Lesson 1

Topic: Exploring radioisotopes

Introducing radioactive decay

Lesson concepts:

- All matter is made of atoms, which are composed of protons, neutrons and electrons; natural radioactivity arises from the decay of nuclei in atoms
- Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries
- Scientific ideas and information can be communicated using scientific language, conventions and representations

Learning alerts

Be aware of:

- Students thinking that all radiation is necessarily dangerous irrespective of level.
- Students thinking that changes in the number of neutrons in an atom's nucleus result in a change in the type of element.

Suggested next steps for learning

- Explain that some types of radiation are harmful but radiation is naturally present in the environment.
- Explain that the number of protons in the nucleus determines the type of element. Changing the number of neutrons does not necessarily change the number of protons.

Science start-up notes

In this activity, students will be required to write notes on the work of Marie Skłodowska-Curie.

Lesson notes

In this lesson, students will complete several activities that require them to identify and describe radioactive decay processes.

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Science prior knowledge answers

1. a) radioisotope — an isotope which is subject to radioactive decay

   b) radioactive decay — natural change in the composition of an atomic nucleus; the process by which radioisotopes decay and emit radiation.

2. Which particle in the nucleus determines the stability of an isotope?

   The neutron in the nucleus determines the stability of an isotope. There must be enough neutrons in proportion to protons to hold the nucleus together.

3. Marie Skłodowska-Curie:

- used techniques devised by her husband to measure the radiations in pitchblende (an ore containing uranium)
- identified there were radiations from the ore more radioactive than the ore itself
- was the first scientist to use the term radioactive, to describe elements that give off radiation as their nuclei break down
- was joined by her husband in her research and in 1898 they announced their discovery of polonium and radium
- in 1903, shared with her husband and another French scientist the Nobel Prize in Physics for the discovery of radioactive elements. Marie Skłodowska-Curie became the first woman to win the Nobel Prize
- was awarded the Nobel Prize in 1911 in chemistry, for her work on radium and radium compounds.

Lesson answers

4. No response required.

5. Sheet 1 — Exploring radioactive decay (attached).

6. a) No response required.

   b) All of the barriers (not considering air) were able to stop the alpha particles (a sheet of paper, or even the skin of our bodies, will stop alpha particles). Glass and lead stopped the beta particles. Lead was the most efficient at stopping the penetrating and damaging gamma radiation.

   c) The further the distance from the radiation source, the lower the amount of radiation measured. Alpha particles travelled the shortest distance and gamma radiation the greatest distance.

   d) Gamma radiation could cause harm because it can pass through the most types of material and travel the furthest distance.

7. A radioisotope achieves stability by emitting radiation and/or particles when it decays.

   The ionising radiation emitted from an unstable atom's nucleus can be in the form of alpha or beta particles or gamma radiation.

Topic: Exploring radioisotopes

Introducing half-life

Lesson concepts:

- All matter is made of atoms, which are composed of protons, neutrons and electrons; natural radioactivity arises from the decay of nuclei in atoms
- Advances in science and emerging sciences and technologies can significantly affect people's lives
- Scientific ideas and information can be communicated using scientific language, conventions and representations

Learning alerts

Be aware of:

- Students thinking that all radiation is necessarily dangerous irrespective of level.
- Students misunderstanding half-life — in particular, conceiving that radiation would be extinguished in two half-lives, rather than reducing by half of what remains after each half-life.

Suggested next steps for learning

- Explain that some types of radiation are harmful but radiation is naturally present in the environment.
- Demonstrate half-life as a fixed proportion of a reducing amount.

Science prior knowledge notes

In this activity, students will fill in a table as a review of the types of radiation.

Lesson notes

In this lesson, students will examine the radioactive decay of a radioisotope.

In the activity, small pieces of paper are used as the atoms with one side to be an unstable atom and the other side representing that the atom has decayed to a more stable state. They count how many stable atoms are found each time the 'atoms' are observed then record the remaining unstable number. This shows a pattern over time that we call a half-life, a special characteristic of radioactive decay processes.

