PEARSON

Science

STUDENT BOOK | VICTORIA

9

Topic 4 Atomic structure and radioactivity

Prior knowledge

Chemical and physical changes

1 a physical change
  b chemical change
  c chemical change
  d physical change

Exothermic and endothermic reactions

2 An exothermic reaction releases energy, often causing an increase of temperature to the surroundings. An endothermic reaction absorbs energy, often causing a decrease in temperature of the surroundings.

Chemical energy transformations

3 D electrical energy

4 Potential energy is the stored energy of the chocolate bar that can be transformed into another form of energy.

Elements, compounds and mixtures

5 Li – lithium, Ni – nickel, Co – cobalt, Al – aluminium, O – oxygen

Word and chemical equations

6 Reactants: calcium (Ca) and hydrochloric acid (HCl)
  Products: hydrogen (H_2) and calcium chloride ($CaCl_2$)

4.1 Marie Curie and elements

Check your understanding

SC 1: I can describe the challenges Marie Curie faced as a scientist

Marie Curie discovered polonium and radium.

SC 2: I can explain how Marie Curie improved knowledge of atoms and radioactivity

Polonium has a half-life of 138 days, meaning that half the sample decays rapidly into other elements every 138 days. This made it difficult to collect a large enough, stable sample before it transformed into something else.

SC 3: I can explain how Marie Curie's discoveries were accepted and recognised by the scientific community

Marie Curie won the Nobel Prize in Physics with Pierre Curie and Henri Becquerel in 1903 for their work on radioactivity, including the discovery of polonium and radium. She won the Nobel Prize in Chemistry in 1911 for her work in isolating radium.

Lesson review

1 Radioactivity is the amount of radiation emitted from a nucleus undergoing nuclear decay.

2 Answers may include:
- Personal: balancing motherhood and work, death of husband, decline of health
- Professional: gender discrimination, scepticism with her results

3 Tonnes of pitchblende were dissolved in concentrated acids and radium salts were extracted.

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4 Answers may include: First female teacher at Sorbonne, first female professor, laboratory named after her, honours and gifts given by various countries (such as USA), having the element curium named after her and her husband, being enshrined in the Panthéon in Paris.

4.2 Modelling atomic structure

Method

Sample method that could be used to make a 3D model of a carbon atom.

1 Use red modelling clay to make six small balls (proton particles), each about 1.5 cm in diameter.
2 Use blue modelling clay to make six smaller balls (electron particles), each about 0.5 cm in diameter.
3 Mix some blue and red modelling clay to create purple modelling clay, then make six balls (neutron particles), each about 1.5 cm in diameter.
4 Carefully push the red and purple particles together to form the nucleus of an atom. The red and purple particles should be touching but not squashed.
5 For a 2D model, place the nucleus in the centre of a sheet of A3 paper.
6 Position the blue balls around the outside of the nucleus.
7 For a 3D model, use the toothpicks or skewers to position the blue balls around the nucleus.

Results

The models should clearly show the relative position and size of the protons, neutrons and electrons and should be labelled, possibly with the use of a key.

Conclusion

1 Proton: positive, neutron: no charge and electron: negative.
I showed this with labels/colour coding/the key.
2 Relative masses of the particles are:
Proton: 1, neutron: 1 and electron: 1/2000.
I showed this by making the protons and neutrons the same size and the electrons much smaller.
3 By placing Electrons on the outside of the model and using arrows/orbits to show how they moved around the protons and neutrons in the atom.

Evaluation

1 Answers may include using balls rather than plasticine so that all protons and neutrons were the same size, hanging the model in space to make it a more realistic 3D model, using wire to show the electrons on an orbit around the nucleus, using a key and colour coding to reduce the need for labels, add information about each particle to the model.
2 Answers may include having to find out the size and properties of the protons, neutrons and electrons; having to find out the correct numbers of subatomic particles in the different atoms; realising that all atoms are made up of the same subatomic particles.

4.3 Contributions to atomic theory

Plan

Answers may include:

Dalton's model consisted of the following ideas:

- Atoms of a given element are identical to each other.
- Atoms of different elements are different from each other.
- In a chemical reaction, atoms will rearrange to create different substances.

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Thomson discovered the electron and proposed a plum-pudding model:

- Atoms are neutral overall.
- Electrons are scattered throughout a sphere of positive charge.

Rutherford proposed that the mass of the atom is contained in a small nucleus and that most of the atom is empty space.

