5 Chemistry — the inside story

Why learn this?

The air that you breathe, the gunpowder in fireworks and the boiling hot spray discharged by a bombardier beetle are all examples of chemicals. In fact everything around you, including your own body, is entirely composed of chemicals. Chemistry is the study of substances and the way that they behave on their own or when combined with other substances. To understand the behaviour of substances, you need to take a look inside to find out what they are made of.

The characteristics of a chemical, including its colour, state of matter and reactivity, are determined by the types of atoms that make up the chemical and the type of bonding between the atoms.

In this chapter, students will:

5.1 outline how atomic structure theory has changed over the centuries as well as describe the modern atomic model

5.2 explain by referring to the electron shells of atoms how they may form ions

5.3 use the periodic table of elements to compare characteristics of element families and to predict physical and chemical properties of elements

5.4 compare the shell arrangements within atoms in different groups

5.5 describe how ionic bonds form between atoms

5.6 explain how the electron structure of atoms influences their formation of covalent bonds

5.7 determine the molecular formulae for ionic and covalent compounds.

Do you have the inside information?

All chemicals — in other words all substances — are made up of tiny particles. These tiny particles are so small that you can't see them, even with the most powerful light microscope. You probably already know quite a lot about the particles inside chemicals. This knowledge is the first step in your quest to find out why chemicals behave the way they do.

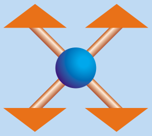
Answer the questions below to find out how much you already know about the inside story on chemicals.

1. The substances around you and inside you can be placed into three groups — elements, compounds and mixtures.
   (a) Which one of these groups contains chemicals that are made up of only one type of atom?
   (b) Which one of these groups is the least likely to be found naturally in the Earth's crust?
   (c) What is the difference between a compound and a mixture?
   (d) Arrange the substances listed below into the three groups of substances to complete the table below right.
2. Elements, compounds and mixtures are made up of tiny particles called atoms and molecules.
   (a) How is a molecule different from an atom?
   (b) List two elements that can be made up of molecules.
   (c) List two compounds that are made up of molecules.
   (d) Name one compound that is not made up of molecules.
3. Which of the diagrams below represent:
   (a) an atom of an element?
   (b) a molecule of an element?
   (c) a molecule of a compound?

A

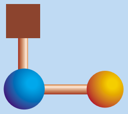
B

C



D

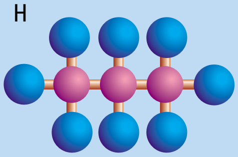
E



F

G

H



I

4. Identify the chemical element or elements that match each of the following descriptions.
   (a) They combine chemically to produce water.
   (b) It is neither a metal nor a non-metal and is used in electric circuits inside electronic devices such as computers and mobile phones.
   (c) It has the symbol Na.
   (d) They combine chemically to produce the compound that we know as pure salt.
   (e) It is the only metal that exists as a liquid at normal room temperatures.

gold
blood
carbon dioxide
diamond
iron
sea water
air
chocolate thick shake
copper
table salt
soil
ammonia
concentrated hydrochloric acid
pure water
calcium
brass
sodium hydroxide
oxygen

SUBSTANCES		
Elements	Compounds	Mixtures

5.1

SCIENCE AS A HUMAN ENDEAVOUR

Chemical building blocks

All matter in the universe is made up of tiny particles of different kinds. While atoms are not the smallest of these particles, they are the smallest particles that exhibit specific chemical properties. What these properties are depends upon the type of atom that you are looking at. By now you have probably learned that there are 92 individual types of naturally occurring atoms on Earth. What you may not know is that it has taken thousands of years for us to gain our present understanding of what an atom is, what makes them different from each other and how these differences contribute to their various chemical and physical properties.

A history of ideas about the atom

Most of our knowledge about the 'building blocks' of matter is less than one hundred years old. We now know those 'building blocks' as atoms. The idea that matter was made up of atoms was first suggested about 2500 years ago by a Greek philosopher named Democritus. Since then, various theories and models of the atom have been accepted, rejected and modified. The flow chart below shows how our knowledge about the atom developed.

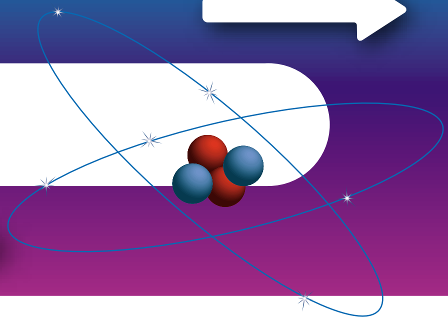
About 400 BC: Greek philosopher Democritus first suggested that all substances consisted of tiny indestructible particles called atoms.

1808: John Dalton's atomic theory proposed that:
- all matter consisted of tiny particles called atoms
- atoms could not be divided into smaller particles
- atoms of the same element were alike
- atoms combined in simple whole number ratios.

1897: English scientist Sir J. J. Thomson explained that the atom contained negatively charged particles called electrons. His model suggested that atoms were positively charged spheres with negatively charged electrons embedded in them like the fruit in a plum pudding.

1911: Lord Rutherford proposed that the atom consisted mostly of empty space with a dense nucleus containing positively charged protons in the centre. Negatively charged electrons orbited the nucleus. Although Lord Rutherford's model of the atom was essentially the same as today's accepted model, its one flaw was that it proposed that the orbiting electrons would eventually lose energy and spiral in towards the nucleus.

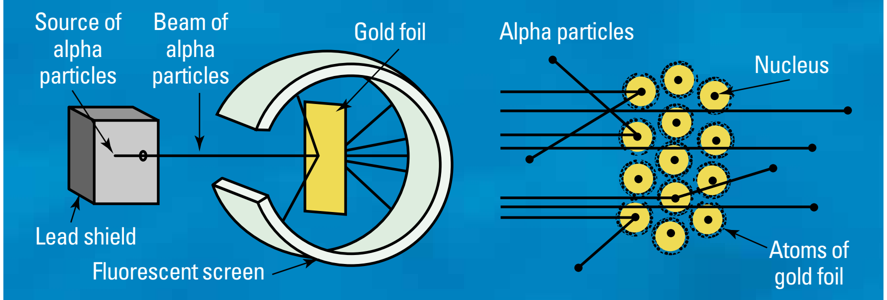
1913: Niels Bohr, a scientist who had studied with Rutherford, modified the model by suggesting that electrons orbit the nucleus at different energy levels. Only electrons with specific amounts of energy could exist at each level. His model proposed that electrons could move from one level to another by gaining or losing 'packets' of energy. Although Bohr's model explained why electrons did not spiral in towards the nucleus, it did not explain all of the known properties of atoms.



1932: Sir James Chadwick discovered that the nucleus contained particles called neutrons, as well as positively charged protons. Neutrons had no electric charge and a mass about the same as a proton.

HOW ABOUT THAT!

Lord Rutherford's model of the atom was based on experiments in which he fired tiny positive alpha particles at very thin sheets of gold foil. Most of the particles went straight through the gold foil and very few were reflected back. He explained that the few particles that were reflected back were repelled by a very small, positively charged nucleus in the atoms of the gold. Most of the alpha particles, he said, continued through the foil because each gold atom consists mainly of empty space. Lord Rutherford said later that his observations were about as credible as if you had fired a 16-inch shell at a piece of tissue paper and it had come back and hit you!



An enlarged view of the gold foil experiment

Ernest Rutherford determined that the majority of the mass in an atom was located in the centre and that most of an atom's volume is empty space by firing positively charged particles at gold atoms in a thin foil and then looking at the paths the fired particles took. In investigation 5.1 you can model this process by firing ball bearings at a hidden nucleus and using the way the marbles bounce back to determine where the hidden nucleus is.

The current model

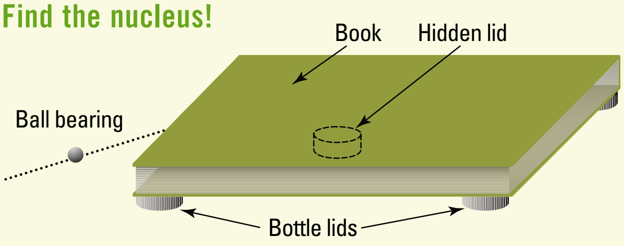
At the moment, the accepted model of an atom is that it consists of a small, dense **nucleus** made up of **neutrons** (uncharged particles) and **protons** (positively charged particles) that is surrounded by rapidly moving, negatively charged **electrons**. While the neutrons and protons are roughly the same size, an electron is about 1/2000th the size of a proton.

The neutrons and protons of a nucleus are tightly bound together by very strong **nuclear forces**. The protons are all positively charged and, as you'll probably recall from your earlier studies, objects that have the same charge tend to repel each other. If it weren't for the strong nuclear forces, the protons would push each other away and the nucleus (and the atom) would disintegrate!

On the other hand, there is an attractive force between the negatively charged electrons and the positively charged protons. It is this force which keeps the electrons moving around the nucleus.

INVESTIGATION 5.1

Find the nucleus!



A model of Rutherford's experiment

AIM **To model Rutherford's nuclear model of the atom**

You will need:

a hardcover textbook at least A4 in size
5 lids from soft-drink bottles
a 10 mm diameter ball bearing

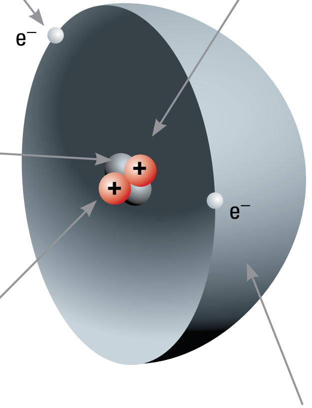
- Suspend the textbook above the bench top by placing a lid under each corner.
- While the rest of the group turns their backs, one member will lift the textbook and place the fifth lid somewhere within the area bounded by the four lids. They will then replace the textbook. This fifth lid represents the nucleus of the atom.
- Once the other students have turned around, they are to take turns rolling the ball bearing under the textbook to pinpoint the location of the nucleus, taking note of how many times the ball bearing is rolled before the nucleus is struck for the first time.
- When the shooters have come to a final decision as to where the nucleus is located, the student who did the hiding must lift the textbook to reveal whether the shooters were correct.
- Repeat with different students in the group taking turns to hide the nucleus. In each case, remember to note how many times the ball bearing was rolled before the nucleus was first struck.