Science prior knowledge answers

	Type of radiation			
	alpha	beta		gamma
		beta positive	beta negative	
symbol	α	$\beta +$	$\beta -$	γ
description	**2 protons and 2 neutrons**	proton converts to a neutron	**neutron converts to proton**	high-energy electromagnetic radiation
Change to atomic number	**decrease by 2**	**decrease by 1**	**increase by 1**	unchanged
change to mass number	**decrease by 4**	**unchanged**	unchanged	unchanged
penetration through matter	limited, can be stopped by sheet of paper, skin	moderate: travels 1–2 m	moderate: travels 1–2 m	**very high; not completely stopped by anything**

2. Radiation is not only found near large chunks of unstable isotopes. There is a background of radiation around us all the time. It comes from unstable isotopes that exist naturally in the world — rocks under the ground, isotopes in the air, isotopes found in living things and even a small amount that arrives from the sun. This is referred to as background radiation because it is always in the background around us every day.

Lesson answers

3. Sheet 3 — Simulating radioactive decay (attached).

4. a)

Time (sec)	Number of half-lives	Percentage of sodium-25 atoms remaining
0	0	**100**
59	1	**50**
118	2	**25**
177	3	**12.5**

b)

- During alpha decay, a nucleus emits a bundle containing **two protons and two neutrons**, changing to the nucleus of a different element in the process.
- During beta decay, a nucleus emits a bundle containing an **electron**, changing to the nucleus of a different element in the process.
- It is **impossible** to predict exactly when the nucleus of a particular atom will decay.
- The time taken for the radioactivity of a substance to halve is called its radioactive half-life. Every type of radioisotope has a **different** half-life.

5. The process by which unstable atoms break apart and emit radiation is called radioactive decay.
6. The diagram shows a small amount of radioisotope Z with each pink rectangle representing an unstable atom. After one half-life 50 per cent of the atoms (4 atoms) have spontaneously radioactively decayed. This is indicated by the rectangles now being a blue colour. After another half-life 50 per cent of the remaining atoms (2 atoms) have radioactively decayed. One more half-life is shown and further 50 per cent of the remaining atoms (1 atom) has been shown to have radioactively decayed.

7. a) 50g
   b) 25g
   c) 3g approx. (3.125g)

8. a) The half-life of an isotope used in the body should be relatively short. This allows the materials to decay to a safe level of radiation similar to the background we experience every day. If radiation was produced at a higher level over a longer time it could harm the body cells.
   b) When storing isotopes for medical use, staff need to consider the half-life of the substance. Because these isotopes decay and reduce their radioactivity over time they cannot be left too long or they would become useless.

Lesson 3

Topic: Exploring radioisotopes

Applying concepts about radioisotopes

Lesson concepts:

- All matter is made of atoms, which are composed of protons, neutrons and electrons; natural radioactivity arises from the decay of nuclei in atoms
- Advances in science and emerging sciences and technologies can significantly affect people's lives
- Scientific ideas and information can be communicated using scientific language, conventions and representations

Learning alerts

Be aware of:

- Students thinking that all radioactivity is dangerous and being alarmed about consuming carbon-14 in their normal diet.
- Students thinking that carbon-14 will run out completely as decay continues.

Suggested next steps for learning

- Explain that all living organisms ingest carbon, which contains a very small percentage of the carbon-14 isotope, and that this is not harmful.
- Explain that carbon-14 is constantly being generated in the atmosphere which makes its occurrence relatively constant.

Lesson notes

Students will recognise that radioisotope dating procedures inform the study of the dispersal patterns of humans and the antiquity of habitation by Indigenous Australians on the Australian continent. Students also recognise limitations of carbon dating techniques.

In this lesson students will discuss the use of carbon-14 in radiocarbon dating of organic materials. They will learn about the accuracy of radiocarbon dating and evaluate the accuracy and usefulness of radiocarbon dating to date organic materials and artefacts.

Practical information

This lesson has embedded Indigenous perspectives. The students will examine how radioisotope dating procedures inform the study of long-term human habitation of the Australian continent.

Science prior knowledge answers

1. a) Carbon-12 is most abundant. The average atomic mass for carbon is 12.01 which is closest to 12. This means there must be more carbon 12 than the other two isotopes which both have greater atomic masses.

   b) Carbon-14 would be the most unstable. Carbon-14 has 8 neutrons and 6 protons. It has the highest ratio of neutrons to protons, making the nucleus less stable.