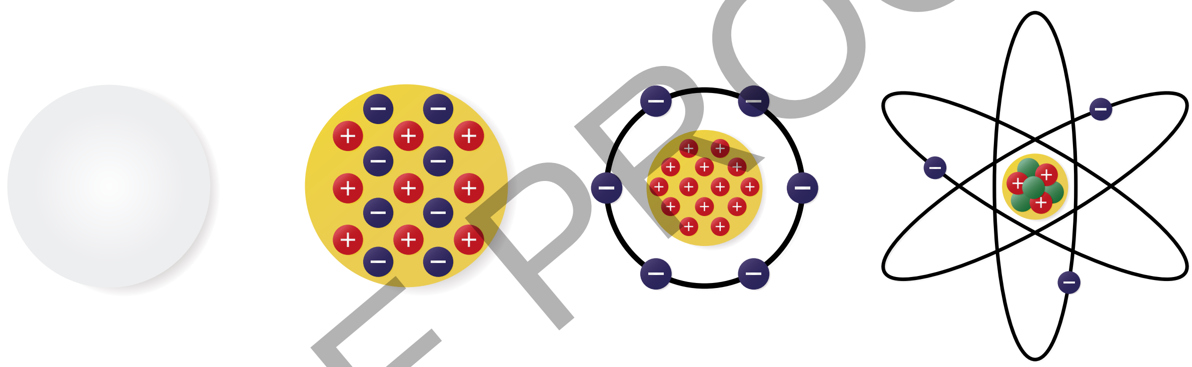
- The electrons occupy some of the space around the nucleus.
- This discovery came about when Rutherford proved that most alpha particles could pass through gold foil without changing direction, which suggested that much of the atom was empty space.

Bohr's planetary model proposed that:

- The nucleus is surrounded by orbiting electrons at different energy levels.
- Electrons have definite orbits.
- The evidence was atomic spectra, which suggested that electrons could only have certain amounts of energy.

Conduct

Sample answer:



1803
John Dalton
Atoms are hard, indivisible spheres

1897
J. J. Thomson
Atoms contain smaller particles (protons and electrons)

1911
Ernest Rutherford
Electrons are on the outside of the atoms

1913
Niels Bohr
Electrons circle the nucleus in orbits

Improve

Sample answer: The model that we made did not clearly show that the electrons were moving around the nuclei of the atom, so we added arrows to the orbits to indicate this.

Evaluate

1 Sample answer: When Rutherford proposed the nuclear model of the atom, he was able to use a technology that was able to produce a stream of alpha particles, and to detect the presence of alpha particles using a type of photographic film. The patterns that were revealed enabled him to deduce that most of the atom was in fact empty space.

2 Sample answer: Neutrons were the last subatomic particle to be discovered because they are not charged and therefore difficult to detect, whereas the discovery of electrons by J. J. Thomson was based on the fact that the electrons had a negative charge. The discovery of electrons was a major shift in the understanding of the atom. Before that, atoms were thought to be just solid spheres. The discovery of neutrons in the nucleus did not change the overall model for the atomic structure, but it greatly improved our understanding of the nucleus of the atom.

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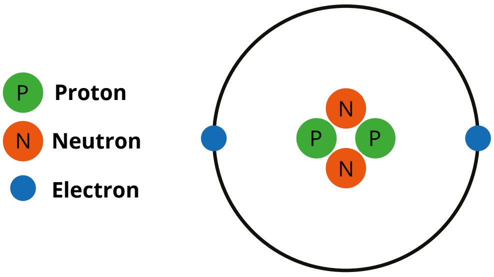
4.4 Elements and atoms

Check your understanding

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 number of atoms based on the number of protons and neutrons they contain

mass number = number of protons + number of neutrons

mass number = 11 + 12 = 23

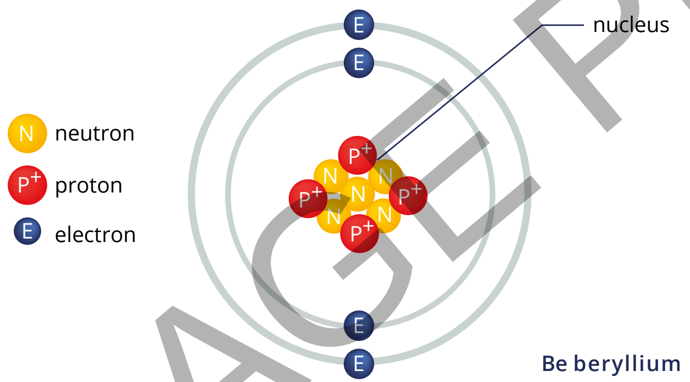
SC 3: I can calculate the number of neutrons an atom contains from its mass number and atomic number

number of neutrons = mass number – atomic number

number of neutrons = 40 – 18 = 22

Lesson review

1



2 mass number of a uranium atom = number of protons + number of neutrons
mass number of uranium atom = 92 + 146 = 238

3 number of neutrons = mass number – atomic number
number of neutrons = 31 – 15 = 16

4
- **a** Chlorine, as it has an atomic number of 17.
- **b** Magnesium, as it has an atomic number of 12.
- **c** Phosphorus, as it has an atomic mass of 15 (mass number – number of neutrons = 31 – 16 = 15).

