The atom

1

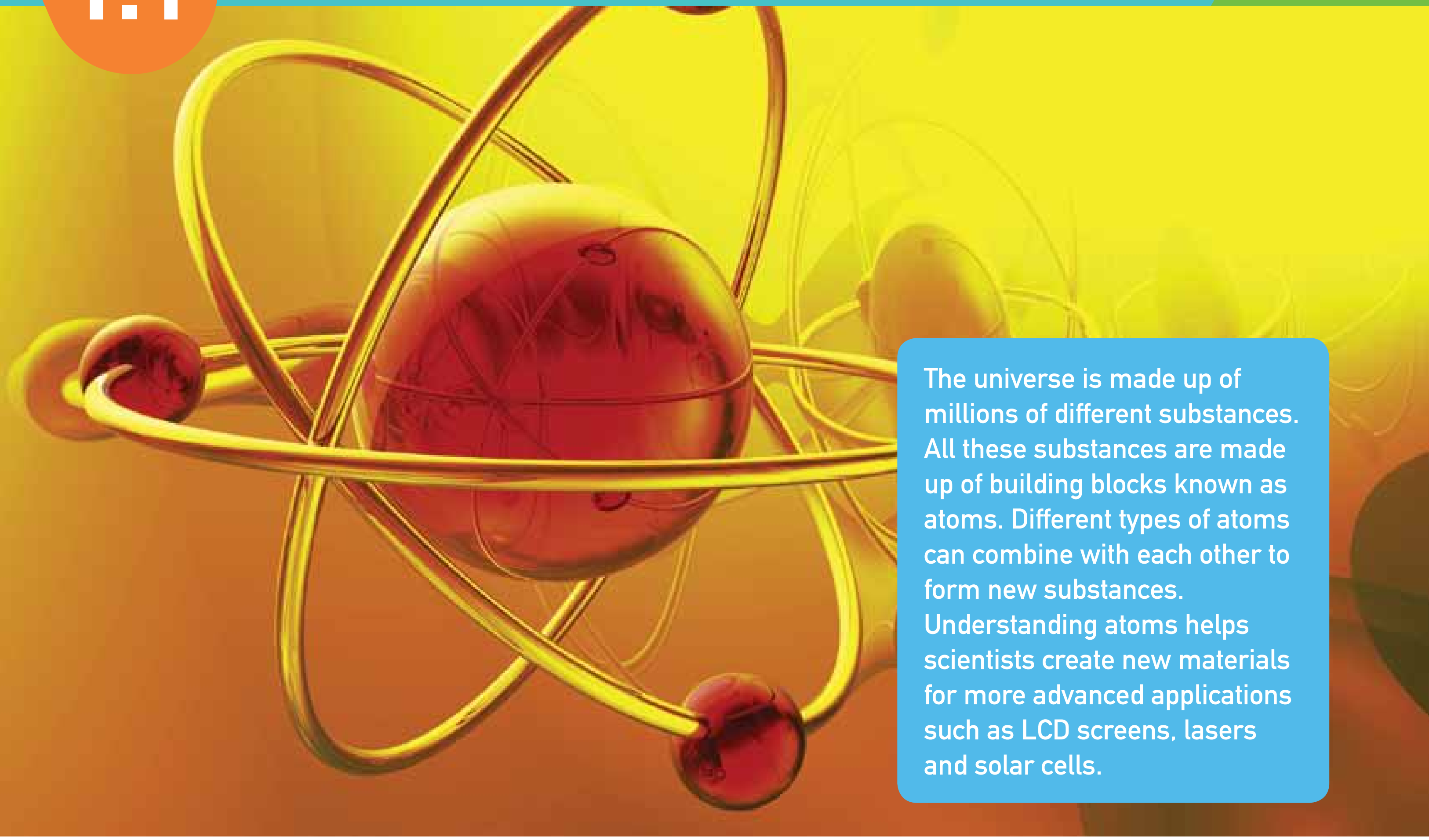
HAVE YOU EVER WONDERED ...

- how fireworks produce different colours?
- what causes stalagmites and stalactites to grow inside caves?
- how lightning is formed?
- how to measure fossil age?
- where nuclear bombs get their destructive power?

After completing this chapter students should be able to:

- describe the structure of an atom
- outline the development of atomic models
- distinguish between atoms and ions
- use chemical formulas to identify ionic compounds
- distinguish between chemical and nuclear reactions
- compare the properties of protons, neutrons and electrons
- describe how alpha and beta particles and gamma radiation are released from unstable atoms.

1.1 Atoms



The universe is made up of millions of different substances. All these substances are made up of building blocks known as atoms. Different types of atoms can combine with each other to form new substances. Understanding atoms helps scientists create new materials for more advanced applications such as LCD screens, lasers and solar cells.

Atomic building blocks

Look around you and you will see thousands of different materials—paper, plastic, wood, glass, skin and many more. All these different materials are made up of tiny building blocks, known as **atoms**.

Atoms are so small that they cannot be seen by even the most powerful optical microscope. To see atoms, scientists must use a special type of microscope known as a scanning tunnelling microscope or STM. Figure 1.1.1 shows an image of silicon atoms taken with an STM. Atoms can stick together in different combinations to build countless types of different substances.

There are 118 known types of atoms and only 91 of these are found naturally on Earth. The remaining 27 types of atoms must be made in a laboratory. Scientists list the 118 atoms from smallest to largest on the periodic table as shown in Figure 1.1.2. Each square in the **periodic table** represents one type of atom and is labelled with the atom's chemical name and chemical symbol.

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Temporary elements

The existence of elements 113 to 118 is difficult to confirm because they are so radioactive that they can only exist for a fraction of a second. Until confirmed, these elements are given temporary names and temporary symbols of three letters.

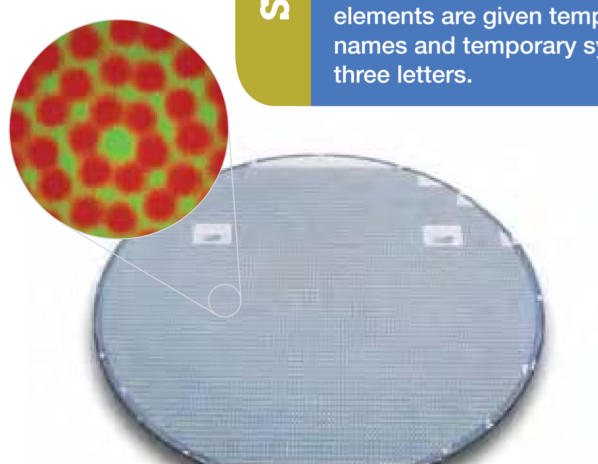

Figure 1.1.1 Billions of silicon atoms stick together like blocks of Lego to create this wafer of pure silicon. Silicon wafers are mostly used in the computer industry to make microchips.

KEY

- Non-metals
- Metals
- Metalloids

atomic number — 13
symbol — Al
name — aluminium

1 H hydrogen																	2 He helium
3 Li lithium	4 Be beryllium											5 B boron	6 C carbon	7 N nitrogen	8 O oxygen	9 F fluorine	10 Ne neon
11 Na sodium	12 Mg magnesium											13 Al aluminium	14 Si silicon	15 P phosphorus	16 S sulfur	17 Cl chlorine	18 Ar argon
19 K potassium	20 Ca calcium	21 Sc scandium	22 Ti titanium	23 V vanadium	24 Cr chromium	25 Mn manganese	26 Fe iron	27 Co cobalt	28 Ni nickel	29 Cu copper	30 Zn zinc	31 Ga gallium	32 Ge germanium	33 As arsenic	34 Se selenium	35 Br bromine	36 Kr krypton
37 Rb rubidium	38 Sr strontium	39 Y yttrium	40 Zr zirconium	41 Nb niobium	42 Mo molybdenum	43 Tc technetium	44 Ru ruthenium	45 Rh rhodium	46 Pd palladium	47 Ag silver	48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium	53 I iodine	54 Xe xenon
55 Cs caesium	56 Ba barium	57–71 lanthanoids	72 Hf hafnium	73 Ta tantalum	74 W tungsten	75 Re rhenium	76 Os osmium	77 Ir iridium	78 Pt platinum	79 Au gold	80 Hg mercury	81 Tl thallium	182 Pb lead	83 Bi bismuth	84 Po polonium	85 At astatine	86 Rn radon
87 Fr franchium	88 Ra radium	89–103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadium	111 Rg roentgenium	112 Cn copernicium	113 Uut ununtrium	114 Uuq ununquadium	115 Uup ununpentium	116 Uuh ununhexium	117 Uus ununseptium	118 Uuo ununoctium

Lanthanides	57 La lanthanum	58 Ce cerium	59 Pr praseodymium	60 Nd neodymium	61 Pm promethium	62 Sm samarium	63 Eu europium	64 Gd gadolinium	65 Tb terbium	66 Dy dysprosium	67 Ho holmium	68 Er erbium	69 Tm thulium	70 Yb ytterbium	71 Lu lutetium
Actinides	89 Ac actinium	90 Th thorium	91 Pa protactinium	92 U uranium	93 Np neptunium	94 Pu plutonium	95 Am americum	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fremium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium

Figure 1.1.2 The periodic table of elements. Most chemical symbols are made up of one or two letters. The first is always capitalised and the second is lowercase.

Atoms in elements and compounds

When atoms stick together they can form either clusters of atoms known as **molecules** or large grid-like structures known as **crystal lattices**. Examples of both are shown in Figure 1.1.3. For example, water (H_2O) is made up of molecules. Every water molecule is identical and contains two hydrogen atoms (H) and one oxygen atom (O). On the other hand, a grain of beach sand is a crystal lattice of silicon (Si) and oxygen (O) atoms. The number of atoms in the lattice depends on the size of the grain of sand.

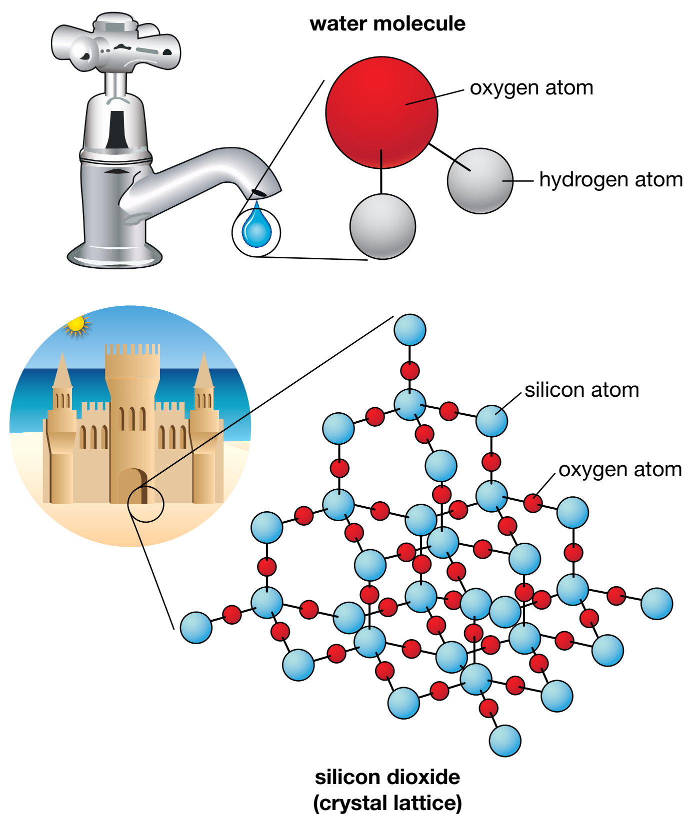

Figure 1.1.3 Atoms can form molecules like the water molecule, or large crystal lattices like the silicon and oxygen atoms in beach sand.

SciFile

The atomic universe

Approximately 98% of the atoms in the universe are either hydrogen (H) or helium (He) atoms. These atoms make up the Sun and the stars. The other types of atoms make up only 2% of all the atoms in the universe.

Elements

If a substance is made up of just one type of atom, it is referred to as an **element**. Molecular elements are made up of small molecules like the ones shown in Figure 1.1.4. Carbon is a unique element because carbon atoms can form extremely large molecules. A buckyball is made up of 60 carbon atoms (C_{60}) in the shape of a soccer ball, and a nanotube can have thousands of carbon atoms forming a long cylinder.

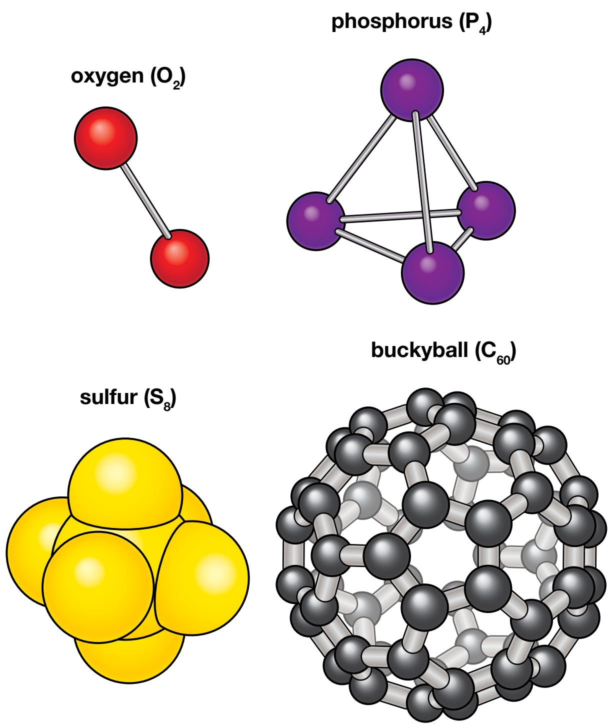

Figure 1.1.4 In these molecular elements, each molecule is made up of just one type of atom. This diagram shows two different ways of showing the structure of molecules.

Carbon is also the only non-metallic element that can also form crystal lattices. The diamond found in jewellery and the graphite in pencil 'leads' are two forms of carbon crystal lattices. Metallic elements always form crystal lattices. Figure 1.1.5 shows a comparison of these two types of lattices.

Compounds

If a substance is made up of molecules or a crystal lattice with different types of atoms, then it is known as a **compound**. The molecules that make up compounds range from small to very large. For example, the sugar molecule in Figure 1.1.6 is made up of just 24 atoms. In contrast, a single molecule of DNA inside your cells is made up of billions of atoms and can be stretched to over a metre in length.

