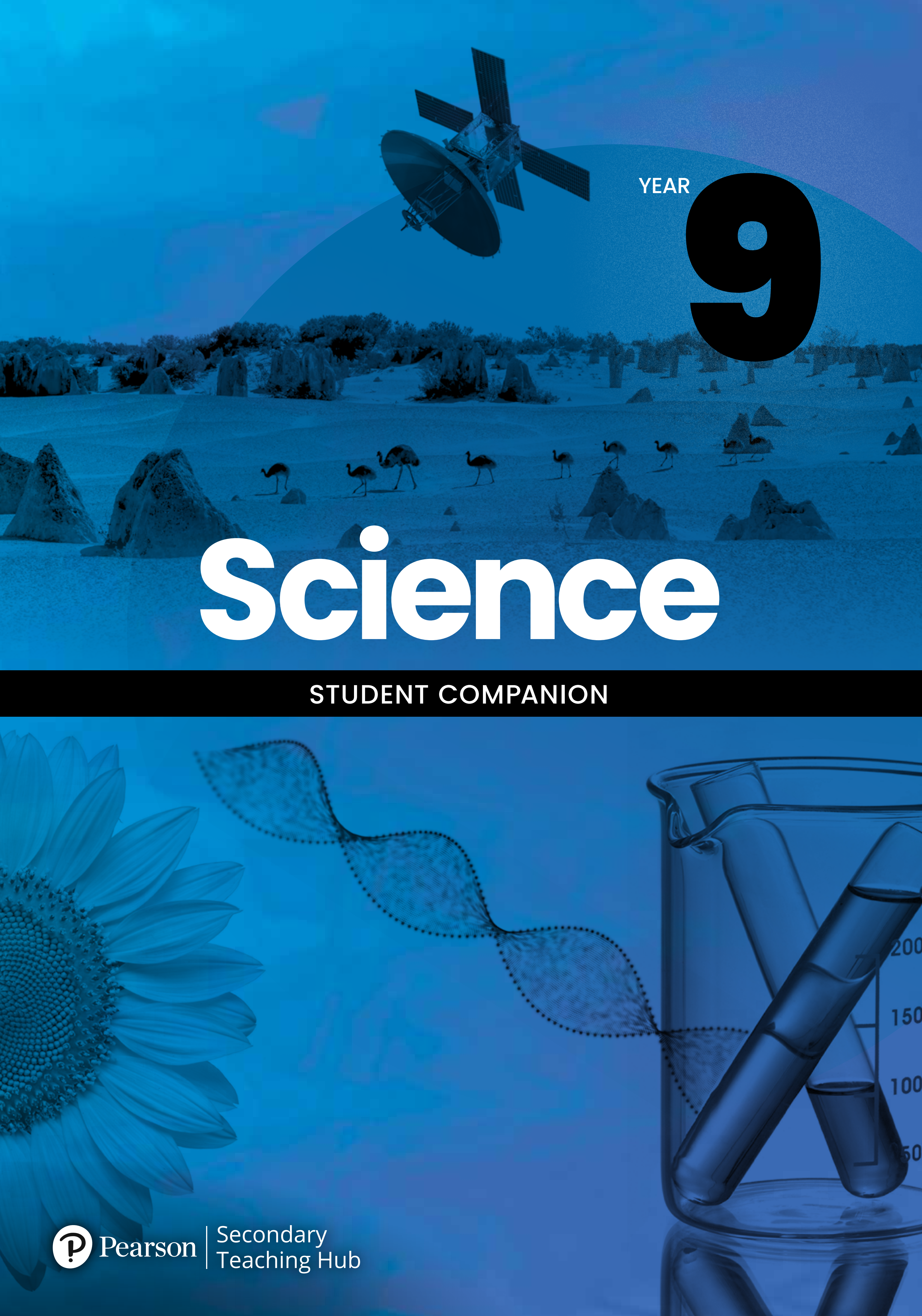

YEAR 9

Science

STUDENT COMPANION

Pearson | Secondary Teaching Hub

Pearson Secondary Teaching Hub Science 9

Student Companion

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We respect the living cultures of Aboriginal and Torres Strait Islander peoples and their ongoing connection to Country across lands, sky, seas, waterways and communities. We celebrate the richness of Indigenous Knowledge systems, shared with us and with schools Australia-wide.

We pay our respects to Elders, past and present.

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Contents

1 Body systems: Control and coordination 1

Check your prior knowledge 1
1.1 Introduction to the nervous system 3
1.2 Feedback mechanisms in the endocrine system 9
1.3 Maintaining body temperature 15
1.4 Practical investigation: Changing temperature 20
1.5 Glucose levels in the body 23
1.6 Pathogens 27
1.7 Practical investigation: Investigating the presence of pathogens 33
1.8 Body responses to pathogens 38
Topic review 41

2 Reproduction and survival of species 43

Check your prior knowledge 43
2.1 Introduction to reproduction 44
2.2 Asexual reproduction in plants 49
2.3 Sexual reproduction in plants 52
2.4 Practical investigation: Reproductive structures in a flower 56
2.5 Inquiry activity: Effect of bee populations on plant reproduction 60
2.6 Male and female reproductive systems 63
2.7 Pregnancy 67
2.8 Inquiry activity: Modelling an aspect of human reproduction 72
2.9 Raising healthy offspring 75
Topic review 78

3 Wave and particle models of energy transfer 80

Check your prior knowledge 80
3.1 Energy of particles and heat conduction 81
3.2 Practical investigation: Heat conduction in materials 84
3.3 Heat convection 87
3.4 Transfer of electrical energy 91
3.5 Practical investigation: Using resistance to control electric current 95
3.6 Longitudinal and transverse waves 98
3.7 Electromagnetic radiation 102
3.8 Inquiry activity: Energy transfer and wi-fi 106
3.9 Practical investigation: Investigating heat radiation 110
Topic review 112

