to have a half-life of 10 hours and the activity at the start of the experiment was 80 counts per second (cps). Draw a decay curve for this radioactive source using the graph below.



**2** One of the radioisotopes that was released into the environment as a result of the Chernobyl nuclear disaster was caesium-137, which has a half-life of 30 years. Assuming that a safe level of radiation is 2.5 cps, and that the escape of the caesium-137 resulted in levels of radiation of around 40 cps, estimate how long it would take for the radiation from this amount of caseium-137 to return to a safe level.

**3** Consider the decay curve for the radioisotope shown here.




**(a)** Estimate the half-life of this radioisotope.

**(b)** State the name of the type of trend shown by these results.

**(c)** Predict the activity of the sample after 75 hours and after 90 hours.

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## Topic review

1 In 1911 Ernest Rutherford used alpha particles to discover that most of the mass of an atom was contained in the nucleus of the atom.

**(a)** Describe what an alpha particle is.

**(b)** Describe the technology that was required for Rutherford to carry out his experiments.

**(c)** Explain how Rutherford's discovery changed scientists' understanding of electrons compared with Thomson's model proposed in 1904.

2 Draw a labelled representation of an atom of carbon-12.

3 Carbon-12 and carbon-13 are isotopes. Using these examples:

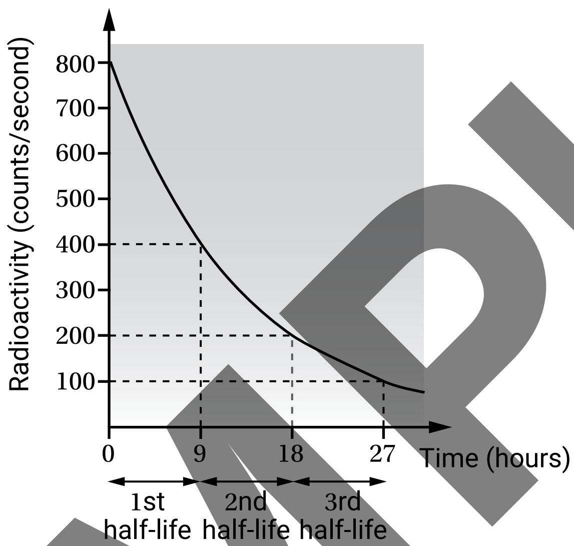
**(a)** explain the meaning of the word 'isotope' in terms of subatomic particles

**(b)** explain the meaning of the word 'isotope' in terms of atomic number and mass number.

**4** Complete the following table.

| Element | Atom | Number of protons | Number of neutrons | Mass number |
|---|---|---|---|---|
| | $^{35}_{17}Cl$ | | | 35 |
| neon | | 10 | 12 | |
| calcium | | | | 40 |
| | | 92 | | 238 |

**5** The graph below shows a radioactive decay curve.




**(a)** Use the graph to explain the meaning of exponential decay.

**(b)** Predict the level of radioactivity 45 hours from the start of the experiment.

**6** A student was modelling radioactive decay. They started by flipping 40 coins and putting all the coins that landed as tails to one side. The remaining coins were flipped again and the tails were put aside again. They repeated this procedure until all the coins had been set aside (i.e. they had all come up tails).

**(a)** Describe one strength of this model for representing radioactive decay.

**(b)** Describe one weakness of this model for representing radioactive decay.

**7** Describe three characteristics of carbon-$14$ that make it suitable for dating historical artefacts made from organic material.

**8** Uranium series dating can be used to date rock art produced by First Nations Australians. Explain two reasons that techniques other than carbon dating may be needed to date evidence of the presence of Australia's earliest inhabitants.

**9** In diagnostic nuclear medicine a small amount of a substance containing a radioisotope with a short half-life (e.g. iodine-$123$, a gamma emitter with a half-life of $13$ hours) is added to the body. In brachytherapy, small capsules containing a radioisotope with a longer half-life (e.g. iodine-$125$, with a half-life of $59$ days) are surgically implanted into the patient's body.

**(a)** Describe why a gamma emitter is good for use as a radioactive tracer.

**(b)** Explain why a short half-life is beneficial for a radioactive tracer but a longer half-life is preferred for use in brachytherapy.

**(c)** Describe how the risks of surgically implanting a radioactive source can be reduced.

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