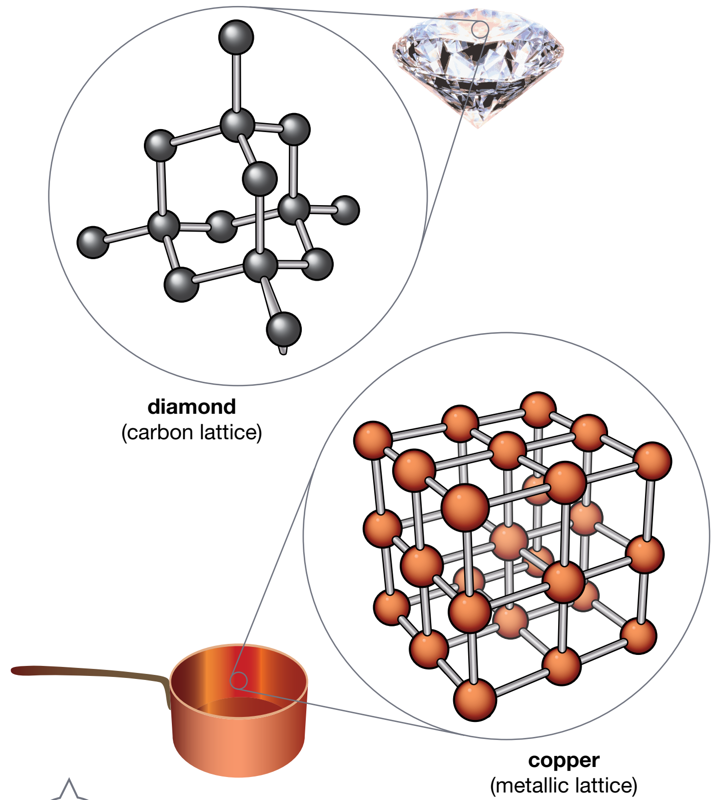

Figure 1.1.5 Crystal lattices made of carbon atoms or copper atoms

Many compounds are crystal lattices. Common table salt is a lattice of sodium (Na) and chlorine (Cl) arranged into a three-dimensional grid, as shown in Figure 1.1.6.

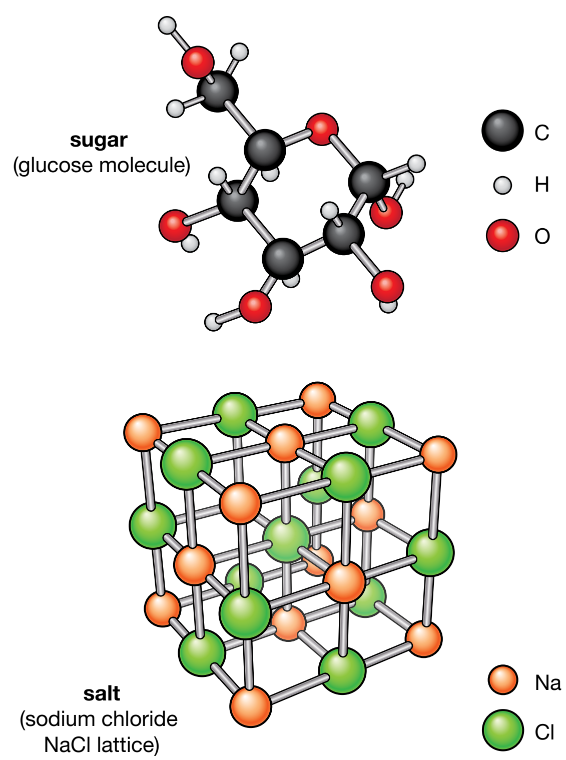

Figure 1.1.6 A sugar molecule and a sodium chloride lattice are both compounds because they both contain more than one type of atom.

Inside atoms

Scientists once thought that atoms were hard and unbreakable. Today, they know that atoms are made up of even smaller particles known as subatomic particles. Each atom is made up of three types of subatomic particles: **protons**, **neutrons** and **electrons**.

The protons and neutrons form a cluster that sits at the centre of the atom, as shown in Figure 1.1.7. This cluster is known as the **nucleus**. The electrons are much smaller and move very fast around the nucleus in shells. These shells form an electron cloud that surrounds the nucleus.

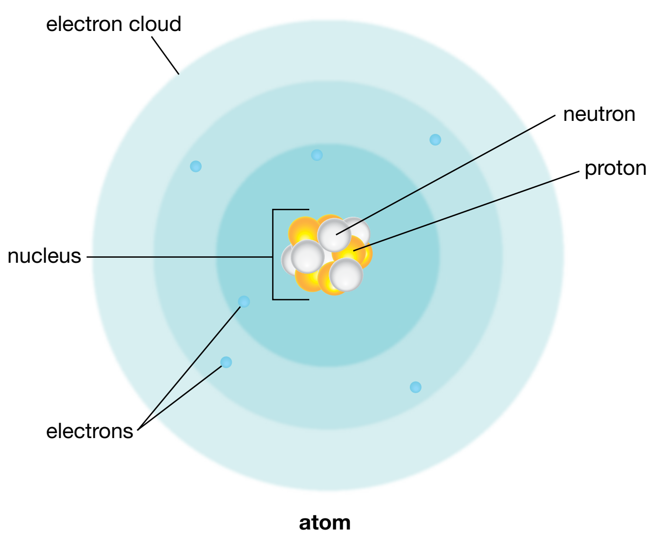

Figure 1.1.7 Atoms are made up of subatomic particles known as protons, neutrons and electrons.

Table 1.1.1 summarises some of the important properties (characteristics) of protons, neutrons and electrons. Protons and neutrons are similar in size. However, protons have a positive electric charge while neutrons have no electric charge. Electrons are approximately 1800 times smaller than protons and neutrons, and have a negative electric charge.

Table 1.1.1 Properties of subatomic particles

Subatomic particle	Location	Mass compared with the mass of an electron	Electric charge
Proton	Nucleus	x 1800	+1
Neutron	Nucleus	x 1800	0
Electron	Electron cloud around the nucleus	x 1	–1

The negatively charged electron causes it to be attracted to the positively charged protons in the nucleus. This is because opposite electric charges attract each other, a bit like the way opposite poles of a magnet attract each other. As a result, the electrons are held in their clouds around the nucleus.

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The origin of atoms

The word ‘atom’ comes from the ancient Greek philosopher Democritus. He described them as *atomos*, which means unbreakable or indivisible.

INQUIRY science 4 fun

Electrostatic attraction

Can you use electrostatic force to stick a balloon to the wall?

Yes

Collect this …

- a balloon
- a head of clean, dry hair

Do this …

1 Inflate the balloon and tie a knot in it.
2 Rub the balloon vigorously on the hair.
3 Gently place the balloon in contact with a wall and see if it will stay.

Record this …

Describe what you saw.

Explain why you think this happened.

Atomic nuclei

It is the number of protons in the nucleus that defines the type of atom, and therefore which element it belongs to. For example, all hydrogen (H) atoms have 1 proton in their nucleus, helium (He) atoms have 2 protons, lithium (Li) atoms have 3 protons, and so on. Scientists refer to the number of protons in the nucleus as the **atomic number**. The total number of protons and neutrons in the nucleus is the atom’s **mass number**.

Writing atomic symbols

SKILL BUILDER

To show the mass number and atomic number of an atom, scientists write an atomic symbol. The atomic symbol for helium is:

$$\text{Mass number} \rightarrow \; \text{Atomic number} \rightarrow \; {}^{4}_{2}\text{He}$$

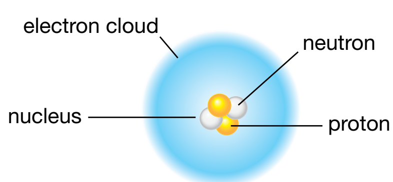
The **atomic symbol** is made up of the chemical symbol for helium (He), with the mass number above and the atomic number below. From this symbol it is possible to work out the number of neutrons in the nucleus by subtracting the atomic number from the mass number.

Number of neutrons = 4 – 2 = 2

It is also possible to work out the number of electrons, which is equal to the atomic number:

Number of electrons = atomic number = 2

Therefore the atomic symbol can be used to obtain a complete description of the structure of the atom, which is illustrated in Figure 1.1.8.



atom of helium

Figure 1.1.8 This helium atom has two protons and two neutrons. So its atomic number is 2 and its mass number is 4. Helium also has 2 electrons but these are not normally shown in the electron cloud.

WORKED EXAMPLE
Atomic symbols and atomic structure

Problem

Determine the number of protons, electrons and neutrons in:

$${}^{39}_{19}\text{K}$$

Solution

1 Number of protons = atomic number = 19

2 Number of electrons = atomic number = 19

3 Number of neutrons = mass number – atomic number
= 39 – 19
= 20

1.1

Isotopes

Atoms of the same element may have different numbers of neutrons. For example, most helium atoms have 2 protons and 2 neutrons. These atoms have a mass number of 4 and so are known as helium-4. However, helium-3 atoms also exist. Helium-3 atoms contain 2 protons but only 1 neutron, so their mass number is 3. Atoms that have the same number of protons but different numbers of neutrons are referred to as **isotopes**.

Almost every element has two isotopes and sometimes many more. Hydrogen has three isotopes: hydrogen-1, hydrogen-2 and hydrogen-3. These are shown in Figure 1.1.9. The most common isotope is hydrogen-1, which has a single proton as its nucleus. It makes up 99.98% of hydrogen atoms on Earth and is sometimes referred to as protium. Hydrogen-2 is more commonly known as deuterium and has 1 proton and 1 neutron. Hydrogen-3 is known as tritium and has 1 proton and 2 neutrons. These isotopes of hydrogen are used in nuclear power plants to make the generation of power more efficient.

1.2

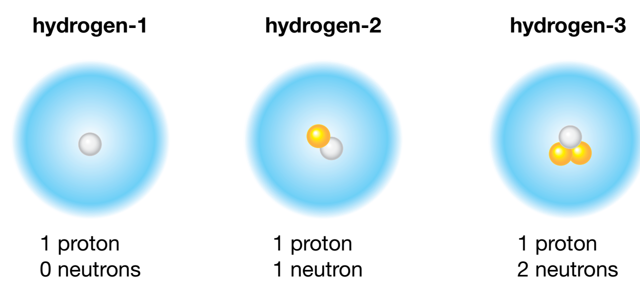


Figure 1.1.9 These isotopes of hydrogen all have the same number of protons but different numbers of neutrons.

Electrons and the nucleus

The number of electrons surrounding the nucleus of an atom is exactly equal to the number of protons in the nucleus. As a result, atoms are charge **neutral** (have no charge) because the positive charge of the protons is exactly balanced by the negative charge of the electrons.

Although each electron is 1800 times smaller than a proton, together the electrons form ‘clouds’ around the nucleus. The clouds can be 100 or even 1000 times wider than the nucleus. This means that if the nucleus was the size of a golf ball, the electrons would form clouds the size of a football stadium. It also means that most of an atom is empty space.

Mini-Me

If all the electrons in your body collapsed onto the nuclei, you would shrink to the size of a flea. But you would still weigh the same.

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The New Zealand scientist Ernest Rutherford discovered that the nucleus only takes up a small fraction of the space inside an atom. In his famous experiment, Rutherford fired a beam of helium nuclei (alpha particles) at a thin sheet of gold foil. This is shown in Figure 1.1.10. To his surprise, most of the nuclei passed straight through the foil and only a small fraction were deflected back. Up until that point, most scientists had believed that atoms were completely solid. Rutherford realised that atoms are mostly empty space. However, they had a small, positively charged nucleus surrounded by a cloud of electrons.

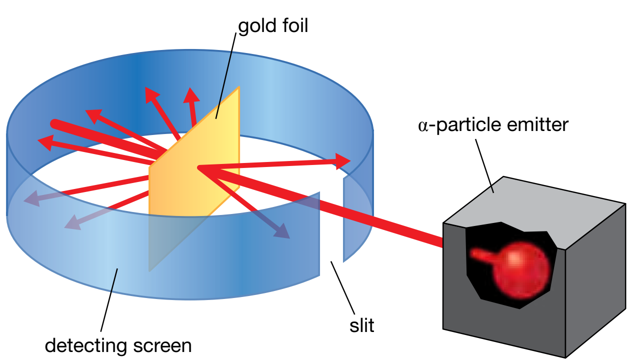

Figure 1.1.10 In Rutherford's famous experiment, a beam of helium nuclei (alpha particles) was fired at gold foil. Most of the alpha particles went straight through and only a small number were deflected. He concluded that atoms are mostly empty with a small, positively charged nucleus and a large negatively charged electron cloud.

Electron shells

The electrons in an atom are attracted to the nucleus by the positive charge of the protons. However, the electrons never fall into the nucleus. This is because the electrons are trapped inside **electron shells**, which surround the nucleus like the layers of an onion, as shown in Figure 1.1.11.

Jumpy electrons

Electrons in atoms move constantly and can even jump up and down between the electron shells. When the electrons move between the electron shells, they produce coloured light. This is how fireworks produce their spectacular coloured light displays and also how neon signs work.

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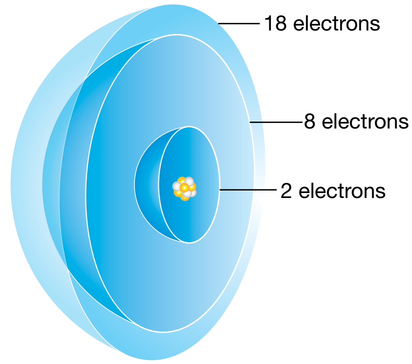


Figure 1.1.11 The electrons that surround an atom cannot move around freely. They are held in electron shells that surround the nucleus like layers of an onion. The number of electrons that each shell can hold depends on the size of the electron shell.

Many of the electron shells in an atom are empty. The biggest known element at present has 118 electrons in 6 shells. The 1st electron shell is the innermost shell. It is the smallest electron shell and can only contain 2 electrons. Once the 1st electron shell is full, electrons start to fill the 2nd electron shell, which can hold up to 8 electrons. The 3rd electron shell holds up to 18 electrons. The 4th electron shell can hold 32 electrons.

The number of electrons in each shell of an atom is known as its **electron configuration**. For example, carbon has 6 protons and therefore 6 electrons. The first 2 electrons fill the 1st electron shell, and the remaining 4 electrons go into the 2nd electron shell. Therefore the electron configuration for carbon is 2,4 as shown by the electron shell diagram in Figure 1.1.12.

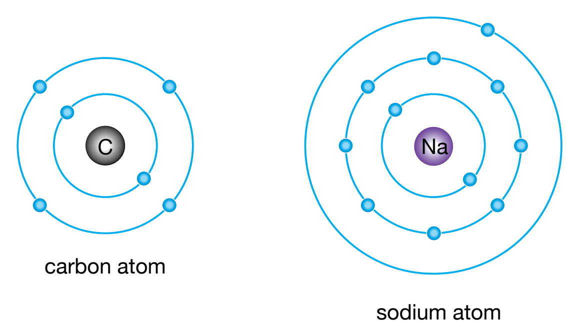


Figure 1.1.12 The electron configuration of an atom can be represented by electron shell diagrams. The electron shells are always filled from the innermost shell to the outermost shell. Carbon has only two shells occupied. Sodium has three shells occupied.