4 Conservation of energy and efficiency in systems 115

Check your prior knowledge 115
4.1 Conservation of energy 116
4.2 Practical investigation: Energy transformations 119
4.3 Energy calculations 121
4.4 Practical investigation: Investigating gravitational potential energy and kinetic energy 124
4.5 Wasted energy 128
4.6 Energy efficiency 131
4.7 Sankey diagrams 135
4.8 Practical investigation: Efficiency of a roller-coaster 139

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Contents

4.9 Improving efficiency 144
4.10 Inquiry activity: Impacts of energy efficiency 147
Topic review 151

5 Atomic structure and radioactivity 156
Check your prior knowledge 156
5.1 Marie Curie and elements 157
5.2 Practical investigation: Modelling atomic structure 160
5.3 Inquiry activity: Contributions to atomic theory 162
5.4 Elements and atoms 164
5.5 Isotopes 168
5.6 Radioactivity and nuclear decay 172
5.7 Half-lives 176
5.8 Practical investigation: Modelling radioactive decay 180
5.9 Inquiry activity: Radioactivity in medicine 182
Topic review 184

6 Chemical reactions: rearranging atoms 188
Check your prior knowledge 188
6.1 Chemical reactions 190
6.2 Practical investigation: Conservation of mass in a chemical reaction 196
6.3 Types of chemical reactions 199
6.4 Practical investigation: Comparing chemical reactions 203
6.5 Atomic rearrangement in chemical reactions 207
6.6 Balancing chemical equations 211
6.7 Uses of chemical reactions 217
6.8 Inquiry activity: Advantages of green chemistry 223
6.9 Practical investigation: Combustion reactions of fuels 225
Topic review 228

7 The carbon cycle and global systems 231
Check your prior knowledge 231
7.1 Earth's spheres 233
7.2 Introduction to the carbon cycle 238
7.3 Practical investigation: Investigating cellular respiration and photosynthesis in plants 243
7.4 Practical investigation: The greenhouse effect 247
7.5 Carbon dioxide and the greenhouse effect 251
7.6 Monitoring greenhouse gas emissions 257
7.7 Reducing carbon dioxide in the atmosphere 260
Topic review 265

* These markers indicate that the images or words used in this section may be culturally sensitive to some Aboriginal and Torres Strait Islander peoples.

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 support teaching and learning by providing learners with a place to create a portfolio of learning to suit their individual needs, whether you are:

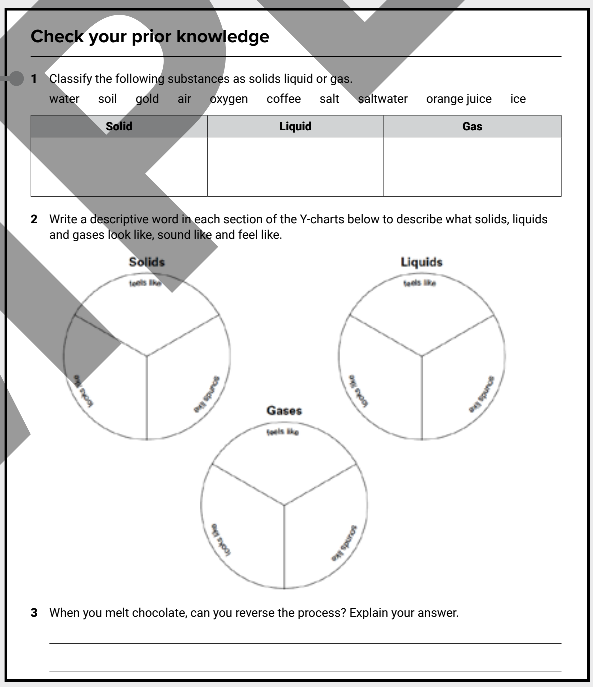
- supporting a blended classroom using the strengths of print and digital
- preparing for exams by creating a study guide or bound reference
- needing a tool to differentiate learning
- looking for meaningful homework tasks.

Learners can develop their portfolio of learning 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 topics in the Australian Curriculum. These questions provide insight into learners' prior knowledge before beginning a topic, allowing teachers to adapt their teaching and support as needed.


Check your prior knowledge

1 Classify the following substances as solids liquid or gas.
water soil gold air oxygen coffee salt saltwater orange juice ice

Solid	Liquid	Gas

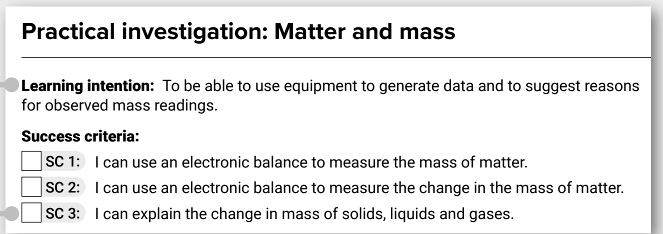
2 Write a descriptive word in each section of the Y-charts below to describe what solids, liquids and gases look like, sound like and feel like.

3 When you melt chocolate, can you reverse the process? Explain your answer.

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.


Practical investigation: Matter and mass

Learning intention: To be able to use equipment to generate data and to suggest reasons for observed mass readings.

Success criteria:
- SC 1: I can use an electronic balance to measure the mass of matter.
- SC 2: I can use an electronic balance to measure the change in the mass of matter.
- SC 3: I can explain the change in mass of solids, liquids and gases.

Icons and features

hub

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

SPARKlab

SPARKlab icons direct learners to alternative, online practical investigations.

MATERIALS

Handle pin with care

- 2 × 100 mL beakers
- measuring cylinder
- plastic cling wrap
- ice cubes
- warm water
- 2 × balloons (uninflated)
- 3 × lengths of string (each about 30 cm long)
- 1 m ruler
- heavy object (such as a book)
- pin
- needle
- electronic balance (accurate to at least 0.1 g)

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
Try to inflate the balloons to the same size at the start.