DISCUSSION

1. **Determine the average number of times your group had to roll the ball bearing before striking the nucleus.**
2. **Imagine that one of the nucleus hiders decided to put the nucleus/bottle cap in their pocket rather than under the textbook. How many times do you think you would have had to roll the ball bearing to discover that there was no nucleus there?**

The distance between the electrons and the nucleus is huge. If the nucleus of the simplest atom (hydrogen) were the size of an orange, its electron would be about 10 kilometres away! As a result, most of the volume of an atom is made up of empty space. Yet when we look at very high resolution scans from powerful electron microscopes, the atoms look more like little solid balls. How can that be if they are mostly empty space?

Think of whirling a yoyo on its string in a circle. If you swing it around at a low speed, it is quite easy to see the yoyo. If you swing it very fast, however, the moving yoyo seems to turn into a blurry circle rather than an individual object. This is kind of what happens with the electrons except, because they move very fast all around the nucleus, the moving electrons form a sort of fuzzy sphere or shell around the nucleus. This is sometimes referred to as the **electron cloud**.



Electrons are about 1/2000th the size of protons and neutrons. Electrons have an electrical charge of negative one (–1). An atom has the same number of electrons as protons. The charges balance out so an atom has no electrical charge. It is said to be neutral.

Protons and neutrons are almost the same size. A proton has an electrical charge of positive one (+1). The number of protons in an atom determines what type of atom it is. For example, every atom with seventy-nine protons is a gold atom, and every gold atom has seventy-nine protons. Substances that are made up of only one type of atom are called **elements**.

A neutron has no electrical charge.

Protons and neutrons make up the nucleus. They are held together by very strong nuclear forces. Almost all of the mass of an atom is in the nucleus.

Electrons move rapidly around the nucleus. Although they follow no set paths, electrons are always found in regions called **electron shells**.

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work sheet 5.1 The structure of the atom

ACTIVITIES

REMEMBER

1 Using the present model, name the three parts of an atom. **Explain** (a) what electric charges they carry and (b) where they may be found in the atom.

2 **Describe** the 'plum pudding' model of the atom.

3 In what ways were the atomic models of Democritus and Dalton (a) similar (b) different?

4 What was the main problem with Rutherford's 'planetary' model of the atom?

5 Which scientist first named (a) electrons (b) protons (c) neutrons?

6 **Explain** why the model of the atom has changed over time.

7 **Explain** how protons are different from neutrons. How are they similar?

8 **Describe** the differences between protons and electrons.

9 **Recall** where most of an atom's mass is located.

10 What holds the protons and neutrons together in the nucleus of an atom?

THINK

11 Why do you think that the neutron was the last of the atom components to be discovered?

12 Why has no-one been able to directly observe the nucleus of an atom up to now?

13 Is the current model of the atom a theory or a fact? **Explain** your answer.

14 Was John Dalton's statement, that atoms are indivisible, correct? **Explain**.

CREATE

15 Use the information on these pages to make 3D versions of the different atomic models that have been formulated over the centuries.

INVESTIGATE

16 **Investigate** one of the following scientists and describe their contributions to our knowledge about the structure of the atom. In your report you need to include: (a) full name, place of birth, date of birth and death; (b) a brief description of the type of work the scientist did in his/her lifetime; (c) their contribution to our understanding of the structure of the atom; (d) the technology available to the scientist that enabled him/her to make the discovery; (e) description of how relevant the scientist's theory is to today's understanding of the structure of the atom. Choose from: John Dalton, Sir William Ramsay, Marie Curie, J. J. Thomson, Henry Moseley, Max Planck, Eugen Goldstein, Lord Rutherford, Frederick Soddy, Sir James Chadwick, Niels Bohr, Louis de Broglie, Lise Meitner.

17 Today we know of many particles smaller than neutrons and protons. Find out more about some of these particles and how they are investigated.

5.2

All charged up!

eLesson

The atom

Watch a video from *The story of science* about development of the model of the atom.

eles-1775

Electron shells

All neutral atoms have the same number of electrons as they do protons — in other words, the same number of negative charges as positive charges. In the simplest atom, the hydrogen atom, there is one proton and one electron.

One of the largest atoms, uranium, has 92 protons and 92 electrons. This means that there are an awful lot of electrons flying around the nuclei of many atoms, yet they don't run into each other. In fact, the electrons move between layers of spherical shells so that there are only a few electrons in the same vicinity.

Each electron shell has room for only a certain number of electrons, and the further out from the nucleus an electron shell is, the more electrons it can hold. A general rule is that the maximum number of electrons that a shell can hold is equal to $2n^2$ where n is the shell number.

This means that the first shell ($n = 1$) can hold $2 \times 1^2 = 2$ electrons at most while the second shell ($n = 2$) can hold a maximum of $2 \times 2^2 = 8$ electrons. The third shell can take a maximum number of $2 \times 3^2 = 18$ electrons and so on up to the seventh shell. These outermost shells are filled only in the largest atoms.

It is often useful to represent the structure of an atom with an **electron shell diagram**. In these diagrams the nucleus of the atom, containing protons and neutrons, is drawn in the middle. Electron shells are drawn as a series of concentric rings around a nucleus.

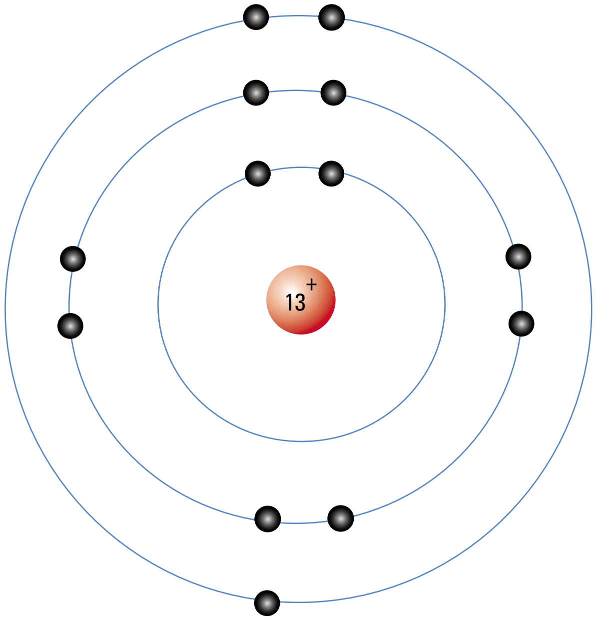
The shells closest to the nucleus contain electrons that have the lowest energy. As you go through the shells away from the nucleus, the electrons have increasing amounts of energy. While things get a bit more complicated in the third shell (as we shall see later in the chapter), electrons moving around a nucleus are generally arranged so that the lowest shells fill first. Let's see how this works.

The nucleus of an aluminium atom is surrounded by shells of electrons in the following diagram. Aluminium has 13 protons in its nucleus, so it must have 13 electrons distributed among its shells. Filling the shells from the lowest levels, we can see that the first shell will be filled with two electrons, and the second shell will be filled with eight electrons. This accounts for 10 of our 13 electrons. The last three electrons will be located in the third shell from the nucleus.

You will note from the diagram that the electrons are shown in pairs. This reflects an aspect of atomic structure that you will cover in more depth in your senior science studies.

The electron arrangement of an atom can be written by showing the number of electrons in each shell from the innermost shell, with commas in between. For example, the electron arrangements of aluminium, sodium and oxygen can be written as:

Aluminium	2, 8, 3
Sodium	2, 8, 1
Oxygen	2, 6.

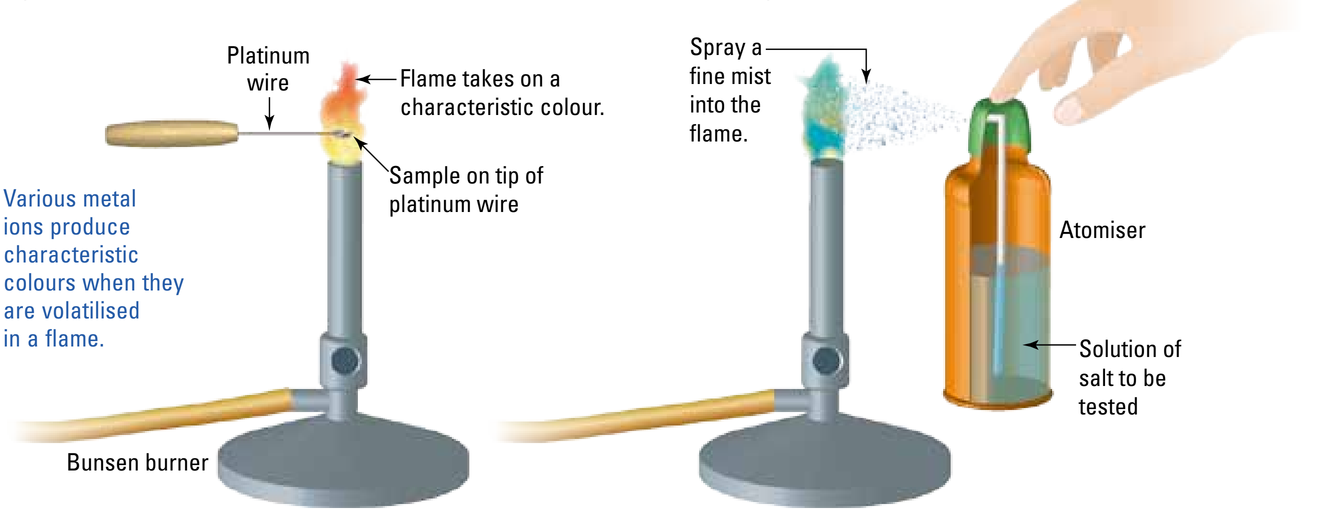


Aluminium has 13 protons and, therefore, 13 electrons. The electrons fill the first two shells completely. Three electrons are in the outermost shell.