The electron configuration for a sodium atom is 2,8,1. This is because sodium atoms contain 11 electrons. The first 2 electrons fill the 1st electron shell, the next 8 electrons fill the 2nd electron shell, and the remaining electron goes into the 3rd electron shell.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

History of the atomic model

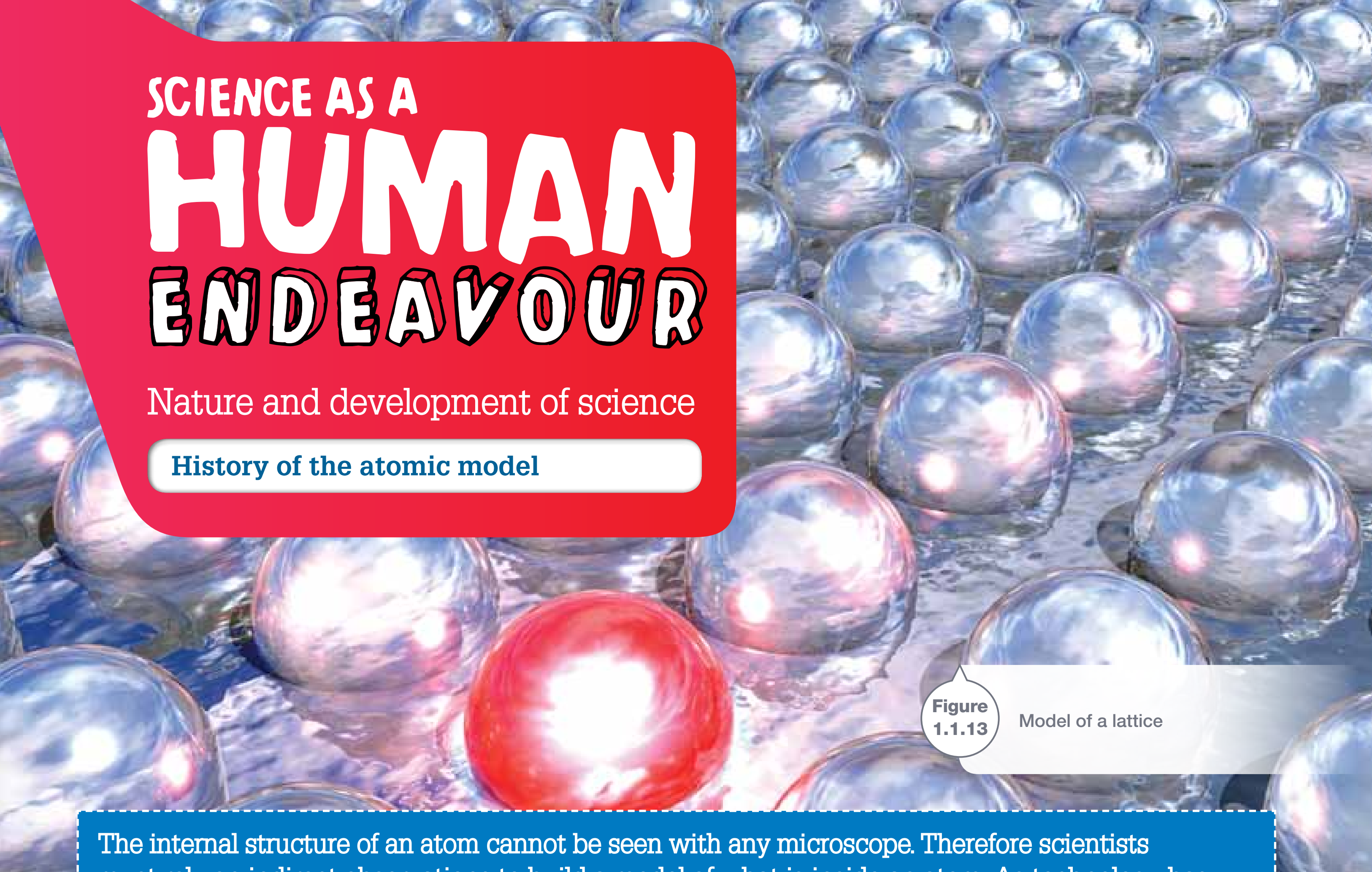
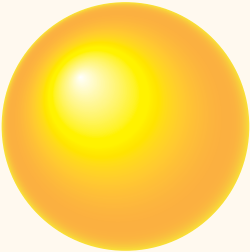
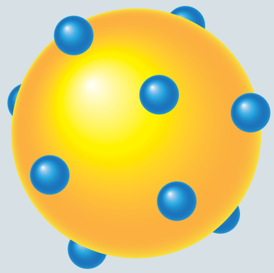
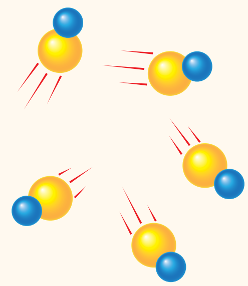
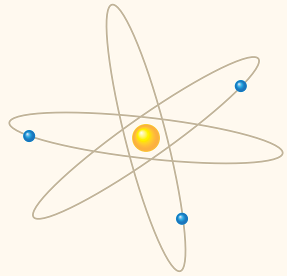
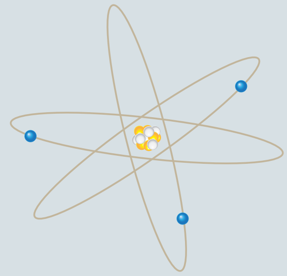
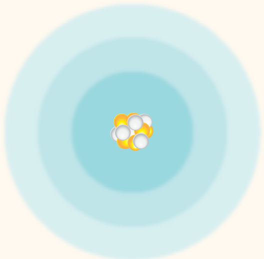


Figure 1.1.13 Model of a lattice

The internal structure of an atom cannot be seen with any microscope. Therefore scientists must rely on indirect observations to build a model of what is inside an atom. As technology has advanced, scientists' understanding of atoms has increased and the **atomic model** has evolved.

Year	Observation and theory	Model
Early BCE	The ancient Greeks believed that all matter was made up of only four fundamental elements: earth, fire, air and water. This was the basis of the continuum model, which predicted that regardless of the number of times you halve a piece of matter, it can always be broken down into even smaller pieces.	 Continuum model
460–370 BCE	Greek philosopher Democritus suggested that matter was not continuous but made up of tiny, solid and unbreakable particles. He was the first to use the term *atomos* meaning 'indivisible'.	 Solid-ball model

Year	Observation and theory	Model
1904	British scientist Joseph John Thompson (J.J. Thompson) discovered the electron and its negative charge in 1897. However, Thompson knew that there must also be a source of positive charge in the atom to make the atom charge neutral. Therefore, in 1904 he proposed the plum pudding model. In this model, an atom is thought of as a round ball of positive charge with negatively charged electrons embedded in it (like plums or sultanas in a plum pudding).	 Plum pudding model
1904	Hungarian scientist Philipp Lenard described atoms as mostly empty spaces filled with fast-moving ‘dynamides’. These were neutrally charged particles made up of a heavy positive particle stuck to a light negative particle.	 Dynamide model
1911	New Zealand scientist Ernest Rutherford performed an experiment where he fired a beam of positively charged alpha particles at gold foil. He found that while most of the alpha particles went through the foil, a small number were deflected. This led to the development of a nuclear model of the atom in which most of the mass is believed to be contained in a small positive nucleus surrounded by a large space occupied by negative electrons.	 Nuclear model
1913	Danish scientist Niels Bohr modified Rutherford’s model and proposed that electrons can only travel along certain pathways around the nucleus, called orbits. As a result, this model is sometimes called the planetary model. This model explained why different elements produce different-coloured light when heated. This observation is due to the electrons moving from higher to lower orbits and emitting coloured light in the process.	 Planetary model
1932	English scientist James Chadwick discovered the neutron, showing that the nucleus was not just a mass of positive charge but a cluster of positively charged protons and charge-neutral neutrons.	 Planetary model with neutrons
1932–today	Today, scientists have concluded that the position of an electron in an atom can never be known exactly. This means that it is impossible for electrons to revolve around the nucleus in specific orbits as suggested by Niels Bohr. Instead, the electrons form clouds around the nucleus. Scientists can predict the shape of these clouds but never the exact location of electrons within them.	 Electron cloud model

1.1 Unit review

Remembering

1 **List** the three subatomic particles that make up atoms.

2 **State** Rutherford's famous discovery about the structure of the atom.

3 **Recall** the maximum number of electrons that can be held in the 1st, 2nd and 3rd electron shells.

4 **Name** the force that attracts the electrons to the nucleus.

5 **State** the name of the atomic model proposed by:
- **a** Ernest Rutherford
- **b** Niels Bohr
- **c** Philipp Lenard
- **d** Joseph John Thompson.

Understanding

6 **Define** the term *isotope*.

7 **Define** the terms *atomic number* and *mass number*.

8 **Explain** why electrons:
- **a** form a cloud around the nucleus
- **b** don't fall into the nucleus.

9 **Explain** why an atom is electrically neutral.

10 **Describe** Rutherford's experiment and how it allowed him to understand more about the structure of an atom.

11 **Explain** what the atomic number tells you about the structure of an atom.

Applying

12 **Identify** which atoms in Figure 1.1.14 are isotopes of the same element.

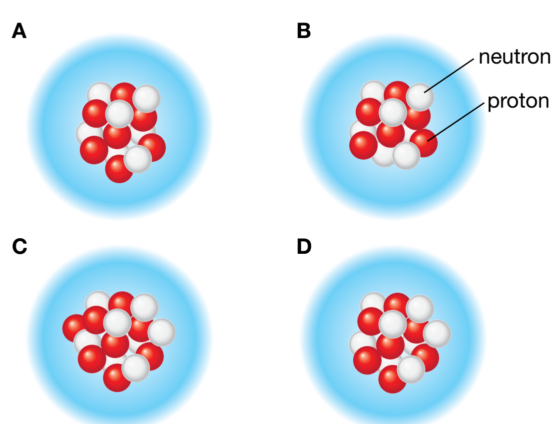


Figure 1.1.14

13 **Identify** the atomic symbol for the isotopes carbon-12, carbon-13 and carbon-14. (Hint: All carbon atoms have 6 protons.)

14 **Identify** the electron configuration of a magnesium atom (atomic number = 12).

Analysing

15 **Compare** elements and compounds.

16 **Calculate** the number of protons, neutrons and electrons in the following atoms:
- **a** ${}^{4}_{2}\mathrm{He}$
- **b** ${}^{16}_{8}\mathrm{O}$
- **c** ${}^{28}_{14}\mathrm{Si}$
- **d** ${}^{207}_{82}\mathrm{Pb}$
- **e** ${}^{238}_{92}\mathrm{U}$

Evaluating

17 **Evaluate** the view that atoms are like blocks of Lego.

18 **Propose** why scientists have developed atomic symbols to help communicate their results.

Creating

19 **Construct** the electron shell diagram of a sulfur atom that has the electron configuration 2,8,6.

20 **Construct** a timeline showing the major developments towards the modern atomic model.

Inquiring

1 Research the life and achievements of a scientist who has contributed to the understanding of the atomic model.

2 **a** Construct electron configuration diagrams for fluorine, neon and sodium.
- **b** Compare and contrast the three.
- **c** Use the available resources to research the following physical properties of each.
  - **i** Is it a metal or a non-metal?
  - **ii** Does it form molecules or crystal lattices, or exist as single atoms?
  - **iii** Is it a solid, a liquid or a gas at room temperature?
  - **iv** Does it react easily with other chemicals?
- **d** List three uses of each element.

1.1 Practical activities

1 Experimenting like Rutherford

Purpose
To estimate the size of an unseen object through indirect observation.

Materials
- a large cereal box with the top and bottom open
- objects of various shapes and sizes that can fit inside the box
- 5 marbles

Procedure
1. This activity requires you to work in pairs.
2. Place the open cereal box on the desk as shown in Figure 1.1.15.

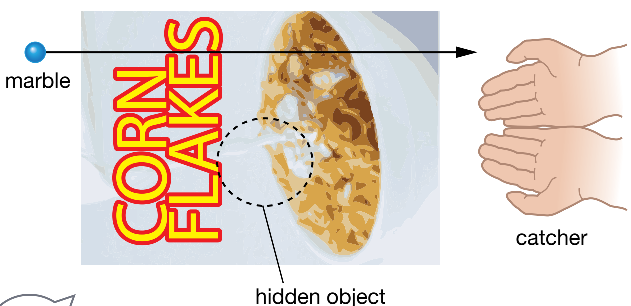


Figure 1.1.15

3. The first person places an object in the box without the other person seeing the object.
4. The second person then rolls the 5 marbles through the box and tries to estimate the size of the object.
5. Record your estimates in the table below and compare them to the real size of the object.
6. Repeat this process three more times, so that each member of the pair has two turns at determining the nature of the hidden object.

Results
Record your results in a table like this one.

	Estimated size	Real size
Object 1		
Object 2		

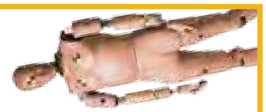
Discussion
1. **Explain** how this experiment is similar to Rutherford's experiment.
2. **Propose** the factors that might have influenced the accuracy of your estimates.
3. **Propose** other properties of the object that may be determined by indirect observation using this technique.

1.1 Practical activities

2 Indirect observation of electron shells

Purpose
To observe coloured light produced when electrons jump from one electron shell to another.

Materials
- cotton buds or small cotton balls
- chloride solutions of barium, sodium, copper, potassium and calcium
- 5 small beakers
- 1 large beaker of water
- Bunsen burner
- tongs



SAFETY

Some of the chemicals in this prac are toxic. Make sure you wear safety glasses and gloves when handling chemicals. Avoid contact with skin, mouth and eyes. Wash your hands thoroughly at the end of the practical.

Procedure
1. Copy the table from the results section into your notes.
2. Pour about 2 to 5 mL of the chloride solutions into labelled beakers—one per beaker. Label the beakers so you can identify each solution.
3. Light the Bunsen burner, leaving it on the yellow safety flame until you are ready to insert a saturated cotton bud or ball. Fill another beaker with water.
4. With the tongs pick up the cotton bud or ball and soak it in the barium chloride solution.
5. Place the soaked cotton bud in the blue flame of the Bunsen burner for about 2 seconds and observe the flame colour. Immediately remove the cotton bud or ball and drop it in the beaker of water. Do not let it catch fire. Record the results in your table.
6. Repeat the procedure for the remaining solutions.

Results
Copy the following table into your workbook and complete it.

Solution	Metal element	Observation
Barium chloride		
Sodium chloride		
Copper chloride		
Potassium chloride		
Calcium chloride		

Discussion
1. Different-coloured light is produced depending on whether the electron shells are far apart or close together.
   - When the electron shells are far apart, green, blue or violet light is produced.
   - When the electron shells are close together, red, orange or yellow light is produced.

   Use your results to **classify** the compounds in your experiment as having electron shells that are either ‘far apart’ or ‘close together’.
2. **Propose** what compounds you might use to make green and purple fireworks.

1.2 Ions

Understanding more about how the electrons move inside an atom allows scientists to control how atoms react with each other. This control has led to the development of products such as artificial bones and wonder drugs that cure life-threatening diseases.

Atoms and ions

Atoms are electrically neutral (have no charge) because they contain an equal number of positive protons and negative electrons. However, if an electron is removed or added, the atom becomes charged and is now called an **ion**. When an electron is removed from an atom, that atom becomes a positively charged ion. A positive ion is known as a **cation**. If an electron is added to an atom, that atom becomes a negatively charged ion. A negative ion is known as an **anion**.

SciFile

Walking on air

The outer electrons of atoms repel each other when the atoms come very close together. This means that when you walk, the atoms on the sole of your shoe never really touch the ground. They are always separated from the atoms in the ground by a tiny distance—forced apart by the electrostatic repulsion.