5 Refer to the image to answer the following questions.
- **a** number of protons = 5; number of neutrons = 5; number of electrons = 5
- **b** atomic number = number of protons = 5
- **c** mass number = number of protons + number of neutrons = 5 + 5 = 10
- **d** The element is boron.

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6 The mistakes are highlighted in the table.

Element	Number of protons	Number of neutrons	Atomic number	Mass number
Na	11	11	11	23

The number of protons and atomic number are equal and match with Na. The mass number does not match the number of neutrons + number of protons. The correct number of neutrons (when mass number is 23) is 12. The correct mass number (when the number of neutrons is 11) is 22.

As	32	42	33	75

The number of neutrons plus the atomic number equals 75, which matches the mass number. The atomic number for As is 33. However, the number of protons is 32, which is the mistake. The correct number of protons is 33.

Ni	29	36	29	65

The number of protons equals the atomic number. The number of neutrons plus the atomic number equals the mass number. However, it is the incorrect element. The element should be Cu (copper).

Ar	20	19	20	40

The number of protons, atomic number and the element all match. The number of neutrons and mass number are incorrect. If the number of neutrons is 19, the mass number should be 39. If the mass number is 40, the number of neutrons should be 20.

4.5 Isotopes

Check your understanding

SC 1: I can describe, with examples, what an isotope is

Isotopes of an element have the same number of protons but different numbers of neutrons, resulting in different mass numbers.

SC 2: I can identify isotopes of atoms based on the number of protons and neutrons they contain

The number of neutrons in the isotope $^{34}_{16}S$ is 34 − 16 = 18.

SC 3: I can explain, using an example, the different characteristics of isotopes of the same atom

The mass of the isotope changes the boiling point, melting point and density of the element.

Lesson review

1 Atoms with the same number of protons but different numbers of neutrons.

2 carbon-13

3 The mass of uranium-238 is greater than the mass of uranium-235 because uranium-235 has 143 neutrons and uranium-238 has 146 neutrons.

4 **a** Nitrogen-15 has 7 protons and 8 neutrons.

b Nitrogen-15 has 8 neutrons, whereas nitrogen-14 has 7 neutrons.

c A radioisotope is an isotope that is unstable, undergoes nuclear decay and gives out radiation.

d The isotope of nitrogen to have the lowest boiling point is nitrogen-14. The lighter the isotope, the lower the boiling point. The heavier the isotope, the more energy is required for evaporation.

4.6 Radioactivity and nuclear decay

Check your understanding

SC 1: I can identify atoms that are likely to be unstable based on the number of protons and neutrons they contain

Any of the following answers: uranium-235, uranium-238, uranium-234

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SC 2: I can compare alpha, beta and gamma radiation in terms of the properties of the radiation

Gamma rays (highest ability to penetrate materials), beta particles, alpha particles (lowest ability to penetrate materials)

SC 3: I can compare alpha, beta and gamma radiation in terms of the nuclear processes that cause them

Alpha decay and beta decay both result in a new element being formed.

Lesson review

1 The atom is likely to be unstable because the nucleus contains significantly more neutrons than protons.

2 Beta particles are small, negatively charged particles. Materials, such as aluminium, glass and plastic can prevent penetration of beta particles.

3 $^{241}_{94}\text{Pu} \rightarrow {}^{241}_{95}\text{Am}$ undergoes beta particle decay. The mass number does not change but the element does change (indicating the number of protons has changed).

4 beta decay: $^{212}_{83}\text{Bi} \rightarrow {}^{212}_{84}\text{Po} + {}^{0}_{-1}\beta$

alpha decay: $^{212}_{83}\text{Bi} \rightarrow {}^{208}_{81}\text{Tl} + {}^{4}_{2}\text{He}$

5 $^{60}_{27}\text{Co} \rightarrow {}^{60}_{28}\text{Ni} + {}^{0}_{-1}\beta + \gamma$

4.7 Half-lives

Check your understanding

SC 1: I can describe radioactive decay in terms of half-lives

A half-life is the time required for half the atoms in a radioactive sample to decay.