Upwardly mobile electrons

The electron arrangement of an atom may be changed as a result of energy being added to the atom, for example, energy being added in the form of heat from a flame. This extra energy can cause electrons to move further away from the nucleus into orbits with bigger radii. When this occurs the atom is said to be in an **excited state**. This movement is temporary, however, and eventually the electrons drop back to their original shell locations — this is called the atom's **ground state**. When they drop back down, they release that extra energy in the form of light. The colour of this light indicates the amount of energy that the electron has released. The electrons in a particular atom tend to release the same quantities of energy each time, so the different atoms have characteristic light colours associated with them.

A flame test allows the metal present in a salt compound to be identified from the colour a Bunsen flame turns when the compound enters the Bunsen flame. For example, a compound that turns the flame green will most likely contain copper. The diagram below shows two ways of doing a flame test, while a third method is used in Investigation 5.2.



Various metal ions produce characteristic colours when they are volatilised in a flame.

INVESTIGATION 5.2

Flame tests

AIM To observe the visible light radiation that is released when electrons return to their ground state after being raised to an excited state by the energy from a Bunsen flame

You will need:

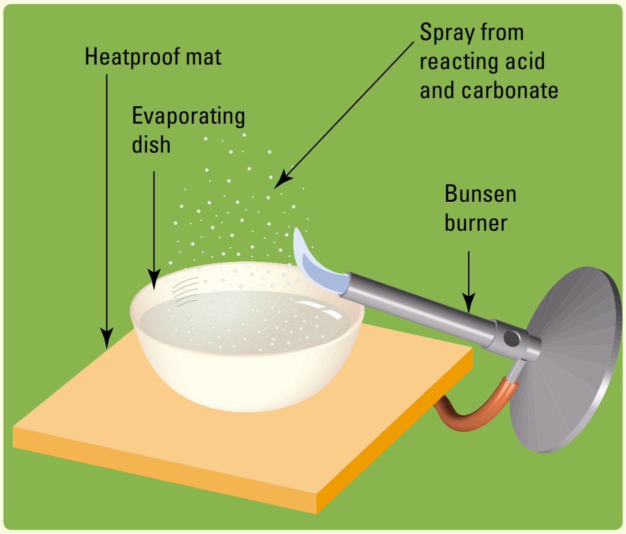
safety glasses and laboratory coat
2M hydrochloric acid
Bunsen burner, heatproof mat and matches
5 evaporating dishes
barium carbonate
sodium carbonate
copper carbonate
potassium carbonate
strontium carbonate
10 mL measuring cylinder
spatula

***CAUTION** Laboratory coats and safety glasses must be worn at all times.*

- Place 10 mL of 2M hydrochloric acid in an evaporating dish and place the dish on the heatproof mat.
- Add a spatula full of the barium carbonate to the evaporating dish.
- Carefully hold the lit Bunsen burner at an angle over the spray produced by the reacting acid and carbonate as shown in the diagram on the right. Observe the change in the colour of the flame.
- Repeat using the other carbonates. Use a different evaporating dish each time.

DISCUSSION

1. **Record the colours produced by the different carbonates in a suitable table.**
2. **Flame tests provide evidence that electrons do actually occupy different shells. Why do elements produce different colours?**
3. **Is it the metal part of the compound or the carbonate part (carbon and oxygen) that produces the colour? How do you know?**



Ions

An **ion** is an atom that has gained or lost one or more electrons. **Positive ions** are atoms that have lost electrons. They have more protons than electrons, so they carry a positive electrical charge. **Negative ions** are atoms that have gained electrons. They have more electrons than protons, so they carry a negative electrical charge.

When the outer shell is full, an atom is more stable. Atoms 'lose' or 'gain' electrons so that their outer shells become 'filled' if they are not already full.

In the case of the sodium atom in the diagram at right, there is one electron in the outer shell — the shell is not full. The sodium atom loses one electron to become more stable. The chlorine atom has seven electrons in its outer shell, but needs eight to have a full shell. So, the chlorine atom gains an electron and forms a negatively charged chloride ion.

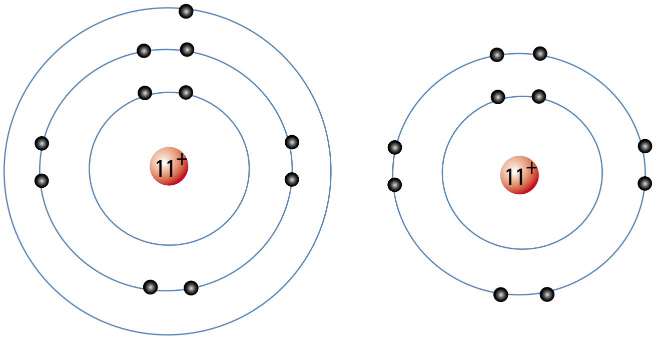
Atoms gain or lose electrons depending on which is the easier way to have a full outer shell. It is easier for sodium to lose that electron than to fill its outer shell. But it is easier for chlorine to gain one electron, rather than lose seven.

Naming ions

Positive ions keep the name of the atom from which they are made. So, a positive ion made from a copper atom is called a *copper ion* and the positive ion formed from boron is called a *boron ion*.

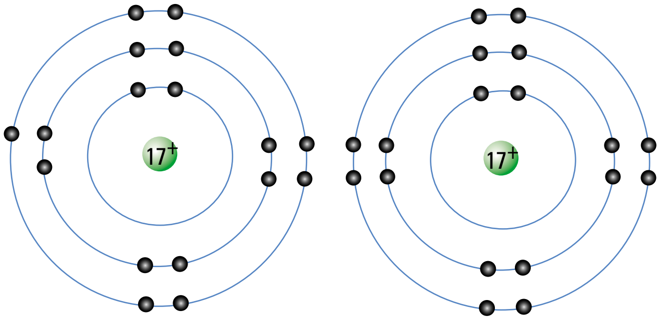
Negative ions, on the other hand, have names that are slightly different from those of the atoms from which they are derived. For example, the negative ion formed by fluorine is called a *fluoride ion* while the negative ion that nitrogen forms is called the *nitride ion*.

In general, the name of a negative ion is found by using the first part of the atom's name and then adding 'ide' to the end of it.



Sodium atom (Na) Sodium ion (Na^+)

Sodium atoms lose electrons to become positive sodium ions.



Chlorine atom (Cl) Chlorine ion (Cl^-)

Chlorine atoms gain electrons to become negative chloride ions.

Writing ions

We can show whether an ion is positive or negative by using the chemical symbol for the atom that the ion is derived from and adding the appropriate sign as a superscript. We can also show in the superscript how many electrons the atom has gained or lost to become an ion. For example, calcium tends to form a positive ion by losing 2 of its electrons, so the calcium ion is written as Ca^{2+}. Chlorine gains a single electron to form a negative ion which is written as Cl^{1-} or as just Cl^-.

The table below shows the names and symbols of some common ions.

Positive ions			Negative ions		
Atom name	**Ion name**	**Chemical symbol**	**Atom name**	**Ion name**	**Chemical symbol**
lithium	lithium	Li^+	iodine	iodide	I^-
sodium	sodium	Na^+	fluorine	fluoride	F^-
potassium	potassium	K^+	chlorine	chloride	Cl^-
calcium	calcium	Ca^{2+}	oxygen	oxide	O^{2-}
aluminium	aluminium	Al^{3+}	nitrogen	nitride	N^{3-}

HOW ABOUT THAT!

People who are lucky enough to have seen an aurora — either the Aurora Borealis in the north or the Aurora Australis in the south — describe it as looking like massive coloured curtains of light that shift like they are being blown by the wind, and in a way they are! This amazing light show is caused by the solar wind — a stream of high energy ions produced by the sun — interacting with the gas atoms in our atmosphere within the Earth's magnetic field, which is strongest at the poles. These interactions cause energy in the form of light to be produced, forming the aurora in the layer of the atmosphere called the ionosphere.

The lights of the Aurora Borealis (seen here in Landmannarlaugar, Iceland) are produced by the ions from the solar wind interacting with our atmosphere in the Earth's magnetic field.

ACTIVITIES

REMEMBER

1 What is the name given to the different energy levels that electrons can be found in?

2 How many electrons are needed to fill (a) the first shell (b) the second shell?

3 How is an ion different from an atom?

4 **Explain** how an oxide ion is formed.

5 State whether the following atoms form positive or negative ions: (a) oxygen; (b) boron; (c) chlorine; (d) lithium.

6 The ion formed from a zinc atom has the symbol Zn^{2+}. (a) Does the zinc atom lose electrons or gain electrons to form this ion? (b) How many electrons does it gain or lose to form the ion?

THINK

7 Look at the diagram of the sodium atom and sodium ion on page 173. (a) How many electrons does the atom have? (b) How many electrons does the ion have? (c) **Explain** why the sodium ion carries a positive charge.

8 How many electrons are there in: (a) a neutral carbon atom with 6 protons? (b) a neutral neon atom with 10 protons?

9 Copy and complete the following table using the information on these pages as well as the periodic table on pages 176–7. The first entry has been done for you.