Cations

A cation is formed when an atom loses electrons. An atom will tend to form cations if its outermost electron shell is mostly empty. The atom will usually lose all the electrons in the outermost shell so that only filled shells remain, as demonstrated in Figure 1.2.1.

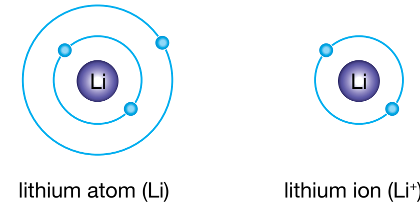


Figure 1.2.1 Lithium forms a cation because its outermost shell is mostly empty.

Almost all cations come from metal atoms. This is because metal atoms have few electrons in their outermost electron shell and these electrons are only weakly bound to the atom. Table 1.2.1 lists some common cations.

Table 1.2.1 Common cations

Charge	Cation name	Chemical symbol
+1	Hydrogen ion	H^+
	Lithium ion	Li^+
	Sodium ion	Na^+
	Potassium ion	K^+
	Copper(I) ion	Cu^+
+2	Copper(II) ion	Cu^{2+}
	Beryllium ion	Be^{2+}
	Magnesium ion	Mg^{2+}
	Iron(II) ion	Fe^{2+}
+3	Iron(III) ion	Fe^{3+}
	Aluminium ion	Al^{3+}

An important non-metallic cation comes from hydrogen (H). Hydrogen ions (H^+) are formed whenever an acid is dissolved in water.

As you can see from Table 1.2.1, the symbols used to represent cations are made up of the atomic symbol and the charge on the ion. For example, sodium atoms (Na) lose one electron, so the sodium ion has a charge of +1. This is represented by the symbol Na^+. Magnesium (Mg) atoms lose two electrons and so the magnesium ion is represented as Mg^{2+}.

SKILL BUILDER

Naming ions

The name of a cation is the same as the name of the atom. However, in some cases an atom can form more than one type of cation, depending on how many electrons it loses. For example, copper atoms (Cu) may lose one or two electrons to produce the copper ions Cu^+ and Cu^{2+}. To distinguish between these two ions, scientists add a roman numeral to the ion name that indicates the number of electrons lost. Therefore, the copper ion Cu^+ is referred to as the copper(I) ion. The ion Cu^{2+} is referred to as the copper(II) ion. Iron (Fe) can also form two types of cations: iron(II) Fe^{2+} or iron(III) Fe^{3+}.

Anions are named differently. The chemical name for an anion is similar to the name of the atom but ends in *-ide*. For example, chlorine atoms (Cl) form chloride ions Cl^-; oxygen atoms (O) form oxide ions O^{2-} and nitrogen atoms (N) form nitride ions N^{3-}.

Anions

An anion is produced when an atom gains electrons. This will occur if the outermost electron shell of the atom is almost full. In that case, the atom gains additional electrons until the shell is filled. This is shown in Figure 1.2.2.

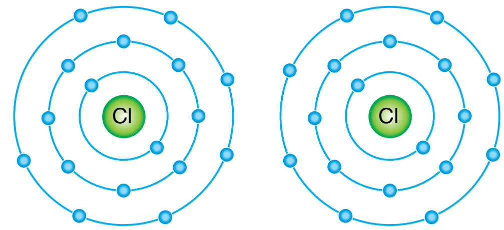


Figure 1.2.2 Chlorine forms an anion because its outermost shell is almost full. The extra electron completes the electron shell.

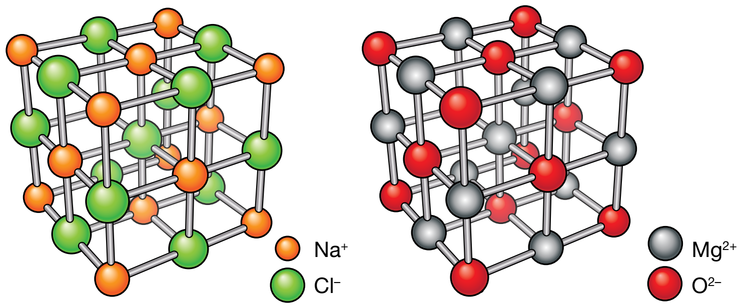
All anions come from non-metallic atoms. These atoms gain electrons in their outer electron shell. Table 1.2.2 lists some common anions. The symbols used to represent anions are similar to those used for cations. They are made up of the chemical symbol for the atom and the charge of the ion. For example, a chlorine atom gains one electron and so it has a charge of –1. Therefore, the ion is represented by the symbol Cl^-. An oxygen atom (O) gains two electrons, so the ion is represented as O^{2-}.

Table 1.2.2 Common anions

Charge	Anion name	Chemical symbol
–1	Fluoride	F^-
	Chloride	Cl^-
	Bromide	Br^-
	Iodide	I^-
–2	Oxide	O^{2-}
	Sulfide	S^{2-}
–3	Nitride	N^{3-}
	Phosphide	P^{3-}

Ionic compounds

When anions and cations come together, they form compounds made up of large crystal lattices. These compounds are known as **ionic compounds**. Common table salt is an ionic compound with the chemical name sodium chloride (NaCl). Other ionic compounds are lithium chloride (LiCl), potassium fluoride (KF) and magnesium oxide (MgO). Figure 1.2.3 shows two examples.



salt, or sodium chloride (NaCl) | magnesium oxide (MgO)

Figure 1.2.3 Sodium chloride and magnesium oxide are ionic compounds.

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Chemical names and formulas

Naming ionic compounds is very easy. You simply write the name of the cation followed by the name of the anion. For example, the ionic compound known as calcium oxide is made up of calcium cations (Ca^{2+}) and oxide anions (O^{2-}). The ionic compound known as copper(I) chloride is made up of copper(I) cations (Cu^{+}) and chloride anions (Cl^{-}).

Writing the chemical formula is slightly more difficult. When writing the chemical formula for an ionic compound, you must ensure that there is an equal number of positive and negative charges so that the total charge is zero. In the case of sodium chloride, the sodium ion has a charge of +1 and the chloride ion has a charge of –1. Therefore, the chemical formula is just NaCl because you only need one of each to balance the charges fully. The charges are not shown in the chemical formula because the total charge is zero.

However, in the case of magnesium chloride, the magnesium ion has a charge of +2 and the chloride ion has a charge of –1. Therefore, two chloride ions are needed to balance the charge of each magnesium ion. This is represented in the chemical formula by writing $MgCl_2$.

Ionic bonding

Cations and anions are attracted to each other because they have opposite electric charges. When cations come close to anions, they stick together, forming an **ionic bond** as shown in Figure 1.2.4.

The ionic bonds holding crystal lattices together are very strong. Therefore, ionic compounds usually:

- are hard
- are brittle
- have high melting points.

SKILL BUILDER

Writing ionic formulas

To determine the chemical formula of iron(III) oxide, you need to:

1. Identify the cation and anion, and write the chemical symbols for each.

   Fe^{3+} iron(III) cation — O^{2-} oxide anion

2. Swap the charges on the ions, writing them at the bottom this time.

   Fe_{2-} — O_{3+}

3. Remove the charges and write the two symbols together.

   Fe_2O_3

4. Check to see if the numbers can be divided by the same number (common factor). If so, divide both by the common factor. In this case, 2 and 3 do not have a common factor, so the chemical formula remains:

   Fe_2O_3

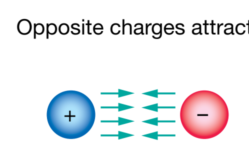


Figure 1.2.4 In ionic compounds, the ions are held together by the electrostatic attraction of their opposite charges. An ionic bond is formed.

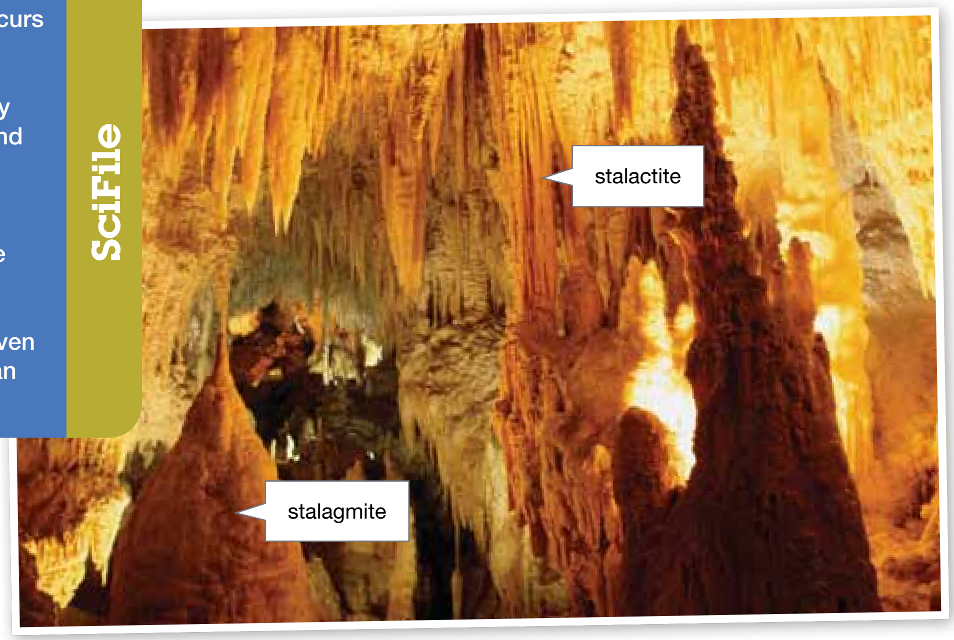
Ionic compounds are hard because it takes a lot of force to break the ionic bonds. They are brittle because the ionic bonds hold the ions in fixed positions and this means the lattice shatters rather than bends. They have high melting points because high temperatures are required to break the strong ionic bonds and allow the ions to flow freely as a liquid. Ionic compounds are also often brightly coloured, like the ones in Figure 1.2.5.

Figure 1.2.5 These brightly coloured crystals are all examples of ionic compounds.

SciFile

Cave crystals

The process of recrystallisation occurs continually in caves to form stalagmites and stalactites. Stalagmites and stalactites are very large crystals that form when ground water seeps through the roof of a cave, bringing with it dissolved calcium compounds. The drops of water deposit small amounts of the calcium compound crystals on the roof of the cave and on the floor directly below. Over hundreds or even thousands of years this process can grow crystals over 50 metres high.



Ions in solution

Some ionic compounds are soluble (dissolve) in water, while others are insoluble (do not dissolve). How easily an ionic compound dissolves is known as its **solubility**.

When an ionic compound dissolves in water, the water particles surround the cations and anions. This is shown in Figure 1.2.6. This breaks the crystal lattice apart and prevents the ions from sticking back together. The ions are then spread evenly throughout the water and they are said to be *in solution*. If the water is then removed through boiling or evaporation, the ions can stick together once more. This process is known as recrystallisation. An example of recrystallised crystals is shown in Figure 1.2.7.

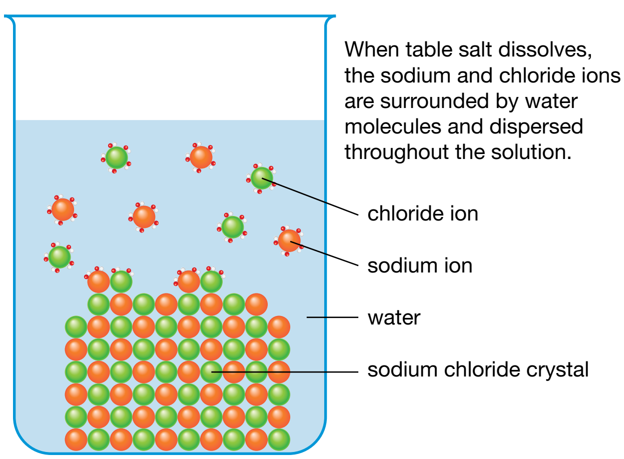


Figure 1.2.6 When an ionic compound dissolves in water, the water particles surround the ions and distribute them evenly throughout the solution.

Figure 1.2.7 When an ionic compound dissolves in water, it forms a clear solution. When the water is removed by evaporation or boiling, the ionic compound recrystallises.

INQUIRY science 4 fun

Recrystallising ionic compounds

Yes

How does the rate of recrystallisation affect the shape of crystals?

Collect this ...

- table salt (or any other soluble ionic compound)
- beaker or other glass container
- water
- spoon or stirring rod
- two watch-glasses or small dishes.
- magnifying glass (optional)

Do this ...

1. Fill the beaker with water and dissolve as much salt as possible, stirring as you go.
2. Pour a small amount of the salt solution into each of the watch-glasses or dishes.
3. Place one watch-glass in a cool dark place and the other in a warm sunny place.
4. Leave both solutions to evaporate completely.
5. Examine the shape of the crystals in both watch-glasses.

Record this ...

Describe what you saw.

Explain why you think this happened.

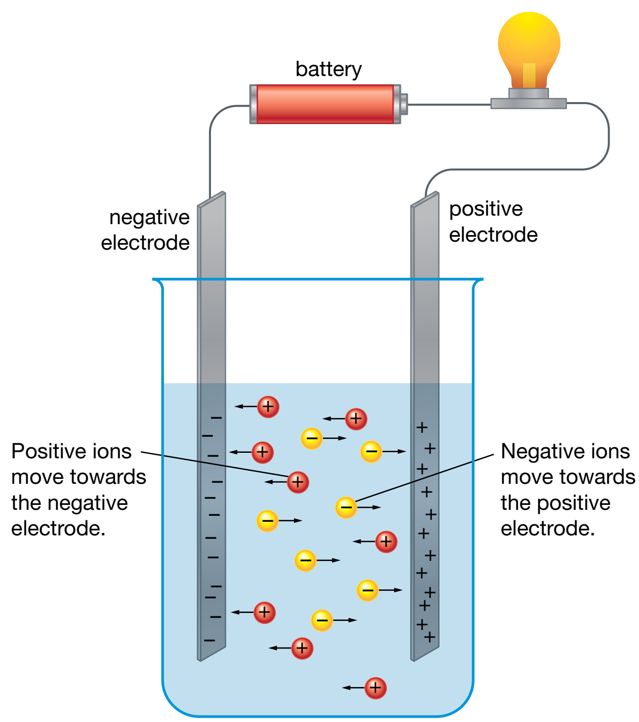


Figure 1.2.8 When positive and negative electrodes are put into a solution of an ionic compound, the cations (+) move towards the negative electrode and the anions (–) move towards the positive electrode. This allows electrical current to flow around the circuit.

When ions are in solution, they can move freely through the liquid. This means that they can create a flow of electrical charge and therefore they conduct electricity. If positive and negative electrodes are placed in the solution, the cations (+) will move towards the negative electrode and the anions (–) will move towards the positive electrode, as shown in Figure 1.2.8. This allows the electrical current to flow through the entire circuit. Only liquids that contain ions will allow electrical current to flow. Liquids such as oil or kerosene do not contain ions and therefore do not conduct electricity.

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Lightning

When lightning strikes during a thunderstorm it is because electrical charges in the clouds have become so strong that they ionise the atoms in the air. These regions of charged air particles allow the static charge in the clouds to travel down to the Earth's surface, producing a spectacular flash of light.