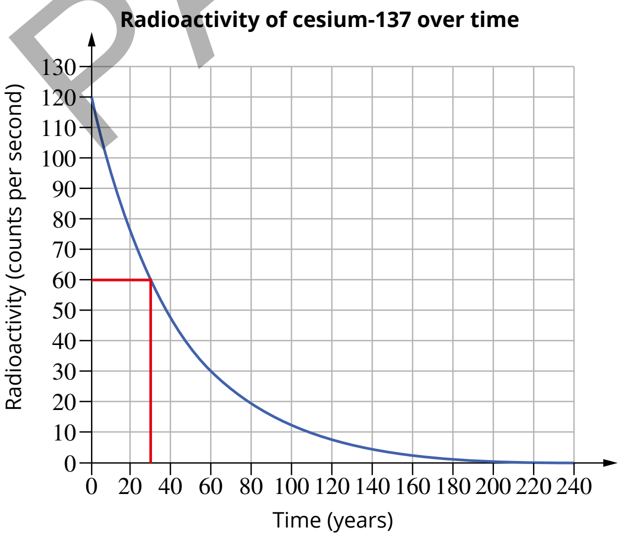
SC 2: I can use half-lives to predict change in levels of radioactivity over time

100 Bq. The half-life of bismuth-210 is 5 days, so after 5 days, the Geiger counter will measure half the value that was measured initially.

Lesson review

1 The half-life is calculated by measuring the becquerels of a radioisotope over time and calculating the time taken for the initial becquerels value to halve.

2 30 years



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3 To predict the level of radioactivity, you can repeatedly halve the initial amount of the radioisotope after each half-life period. This process allows you to determine how much of the radioisotope remains after a given number of half-lives.

4 After 15 years (which is three half-lives), the remaining radioactivity would be $\frac{100}{2} = 50\%$, $\frac{50}{2} = 25\%$, $\frac{25}{2} = 12.5\%$ of the original radaioactivity, i.e. 12.5 counts per second.

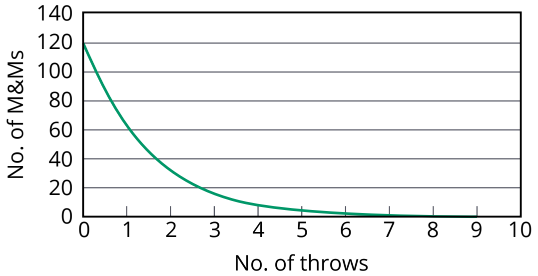
4.8 Modelling radioactive decay

Results

1 Sample results:

Number of throws	0	1	2	3	4	5	6	7	8	9	10
Number of M&Ms® showing the letter M	120	61	33	15	7	3	1	1	0	0	0

2 Sample graph, based on results above.



Conclusion

1 The shape of the graph is exponential.

2 The half-life is one throw of the M&Ms® because on each throw the number of M&Ms® reduced by approximately a half.

Evaluation

Sample answer:

Whether an 'atom' in the model is removed ('decays') depends on the probability of it landing one way up or the other. In the same way, a radioactive atom will decay into another atom according to probability. Therefore, the experiment models the random nature of radioactive decay well. The numbers involved in this model is very low so it doesn't take long for there to be no 'active' atoms left, whereas in real radioactive decay, it will take much longer for all atoms to decay.

In real situations, the half-life for radioactive decay is measured in units of time, ranging from seconds to thousands of years, depending on the substance. In this experiment, the half-life is represented by the number of throws, which cannot be changed. As a result, the experiment demonstrates the concept of half-life well, but it is not a fully realistic representation.

4.9 Carbon dating

Check your understanding

SC 1: I can describe how radioactive decay is used to date artefacts

Radiocarbon dating measures the amount of carbon-14 remaining in an organic artefact. By comparing this to the initial amount of carbon-14 and using its half-life, scientists can calculate the time since the artefact was last alive.

SC 2: I can explain how dating techniques have been used to establish timelines for the presence of First Nations Peoples on the Australian continent

Any of the following organic materials: charcoal, bone fragments, soil, shells, preserved spiders and insects.

Lesson review

1 Radiocarbon dating would involve measuring the remaining carbon-14 in the wood, comparing it to the expected initial amount, and calculating the age based on the known half-life of carbon-14 (5730 years).

2 The approximate age of the woolly mammoth fossil will be 17 190 years. 12.5% is three half-lives, so 3 multiplied by 5730 is 17 190 years.

3 Any of these are correct: the size of the sample, quality of the sample, contamination, if the sample is over 50 000 years old.