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
volume the amount of space that a substance or object occupies
mass the amount of matter in a substance

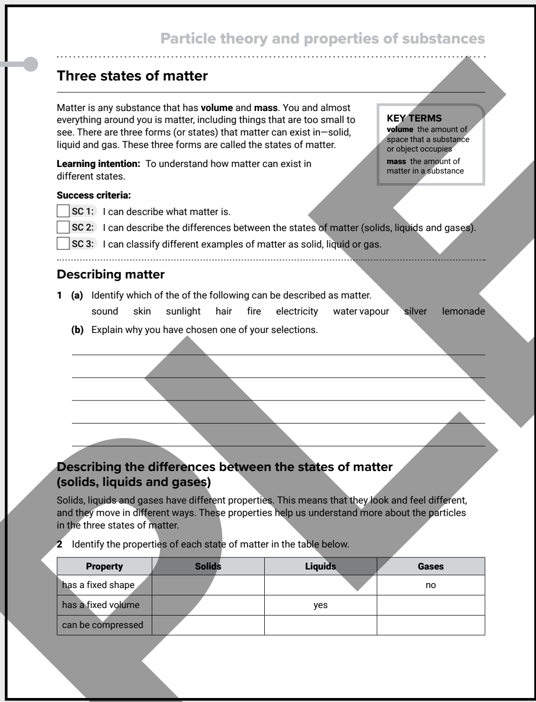
Key term boxes provide learners with definitions for the bolded key terms found throughout the text, supporting the development of their scientific vocabulary and literacy.

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.

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.


Particle theory and properties of substances

Three states of matter

Matter is any substance that has **volume** and **mass**. You and almost everything around you is matter, including things that are too small to see. There are three forms (or states) that matter can exist in—solid, liquid and gas. These three forms are called the states of matter.

KEY TERMS
volume the amount of space that a substance or object occupies
mass the amount of matter in a substance

Learning intention: To understand how matter can exist in different states.

Success criteria:
- SC 1: I can describe what matter is.
- SC 2: I can describe the differences between the states of matter (solids, liquids and gases).
- SC 3: I can classify different examples of matter as solid, liquid or gas.

Describing matter

1 (a) Identify which of the of the following can be described as matter.
sound skin sunlight hair fire electricity water vapour silver lemonade
(b) Explain why you have chosen one of your selections.

Describing the differences between the states of matter (solids, liquids and gases)

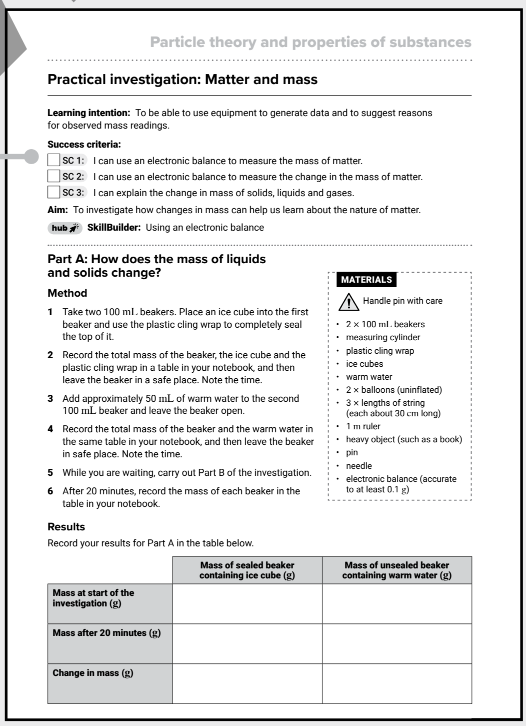
Solids, liquids and gases have different properties. This means that they look and feel different, and they move in different ways. These properties help us understand more about the particles in the three states of matter.

2 Identify the properties of each state of matter in the table below.

Property	Solids	Liquids	Gases
has a fixed shape			no
has a fixed volume		yes	
can be compressed			

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.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Practical investigation: Matter and mass

Learning intention: To be able to use equipment to generate data and to suggest reasons for observed mass readings.

Success criteria:
- SC 1: I can use an electronic balance to measure the mass of matter.
- SC 2: I can use an electronic balance to measure the change in the mass of matter.
- SC 3: I can explain the change in mass of solids, liquids and gases.

Aim: To investigate how changes in mass can help us learn about the nature of matter.

hub **SkillBuilder:** Using an electronic balance

Part A: How does the mass of liquids and solids change?

Method

1 Take two 100 mL beakers. Place an ice cube into the first beaker and use the plastic cling wrap to completely seal the top of it.
2 Record the total mass of the beaker, the ice cube and the plastic cling wrap in a table in your notebook, and then leave the beaker in a safe place. Note the time.
3 Add approximately 50 mL of warm water to the second 100 mL beaker and leave the beaker open.
4 Record the total mass of the beaker and the warm water in the same table in your notebook, and then leave the beaker in safe place. Note the time.
5 While you are waiting, carry out Part B of the investigation.
6 After 20 minutes, record the mass of each beaker in the table in your notebook.

MATERIALS
Handle pin with care
- 2 × 100 mL beakers
- measuring cylinder
- plastic cling wrap
- ice cubes
- warm water
- 2 × balloons (uninflated)
- 3 × lengths of string (each about 30 cm long)
- 1 m ruler
- heavy object (such as a book)
- pin
- needle
- electronic balance (accurate to at least 0.1 g)

Results

Record your results for Part A in the table below.

	Mass of sealed beaker containing ice cube (g)	Mass of unsealed beaker containing warm water (g)
Mass at start of the investigation (g)		
Mass after 20 minutes (g)		
Change in mass (g)		

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.