2. alpha (α); beta negative ($\beta-$); beta positive ($\beta+$); gamma (γ)

Lesson answers

3. a) Organic materials containing carbon-14 that do not decompose or have been preserved. For example: wood and charcoal; coal, peat; hard plant parts (seeds, pollen); hard animal parts (bone, leather, hair, fur, horns, shells, coral); artefacts made from organic materials (paper, parchment, paintings, pottery)

   b) Radiocarbon dating can be used for items up to 60,000 years old.

   c) Carbon-14 decays by beta decay.

   d) The decay product for carbon-14 is nitrogen-14 and beta particle ($\beta-$).

   e) The half-life of carbon-14 is 5,730 years.

   f) Possible answers:

   - Carbon appears naturally in all living things so will be available in their remains.
   - The stable isotopes of carbon do not decay, so the proportion of carbon-14 remaining in a dead organism will change over time when compared to carbon-12.
   - Both other naturally-occurring isotopes of carbon are stable and do not decay.
   - Of the radioactive isotopes of carbon, carbon-14 is the isotope that has a half-life long enough to use for dating organic items; all three of the others have half-lives less than 30 minutes.
   - Because the other radioactive isotopes of carbon do not occur naturally they would not be expected to be found in the remains of organisms.
   - Carbon is better to use than elements that do not occur naturally in organic items, and although potassium can also be used for dating, it has a much longer half-life and so is better for items that are too old for carbon dating.

   g) Possible answers:

   - Carbon dating is only accurate for items up to around 60,000 years old.
   - Carbon in the air could have been in different concentrations back at the time the fossil was a living thing.
   - Carbon-14 cannot be used to date biological artefacts of organisms that did not get their carbon dioxide from the air, therefore, this rules out carbon dating for most aquatic organisms, because they often obtain at least some of their carbon from dissolved carbonate rock. The age of the carbon in the rock is different from that of the carbon in the air and makes carbon dating data for those organisms inaccurate under the assumptions normally used for carbon dating.

4. No response required.

5. a) The word 'repatriate' means to send home, to go back to their country.

   b) The original dating was inaccurate because:

   - the technology we had at the time and the process was still being developed
   - the remains may have been in poor condition.

- radiocarbon dating was the main technique used at the time. Since that time more dating techniques have been developed. Not all of these are radiometric
- in order to improve the accuracy of dating an artefact, usually more than one dating technique is used and testing is conducted by more than just one laboratory.

c) Ethical considerations when dealing with Aboriginal remains include the following:

- not disturbing or removing the remains
- negotiating entry to sites with the Traditional Owners before any entry
- negotiating which activities are allowed
- identifying who should be present during any activity on the land.

Items of Aboriginal and Torres Strait Islander cultural heritage are, in most cases, owned and protected by Aboriginal and Torres Strait Islander people with traditional or familial links to the items. Death for Aboriginal and Torres Strait Islander people is often associated with complex rituals, and like most cultures, burial sites (or places where human remains are found) are sensitive places of great significance to the Indigenous people. Scientists must consult with the relevant Aboriginal peoples before carrying out any research on an artefact and obtain informed consent. Scientists must exercise due diligence and reasonable precaution before undertaking an activity which may harm Aboriginal artefacts. Scientists must ensure reasonable and practicable measures for ensuring that activities are managed to avoid or minimise harm to Aboriginal artefacts. Results of research should be communicated back to the relevant Aboriginal peoples. It is an offence to improperly or indecently interfere with a human body or human remains, whether buried or not.

6. No response required.

7.

Word			Meaning
isotopes	F	A	the process of emission of energetic particles or energetic waves
radioactivity	G	B	composed of 2 protons and 2 neutrons and carries a 2+ charge
alpha radiation	H	C	radioactive decay of an unstable atom where a proton converts to a neutron or a neutron converts to a proton
radiation	A	D	an isotope that is unstable and undergoes radioactive decay
beta radiation	C	E	a high-energy electromagnetic emission caused by radioactive decay
radioisotope	D	F	atoms of an element which have the same number of protons but different numbers of neutrons in the nucleus
beta positive radiation	J	G	the emission of radiation as particles and energy
alpha particle	B	H	decay of an unstable nucleus with the loss of an alpha particle
radioactive decay	K	I	radioactive decay of an atom resulting in the atomic number of the atom increasing by 1 and the mass number remaining the same
gamma radiation	E	J	radioactive decay of an atom resulting in the atomic number of the atom decreasing by 1 and the mass number remaining the same
beta negative radiation	I	K	a process involving a change in the nucleus of an atom resulting in the emission of particle/s and/or energy

8. a) There are 95 protons in the nucleus of americium-241.
   b) The daughter element produced from α-decay is neptunium-237. $^{237}_{93}Np$
   c) α-decay produces radiation which is not very penetrating — it can be stopped by plastic or paper — and so will not damage the house inhabitants. γ-decay produces strongly penetrating radiation that can damage human cells and so would be unsuitable for use in housing.
   d) Half-life = 432 years, hence 864 years represents 2 half-lives.