INVESTIGATE

10 The ionosphere is an important part of Earth's atmosphere. Find out where in the atmosphere it is, who first discovered it, what it is made from and why it is so important to life on Earth.

11 The different colours in the auroras are the result of ions interacting with the gases in the Earth's atmosphere. Find out what gases cause red, blue and green light to be produced in an aurora.

Ion symbol	Ion name	Gained electron or lost electrons?	Number of electrons lost/gained	Total number of electrons in ion
F^-	fluoride	gained	1	10
Be^{2+}				
N^{3-}				
Cl^-				
Sn^{2+}				
Ag^+				

eBook plus work sheet 5.2 Electron shells

5.3

Searching for patterns

Russian chemist Dmitri Mendeleev confidently predicted the properties of the chemical element germanium 15 years before it was discovered. He was able to do this because all known elements had been arranged into a set of rows and columns called the **periodic table**.

The periodic table of elements

Two thousand years ago, only 10 elements had been identified. They were carbon, sulfur, iron, copper, zinc, silver, tin, gold, mercury and lead. By the early nineteenth century, over 50 elements had been identified. Chemists had already begun to search for patterns among the elements in the hope of finding a way to classify them. It was difficult at that time to find patterns because there were still many undiscovered elements.

In 1864, British chemist John Newlands arranged the elements in order of increasing atomic weight and found that every eighth element shared similar properties. In 1869, Mendeleev, building on the work of Newlands and other scientists, discovered a way of organising the elements into rows and columns. This arrangement formed the basis of what we now know as the periodic table. The elements were arranged in rows in order of increasing mass or atomic weight. Mendeleev called the rows of elements periods and the columns, which each contained a 'family' of elements, groups. It is called the periodic table because elements with similar properties occur at regular intervals or periods. In a strange twist of fate, German chemist Lothar Meyer, who worked independently of Mendeleev, also came up with a similar arrangement of the elements at about the same time.

The observation that the physical and chemical properties of the elements recur at regular intervals when elements are listed in order of atomic weight is known as the **Periodic Law**.

An educated guess

Mendeleev was so confident about the Periodic Law that he deliberately left gaps in his periodic table. He was able to predict the properties of the unknown elements that would fill the gaps. Mendeleev predicted the existence of germanium, which he called eka-silicon. This element was discovered in 1886, 15 years later. The table below shows the uncanny accuracy of Mendeleev's predictions.

Mendeleev's work led many scientists to search for new elements. By 1925, scientists had identified all of the naturally existing elements.

The periodic table shown on pages 176–7 includes the names, symbols and atomic numbers of all the known elements. The symbols are a form of shorthand for writing the names of the elements and are recognised worldwide. Some periodic tables describe the properties of each element, including its physical state at room temperature, melting point, boiling point and relative atomic mass. Most elements exist as solids under normal conditions and a few exist as gases. Only two elements exist as liquids at normal room temperature.

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Interactivity

Timeout 'Periodic table'!

In this exciting interactivity, test your ability to classify elements from the periodic table before time runs out.

int-0758

Counting sub-atomic particles

The periodic table is organised on the basis of atomic numbers. The **atomic number** of an element is the number of protons present in each atom. Atoms with the same atomic number have identical chemical properties. Because atoms are electrically neutral, the number of protons in an atom is the same as the number of electrons. The

Properties of eka-silicon as predicted by Mendeleev	Properties of germanium which was discovered in 1886
A grey metal	A grey-white metal
Melting point of about 800 °C	Melting point of 958 °C
Relative atomic mass of 73.4	Relative atomic mass of 72.6
Density of 5.5 g/cm^3	Density of 5.47 g/cm^3
Reacts with chlorine to form compounds with four chlorine atoms bonded to each eka-silicon atom	Reacts with chlorine and forms compounds in a ratio of four chlorine atoms to every germanium atom

mass number of an atom is the sum of the number of protons and neutrons in the atom. The number of neutrons in an atom can therefore be calculated by subtracting the atomic number from the mass number. This information is usually shown in the following way:

$${}^{A}_{Z}\mathrm{E}$$

A = the mass number
= number of protons + number of neutrons
Z = the atomic number
= number of protons
= number of electrons (for a neutral atom)
E = the symbol of the element.

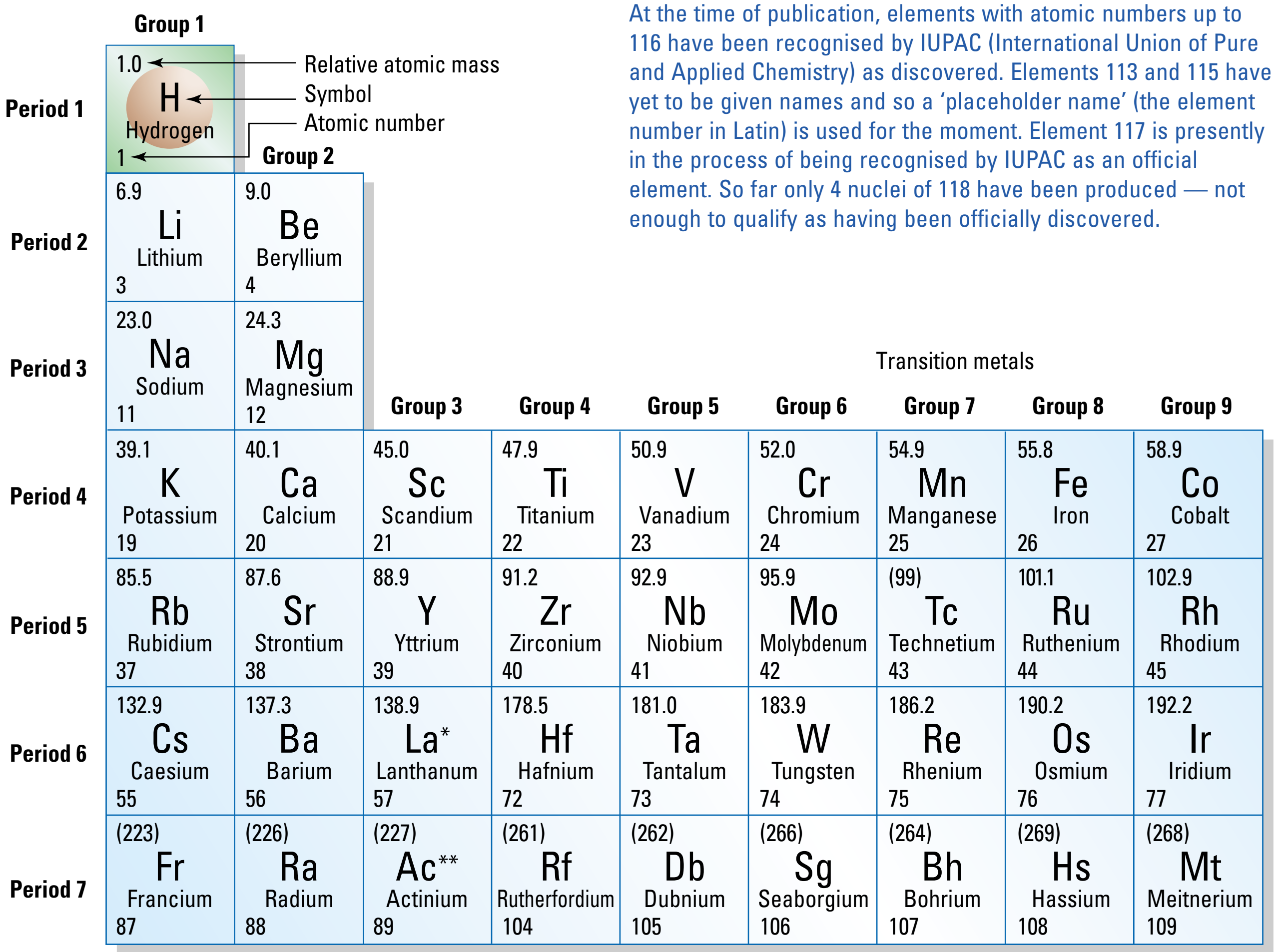
For example, the element iron has a mass number of 56 and an atomic number of 26. It can be represented as follows:

$${}^{56}_{26}\mathrm{Fe}$$

Once you know the atomic number and the mass number of an element, you can work out how many electrons and neutrons are in that element.

The atomic number of iron is 26 because all iron atoms have 26 protons. Iron's mass number of 56 indicates that most iron atoms have a total of 56 protons and neutrons.

At the time of publication, elements with atomic numbers up to 116 have been recognised by IUPAC (International Union of Pure and Applied Chemistry) as discovered. Elements 113 and 115 have yet to be given names and so a 'placeholder name' (the element number in Latin) is used for the moment. Element 117 is presently in the process of being recognised by IUPAC as an official element. So far only 4 nuclei of 118 have been produced — not enough to qualify as having been officially discovered.



Transition metals

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9
Period 1	1.0 H Hydrogen 1								
Period 2	6.9 Li Lithium 3	9.0 Be Beryllium 4							
Period 3	23.0 Na Sodium 11	24.3 Mg Magnesium 12							
Period 4	39.1 K Potassium 19	40.1 Ca Calcium 20	45.0 Sc Scandium 21	47.9 Ti Titanium 22	50.9 V Vanadium 23	52.0 Cr Chromium 24	54.9 Mn Manganese 25	55.8 Fe Iron 26	58.9 Co Cobalt 27
Period 5	85.5 Rb Rubidium 37	87.6 Sr Strontium 38	88.9 Y Yttrium 39	91.2 Zr Zirconium 40	92.9 Nb Niobium 41	95.9 Mo Molybdenum 42	(99) Tc Technetium 43	101.1 Ru Ruthenium 44	102.9 Rh Rhodium 45
Period 6	132.9 Cs Caesium 55	137.3 Ba Barium 56	138.9 La* Lanthanum 57	178.5 Hf Hafnium 72	181.0 Ta Tantalum 73	183.9 W Tungsten 74	186.2 Re Rhenium 75	190.2 Os Osmium 76	192.2 Ir Iridium 77
Period 7	(223) Fr Francium 87	(226) Ra Radium 88	(227) Ac** Actinium 89	(261) Rf Rutherfordium 104	(262) Db Dubnium 105	(266) Sg Seaborgium 106	(264) Bh Bohrium 107	(269) Hs Hassium 108	(268) Mt Meitnerium 109

The group number corresponds to the number of electrons in the outer shell.