Particle theory and properties of substances

Inquiry activity: Investigating freezing

Freezing occurs when particles in a liquid lose energy and their movement slows down. When the particles move less, they form a solid. The temperature at which a liquid becomes solid is called its freezing point.

In this activity, the rate of freezing is the **dependent variable**. The **independent variable** is something that changes the rate of freezing.

In this investigation you will be selecting an independent variable to investigate. You will write an inquiry question about whether changing this independent variable will affect how quickly a liquid freezes.

Learning intention: To be able to develop and test questions to explore freezing.

Success criteria:

☐ **SC 1:** I can develop an investigable question that identifies an independent variable.

☐ **SC 2:** I can design and evaluate a valid method, including the selection of equipment, to test the effect of an independent variable.

☐ **SC 3:** I can write a conclusion based on evidence from the investigation.

KEY TERMS

freezing the change in state from a liquid to a solid

dependent variable a factor that is measured in an investigation to test the effect of changing another factor (the independent variable)

independent variable the factor that is changed in an investigation to find out how it affects another factor (the dependent variable)

Aim

To develop and test an inquiry question that explores freezing.

Plan your investigation

1 Write 2–4 inquiry questions about freezing that you would like to investigate. Remember to include an independent variable in each of your questions.

2 Review your inquiry questions and select one that you will be able to investigate with the materials and time available to you. Write your question for investigation below and check-in with your teacher.

HINTS

The rate of freezing can be influenced by environmental factors that change how quickly something cools. These factors include:

- the amount of liquid
- the type of liquid and if it is mixed with other substances
- the size and shape of the container that the liquid is in.

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

Worked examples

Worked examples provide learners with a step-by-step solution to a problem. The worked examples in the Student Companion correspond to those in the digital lesson and are provided for each skill to:

- scaffold learning
- support skill acquisition
- reduce the cognitive load.

The worked examples are an effective tool to demonstrate what success looks like. The 'try yourself' format of the worked examples in the Student Companion support the gradual release of responsibility. Learners can view a completed worked example and a video walkthrough of the worked example in the corresponding digital lesson and then apply the scaffolded steps themselves to solve a unique problem.

Worked example: Hypotheses and predictions

Problem

Devi was exploring safety and slip hazards at her school and wanted to investigate the effect of water on the friction between two surfaces. Develop a hypothesis and prediction for her to test.

Solution

Thinking	Working
Identify the independent variable. The independent variable is changed by the scientist.	The independent variable is the water.
Identify the dependent variable **The dependent variable changes in response to the independent variable.**	The dependent variable is the amount of friction between two surfaces.
Write a testable hypothesis. **The hypothesis should include the independent variable (the water) and the dependent variable (the amount of friction between two surfaces).**	The hypothesis is: If water is added to two surfaces in contact with each other, then there will be a reduction of friction between the two surfaces.
Write a prediction to test the hypothesis. **The prediction should be based on whether changing the independent variable (adding water) causes an observable change to the dependent variable (the amount of friction between two surfaces).**	The prediction is: If water is added to a wooden plank, then less force will be required to move a wooden block along the plank because there will be less friction between the surfaces.

Try yourself

Problem

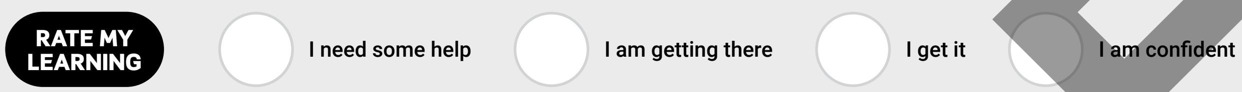
Devi wanted to investigate whether heating a liquid makes it runnier.

Solution

Thinking	Working
Identify the independent variable.	
Identify the dependent variable.	
Write a testable hypothesis.	
Write a prediction to test the hypothesis.	

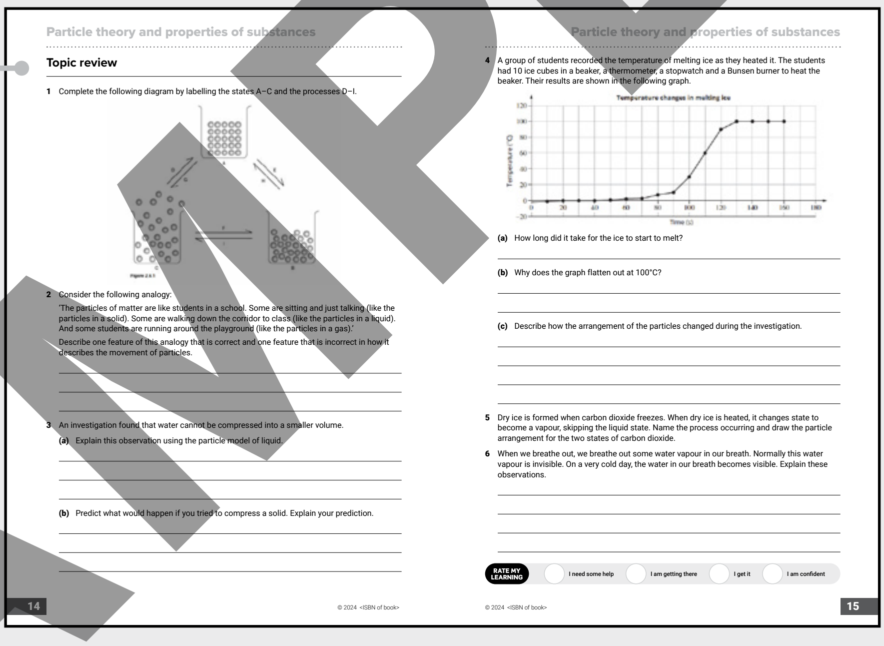
Rate my learning tool

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.



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.