      Amount present after 1 half-life = 0.05 mg (0.1 mg ÷ 2)

      After 864 years the amount present would be 0.025 mg (0.05 mg ÷ 2)

Sheet 1 Answers

Exploring radioactive decay

Task 1: Alpha decay

Marie Skłodowska-Curie was the first to isolate and characterise the element radium. She was also the first to notice a relationship between the particles in the nuclei of thorium and radium atoms.

1. Later scientists expanded on her work, which showed a relationship between the elements shown below. Use a periodic table to complete the table.

Isotope	Atomic number	Mass number	Number of protons	Number of neutrons
thorium-228	90	228	90	138
radium-224	88	224	88	136
radon-220	86	220	86	134
polonium-216	84	218	84	132
lead-212	82	216	82	130

2. Look down the column for atomic number.
   a) How does the atomic number change as you go down the column?

      It decreases by two each time.
   b) Is this trend repeated in the column for number of protons? Explain your answer.

      Yes, the atomic number is a representation of the number of protons.

3. Look down the column for number of neutrons.
   a) How does the number of neutrons change as you go down the column?

      It decreases by two each time.

4. Look down the column for mass number.
   a) How does the mass number change as you go down the column?

      It decreases by four each time.

b) Suggest a reason for the change.

Each element is a result of the two protons and two neutrons escaping the nucleus.

5. How is radium different to thorium?

Radium has 88 protons and 136 neutrons; thorium has 90 protons and 138 neutrons.

6. How is polonium different to lead?

Polonium has 84 protons and 132 neutrons; lead has 82 protons and 130 neutrons.

Rutherford studied the particles emitted during alpha decay, which he called alpha particles.
He suggested that these particles were 'ejected' from the nucleus as the nucleus decayed.

7. Use the example of alpha decay in the previous table to determine what alpha particles are made of.

Two protons and two neutrons (a helium-4 nucleus).

The symbol for alpha decay is:

$$\alpha$$

8. Which element has two protons in its nuclei? helium

9. The atoms that undergo decay are called 'parent isotopes' and the atoms produced by decay are called 'daughter elements'. Identify the daughter elements of each of the parent isotopes that experience alpha decay in the table below.

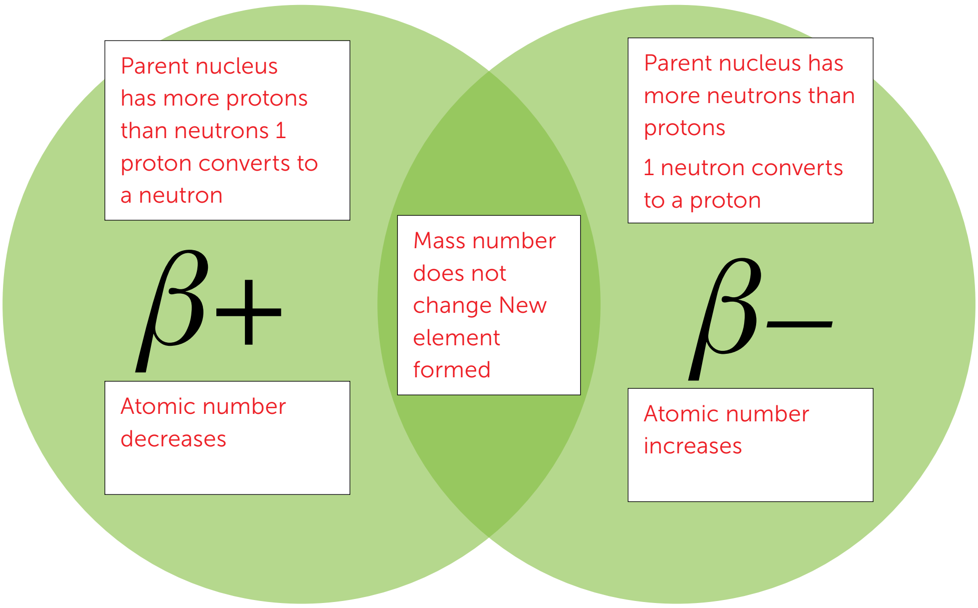
Radioactive parent isotope		Daughter element
$^{106}_{52}Te$	$^{102}_{50}$	**Sn (tin)**
$^{108}_{53}I$	$^{104}_{51}$	**Sb (antimony)**
$^{178}_{81}Tl$	$^{174}_{79}$	**Au (gold)**
$^{224}_{88}Ra$	$^{220}_{86}$	**Rn (radon)**
$^{241}_{95}Am$	$^{237}_{93}$	**Np (neptunium)**