The period number refers to the number of the outermost shell containing electrons.

Legend

🟢 Liquid at room temperature
🟤 Gas at room temperature
All other naturally occurring elements are solid at room temperature.

*Lanthanides 58–71

140.1 Ce Cerium 58	140.9 Pr Praseodymium 59	144.2 Nd Neodymium 60	(147) Pm Promethium 61	150.4 Sm Samarium 62

**Actinides 90–103

232.0 Th Thorium 90	(231) Pa Protactinium 91	238.1 U Uranium 92	(237) Np Neptunium 93	(242) Pu Plutonium 94

To calculate the number of neutrons, the atomic number is subtracted from the mass number to give 30 neutrons:

number of neutrons
= A – Z = 56 – 26 = 30

Since atoms are electrically neutral and protons have a positive charge, each iron atom has 26 electrons:

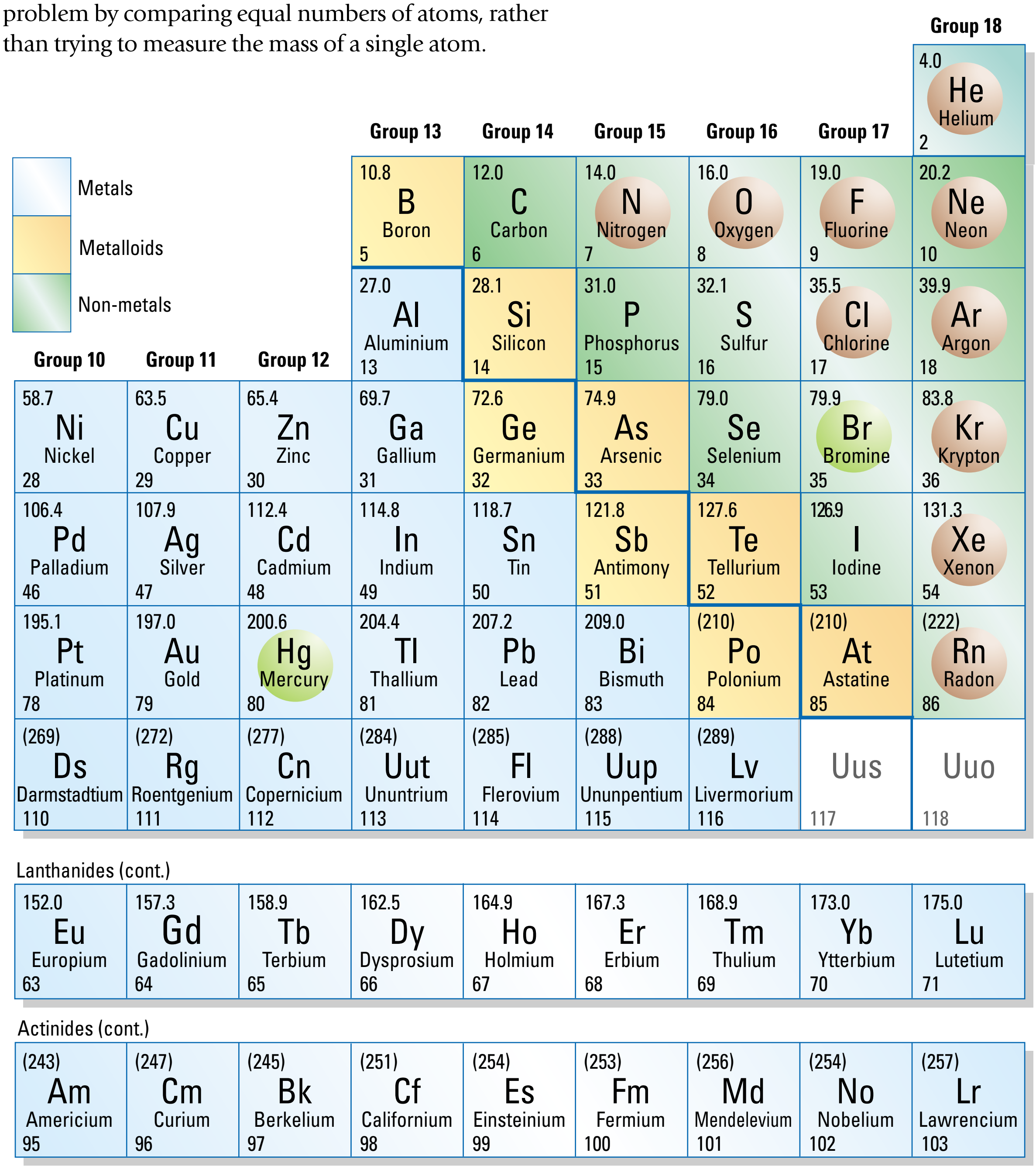
number of electrons
= number of protons = Z = 26

How heavy are atoms?

Measuring and comparing the masses of atoms is difficult because of their extremely small size. Chemists solve this problem by comparing equal numbers of atoms, rather than trying to measure the mass of a single atom.

A further problem arises because not all atoms of an element are identical. Although all atoms of a particular element have the same atomic number, they can have different numbers of neutrons. Hence, some elements contain atoms with different masses. These different masses are used to calculate an average or **weighted mean**, which is based on the relative amounts of each type of atom. This number is referred to as the **relative atomic mass** and is usually not a whole number.

For example, 99.98% of all hydrogen atoms have 1 proton only in their nucleus and so have an atomic mass of 1. However, about 0.015% of hydrogen



🟦	Metals
🟨	Metalloids
🟩	Non-metals

Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16	Group 17	Group 18
								4.0 He Helium 2
			10.8 B Boron 5	12.0 C Carbon 6	14.0 N Nitrogen 7	16.0 O Oxygen 8	19.0 F Fluorine 9	20.2 Ne Neon 10
			27.0 Al Aluminium 13	28.1 Si Silicon 14	31.0 P Phosphorus 15	32.1 S Sulfur 16	35.5 Cl Chlorine 17	39.9 Ar Argon 18
58.7 Ni Nickel 28	63.5 Cu Copper 29	65.4 Zn Zinc 30	69.7 Ga Gallium 31	72.6 Ge Germanium 32	74.9 As Arsenic 33	79.0 Se Selenium 34	79.9 Br Bromine 35	83.8 Kr Krypton 36
106.4 Pd Palladium 46	107.9 Ag Silver 47	112.4 Cd Cadmium 48	114.8 In Indium 49	118.7 Sn Tin 50	121.8 Sb Antimony 51	127.6 Te Tellurium 52	126.9 I Iodine 53	131.3 Xe Xenon 54
195.1 Pt Platinum 78	197.0 Au Gold 79	200.6 Hg Mercury 80	204.4 Tl Thallium 81	207.2 Pb Lead 82	209.0 Bi Bismuth 83	(210) Po Polonium 84	(210) At Astatine 85	(222) Rn Radon 86
(269) Ds Darmstadtium 110	(272) Rg Roentgenium 111	(277) Cn Copernicium 112	(284) Uut Ununtrium 113	(285) Fl Flerovium 114	(288) Uup Ununpentium 115	(289) Lv Livermorium 116	Uus 117	Uuo 118

Lanthanides (cont.)

152.0 Eu Europium 63	157.3 Gd Gadolinium 64	158.9 Tb Terbium 65	162.5 Dy Dysprosium 66	164.9 Ho Holmium 67	167.3 Er Erbium 68	168.9 Tm Thulium 69	173.0 Yb Ytterbium 70	175.0 Lu Lutetium 71

Actinides (cont.)

(243) Am Americium 95	(247) Cm Curium 96	(245) Bk Berkelium 97	(251) Cf Californium 98	(254) Es Einsteinium 99	(253) Fm Fermium 100	(256) Md Mendelevium 101	(254) No Nobelium 102	(257) Lr Lawrencium 103

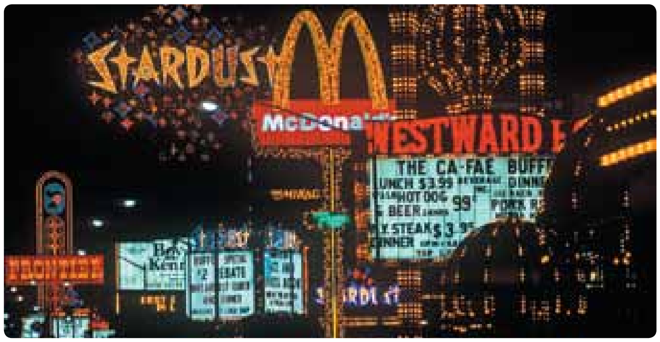
atoms have a proton and one neutron in their nucleus (giving them an atomic mass of 2) and the remaining hydrogen atoms found have one proton and two neutrons in their nuclei, giving them an atomic mass of 3. As a result, the relative atomic mass of hydrogen is 1.008 rather than 1.

Rounding off the relative atomic mass to the nearest whole number will usually give you the mass number (A) of the most common form of an element.

Families of elements

The periodic table contains eighteen groups (or families) of elements, some of which have been given special names. (Remember that these groups form columns in the periodic table.)