Particle theory and properties of substances

Topic review

1 Complete the following diagram by labelling the states A–C and the processes D–I.

2 Consider the following analogy:
'The particles of matter are like students in a school. Some are sitting and just talking (like the particles in a solid). Some are walking down the corridor to class (like the particles in a liquid). And some students are running around the playground (like the particles in a gas).'
Describe one feature of this analogy that is correct and one feature that is incorrect in how it describes the movement of particles.

3 An investigation found that water cannot be compressed into a smaller volume.
(a) Explain this observation using the particle model of liquid.
(b) Predict what would happen if you tried to compress a solid. Explain your prediction.

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Particle theory and properties of substances

4 A group of students recorded the temperature of melting ice as they heated it. The students had 10 ice cubes in a beaker, a thermometer, a stopwatch and a Bunsen burner to heat the beaker. Their results are shown in the following graph.

(a) How long did it take for the ice to start to melt?
(b) Why does the graph flatten out at 100°C?
(c) Describe how the arrangement of the particles changed during the investigation.

5 Dry ice is formed when carbon dioxide freezes. When dry ice is heated, it changes state to become a vapour, skipping the liquid state. Name the process occurring and draw the particle arrangement for the two states of carbon dioxide.

6 When we breathe out, we breathe out some water vapour in our breath. Normally this water vapour is invisible. On a very cold day, the water in our breath becomes visible. Explain these observations.

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

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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

 ISBN 978 0 6557 1380 7

5.1 Marie Curie and elements

Learning intention: To understand the role that Marie Curie played in the modern understanding of atoms

Success criteria:

- [ ] **SC 1:** I can describe the challenges Marie Curie faced as a scientist.
- [ ] **SC 2:** I can explain how Marie Curie improved knowledge of atoms and radioactivity.
- [ ] **SC 3:** I can explain how Marie Curie's discoveries were accepted and recognised by the scientific community.

Although she faced many obstacles, Marie Curie was the first woman to receive a Nobel Prize, the first woman to teach at the prestigious Sorbonne in Paris, and the first and only person to receive two Nobel Prizes in different sciences. In this lesson, you will learn about this extraordinary woman and the contributions she made to science and society.

Challenges Marie Curie faced as a scientist

Poland 1867	Marie is born in Warsaw, Poland. Her family is not wealthy. She cannot formally attend university in Poland because she is a woman, so she has to leave her homeland.
Paris 1891	Marie travels to Paris and begins studying at the Sorbonne. She has to support herself while studying. She studies Physics and Mathematics and is a top student even though she is studying in a different language.
Paris 1893–4	Marie obtains a Master's in Physics in 1893. She completes a second degree in Chemistry. Marie meets Pierre Curie.
Paris 1896	Henri Becquerel discovers invisible rays of high energy. Marie names this phenomenon 'radioactivity' and starts working to isolate the element that is creating the radioactivity.
Paris 1897	Marie has her first child, Irene. Marie constantly has to juggle work with motherhood.
Paris 1898–1900	Marie and Pierre first identify polonium in 1898, and Marie names it after her homeland. Radium is isolated later in 1898. Marie becomes the head of the Physics Laboratory and begins teaching at a girls' school.
Paris 1903	Marie achieves a Doctor of Science degree from the Sorbonne, the first woman to do so. Henri Becquerel, Marie and Pierre are nominated for a Nobel Prize for their discoveries of radioactivity, polonium and radium. Initially, Marie's name is left off the acknowledgement, but Pierre refuses to accept it without her being recognised.
Paris 1906	Pierre dies in an accident. Marie begins teaching some of his Physics classes while completing their research on her own.
Paris 1911	Marie works to produce a method to isolate radium from a uranium-rich mineral called pitchblende. She works with large quantities of pitchblende in an unventilated laboratory. The work earns her a nomination for a second Nobel Prize.
Paris 1914	Marie is appointed as the Director of the Curie Laboratory at the University of Paris, gaining worldwide recognition. During World War I she creates mobile X-ray units and trains people (mostly women) to use them to treat casualties more quickly during the war.

United States of America 1929	Marie is invited to the United States on several occasions to receive accolades. In 1929 she receives a gift of US$50 000, which she puts towards her research.
Paris 1934	Marie dies, leaving a legacy. Her daughter Irene also studies Physics and produces the first radioisotopes, which will be used for medical purposes. Irene and her husband Frederic receive a Nobel Prize in 1935 for their work.

1 List three hardships that Marie had to overcome to achieve her scientific discoveries.

Marie Curie's contribution to our knowledge of atoms and radioactivity

Radioactivity

When Henri Becquerel first discovered **radioactivity**, he was unsure what he had found. He knew it was 'invisible **radiation**' and he knew it was not X-rays. The work of Marie and Pierre Curie expanded on the knowledge of this 'invisible radiation'.

KEY TERMS

radioactivity amount of radiation emitted from a nucleus undergoing nuclear decay

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

ionising radiation any form of radiation that has the ability to remove electrons from atoms and molecules

Detecting radiation

Becquerel had found that photographic plates were affected by nearby uranium salts, meaning the uranium salts were emitting **ionising radiation**.

Energy from within atoms

Marie and Pierre discovered that the source of the ionising radiation was two elements, which they named polonium and radium. Marie hypothesised that the ionising energy was not coming from the arrangement of the atoms but from within the atoms themselves.

Isolating radium

Marie had no luck isolating polonium, so she turned to radium. Using large quantities of the metal ore pitchblende, Marie created a chemical process to isolate the radium from the other elements in the mineral. She succeeded in isolating the radium salt, which paved the way for industry to use the method to produce larger quantities. Marie and Pierre published their findings and presented them at the 1900 International Congress of Physics.