Task 2: Beta decay

Ernest Rutherford discovered another type of radiation that he called beta radiation. Scientists have since found that beta radiation has two forms.

β+ (Beta positive)	β– (Beta negative)
Parent nucleus has more protons than neutrons.	Parent nucleus has more neutrons than protons.
One proton converts to one neutron.	One neutron converts to one proton.
Atomic number goes down.	Atomic number goes up.
Mass number stays the same.	Mass number stays the same.

1. Use the information in the table to complete this Venn diagram



2. What are the daughter elements formed by the β+ decay of these radioactive parent isotopes?

a)	$^{7}_{4}Be$	$^{7}_{3}$	**Li (lithium)**
b)	$^{30}_{18}Ar$	$^{37}_{17}$	**Cl (chlorine)**
c)	$^{55}_{26}Fe$	$^{55}_{25}$	**Mn (manganese)**
d)	$^{67}_{26}Ga$	$^{67}_{30}$	**Zn (zinc)**

3. What are the daughter elements formed by the β- decay of these radioactive parent isotopes?

a)	$^{60}_{27}\text{Co}$	$^{60}_{28}$	Ni (nickel)
b)	$^{14}_{6}\text{C}$	$^{14}_{7}$	N (nitrogen)
c)	$^{35}_{16}\text{S}$	$^{35}_{17}$	Cl (chlorine)
d)	$^{40}_{19}\text{K}$	$^{40}_{20}$	Ca (calcium)

Gamma radiation

In 1900, Paul Villard discovered the third common type of radiation, which Rutherford called gamma radiation and represented as the Greek letter γ.

This form of energy is emitted by radioisotopes but does not cause a change in the number of protons or neutrons in the nucleus. Gamma radiation is a way for nuclei to move from an unstable high-energy state to a more stable low-energy state.

Geiger counter

The Geiger counter is an instrument which can detect alpha, beta and gamma radiation. Sometimes the instrument is referred to as the Geiger–Müller tube. This is because Hans Geiger developed the concept of radiation detection in 1908 and then worked collaboratively with Walther Müller to build a working model in 1928.

Task 3: Representing radioactive decay

Most radioisotopes undergo a series of decay processes involving all three types of radiation until a stable daughter element is formed. This series of changes is called a nuclear decay chain.

1. The decay of aluminium-24 to neon-20:

$$^{24}_{13}\text{Al} \xrightarrow{\alpha} {}^{20}_{11}\text{Na} \xrightarrow{\beta+} {}^{20}_{10}\text{Ne}$$

2. The decay of sodium-30 to magnesium-26:

$$^{30}_{11}\text{Na} \xrightarrow{\alpha} {}^{26}_{9}\text{F} \xrightarrow{\beta-} {}^{26}_{10}\text{Ne}$$

$$^{26}_{10}\text{Ne} \xrightarrow{\gamma} {}^{26}_{10}\text{Ne}$$

$$^{26}_{12}\text{Mg} \xleftarrow{\beta-} {}^{26}_{11}\text{Na} \xleftarrow{\beta-} {}^{26}_{10}\text{Ne}$$

Sheet 3 Answers

Simulating radioactive decay

What is the half-life of a radioisotope?

Half-life is the time it takes for half of a sample of radioisotope to undergo radioactive decay.

A radioisotope 'X' has a half-life of 1 year.

Table 1: The radioactive decay of X — Theoretical results

Number of half-lives	Number of radioactive atoms of X present after half-life decay	Number of radioactive atoms of X decayed
0	64	0
1	**32**	**32**
2	**16**	**16**
3	**8**	**8**
4	**4**	**4**
5	**2**	**2**
6	**1**	**1**

Aim

To simulate the radioactive decay of a radioisotope.