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1.5

1.2 Unit review

Remembering

1 **List** the chemical names and symbols of three cations and three anions.

2 **Name** a non-metallic cation.

3 **State** how the end of the chemical name is changed to distinguish an anion from its atom.

4 **State** whether ionic compounds form molecules or crystal lattices or both.

5 **Recall** the term used to describe how well an ionic compound dissolves in water.

6 Name the following ions.
- a K^+
- b Br^-
- c S^{2-}

Understanding

7 **Define** the terms *cation* and *anion*.

8 a **Explain** when the name of a cation might be followed by a roman numeral.
- b **State** an example.

9 **Outline** what happens when an ionic compound dissolves in water.

10 **Explain** why an electrical current can be passed through a solution of a dissolved ionic compound.

Applying

11 **Identify** three ionic compounds that you might find around the home.

12 **Apply** your knowledge of ions to **explain** how the following are produced.
- a Cl^-
- b Na^+
- c O^{2-}
- d Ca^{2+}
- e Al^{3+}

13 **Identify** the ionic compound formed and its chemical formula when the following form ionic bonds.
- a sodium cations (Na^+) and chloride anions (Cl^-)
- b magnesium cations (Mg^{2+}) and oxide anions (O^{2-})
- c aluminium cations (Al^{3+}) and fluoride anions (Fl^-)
- d copper(II) cations (Cu^{2+}) and bromide anions (Br^-)
- e iron(III) cations (Fe^{3+}) and oxide anions (O^{2-})

Analysing

14 **Compare** atoms and ions.

15 **Compare** the names of the ions:
- a Fe^{2+} and Fe^{3+}
- b Cr^{4+} and Cr^{6+}

Evaluating

16 An unknown element 'X' forms a cation with charge +3. Another unknown element 'Y' forms an anion with charge –2.
- a **Evaluate** which element is most likely to be:
  - i metallic
  - ii non-metallic.
- b **Propose** the chemical formula for the ionic compound formed from X and Y.

17 When ionic compounds are heated to high temperatures, they melt to form a liquid.
- a **Assess** whether or not this liquid will conduct electricity.
- b **Justify** your answer.

Creating

18 **Construct** a labelled diagram of a solution of copper(II) chloride with positive and negative electrodes. Indicate on the diagram the direction in which the ions will move through the solution.

19 **Construct** electron shell diagrams of the following atoms and then write the symbol for the ion they form.
- a sodium (Na) 2,8,1
- b fluorine (F) 2,7
- c oxygen (O) 2,6

Inquiring

1 Research the term *ionic liquids*. What are they and how could they be useful?

2 The ionosphere is the uppermost part of our atmosphere and contains ions. Research how the ionosphere is formed and how it is useful to humans.

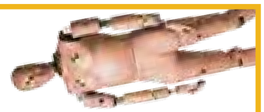
3 Design an experiment to test the hypothesis that ionic compounds such as salt cannot be dissolved in non-ionic solvents such as methylated spirits, glycerol or kerosene.

1.2 Practical activities

1 Making ionic compounds

Purpose

To observe how two different ionic compounds can be created from two ionic compounds in solution.



SAFETY

Some of the chemicals in this prac are toxic. Be sure to wear safety glasses and gloves when handling chemicals. Avoid contact with skin, mouth and eyes. Wash your hands thoroughly at the end of the practical.

Materials

- 0.1 M solution of sodium sulfide (Na_2S)
- 0.1 M solution of copper(II) chloride ($CuCl_2$)
- 3 large test-tubes in a test-tube rack
- small funnel
- filter paper
- pipette
- a 20 mL measuring cylinder
- 2 watch-glasses
- optional: hand lens or microscope

Procedure

1. Copy the table from the results section into your workbook.
2. Use the pipette to measure out 10 mL of the sodium sulfide solution and pour this into a large test-tube.
3. Rinse the measuring cylinder.
4. Measure out 10 mL of the copper(II) chloride solution and add it to a different test-tube.
5. Create the insoluble compound copper(II) sulfide by pouring the sodium sulfide into the test-tube with the copper(II) chloride solution.
6. Place the funnel into the third test-tube and add a fluted filter paper to it.
7. Separate the solid copper(II) sulfide from the liquid by pouring the mixture through the filter paper.
8. Place the filter paper on a watch-glass, but open the paper up and leave it to dry overnight.
9. Observe the copper(II) sulfide using your eyes, a hand lens or a microscope.
10. Pour some of the filtrate solution from the test-tube into a watch-glass and leave it in a warm place to evaporate overnight. This should recrystallise an ionic solid.
11. Observe the crystals on the watch-glass, using your eyes, a hand lens or a microscope.

Results

Construct and complete the following table.

	Observations
The 0.1 M solution of sodium sulfide	
The 0.1 M solution of copper(II) chloride	
The mixture of the two solutions	
The solid copper(II) sulfide after filtration	
The remaining solution (filtrate) after filtration	
The copper(II) sulfide after drying	
The recrystallised ionic compound	

Discussion

1. **List** all the cations and anions involved in this experiment.
2. a **Describe** what happened when the two initial solutions were mixed.
   b **Explain** why this happened.
3. **Deduce** which ions went into making the solid in the filter paper and then write its chemical formula.
4. **Deduce** which ions must have been left in solution after the solutions were mixed.
5. **Predict** the chemical name and chemical formula of the recrystallised solid.
6. **Propose** whether the re-cystallised compound is pure or not. Use your observations to support your answer.

1.2 Practical activities

2 Detecting ions by indirect observation

Purpose

To use electrical conduction to determine whether common household compounds form ions.

Materials

- 250 mL beaker
- distilled water
- sugar (sucrose)
- salt
- tea bag
- coffee
- vinegar
- vegetable oil
- 1.5V battery or DC voltage source
- wires with alligator clips
- ammeter
- electrodes

Procedure

1. Copy the table from the results section into your workbook.
2. Use the wire to connect the voltage source, ammeter and electrodes in a circuit as shown in Figure 1.2.9.
3. Fill a beaker with distilled water.

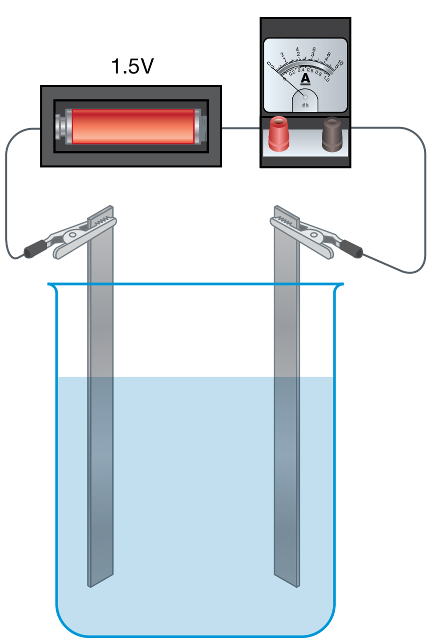


Figure 1.2.9

4. Place the electrodes in the water and record the current.
5. Replace the distilled water with a salt water solution and repeat the measurement with the ammeter.
6. Rinse the beaker and the electrodes with distilled water.
7. Make up separate solutions of sugar, coffee and tea using distilled water.
8. Repeat the measurement of current for all the other solutions, remembering to rinse the beaker and electrodes with distilled water each time.

Extension

9. Repeat step 4 but try a globe in place of an ammeter. Will the globe light up?

Results

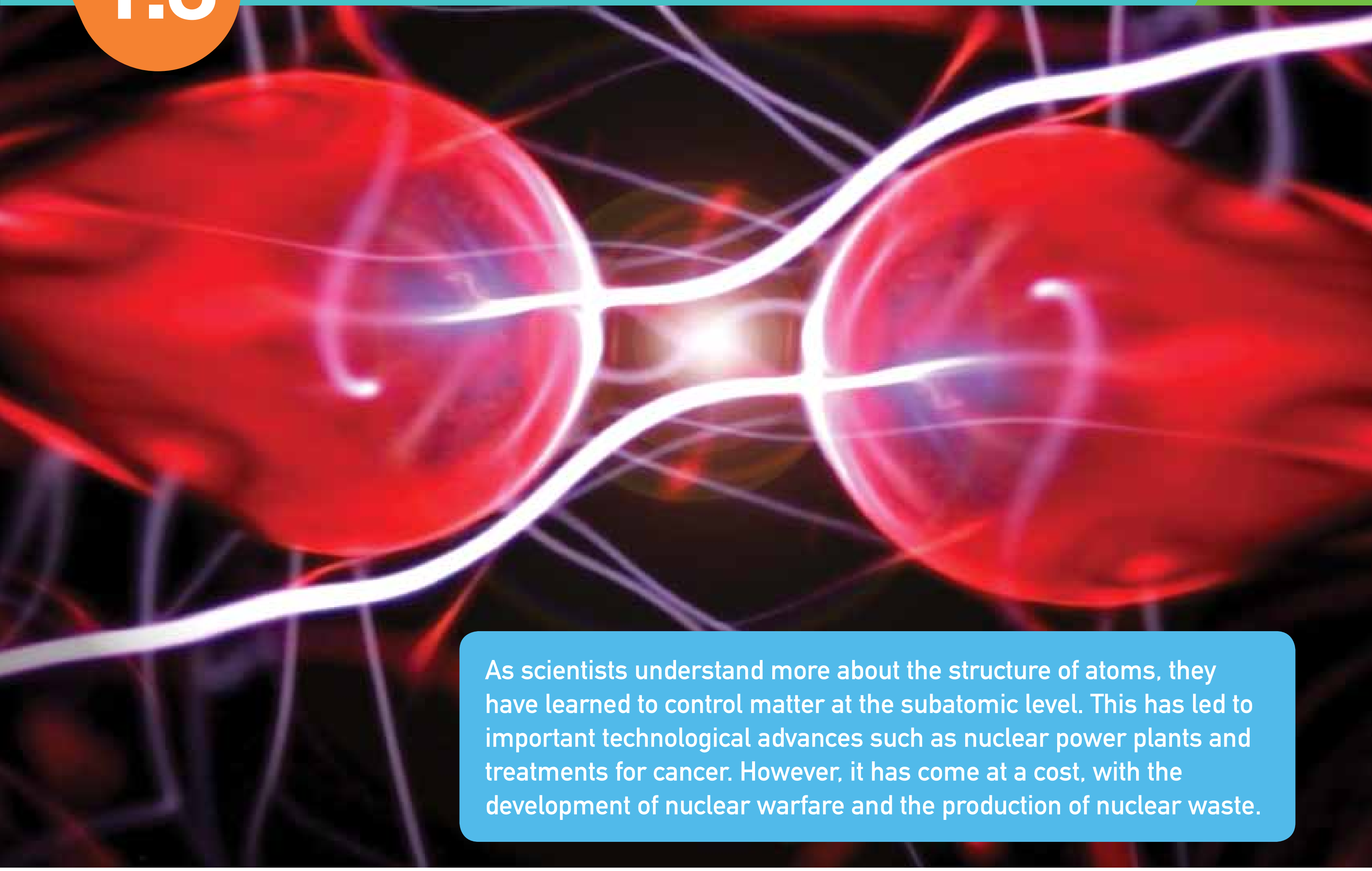
Construct and complete the following table.

Solution	Current detected? (Yes/No)	Ions present? (Yes/No)
Distilled water		
Salt water solution		
Sugar solution		
Coffee solution		
Tea solution		
Vinegar		
Vegetable oil		

Discussion

1. **List** all the solutions in which ions were present and all the solutions in which ions were not present.
2. **Explain** why a current flowing indicates the presence of ions.
3. In the cases where no current flowed, **propose** whether the compounds form atoms, molecules or lattices in solution. **Justify** your answer.

1.3 Nuclear decay and radiation



As scientists understand more about the structure of atoms, they have learned to control matter at the subatomic level. This has led to important technological advances such as nuclear power plants and treatments for cancer. However, it has come at a cost, with the development of nuclear warfare and the production of nuclear waste.

Nuclear decay

A nucleus is a cluster of protons and neutrons that sits at the centre of an atom, surrounded by a cloud of tiny electrons. However, the nucleus is not just standing still. The protons and neutrons are constantly moving, vibrating, pulsating, rotating and rearranging, causing some to emit **electromagnetic radiation** called gamma rays. Occasionally, some nuclei even eject particles at high speed. This emission of electromagnetic radiation or particles is known as a **nuclear reaction** or **nuclear decay**.

During nuclear decay, atoms may change from one element to another. This change to another element is known as **transmutation**. Transmutation never occurs during everyday chemical reactions such as those that happen when you breathe, bake a cake or burn paper. It only occurs during nuclear decay.

An example of nuclear decay is an atom of sodium (Na) metal changing into the noble gas, neon (Ne). You can see this in Figure 1.3.1.

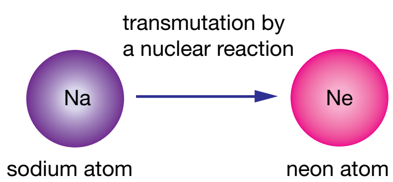


Figure 1.3.1 When a sodium (Na) atom undergoes nuclear decay, it changes into a different atom entirely—neon (Ne). This process is known as transmutation.

Ambitious alchemists

SciFile

In the Middle Ages, people known as alchemists tried to turn lead into gold through magic and various chemical reactions. Today, scientists know the alchemists' attempts were pointless and that only transmutation could convert lead into gold.

Types of nuclear decay

There are three types of nuclear decay. These are alpha decay, beta decay and gamma decay.

Alpha decay

During **alpha decay**, a nucleus ejects an **alpha particle**, which is a cluster of two protons and two neutrons. The alpha particle is given the symbol α. However, the particle is identical to a helium-4 nucleus, and so it may also be referred to as $^{4}_{2}He^{2+}$.

Alpha decay only occurs in atoms with very heavy nuclei—this is usually where the mass number (protons plus neutrons) is greater than 100. For example, the radioisotope uranium-238 ($^{238}_{92}U$) undergoes alpha decay as shown in Figure 1.3.3.

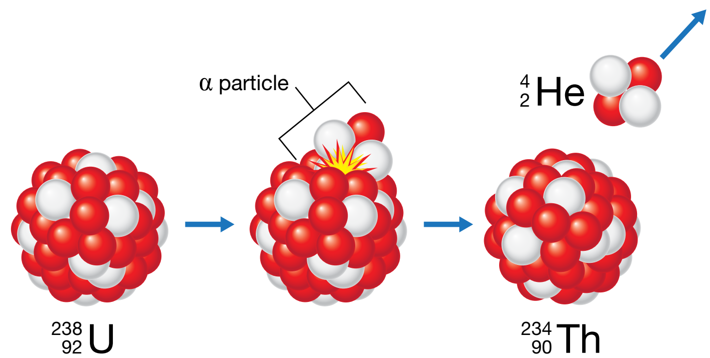


Figure 1.3.3 When a uranium-238 nucleus undergoes alpha decay, it becomes a thorium-234 atom. The element uranium has become the element thorium.

Initially, the uranium-238 atom has 92 protons and 146 neutrons. When the uranium-238 ejects an alpha particle, the nucleus loses 2 protons and 2 neutrons. Therefore, the atom becomes a thorium-234 atom with 90 protons and 144 neutrons. In other words, the atomic number has decreased by 2 while the mass number has decreased by 4. Through this nuclear reaction, the uranium atoms become thorium atoms, an entirely different element.