- Group 1 elements are known as the **alkali metals**. The alkali metals all react strongly with water to form basic solutions.
- Group 2 elements are referred to as the **alkaline earth metals**.
- Group 17 elements are known as the **halogens**. The halogens are brightly coloured elements. Chlorine is green, bromine is red-brown and iodine is silvery-purple.
- Group 18 elements are known as the **noble gases**. The noble gases are inert and do not readily react with other substances.
- The block of elements in groups 3 to 12 is known as the **transition metal** block.



Illuminated signs use tubes filled with the noble gas neon.

ACTIVITIES

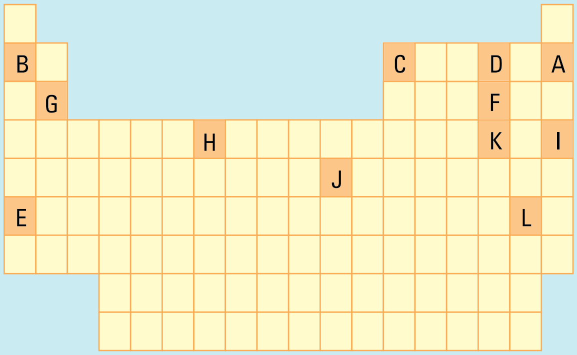
REMEMBER

1 State whether the following statements are true or false.
  (a) The noble gases are found in group 18.
  (b) The non-metals are found in the upper right-hand side of the periodic table.
  (c) There are more metals than non-metals.
  (d) Few elements are found naturally as liquids.

2 **Identify** the element in: (a) group 2, period 3 (b) group 17, period 2 (c) group 1, period 4 (d) group 18, period 3.

3 **Construct** an outline of the periodic table showing where you would find the following elements: the noble gases, the alkali metals, the alkaline earth metals, the halogens and the transition metals.

4 In the outline of the periodic table shown below, some of the elements have been replaced by letters. Using these letters, **identify** which of these elements fit the following categories.



  (a) Two elements that are gases at room temperature
  (b) Two elements that are metals
  (c) Two elements that are transition elements
  (d) An element that is a noble gas
  (e) Two elements that are in the same group
  (f) Two elements that are in the same period
  (g) The elements that are alkali metals
  (h) The element that is a halogen

5 **Distinguish** between the mass number and the relative atomic mass of an element.

6 **Construct** a table showing the name, mass number, atomic number, and number of protons, neutrons and electrons of the following elements.
  (a) $^{12}_{6}\mathrm{C}$
  (b) $^{65}_{30}\mathrm{Zn}$
  (c) $^{40}_{18}\mathrm{Ar}$
  (d) $^{197}_{79}\mathrm{Au}$
  (e) $^{238}_{92}\mathrm{U}$

THINK

7 **Explain** why it is useful to display the elements as a periodic table rather than as a list.

INVESTIGATE

8 Scientists have created all the elements beyond element 92. **Investigate** how they have been made.

CREATE

9 Compose a rhyme, poem or song that can help you learn the names of the first 20 elements in order.

eBook*plus*

work sheets
5.3 Elements and atomic numbers
5.4 Periodic table

5.4

Periodic patterns

Is it a metal?

The line that zigzags through the periodic table separates the **metals** from the **non-metals**. About three-quarters of all elements are classified as metals. The metals are found on the left-hand side of the table. The non-metals are found on the upper right-hand side of the table. Eight elements that fall along this line have properties belonging to both metals and non-metals. They are called **metalloids**. Examples of these elements include silicon, boron and germanium.

Following a trend

There are a number of repeating patterns in the periodic table. The most obvious is the change from metals on the left of each period to non-metals on the right. Other patterns exist in the physical and chemical properties of elements in the same group or period. Some of these trends are shown in the table at the top of the next page.

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Interactivity

It's elementary

In this revelation game you must identify common elements from their symbols to reveal the full periodic table. You must answer quickly to complete the game in time.

int-0229

eLesson

Davey and potassium

Watch a video from *The story of science* about the discovery of potassium.

eles-1773

INVESTIGATION 5.3

Chemical properties of metals and non-metals (Teacher demonstration)

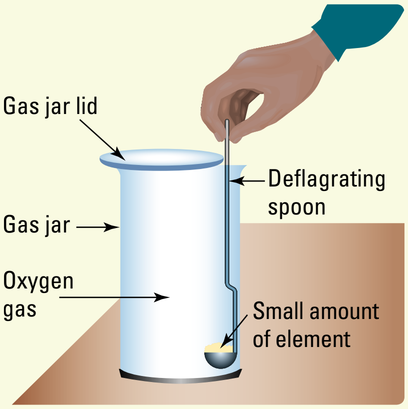
AIM To investigate and compare some reactions of metals and non-metals

You will need:

safety glasses, gloves and laboratory coat
1M hydrochloric acid
water
magnesium
iron filings
copper filings
sulfur powder
universal indicator
4 test tubes
4 gas jars filled with oxygen gas
4 deflagrating spoons
dropping pipette
spatula
Bunsen burner, heatproof mat and matches

CAUTION *The heating part of this experiment should be done in a fume cupboard. Safety glasses, gloves and laboratory coats must be worn at all times.*

- Place a small quantity of magnesium in a test tube. Add about 2 mL of hydrochloric acid. Record any observations in a suitable table.
- Repeat using the iron filings, copper filings and sulfur powder.
- Place a small amount of magnesium in a deflagrating spoon and heat it. When hot, place it into the gas jar full of oxygen gas. **Do not look directly at the flame**. Record your observations.
- Repeat using the iron and copper filings. Record your observations.



Burning sulfur in oxygen in a gas jar

- Repeat using a small amount of sulfur powder.

This part of the experiment must be performed in a fume cupboard.

- Add about 10 mL of water to each jar and shake. Add 3 drops of universal indicator. Record the colour and determine the pH of the solution.

DISCUSSION

1. Use the periodic table to determine which of the elements tested were metals and which were non-metals.
2. Describe any differences between the effect of acids on metals and non-metals.
3. Describe what happened when the metals and non-metals reacted with oxygen.
4. The metal or non-metal oxides formed in the gas jars dissolved in water to form acidic and basic solutions. What type of solution did the metals form? What type of solution did the non-metals form?

Characteristic	Pattern down a group	Pattern across a period
Atomic number and mass number	Increases	Increases
Atomic radius	Increases	Decreases
Melting points	Decreases for groups 1 to 5 and increases for groups 5 to 8	Generally increases then decreases
Reactivity	Metals become more reactive and non-metals become less reactive	Is high, then decreases and then increases. Group 8 elements are inert and do not react.
Metallic character	Increases	Decreases

Explaining the periodic table

When Mendeleev and Meyer grouped elements on the basis of their similar chemical properties, they were not aware of the existence of electrons. We can now explain many of their observations using our understanding of electron shells.

Atoms in the same group of the periodic table have similar properties because they have the same number of electrons in their outer shells. (The outer shell is the last shell to be filled by electrons.) The number of electrons in the outer shell relates to the group number in the periodic table. Hence, all elements in group 1 have one electron in their outer shell and all elements in group 18 (with the exception of helium) have eight electrons in their outer shell.

INVESTIGATION 5.4

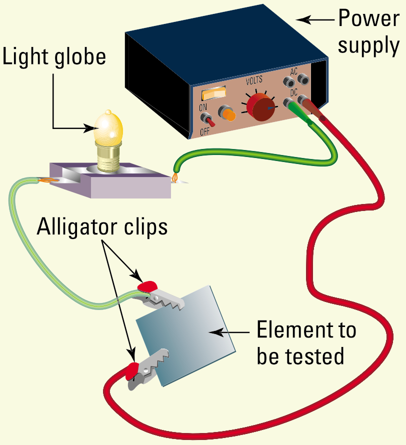
Comparing the properties of two metal families

AIM To investigate and compare metal elements from group II (the alkali earth metals) and the transition metals

You will need:

small samples of magnesium, iron and copper
'rice grain' equivalent amounts of calcium chloride, magnesium chloride, iron chloride and copper chloride
spatula
5 test tubes and a test-tube rack
electric circuit to measure conductivity (2-volt power supply, 3 connecting leads, 2 alligator clips and a light globe and holder)
2M hydrochloric acid
water
matches
stirring rod
safety glasses and laboratory coat

- Record the results of the following experiments in an appropriate table.
- Describe the physical state (solid, liquid or gas) of each of the elements.
- Describe the physical appearance of each of the elements.
- Set up the circuit as shown in the diagram above right and determine whether each of the elements conducts electricity.
- Determine whether any of the elements react with water by placing a small sample in 2 mL of water in a test tube. Record any changes that occur in your table.



Circuit used to measure electrical conductivity

- Determine whether the metals react with acid by placing a small sample of each metal in 1 mL of 2M hydrochloric acid in a test tube. If a gas is produced, test it by holding a lit match at the mouth of the test tube. Make sure the test tube is pointed away from you. If hydrogen is present, a 'pop' will be heard. If oxygen is present, the match should burn more brightly. If carbon dioxide is present, the match should go out.
- Your teacher may show or describe to you how the metal calcium responds to some of the tests described previously.
- Add a small amount of each of the metal compounds (magnesium chloride, calcium chloride, iron chloride and copper chloride) to 5 mL of water. Comment on their solubility and the colour of any solution made.