4 Fossilised mud wasp nests were used to date rock paintings by collecting organic material from nests located underneath and on top of the rock paintings. This organic material was analysed for carbon-14. The age of the nest beneath provides a minimum age, while the age of the nest on top provides a maximum age. Together, these dates help estimate when the painting was created.

4.10 Radioactivity in medicine

Plan

Answers should include an outline of how the findings of the research will be presented, as well as specific student roles if it is carried out as a group activity. There should be an indication of what sources are used for information and how information will be organised and collected. At this stage a brief overview of the technique can be noted, along with some potential risks.

Conduct

Answers should include a significant number of the following points.

- Information about how diagnostic data is analysed
- Evaluation of the reliability or accuracy of results
- Ethical issues involved in the use of the technique
- Identification of which radioisotopes are used, and justification for their selection in this specific application
- Details of any medical procedures, including surgery if required
- An indication of the normal success rates for the treatment
- The short-term and long-term risks associated with the technique, based on the properties of the radioisotopes and the radiation involved in the techniques
- Specific ways that risks are reduced for patients and potentially medical practitioners, including alternate treatments if required
- Future predictions should be based on knowledge of the process and can include predictions based on future changes in technology, including information technology and artificial intelligence.

Improve

Answers will vary depending on feedback received and the content of the original inquiry.

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Topic review

Remember

1 Answers may include: discover polonium, discover radium, created mobile X-ray units, coined the term 'radioactive', started research into cancer treatments.

2 The atomic number is the number of protons in an atom's nucleus, and the mass number is the total number of protons and neutrons.

3 A physical process, such as melting or boiling, will separate the two isotopes.

Understand

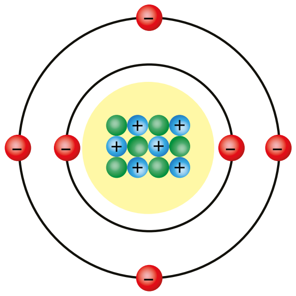
4 Protons are positively charged particles located in the nucleus, neutrons have no charge and are also in the nucleus, while electrons are negatively charged particles that orbit the nucleus.

5 Radiocarbon dating of artifacts and remains has been used to establish that First Nations Peoples have been present in Australia for over 65 000 years.

Apply

6 Rutherford's experiment showed that atoms have a small, dense, positively charged nucleus, disproving the plum pudding model and leading to the nuclear model of the atom.

7 **carbon-12**



6 neutrons + 6 protons = 12
6 electrons

8 Alpha particles are heavy and positively charged, beta particles are lighter and negatively charged, and gamma rays are high-energy, uncharged electromagnetic waves.

9 Answers should include the key points that the coins need to land on head or tails in a random way (either shaken from a jar, flipping them, etc). The coins that land on heads are removed and counted. The remaining coins are then picked up and tossed again using the same random method. The coins that land on heads are removed and counted and the experiment continues until all the coins are collected. The student will need to plot the graph showing the number of coin tosses verses the number of heads.

Analyse

10 Carbon-12 is stable with 6 neutrons, while carbon-14 is radioactive with 8 neutrons and used in radiocarbon dating. Both isotopes have 6 protons.

11 Isotopes with short half-lives, like iodine-131 (8 days), are useful for medical diagnostics, while those with long half-lives, like potassium-40 (1.25 billion years), are used for geological dating.

12 25% of carbon-14 is two half-lives. The age of the human bones is 5730 years multiplied by 2 = 11460 years.

13 Radioactivity is used in imaging techniques like PET scans for diagnosis and in radiation therapy to target and destroy cancer cells.

14 Marie Curie was exposed to large amount of radium-226 in her research so her body would contain small amounts of radium-226. Radium-226 has a half-life of 1600 years, and both radium-226 and its 9 decay products emit radiation. To protect the surrounding environment and people, her coffin is lead-lined to prevent the radiation from escaping and causing damage.

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Extension

15 Content of the posters should include:

- Cobalt-60 (half-life 5.27 years) and ceasium-137 (half-life 30.2 years) are commonly used for sterilisation.
- Sterilisation is important to prevent illness and the spread of disease by microbes.
- Other methods of sterilisation include autoclaving, steaming, heat, chemicals (e.g. disinfectants) as well as others.
- Products that are sterilised include medical devices, medicines, food and food packaging, cosmetics, agricultural supplies, other organic items imported from overseas, etc.
- Radioisotopes are used because gamma radiation does not damage the product or the packaging and the radioisotope can remain effective for many years due to the half-lives being long.

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