2 Describe Marie Curie's hypothesis about the source of radioactivity.

Acceptance and recognition of Marie Curie's discoveries

Marie was the first woman to win a Nobel Prize, sharing the prize in Physics with Henri Becquerel and Pierre in 1903. In 1911, Marie received a second Nobel Prize, this time in Chemistry, for isolating radium. To date, she is the only person to have received two Nobel Prizes in two different scientific fields.

In 1906, Marie was invited to teach at the Sorbonne, the first woman to do so, as a Professor of General Physics. In 1914, Marie became the Director of the Curie Laboratory at the University of Paris.

After her death, the element curium was discovered and named after Marie and Pierre. In 1995 Marie's remains were enshrined in the Panthéon in Paris, an honour reserved for only the most revered people in France.

3 Make a list of the ways in which Marie Curie's discoveries were accepted and recognised by the scientific community.

Lesson review

1 Think about the research Marie and Pierre Curie undertook in 1898. They were trying to isolate the elements inside pitchblende that gave rise to radioactivity. Suggest a modern technology that may have aided the research. Explain how this would have helped.

2 Becquerel's work laid the foundation for the Curies' work. What information did the Curies contribute to the understanding of atoms and radioactivity?

3 At the same time as Marie and Pierre Curie were working on isolating radium, Ernest Rutherford, a New Zealand scientist, was investigating 'the disintegration of elements and the chemistry of radioactive substances'. How might Rutherford have benefited from the work of the Curies?

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

5.2 Practical investigation: Modelling atomic structure

Learning intention: To be able to use a model to show how atoms are made up of subatomic particles

Success criteria:

- [ ] SC 1: I can create a representation of an atom that shows the relationships between the subatomic particles including protons, neutrons and electrons.
- [ ] SC 2: I can describe the key features of each subatomic particle.

Background

An atom is made up of three types of subatomic particles: **protons**, **electrons** and **neutrons**. In this practical investigation, you will explore the structure of the atom and its subatomic particles to help you visualise both what an atom looks like and the key features of the atomic particles.

KEY TERMS

proton a subatomic particle with a positive electric charge, located in the nucleus of an atom

electron a subatomic particle with a negative electric charge, located around the nucleus of an atom

neutron a subatomic particle with no electric charge, located in the nucleus of an atom

Aim

To construct a model of an atom that shows the internal structure

⚠ Complete a risk assessment that outlines the risks and precautions you need to take to minimise them.

MATERIALS

- different colour modelling clay to represent the different subatomic particles
- large toothpicks or skewers
- A3 sheets of paper and colouring pens
- sticky labels

Method

Using the materials you have been provided, write the steps to construct a model of an atom in the space below. You can choose which atom to build, or your teacher may assign you an atom. Make the subatomic particles different colours and add labels to your model.

If you are not able to produce a three-dimensional model, you can design a two-dimensional representation.

Results

Present your model to other students and/or your teacher and request feedback.

- [ ] Check in with your teacher to discuss your risk assessment.

Conclusion

1 What is the charge on the protons, neutrons and electrons? How did you represent this in your model?

2 What is the relative mass of the protons, neutrons and electrons? How did you represent this in your model?

3 The electrons in an atom move around the nucleus of the atom. How did you represent this in your model?

Evaluation

1 Based on feedback received and after viewing other models, explain one improvement that you could make to your model.

2 Describe how constructing a model helped you to improve your understanding of atomic structure.

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5.3 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 atoms.
- [ ] 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 or three-dimensional diagrams 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 a two- or three-dimensional timeline that summarises the four models of the atom. In the timeline, 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.

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5.4 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.

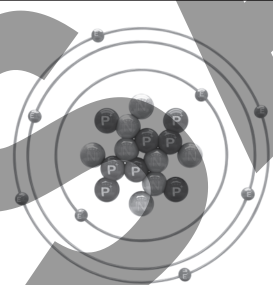
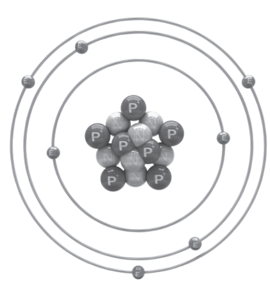
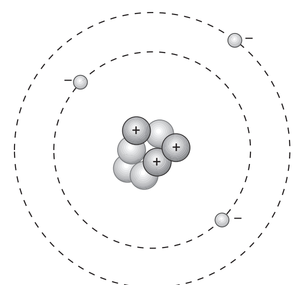
KEY TERMS

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

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

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.

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

	$^{24}_{12}\text{Mg}$	$^{71}_{35}\text{Cl}$	$^{48}_{22}\text{Ti}$
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 ($A - Z$).

This means that 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						
^{138}Ba						
^{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) What is its mass number? ____________________

3 An atom has 15 protons and its mass number is 31.

(a) Identify this atom. ____________________

(b) How many neutrons does it have? ____________________

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5.5 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.

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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5.6 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.

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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 1.

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.

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Lesson review

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

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

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

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 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.

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

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

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

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

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5.7 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.

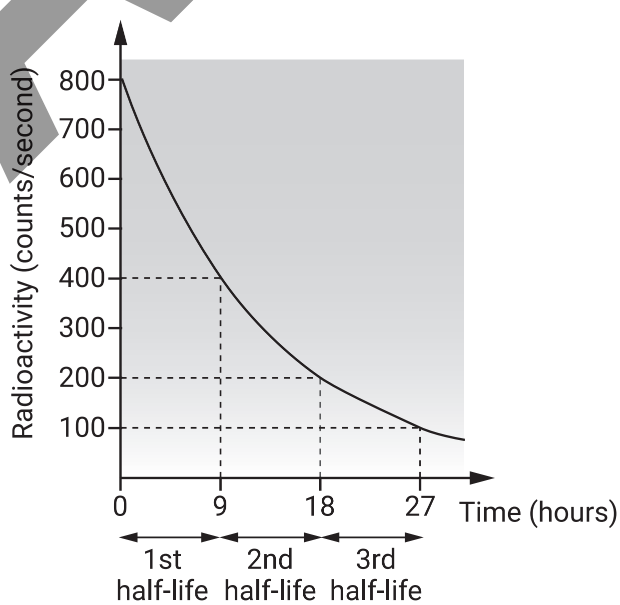
Different isotopes have different half-lives. For example, carbon-14 always has a half-life of 5730 years, and radon-222 always has a half-life of 3.8 days. Half-life can be written as t½.