DISCUSSION

1. **What are the properties of copper and iron? Are there any similarities?**
2. **What are the properties of calcium and magnesium? Are there any similarities?**
3. **List the metals in order of reactivity with water and acids. List them in order of most reactive to least reactive.**
4. **Were there any differences between solubilities of the metal compounds or the colours of the solutions they formed? Describe these differences.**
5. **Write down the name of the specific group in the periodic table to which each of the elements belong.**
6. **What could you infer about the properties of elements in the same group? Give reasons for your answer.**

Shell by shell

The largest atoms contain up to seven shells of electrons. Thus, there are seven periods (rows) in the periodic table. (Look at the periodic table on pages 176–7 to confirm this.) The period number tells you the number of shells containing electrons. The first shell can hold up to two electrons, so there are two elements in the first period (with hydrogen containing one electron in the first shell and helium containing two electrons in the first shell). The second shell holds up to eight electrons, so there are eight elements in the second period.

Element	Symbol	Atomic number	Electronic configuration
Oxygen	O	8	2, 6
Fluorine	F	9	2, 7
Neon	Ne	10	2, 8
Sodium	Na	11	2, 8, 1
Magnesium	Mg	12	2, 8, 2
Sulfur	S	16	2, 8, 6
Chlorine	Cl	17	2, 8, 7
Argon	Ar	18	2, 8, 8
Potassium	K	19	2, 8, 8, 1

Note that the fourth shell of the potassium atom begins filling before the third shell is full.

Even though the third shell can hold up to 18 electrons, there are only eight elements in the third period. This is because the outer shell of an atom can never hold more than eight electrons as the atom would then become unstable. Therefore, while the third shell is yet to be filled, electrons begin to fill the fourth shell in both potassium and calcium atoms. This stabilises the atoms because the third shell is no longer the outer shell. The filling of the third shell resumes in the block of elements from scandium to zinc (the transition metals). Once the third shell is full, the fourth shell continues to fill from gallium to xenon.

HOW ABOUT THAT!

Lead poisoning was a common occurrence in ancient Rome because the lead the Romans used to make their water pipes and cooking utensils slowly dissolved into the water.

Acute lead poisoning causes mental impairment and personality changes. The effects of lead poisoning are not immediately noticeable. They occur gradually as the amount of lead in the body accumulates over time. Some historians attribute the strange behaviour of several Roman emperors to lead poisoning.

In the Middle Ages plates, cups and other drinking vessels were often made from pewter, an alloy of lead and tin. The acids in food and drinks caused lead to leach out and cause poisoning.

Until 1986, lead was added to petrol to stop the 'knocking' in car engines. Unleaded fuel was introduced at that time to allow a device called a catalytic converter to prevent pollutants such as nitrous oxides, carbon monoxide and unburnt fuel from being emitted from car exhausts. With lead in the petrol, these devices couldn't work. It was also believed that lead emissions from cars were causing a build-up of lead in the humans in built-up areas.

The word 'plumber' is derived from the Latin word *plumbum*, meaning lead. Look up the symbol for lead in the periodic table. Where do you think this symbol came from?

ACTIVITIES

REMEMBER

1 **Describe** what happens to the metallic character of the elements as you go across the periodic table.

2 What information about the electron arrangement is given by the group number of an element?

3 What information about the electron arrangement is given by the period number of an element?

THINK

4 **Explain** why water does not appear in the periodic table.

5 Name the elements that have an electron arrangement of: (a) 2,4 (b) 2,8,5 (c) 2 (d) 2,8,8,2.

6 Write the electron arrangement for each of the following elements.
  (a) Boron
  (b) Neon
  (c) Potassium
  (d) Fluorine
  (e) Silicon

7 If an element has one electron in its outer shell, is it a metal or a non-metal? **Explain** your answer.

8 If an element has seven electrons in its outer shell, is it a metal or a non-metal? **Explain** your answer.

9 What is special about elements that have eight electrons in their outer shell?

10 What experimental evidence is there to show that electron shells actually exist?

INVESTIGATE

11 It is said that the stars are the 'element factories of the universe'; that is, stars make the elements. Do some research and investigate how the stars make elements.

12 Choose an element and research the following information about it: (a) when it was discovered (b) who discovered it (c) how it is found in nature (d) its properties and uses.

13 The electron arrangement of elements is more complex than the explanation given here. Find out about subshells and orbitals and how they are involved in determining how electrons are arranged in atoms.

5.5

Ionic compounds

Molecules and compounds

Atoms are not often found on their own. When the outer shell electrons of atoms interact, atoms can become chemically joined together to form molecules. The join is called a **chemical bond** (or **molecular bond**). Bonds can form between atoms of the same element or between atoms of differing elements. You should recall from your earlier Science studies that a substance that is made from atoms of differing elements bonded to each other is called a **compound**.

Knowledge of the electron shell structures of atoms helps us to understand how compounds like sodium chloride (table salt) form. When atoms react with each other to form compounds, it is the electrons in the outer shell that are important in determining the type of reaction which occurs.

It's great to be noble

In 1919, Irving Langmuir suggested that the noble gases do not react to form compounds because they have a stable electronic configuration of eight electrons in their outer shell. Most other atoms react because their electron arrangements are less stable than those of the noble gases. The atoms become more stable when they attain an electron arrangement that is the same as the noble gases. Chemical reactions can allow atoms to obtain this arrangement. The table below shows the electron arrangement of a few elements. Notice how the electron arrangements of the two noble gases, neon and argon, show eight electrons in their outer shells. The atoms of the other elements must gain or lose electrons to attain full outer shells. In this way they become more stable, ending up with the electron arrangement of the nearest noble gas in the periodic table.

Giving and taking electrons

Atoms that have lost or gained electrons and therefore carry an electric charge are called ions. Metal atoms, such as sodium, magnesium and potassium, have a small number of outer shell electrons. They form ions by losing the few electrons that they have in their outer shell. This means that metal ions have more protons than electrons and so the ions are positively charged. For example, the magnesium atom loses its two outer shell electrons to become a positively charged magnesium ion. The symbol for the magnesium ion is Mg^{2+}. The '2+' means that two electrons have been lost to form the ion. Positively charged ions are called **cations**.

Non-metal atoms form ions by gaining electrons to fill their outer shell. In these ions there are more electrons than protons, so they are negatively charged. For example, the chlorine atom gains one electron to fill its outer shell, becoming a negatively charged chloride ion. Its symbol is Cl^-. The '–' means that one electron has been gained to form the ion. Negatively charged ions are called **anions**.

The diagram at the top of the next page shows how sodium and chlorine atoms lose and gain electrons respectively to form ions. Note that the sodium atom becomes a sodium ion and that the chlorine atom becomes a chloride ion. (Remember, when non-metals form ions, the suffix '-ide' is used.)

Compounds such as sodium chloride, copper sulfate, calcium carbonate and sodium hydrogen carbonate all form when atoms come in contact with each other and lose or gain electrons. Compounds formed in this way are called **ionic compounds**.

Ionic compounds form when metal and non-metal atoms combine. A sodium atom loses an electron to form an ion, and a chlorine atom gains an electron to form an ion. The electrons are transferred from one

Interactivities

Shell-shocked?

This interactivity challenges you to create a model of the electron shell of an atom and indicate its energy levels.

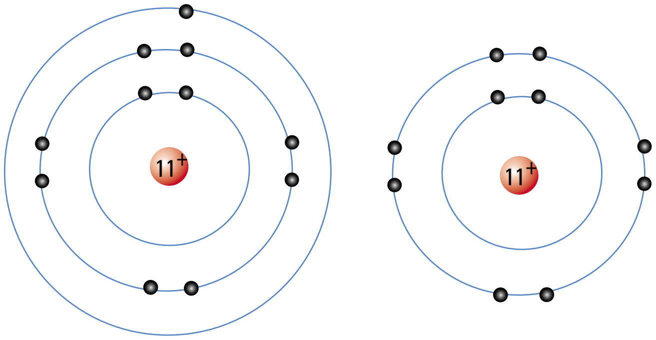
int-0676

Pass the salt

Use this interactivity to test your knowledge on what it means to be ionic.

int-0675

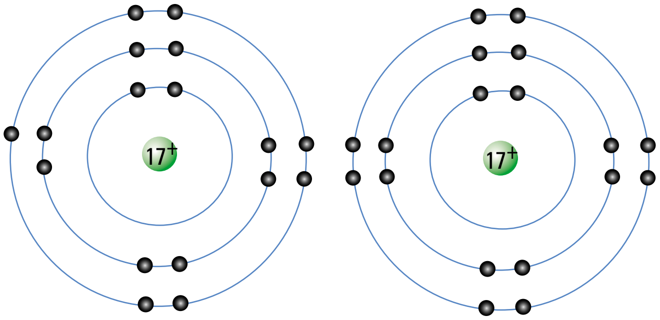
Element	O	F	**Ne**	Na	Mg	S	Cl	**Ar**	K
Electron arrangement	2, 6	2, 7	**2, 8**	2, 8, 1	2, 8, 2	2, 8, 6	2, 8, 7	**2, 8, 8**	2, 8, 8, 1



Sodium atom (Na)

Sodium ion (Na^+)

Sodium atoms lose electrons to become positive sodium ions.