Beta decay

Beta decay occurs when the nucleus ejects a **beta particle**, which is given the symbol β. Beta particles are identical to electrons and therefore are very small and have a negative charge. When the nucleus undergoes beta decay, a neutron is converted into a proton. This increases the atomic number by one, meaning a new element is formed. However, the mass number does not change because the total number of protons and neutrons stays the same.

Radioisotopes

Most of the atoms that make up the world around you contain **stable nuclei**. This means that the nuclei will never undergo nuclear decay. However, a tiny fraction of atoms have **unstable nuclei**. These unstable atoms could eject particles or electromagnetic waves from their nucleus at any moment and undergo nuclear decay. These unstable atoms are known as **radioisotopes**.

Each type of atom may have several isotopes but only some isotopes are **radioactive**. Isotopes are atoms that have the same number of protons but a different number of neutrons. For example, carbon has three naturally occurring isotopes called carbon-12, carbon-13 and carbon-14, as shown in Figure 1.3.2. They are all types of carbon atoms because they all contain 6 protons. However, carbon-12 has 6 neutrons, carbon-13 has 7 neutrons and carbon-14 has 8 neutrons. As extra neutrons are added to a nucleus, it becomes unstable. For example, carbon-12 and carbon-13 are stable but carbon-14 is unstable and therefore is radioactive.

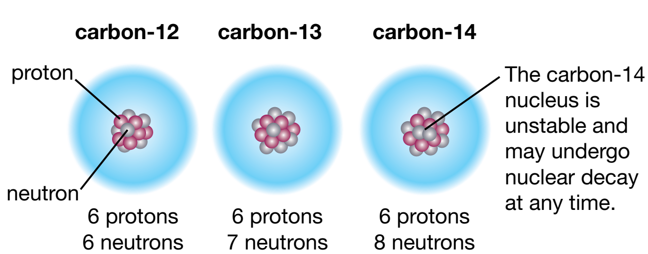


Figure 1.3.2 Carbon has three naturally occurring isotopes: carbon-12, carbon-13 and carbon-14. The nucleus of carbon-14 is unstable, so carbon-14 is a radioisotope.

Carbon-14 undergoes beta decay as shown in Figure 1.3.4. The carbon-14 atom has 6 protons and 8 neutrons. When the atom ejects a beta particle (β), one of the neutrons becomes a proton. This turns the atom into a stable nitrogen-14 atom with 7 protons and 7 neutrons.

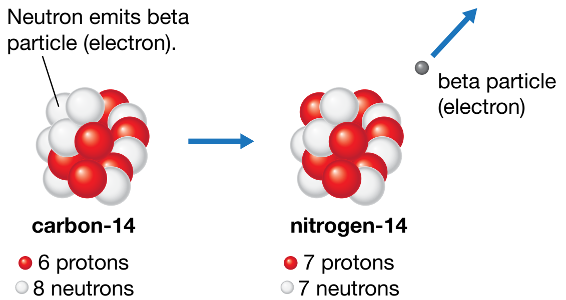


Figure 1.3.4 When a carbon-14 nucleus undergoes beta decay, it becomes a nitrogen-14 atom and emits a beta particle.

Gamma decay

Sometimes the protons and neutrons simply rearrange inside the nucleus but do not emit a particle. Instead they emit a form of electromagnetic wave known as **gamma rays**. This process is known as **gamma decay**. Gamma rays are given the symbol γ. They are like X-rays but are more powerful. The three different types of decay are summarised in Table 1.3.1.

Table 1.3.1 Summary of the products of nuclear decay

	Symbol	Equivalent to	Speed	Charge
Alpha particle	α	a helium nucleus	10% the speed of light	+2
Beta particle	β	an electron	90% the speed of light	–1
Gamma ray	γ	a high-energy X-ray	speed of light	0

Half-life

The rate at which nuclear decay takes place is measured by a radioisotope's **half-life**. The half-life of a radioisotope is the time it takes for half the nuclei to decay. For example, the radioisotope radon-222 decays into polonium-218 with a half-life of 4 days. This means that from 100 radon-222 atoms, 50 would decay over 4 days. Of the remaining 50 nuclei, 25 would decay over the next 4 days. And if you waited another 4 days, only 12 or 13 radon-222 atoms would remain. You can see this illustrated in Figure 1.3.5.

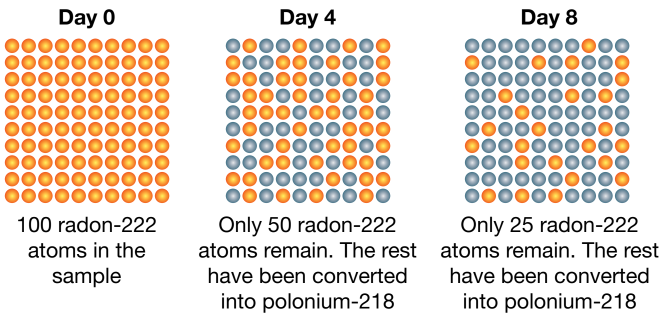


Figure 1.3.5 The number of radon atoms halves every four days.

The half-life of radioisotopes varies from a fraction of a second to millions of years. Table 1.3.2 lists the half-lives of some common radioisotopes.

Table 1.3.2 Half-lives of common radioisotopes

Radioisotope	Half-life
Gold-200	48 minutes
Radon-222	4 days
Iodine-131	8 days
Cobalt-60	5.3 years
Americium-241	460 years
Carbon-14	5730 years
Plutonium-239	24 000 years
Uranium-238	4.5 million years

Carbon dating

Understanding the half-life of radioisotopes has proved very useful to historians and archaeologists. The half-life of carbon-14 is used to determine the age of fossils (like the one in Figure 1.3.6) and ancient materials through a process known as **carbon dating**.

Figure 1.3.6 Archaeologists use carbon dating to determine the age of fossils and artefacts. Artefacts are objects made by humans, such as tools.

Carbon dating relies on the fact that all living things contain a small amount of carbon-14. The amount remains constant throughout the lifetime of the plant or animal. This is because carbon-14 is constantly being absorbed by the organism through its food and air. However, when the organism dies, carbon-14 is no longer absorbed. At that point, the small amounts of carbon-14 in the organism begin to decay into nitrogen-14 with a half-life of 5730 years, as plotted in Figure 1.3.7.

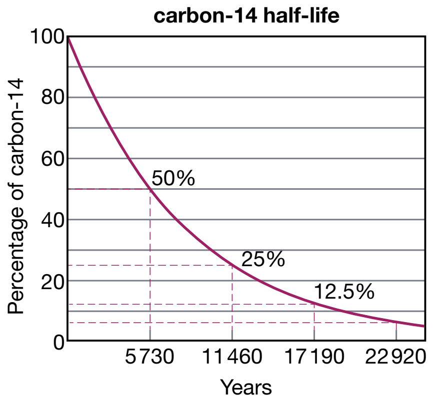


Figure 1.3.7 The percentage of carbon-14 atoms in a plant or animal halves every 5730 years after it dies.

This means an animal that died 5730 years ago will have half the amount of carbon-14 compared with one living today. An animal that died 11 460 years ago will have a quarter the amount of carbon-14 and so on. Therefore, by measuring the amount of carbon-14 in fossils and bones, scientists can get an accurate idea of when the animal lived.

Trees and other plants also contain carbon-14. This means that scientists can also use this technique to calculate the age of tools, paper and fabrics made from plants.

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1.6

Nuclear radiation

The term **nuclear radiation** describes any rays or particles emitted (released) by atomic nuclei. The term includes alpha particles, beta particles and gamma rays. Nuclear radiation can be extremely harmful, especially to living organisms. However, it can also be useful in medicine, industrial processes and scientific research.

Biological effects of radiation

Alpha particles, beta particles and gamma rays are particularly damaging to the cells of living organisms. This is because radiation can enter the cells. Once inside, the radiation destroys biological molecules and causes unwanted chemical reactions.

Alpha particles, beta particles and gamma rays are referred to as **ionising radiation** because they can remove electrons from atoms and molecules. Exposing cells to ionising radiation can cause cells to die or mutate.

Effects of cell death

Cell death occurs when ionising radiation enters the cell and destroys the biological molecules beyond repair. This may result in **radiation burns** or **radiation sickness**.

Radiation burns like the ones in Figure 1.3.8 are caused by short exposure to a very large amount of ionising radiation. The radiation damages the cells on the surface of skin or other organs, causing redness and blistering. However, the side effects are not immediately obvious. It may take 1 or 2 days for itching and redness to appear and then 1 to 3 weeks before the appearance of burns and blisters.

Figure 1.3.8 Radiation burns can be just as severe as burns caused by a fire.

Radiation sickness may result from exposure to a large amount of radiation in a short amount of time, or a lower amount of radiation over a longer period of time. The symptoms include nausea, vomiting, fever, hair loss and diarrhoea. The symptoms may not appear immediately but will appear more quickly if the person has absorbed a larger amount of radiation.

Effects of cell mutation

Cell **mutation** occurs when the ionising radiation damages the DNA inside the cell without causing the cell to die. The DNA inside a cell contains all the genetic information that tells the cell how to function properly. If the DNA is damaged, the cell is reprogrammed and may cause the cell to develop into a cancer, like the skin cancer in Figure 1.3.9. A cell mutation can be caused by even a small amount of radiation. However, the likelihood of cell mutation increases as the exposure to ionising radiation increases.

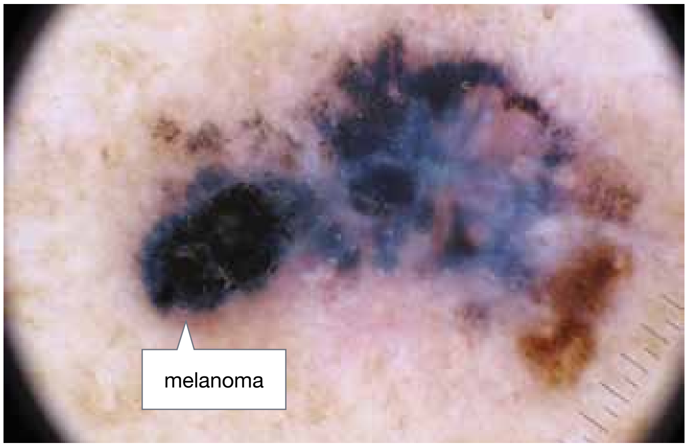


Figure 1.3.9 If ionising radiation damages the DNA in cells, it can cause them to turn into cancers. This malignant melanoma is one type of skin cancer.

If the ionising radiation causes a mutation in sperm or ova (egg cells), the offspring of the organism may be affected. This is known as genetic or inherited mutation. Different animals experience different levels of inherited mutations. For example, the mutations in the offspring of mice and fruit flies are increased significantly if the parents have been exposed to radiation.

However, in humans it is unclear whether large doses of radiation produce mutations in children. Scientists who studied the survivors of the nuclear bombs dropped on Nagasaki and Hiroshima in Japan in 1945 found that children of the survivors did not show an increase in genetic mutations. On the other hand, studies of men who worked with radioactive materials showed that the workers were more likely to have children with leukaemia.

Dose

Whether or not an exposure to radiation is harmful depends on the type of radiation and the amount of radiation. The amount of radiation absorbed is known as the **dose**. Every day you receive harmless doses of radiation from radioisotopes in the ground and radiation that comes to Earth from distant stars. However, people who work with radioactive materials may be exposed to higher doses of radiation if they do not take the correct safety precautions.

A dose of radiation is measured in units called **sieverts**, which have the symbol Sv. A dose of 1 Sv is an extremely large dose that will cause severe radiation sickness. Therefore, scientists usually measure doses in microsieverts (μSv), which is one millionth of a sievert.

Every year you receive approximately 1400 μSv of radiation from isotopes in the ground (**terrestrial radiation**) and 300 μSv from outer space (**cosmic radiation**). These doses are considered extremely small and harmless.

However, the damage caused by exposure to radiation also depends on the type of radiation. Table 1.3.3 lists some of the properties of alpha, beta and gamma radiation.

Table 1.3.3 Summary of nuclear radiation

Radiation	Mass of particles	Speed	Penetration depth	Ionisation ability
Alpha radiation	7000 times heavier than a beta particle	10% the speed of light	Stopped by dead skin or a layer of paper	20 electrons per α particle
Beta radiation	Same mass as an electron	90% the speed of light	Stopped by a 1 mm sheet of aluminium	1 electron per β particle
Gamma radiation	No mass	100% the speed of light	Stopped by several centimetres of lead or concrete	1 electron per γ ray

Mutants aren't monsters

SciFile

The mutations caused by radiation are not the monstrous creatures seen in science fiction movies. Instead, radiation exposure simply increases the frequency of naturally occurring mutations (such as albinism, which causes an absence of colour in the skin and hair). The peacock in the photo is an albino.

Alpha radiation

Alpha particles are large, heavy and slow compared to beta particles and gamma rays. This makes them 20 times better at ionising molecules. However, their large size also means that **alpha radiation** can only travel a few centimetres in air and is easily blocked by a thin sheet of paper or even a layer of dead skin, as illustrated in Figure 1.3.10. As a result, radioisotopes that emit alpha radiation can be handled relatively safely. On the other hand, if isotopes emitting (releasing) alpha radiation get inside the body, the effects can be fatal. Radioactive gases that emit alpha radiation are particularly dangerous when breathed into the lungs.

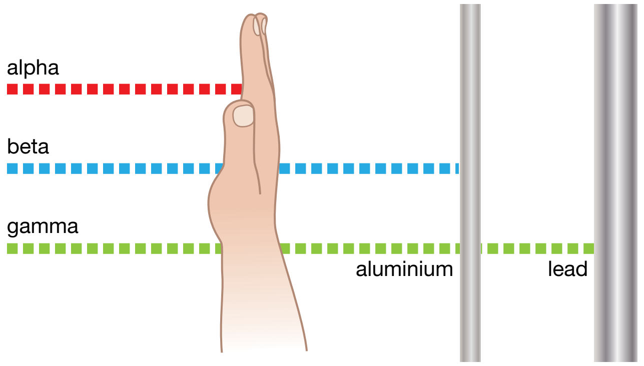
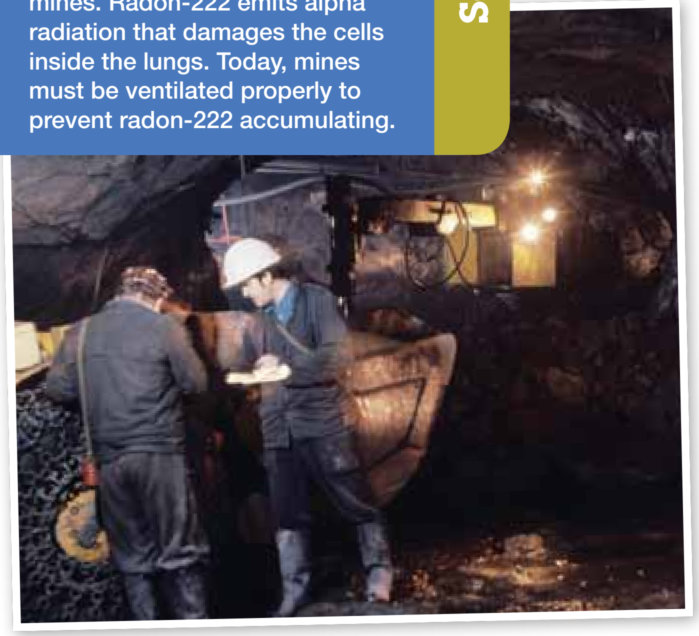


Figure 1.3.10 Alpha particles are stopped by a sheet of paper or dead skin. Beta particles are stopped by a 1 mm plate of aluminium. Gamma rays are only stopped by thick lead or concrete.