Materials

- 64 squares of paper (you will find these at the end of this document)
- 1 × brown paper bag

Method

- Cut out the 64 squares. Each square represents an atom of unstable radioisotope X.
- Place the squares in the brown paper bag.
- Record the number of X atoms you have in Table 2 below.
- Shake the bag and empty the 'atoms' on the desk. If an atom lands X down it has radioactively decayed and is now a stable atom. Remove these stable atoms from your collection and record the number on the table. Each time you empty the bag onto the desk represents one year of time.
- Record the number of unstable atoms of X remaining on the table.
- Return the remaining unstable atoms of X to the bag.
- Repeat steps 4–6 until all atoms of X have decayed.

Data collection

Table 2: Decay simulation results

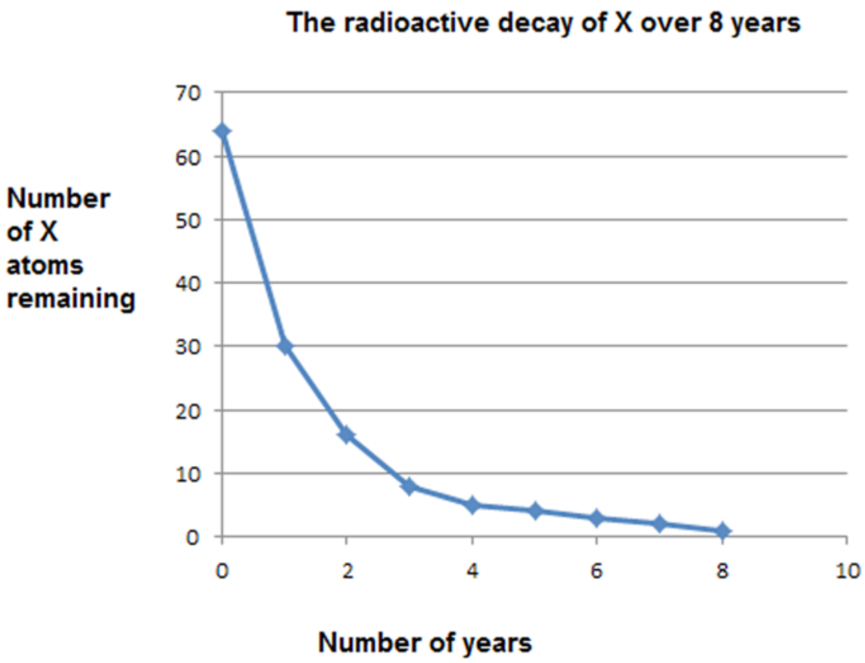
Example:

Number of years	Number of radioactive atoms of X	Number of radioactive atoms of X decayed
0	64	0
1	**30**	**34**
2	**16**	**14**
3	**8**	**8**
4	**5**	**3**
5	**4**	**1**
6	**3**	**1**
7	**2**	**1**
8	**1**	**1**

Analysis of data and observations

Construct a graph of the change in the number of unstable atoms over time and attach it here.

Graph should show an exponential decay, for example:



Describe the graph. What does it tell you?

The graph shows as each year passes fewer atoms of X remain. The decline is exponential. For each year about half the sample of X decays. Students may recognise the exponential nature of the curve.

Discussion

Use your graph to determine how many years it would take for ha lf of the 64 atoms to decay.

How long does it take for the number of atoms to change from 30 to 16?

About 1 year

How long does it take for the number of atoms to change from 16 to 8?

About 1 year

How long does it take for the number of atoms to change from 8 to 4?

About 2 years (anomaly — due to small numbers)

How do your results compare to Table 1: The radioactive decay of X?

The results are similar to the results in Table 1

Is your simulation a good model of the radioactive decay of a radioisotope?

Yes, the simulation is a good model as it shows how approximately all of the sample decays over the period of one half-life (in this case, 1 year).

How could the model be altered to be a better representation of the radioactive decay of an isotope?

Increase the number of radioisotope atoms in the simulation.

Introduce a greater randomness to the decay process.

Runs the simulation several times and use the average number of atoms present after each half-life to graph results.

Conclusion

1–2 sentences. Must relate to the aim.

The simulation can effectively model how radioactive decay occurs. The half-life of the radioactive isotope can be used to predict the amount of the substance present after a certain time.