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 following 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.



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

(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.

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.

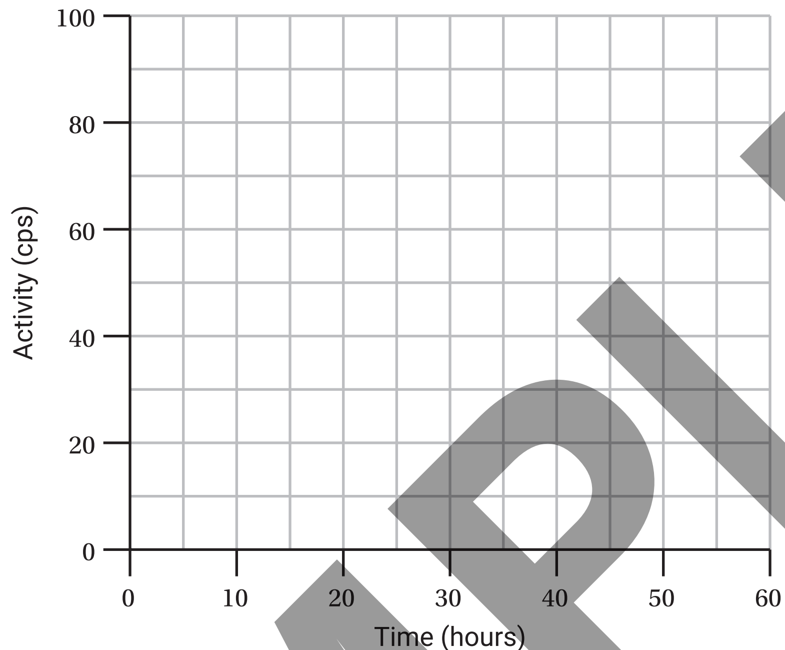
Isotopes with short half-lives

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.

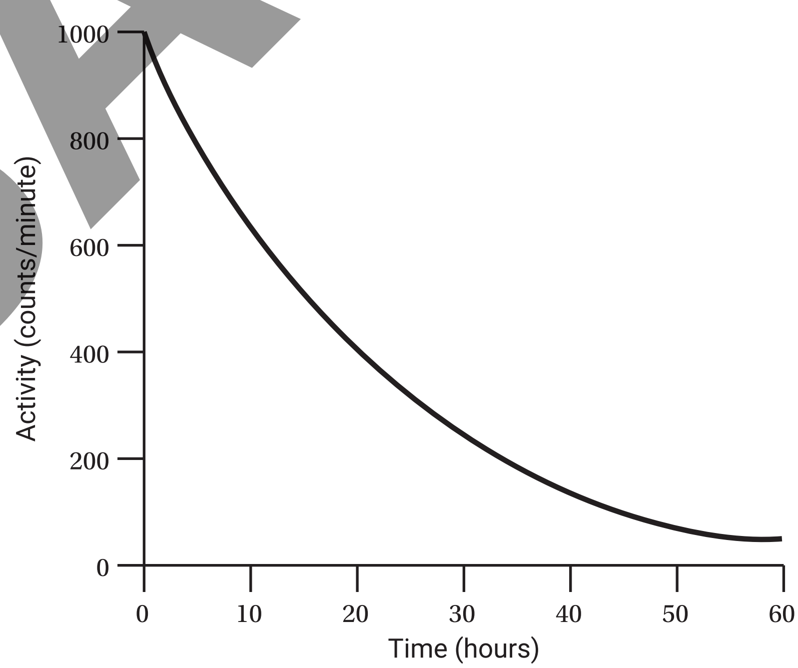
Lesson review

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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5.8 Practical investigation: Modelling radioactive decay

Learning intention: To be able to model radioactive decay

Success criteria:

- [ ] SC 1: I can describe patterns in data collected from a simulation involving half-lives.
- [ ] SC 2: I can compare trend patterns in simulated data to real half-life data.

Background

The nuclear decay of an atom of a radioisotope is a purely random event. We cannot predict when it will happen, but scientists can calculate the chance of it happening over a particular length of time. In this practical investigation, you will model the nuclear decay of radioisotopes and the concept of half-life.

Aim

To model radioactive decay and half-life

MATERIALS

- a packet of M&Ms or Skittles or two-sided tokens
- a clean tray or sheet of A3 paper
- a clean jar or cup

Safety notes

- It is unsafe to eat food in the laboratory. Do not eat any of the lollies during the experiment.

Complete a risk assessment that outlines the risks and precautions you need to take to minimise them.

Method

1 Use the results table below or your own table to record results. Alternatively, construct a spreadsheet with similar columns.

2 Count the total number of M&Ms in the packet and put them into the jar.

3 Shake the jar up to mix the lollies around. Pour the jar of M&Ms onto the clean tray or A3 paper.

4 Count how many M&Ms show the letter M facing upwards. Record this number in the table.

5 Place only the M&Ms showing the letter M back into the jar and dispose of the other M&Ms appropriately.

6 Repeat steps 3–5 until there is only 1 M&M left in the jar.

Results

Number of throws	0	1	2	3	4	5	6	7	8	9	10
Number of M&Ms showing the letter M											

Construct a line graph of the number of M&Ms remaining (those that showed the letter M) versus the number of times the procedure was repeated. Alternatively, use a spreadsheet to plot a graph for you.

hub **SkillBuilder:** Creating a line graph using a spreadsheet

- [ ] Check in with your teacher to discuss your risk assessment.