Deadly mines

SciFile

In the 1940s and 1950s it was discovered that the workers in uranium mines were twice as likely to die of lung cancer. This was due to accumulation of the radioactive gas radon-222 in the mines. Radon-222 emits alpha radiation that damages the cells inside the lungs. Today, mines must be ventilated properly to prevent radon-222 accumulating.



Beta radiation

The beta particles that make up beta radiation are small and fast. This means that **beta radiation** penetrates (enters) the skin more deeply than alpha radiation. As a result, beta radiation is more likely to cause radiation burns to the skin and eyes, like the burns shown in Figure 1.3.11. However, beta radiation can be blocked by a thin plate of aluminium.

Figure 1.3.11 Beta and gamma radiation are the most likely source of radiation burns following a nuclear explosion. This person was burnt by radiation from the atomic bomb dropped on Hiroshima in 1945.

Gamma radiation

Gamma radiation can travel through skin, bone and aluminium, making it extremely dangerous to humans. Only a thick layer of concrete or lead will block the radiation. This is because gamma radiation is made up of electromagnetic waves rather than particles. This means gamma rays do not have any mass or charge and travel at the speed of light. Other forms of electromagnetic waves include radio waves, microwaves, visible light, ultraviolet light and X-rays. However, only gamma rays, X-rays and certain types of ultraviolet light are powerful enough to ionise molecules and cause cell damage.

Useful radiation

While radiation should be handled with care, it can also be very beneficial if used correctly. Radiation is often used for medical treatments and diagnosis, industrial applications and scientific research.

Medical applications

Although radiation causes cancers to grow, it is also one of the most important tools for the treatment of cancers. This style of treatment is known as radiotherapy. During radiotherapy, the cancerous tumour is exposed to high concentrations of radiation. This radiation is used to kill the cells in the tumour and stop them multiplying. However, healthy cells may also be damaged during this process. As a result, radiotherapy comes with serious side effects including skin irritation, ulcers, swelling, nausea, hair loss, heart disease and secondary cancers.

Radioisotopes can also be used for medical diagnosis. In particular, radioisotopes can be used to obtain detailed images of the organs inside the body, like the one in Figure 1.3.12. This process is called nuclear imaging. To obtain a picture of the internal organs, radioisotopes are injected into the body. These radioisotopes collect in the organs and emit a very low dose of gamma radiation that can be detected outside the body to build up an image of the organs.

Figure 1.3.12 Doctors inject the patient with radioisotopes to obtain images of organs inside the body, like this false-coloured PET scan. Brighter areas show a build-up of radioisotope.

Industrial applications

There are a wide variety of industrial applications for radiation. Radiation is commonly used in the process of sterilisation to kill bacteria in medical equipment and even in food. This means that things like bandages and needles can be sterilised without the need for harmful chemicals. Foods treated with radiation lasts longer before rotting or going stale.

Radiation can also be used to 'look' inside objects in the same way that X-rays can be used to look inside you. This is useful in exploring for minerals, oil, gas and water. A similar process is also used to determine the thickness of materials such as paper or metal foils, using the technique shown in Figure 1.3.13.

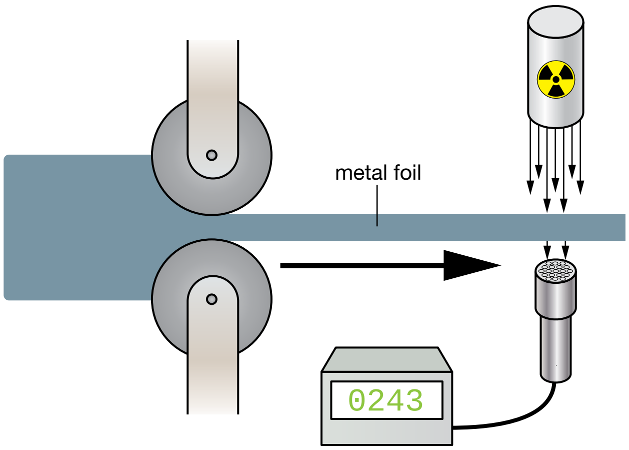


Figure 1.3.13 Engineers can accurately measure the thickness of materials by measuring how much radiation can pass through them.

You can even find radiation being used in your home if you have a certain type of smoke detector. These detectors have a small amount of americium-241, which produces alpha radiation. If there is smoke in the air, the alpha particles are blocked and the alarm sounds (Figure 1.3.14).

Figure 1.3.14 Some smoke detectors use the radioactive element americium-241 to detect smoke particles in the air.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

The power of the nucleus

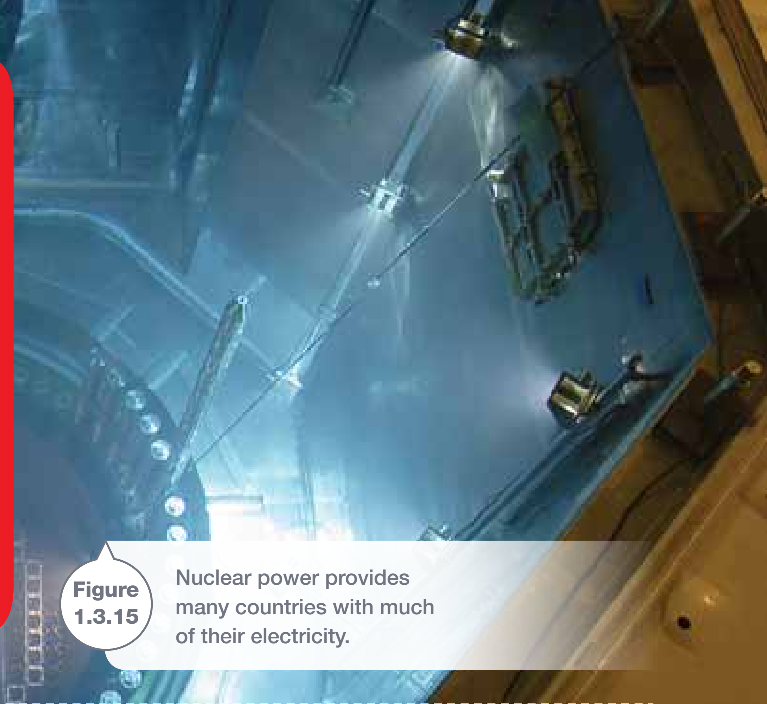


Figure 1.3.15 Nuclear power provides many countries with much of their electricity.

There are two types of nuclear reactions that have changed the face of the Earth and caused intense political, environmental and social debate. They are fission and fusion reactions.

Fission and fusion

In a **fission** reaction, a large nucleus splits into two almost equally sized pieces. During a **fusion** reaction, two small nuclei come together to form a larger nucleus. In both cases, the reactions release huge amounts of energy that can be extremely useful or extremely destructive.

Fission reactions

The most famous fission reaction involves uranium-235. If this radioisotope absorbs a neutron, it forms the highly unstable isotope uranium-236. The uranium-236 then splits into two smaller atoms, krypton-92 and barium-141, releasing a huge amount of energy.

This reaction, shown in Figure 1.3.16, is used to supply 15% of the world's electricity demand and power military naval vessels. However, the reaction creates radioactive waste that cannot be destroyed and must be stored deep underground.

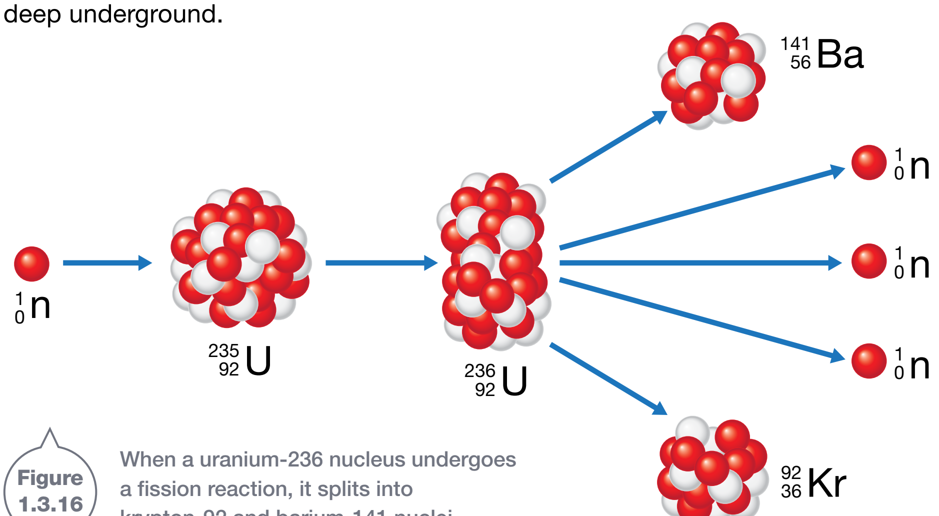


Figure 1.3.16 When a uranium-236 nucleus undergoes a fission reaction, it splits into krypton-92 and barium-141 nuclei.

More disturbing is the use of fission reactions in nuclear weapons. The extreme explosive power of the nuclear reaction and the associated radiation is enough to flatten entire cities. This power was demonstrated tragically during World War II when atomic bombs were dropped on the Japanese cities of Nagasaki and Hiroshima (Figure 1.3.17). The bomb blasts killed about 100 000 people instantly and almost the same number of people in the following 2–4 months due to radiation exposure.

Figure 1.3.17 The extreme power of fission reactions was demonstrated when atomic bombs were detonated (exploded) over Nagasaki and Hiroshima during World War II.

Fusion reactions

Without fusion reactions there would be no life on Earth. This is because fusion reactions power the Sun and give us warmth and light. A fusion reaction occurs when two small nuclei form a single nucleus. For example, if two hydrogen-2 nuclei collided they might form a helium-4 nucleus, as shown in Figure 1.3.18.

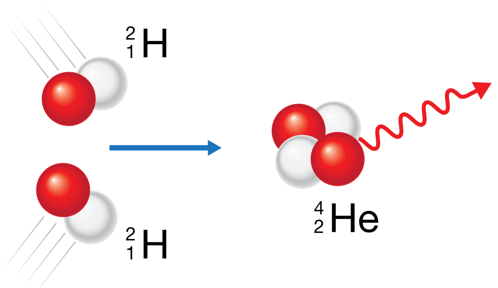


Figure 1.3.18 If two hydrogen-2 (deuterium) nuclei collide at high speed they may fuse together to form a helium-4 nucleus.

Figure 1.3.19 Fusion reactions occur at such high temperatures that scientists must hold the reaction in mid-air with strong magnetic fields that produce a 'magnetic bottle'.

However, the small nuclei strongly repel each other because they both have a positive charge. Therefore, fusion only occurs at extremely high temperatures—over 100 million degrees Celsius. There is no material on Earth that can withstand these temperatures, so scientists trying to create a fusion reactor must suspend the reaction in mid-air by using a powerful magnetic field like the one in Figure 1.3.19.

If fusion reactions could be controlled, they would provide an extremely powerful and clean source of energy. However, the power of fusion can also be used to create the most destructive weapons on Earth—hydrogen bombs. Fortunately, a hydrogen bomb has never been used in a military attack.

1.7

SciFile

The Fukushima disaster

Japan's first-hand experience of the devastating effects of nuclear weapons has made the people of Japan understandably wary about the use of nuclear power. Their fears were realised in March 2011 when a nuclear reactor in Fukushima went into meltdown after the shock of a magnitude 9.0 earthquake and tsunami. This disaster is considered the second-worst nuclear reactor meltdown after the one in Chernobyl, Russia, in 1986. To date, only 37 injuries and 1 death from heart attack have been reported. However, the death toll is likely to increase due to cancer-related deaths in the long term.

In the picture, one-year old Yunna has her face covered to protect her from the radioactive dust sent into the air by the Fukushima meltdown.

1.3 Unit review

Remembering

1 **List** three types of radiation in order from least penetrating to most penetrating.

2 **State** the units that radiation dose is measured in.

3 **Recall** the dose that is likely to cause severe radiation sickness.

4 **Recall** what happens to the atomic number and mass number of a nucleus when it undergoes:
  a alpha decay
  b beta decay.

5 **List** four uses of radiation.

6 Gamma rays are just one type of electromagnetic wave. **List** four others.

Understanding

7 **Define** the term *radioisotope*.

8 **Describe** the nuclear processes of fission and fusion.

9 **Explain** why alpha particles, beta particles and gamma rays are classified as forms of ionising radiation.

10 Alpha particles are 20 times more efficient than beta particles or gamma rays at ionising molecules. **Explain** why they may be considered the least dangerous nuclear radiation.

11 **Define** the term *half-life*.

12 **Explain** how radiation burns and radiation sickness are caused.

Applying

13 **Identify** the atomic symbol for the isotopes oxygen-16, oxygen-17 and oxygen-18. (*Hint*: All oxygen atoms have 8 protons.)

Analysing

14 **Contrast** stable and unstable nuclei.

15 **Compare** the properties of alpha particles, beta particles and gamma rays.

16 **Calculate** the atomic number and mass number of the following nuclei after they undergo alpha decay.
  a $^{241}_{95}Am$
  b $^{240}_{94}Pu$
  c $^{210}_{84}Po$

17 **Calculate** the atomic number and mass number of the following nuclei after they undergo beta decay.
  a $^{22}_{11}Na$
  b $^{14}_{6}C$
  c $^{137}_{55}Cs$

18 **Calculate** the age of a fossil with a carbon-14 content that is:
  a half the normal amount
  b one-quarter the normal amount
  c one-eighth the normal amount
  d one-sixteenth the normal amount.

(*Hint*: Remember that the half-life of carbon-14 is 5730 years.)

Evaluating

19 **Propose** the advantages and disadvantages of nuclear power plants and **list** them in a table.

20 **Propose** why radioisotopes that emit alpha radiation are not used for radio imaging.

Creating

21 **Design** a pamphlet for health department workers advising them of the dangers of different types of radiation they may be exposed to in the workplace.

22 **Construct** a short story describing what you think it would be like to survive a nuclear bomb explosion and the effects of the radiation damage.

Inquiring

1 a Research other methods of nuclear radiation detection such as film badges or cloud chambers. Use a labelled diagram to explain the workings of one method.
  b There are a large number of units for measuring nuclear radiation including gray, rem, rad, curie, becquerel and roentgen. Explain what one of these means, and give the abbreviation for the unit.

2 a The Shroud of Turin has been claimed to be the burial cloth of Jesus Christ. Explain how carbon dating has been used to date the shroud.
  b Use this evidence to make your own deduction about the age and authenticity of the shroud.

3 Investigate what is meant by the term *heavy water* and how it is used in nuclear reactors.

1.3 Practical activities

1 Half-life

Purpose

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

Procedure

1. Copy the table from the results section into your workbook.
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 to 5 until there are no M&Ms left in the jar.

Results

Number of repeats	1	2	3	4	5
M&Ms showing the letter M					

1. Construct a graph of the number of M&Ms remaining (those that showed the letter M) versus the number of times the procedure was repeated.
2. Compile everyone's results into one table and plot the classroom total of M&Ms remaining with each repeat of the procedure.

Discussion

1. **Describe** the shape of the graphs that you produced.
2. **State** the half-life of your M&M sample by finding how many throws it took for the number of M&Ms in your sample to reduce to half.
3. a **Compare** your individual results with the class results.
   b **Propose** which of these results is more reliable.
   c **Justify** your response.
4. **Discuss** how this prac models the half-life of a radioactive element.

Figure 1.3.20 M&Ms can be used to model nuclear decay.

1 Chapter review

Remembering

1 **Recall** the meaning of the following terms.
  a atom
  b molecule
  c crystal lattice
  d isotopes
  e ion

2 a **List** the three subatomic particles that make up an atom.
  b **State** the charge on each.

3 **Recall** how the atomic number and mass number of an atom are calculated.

4 **State** what must happen to an atom to make it:
  a a cation
  b an anion.

5 **List** three types of ionising radiation.

6 **List** four ways in which radiation can be useful.

Understanding

7 **Describe** the structure of an atom.

8 **Explain** Rutherford's famous experiment and how it has contributed to our current understanding of the atomic model.

9 **Describe** how cations and anions form the crystal lattices that make up ionic compounds.

10 **Describe** what happens to the ions in an ionic compound when it dissolves in water.

11 **Explain** why gamma radiation may be considered the most dangerous form of radiation, even though alpha radiation ionises more electrons for each molecule.

12 **Explain** how ionising radiation causes:
  a radiation burns and radiation sickness
  b mutations.

Applying

13 **Identify** the name and chemical formula of the ionic compounds made from:
  a potassium cations (K^+) and chloride anions (Cl^-)
  b calcium cations (Ca^{2+}) and oxide anions (O^{2-})
  c boron cations (B^{3+}) and fluoride anions (F^-)
  d zinc(II) cations (Zn^{2+}) and bromide anions (Br^-)
  e chromium(III) cations (Cr^{3+}) and oxide anions (O^{2-}).

Analysing

14 You discover a new element named jellium (Je) that has a half-life of 5 days. Your sample of jellium contains only 256 atoms. **Calculate** how many jellium atoms there will be after.
  a 5 days
  b 10 days
  c 15 days
  d 20 days.

15 **Calculate** the atomic number and mass number of each of the following atoms after decay.
  a $^{238}_{92}U$ undergoes alpha decay
  b $^{14}_{6}C$ undergoes beta decay
  c $^{241}_{95}Am$ undergoes alpha decay
  d $^{22}_{11}Na$ undergoes beta decay.

Evaluating

16 **Propose** why nuclear fusion as a power source receives more money for research than any other power source.

17 You should never try and break open a smoke detector. **Propose** reasons why.

Creating

18 **Construct** electron shell diagrams for the following atoms.
  a neon (Ne) 2,8
  b magnesium (Mg) 2,8,2
  c lithium (Li) 2,1
  d boron (B) 2,3

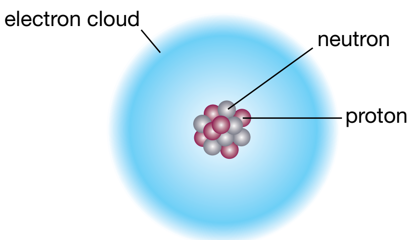
19 **Use** the following ten terms to **construct** a visual summary of the information presented in this chapter.

atom
electron
proton
neutron
isotope
radiation
nuclear reaction
beta particle
alpha particle
gamma ray

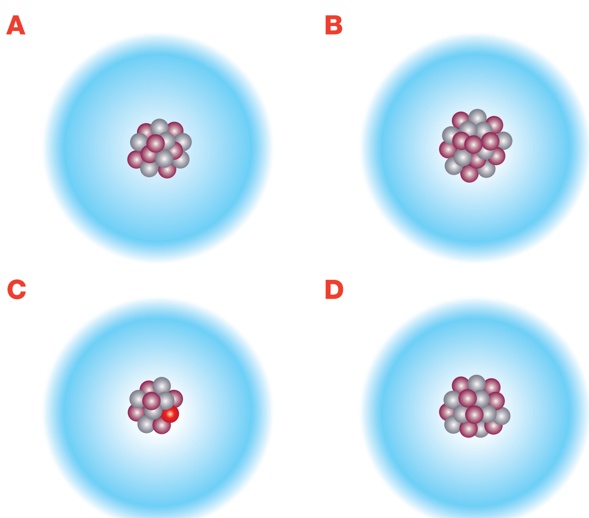
1.8

Thinking scientifically

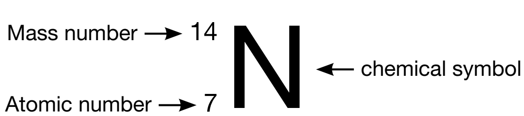
Q1 Isotopes are atoms that have the same number of protons in their nucleus but a different number of neutrons. Determine which of the atoms below is an isotope of this carbon-12 atom.



carbon atom



Q2 Scientists use atomic symbols to communicate the structure of atoms. An atomic symbol consists of the chemical symbol for the element, the atomic number and the mass number. The atomic number is the number of protons. The mass number is the total number of protons and neutrons in the nucleus. Because atoms are charge neutral, the number of electrons must also equal the number of protons. Below is the atomic symbol for a nitrogen-14 atom.



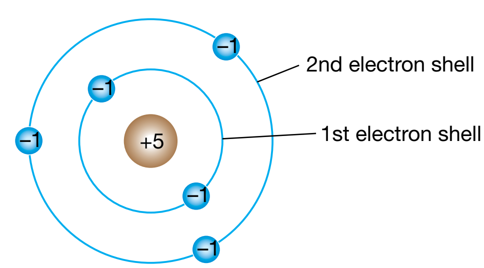
From this information, which of the following best describes the structure of an atom with the atomic symbol $^{196}_{79}\text{Au}$?

A 79 protons, 196 neutrons, 79 electrons
B 79 protons, 196 neutrons, 196 electrons
C 117 protons, 79 neutrons, 117 electrons
D 79 protons, 117 neutrons, 79 electrons

Q3 Atoms are charge neutral because the positive charge on the nucleus is exactly balanced by the negative charge of the electrons. Ions are formed when an atom gains or loses electrons according to the following rules:

- If the outermost electron shell of the atom is mostly empty, the atom will lose its outermost electrons to become a positively charged cation.
- If the outermost electron shell of the atom is mostly full, the atom will gain electrons until the outermost electron shell is filled, becoming a negatively charged anion.

Examine the atom shown below. Given that the second electron shell can hold up to 8 electrons, determine what the charge of its ion will be.



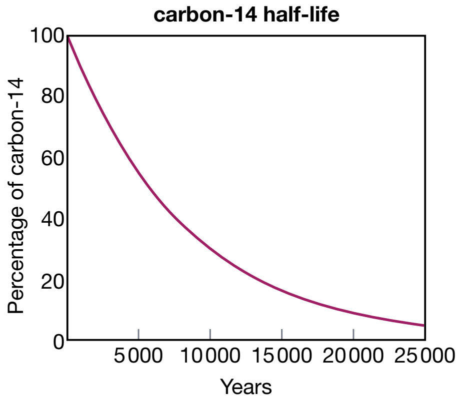
A +3
B −2
C +2
D −3

Q4 Every day you are exposed to small levels of radiation. You receive a dose of approximately 0.82 microsieverts from cosmic radiation and 3.83 microsieverts from radiation sources on Earth.
The best estimate for your total radiation dose each year from these sources is:

A 1500 microsieverts
B 1600 microsieverts
C 1700 microsieverts
D 1800 microsieverts

Q5 An archaeologist working in Cairo, Egypt, discovers an old artefact and takes it back to the lab for carbon dating. The lab results show that there is only 16% of the carbon-14 that would have been found in a similar artefact made today.

Using the graph below for the carbon-14 half-life, determine which is the best estimate for the age of the artefact.



A 5000 years
B 10 000 years
C 15 000 years
D 20 000 years

Q6 A nuclear power plant worker comes into hospital after having an accident where he was exposed to high levels of radiation approximately 30 minutes before. Initially he seems fine but after an hour he starts to feel nauseated and begins vomiting. He is kept in for observation and after a few days develops diarrhoea.

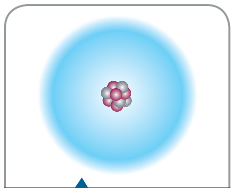
Use the table below to determine the likely dose of radiation that the worker was exposed to.

Dose (Sv)	Symptoms
0–0.5	No obvious effect
0.5–1.0	Vomiting and nausea for about 1 day in 10 to 20% of people. Tiredness, but no serious disability.
1.0–2.0	Mild to moderate nausea in 50% of people with occasional vomiting, setting in within 3–6 hours after exposure, and lasting several hours to a day.
2.0–5.5	Nausea in 100% of people. Vomiting starting 0.5 to 6 hours after irradiation and lasting up to 2 days. This is followed by other symptoms of radiation sickness, e.g. loss of appetite, diarrhoea, minor bleeding.
5.5–10	Severe nausea and vomiting within 15–30 minutes, lasting up to 2 days, followed by severe symptoms of radiation sickness, e.g. loss of appetite, diarrhoea, minor bleeding.
10–20	Immediate nausea, diarrhoea and bleeding
> 20	Immediate disorientation and coma. Onset is within seconds to minutes.

A 0.5–1.0 Sv
B 1.0–2.0 Sv
C 2.0–5.5 Sv
D 5.5–10 Sv

Glossary

Unit 1.1



Atom

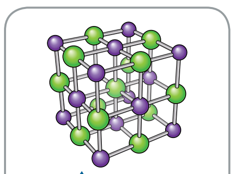
Atom: the fundamental building block of all materials; it consists of a cluster of protons and neutrons surrounded by a cloud of electrons

Atomic model: scientists' representation of an atom determined by experiment and indirect observation

Atomic number: the number of protons in a nucleus; the atomic number determines what type of atom it is

Atomic symbol: a short-hand notation for describing an atom; it consists of the chemical symbol, atomic number and mass number

Compound: a pure substance that is made up of two or more different types of atom chemically joined



Crystal lattice

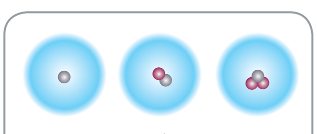
Crystal lattice: a grid-like structure of atoms or ions where each particle is bonded to all of its neighbouring atoms

Electron: a small, negatively charged particle; clouds of electrons surround the nucleus of an atom

Electron configuration: the number of electrons in each of the electron shells of an atom

Electron shell: part of the electron cloud; it is a layer that surrounds the nucleus and can only hold a certain number of electrons

Element: a substance made up of only one type of atom



Isotopes

Isotopes: atoms that have the same number of protons but a different number of neutrons in their nucleus

Mass number: the number of protons and neutrons in an atom

Molecule: a cluster of atoms that makes up an element or a compound

Neutral: having no overall charge

Neutron: a particle with no electric charge; it is found in the nucleus of an atom

Nucleus: a cluster of neutrons and protons at the centre of an atom

Periodic table: table showing all 118 known types of atoms (elements)

Proton: a positively charged particle in the nucleus

Unit 1.2

Anion: a negatively charged ion

Cation: a positively charged ion

Ion: an atom that has lost or gained electrons and therefore has an electric charge

Ionic bond: a bond between a cation and an anion due to electrostatic attraction of their opposite charges

Ionic compound: a compound made up of cations and anions

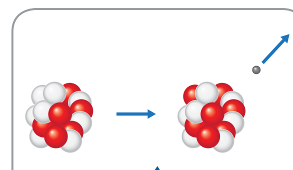
Solubility: how easily a substance dissolves

Unit 1.3

Alpha decay: a nuclear reaction in which a nucleus ejects an alpha particle

Alpha particle: a particle made up of two protons and two neutrons, making it identical to a helium nucleus

Alpha radiation: a form of ionising radiation made up of alpha particles



Beta decay

Beta decay: a form of nuclear reaction in which a beta particle is ejected from the nucleus

Beta particle: a small, negatively charged particle that can be ejected from a nucleus during a nuclear reaction; it is identical to an electron

Beta radiation: nuclear radiation that is made up of beta particles

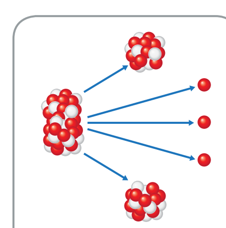
Carbon dating

Carbon dating: a method for judging the age of fossils by analysing the amount of carbon-14 in the fossil

Cosmic radiation: radiation that comes to Earth from distant stars

Dose (radiation): the amount of radiation absorbed over a period of time

Electromagnetic radiation: radiation that travels through a vacuum as waves rather than particles

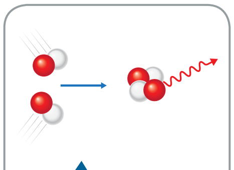


Fission

Fission: a nuclear reaction in which a very large nucleus splits into two smaller nuclei of similar mass number

Glossary

Fusion: a nuclear reaction in which two small nuclei come together to form one larger nucleus



Fusion

Gamma decay: nuclear decay that involves the release of gamma rays

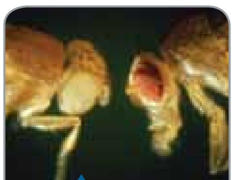
Gamma radiation: a form of ionising radiation made up of gamma rays

Gamma ray: a very high-energy electromagnetic wave that is produced when the protons and neutrons in a nucleus rearrange

Half-life: the time it takes for half a sample of atoms to decay

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

Mutation: a change in the DNA of a cell that causes it to change how it works and reproduces



Mutation

Nuclear decay: when a nucleus undergoes a nuclear reaction and emits radiation

Nuclear radiation: rays or particles that are emitted by a nucleus during a nuclear reaction

Nuclear reaction: a process that causes a nucleus to change, including alpha decay, beta decay, fission and fusion

Radiation burns: redness and blistering on the surface of the skin or other organs caused by intense exposure to ionising radiation

Radiation burns

Radiation sickness: a condition that results from a large dose of ionising radiation, causing significant cell death; symptoms include nausea, vomiting, fever, hair loss and diarrhoea

Radioactive: emitting radiation

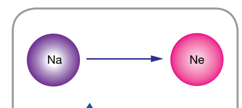
Radioisotope: an isotope with a nucleus that may undergo a nuclear reaction

Sievert: a unit for measuring a dose of radiation

Stable nuclei: nuclei that will never undergo a nuclear reaction

Terrestrial radiation: radiation that originates from radioisotopes in the ground and the atmosphere

Transmutation: a nuclear reaction process that converts one type of atom into a different type of atom



Transmutation

Unstable nuclei: nuclei that may undergo a nuclear reaction at any time