Conclusion

1 Describe the shape of the graph that you produced.

hub **SkillBuilder:** Analysing a line graph

2 The half-life of atoms of a radioisotope is the time it takes for half the nuclei to decay. Describe how half-life is represented in this experimental model.

Evaluation

Discuss how this experiment models radioactive decay and half-life.

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5.9 Inquiry activity: Radioactivity in medicine

Learning intention: To be able to explain the use of radioactivity in medicine

Success criteria:

- [ ] **SC 1:** I can describe how radioactivity can be used in the diagnosis and treatment of cancer.
- [ ] **SC 2:** I can identify and suggest risk mitigation strategies for the use of radiation in medicine.
- [ ] **SC 3:** I can predict how advances in technologies will affect the use of radiation in medicine.

Background

Radiation in medicine is used diagnostically and therapeutically. Diagnostic methods aim to identify causes of medical problems, such as the location of a tumour, the site of bone fractures or the function of an organ. Therapeutic methods use radiation to treat the medical condition. This might involve using high-energy radiation in a controlled way to reduce the growth of cancer cells, by damaging the genetic material (DNA) within the cells. In this inquiry activity, you will learn about the ways that radiation can be used in medicine and conduct some guided research into a particular example of its use.

Aim

To conduct research to explain the use of one example of radioactivity in medicine

Present your findings in a way guided by your teacher. This could be a slide show, a written article or a form of audio-visual presentation.

Plan

1 Decide on the example of the use of radioactivity in medicine that most interests you. Some examples include X-rays, radiography, diagnostic nuclear medicine, radiation therapy, brachytherapy and stereotactic radiosurgery.

2 Decide how you will present your findings.

3 If you are working in a group, assign roles to people in the team.

4 In your presentation or text, you will need to answer the following questions based on the context that you have chosen for your inquiry.

- How is radioactivity used in the diagnosis or treatment of a form of cancer?
- What are the risks associated with this use of radiation in medicine and how are these risks reduced?
- How might advances in technologies affect your chosen use of radiation in medicine into the future?

Conduct

Create your article or presentation based on your planning notes and guidance from your teacher. Ensure that you have included answers to the three questions listed in the plan. Read the notes below for further elaboration.

■ How is radioactivity used in the diagnosis or treatment of a form of cancer?

Consider whether the technique that you are investigating is used to identify, locate or monitor an existing form of cancer or if it is used to reduce the harm caused by the disease. In diagnosis, you can comment on how the data is analysed, how reliable or accurate it is, and whether there are any ethical issues related to the use of the data. For radiotherapy, you can explore how successful the treatment is, whether it involves invasive surgery, the potential length of treatment plans and the financial costs of the therapy. Include the names, and where possible the properties, of the radioisotopes used in the treatments.

- What are the risks associated with this use of radiation in medicine and how are these risks reduced for patients?

Consider the type of radioactive sources used in the treatment in terms of the type of radiation that is emitted, and the half-lives of the radioisotopes used in the procedures. You can consider the short-term risks and also the long-term effects if radioactive material is left in the body, or multiple treatments are required. You can also investigate the potential risks for the health professionals administering the treatments, as well as the patients themselves, and potential alternate treatments if required.

- How might advances in technologies affect your chosen use of radiation in medicine into the future?

Consider factors such as the miniaturisation of technology, the increase in computer speed and capacity, the improvements in three-dimensional imaging and modelling, and the influence of increased use of artificial intelligence. Future societal demands and influences, including changing attitudes to risk, could also influence the use and development of radio medicine.

Improve

After receiving feedback on your presentation or article, describe one improvement that you could make to your inquiry that would improve how you have communicated your findings and ideas.

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Topic review

1 Describe one challenge that Marie Curie faced as a scientist and explain how she overcame that challenge.

2 Draw a labelled representation of an atom that shows the position, charge and relative size of protons, neutrons and electrons.

3 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.

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

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

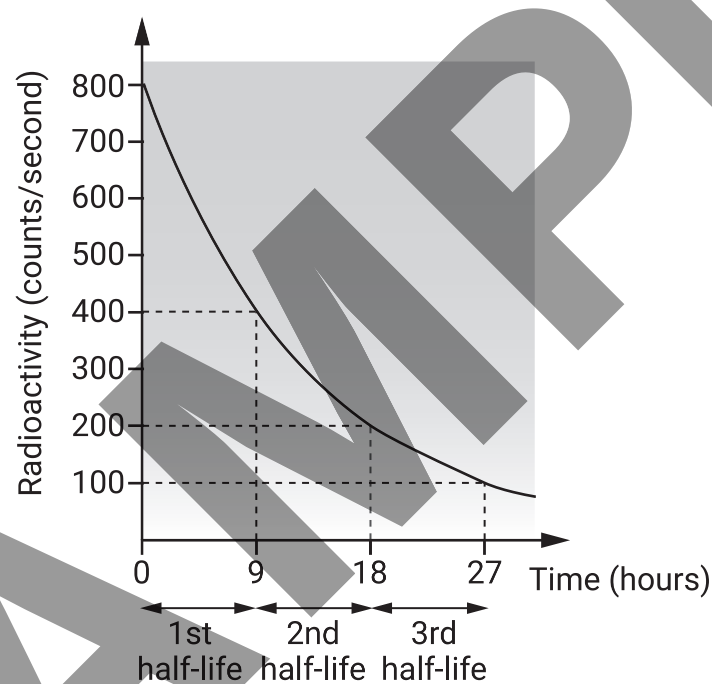
(a) explain the meaning of the word 'isotope' in terms of subatomic particles

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

6 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

7 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.

8 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.

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

10 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.

11 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) Using examples, describe the difference between diagnostic nuclear medicine and radiation therapy (e.g. brachytherapy).

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

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

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

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