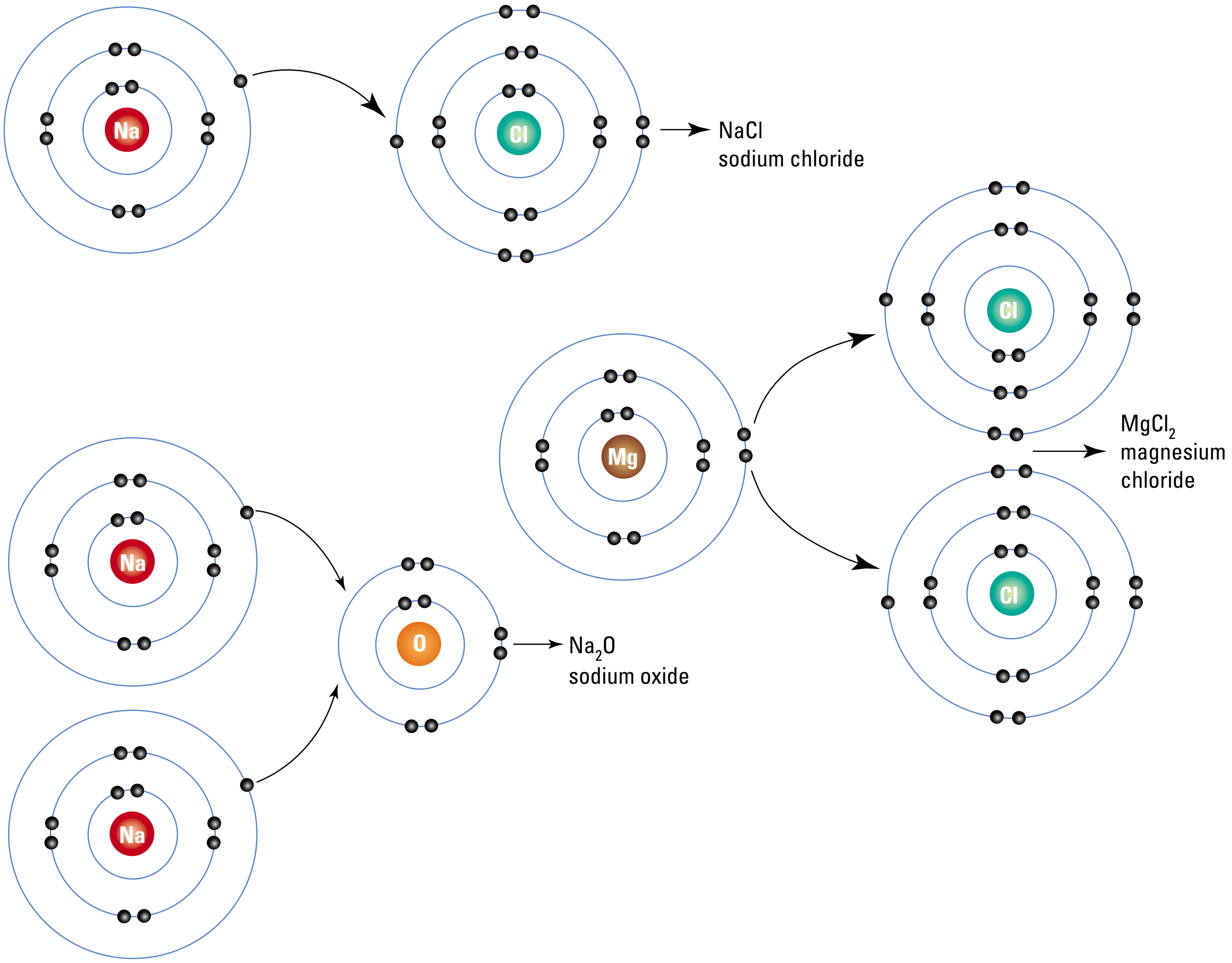
Chlorine atom (Cl)

Chlorine ion (Cl^-)

Chlorine atoms gain electrons to become negative chloride ions.

atom to the other, and the oppositely charged ions that form attract each other and form a compound. This electrical force of attraction between the ions is called an **ionic bond**.

The diagram below shows some examples of the transfer of electrons that occurs when ionic compounds are formed. Note that more than two atoms may be involved to ensure that all the elements achieve a full complement of electrons in their outer shell. For example, when magnesium reacts with chlorine to form magnesium chloride, each magnesium atom loses two electrons. Since each chlorine atom needs to gain only one electron, a magnesium atom gives one electron to each of two chlorine atoms. The resulting Mg^{2+} and Cl^- ions are attracted to each other to form the compound $MgCl_2$.



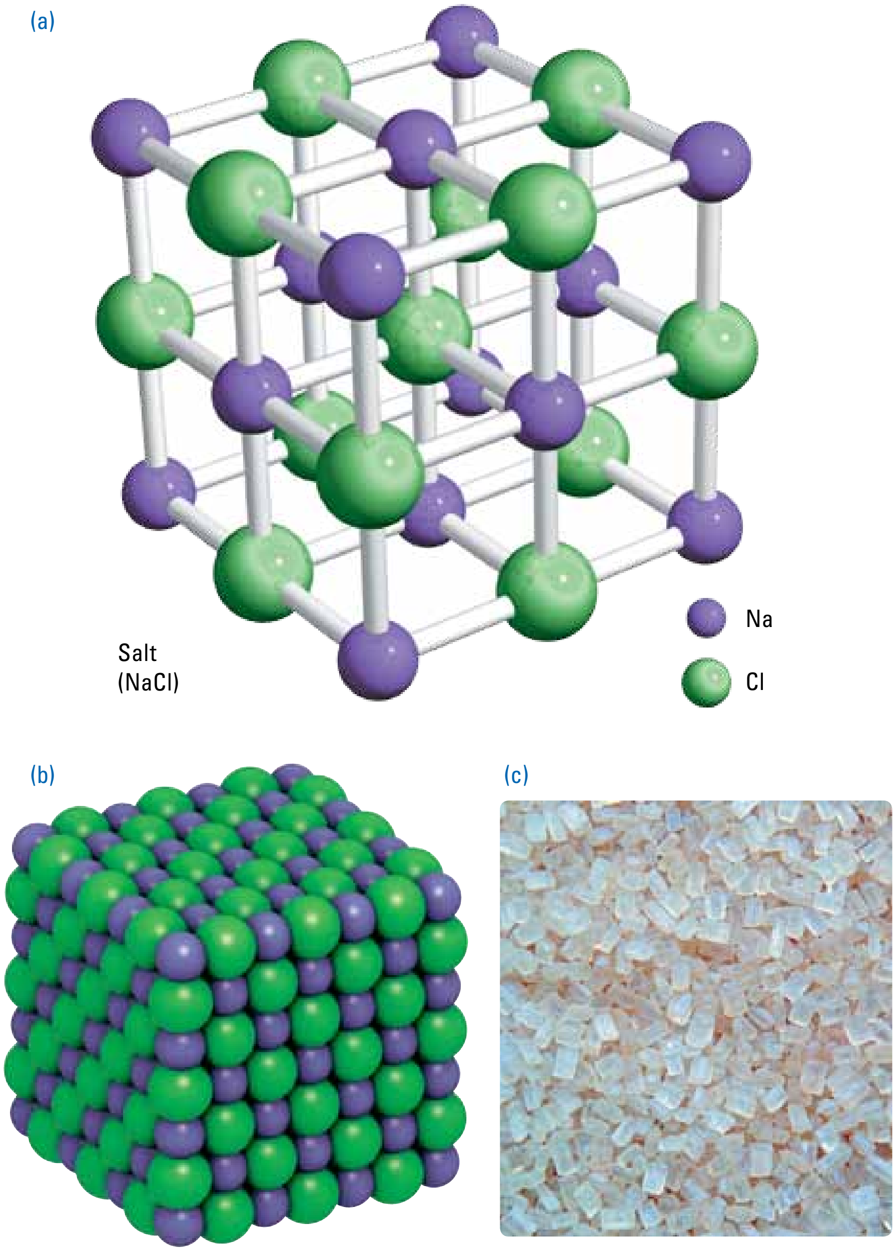
The ‘give’ and ‘take’ of electrons that occurs in the formation of the ionic compounds sodium chloride, magnesium chloride and sodium oxide

Characteristics of ionic compounds

Ionic compounds have the following properties.

- They are made up of positive and negative ions.
- They are usually solids at room temperature.
- They normally have very high melting points because the electrostatic force of attraction between the ions is very strong.
- They usually dissolve in water to form **aqueous solutions**.
- Their aqueous solutions normally conduct electricity.

Ionic compounds usually form lattices of positive and negative ions rather than individual molecules. A lattice is an ordered structure of ions held together by the electrostatic attraction between the positive and negative ions and is the basis of crystal formation.



(a) A stick and ball representation of the lattice structure of sodium chloride; the sticks represent the bonds between the atoms.
(b) The ions in the lattice are effectively held in a tight arrangement.
(c) Individual salt crystals form regular square blocks because of the ionic lattice.

ACTIVITIES

REMEMBER

1 **Define** the term 'ion'.

2 **Describe** how ions form.

3 **Recall** what a positively charged ion is called.

4 **Recall** what a negatively charged ion is called.

5 **Recall** the properties that most ionic compounds have in common.

6 **Describe** the kinds of elements that combine to form ionic compounds.

THINK

7 Why are you unlikely to find an isolated molecule of an ionic compound?

8 Write the symbol for the ion formed by each of the following elements. You can turn back to the periodic table on pages 176–7: (a) sodium (b) nitrogen (c) potassium (d) fluorine.

9 **Identify** how many electrons have been gained or lost by the following ions: (a) Pb^{4+} (b) Br^{-} (c) Cr^{3+} (d) Se^{2-}

10 Which of the following are ionic compounds? Nitrogen dioxide; hydrogen chloride; magnesium sulfide; carbon tetrachloride

11 Draw diagrams to show how each of the following ionic compounds form. (a) Magnesium fluoride (b) Lithium chloride (c) Aluminium sulfide (d) Calcium oxide

IMAGINE

12 Imagine that you are the outer shell electron of a sodium atom and you are going to form the ionic compound sodium chloride. **Describe** your experiences in a piece of creative writing. **Discuss** details such as the physical states, properties of the elements and compound involved, their atomic structure, reasons for forming ions and, finally, the reasons why the ions form the ionic compound.

eBook*plus* work sheet 5.5 Ionic bonding

5.6

Covalent compounds

Ionic compounds form as the result of non-metal atoms effectively 'stealing' electrons from metal atoms. Atoms can also achieve stable electronic configurations by sharing electrons with other atoms to gain a full outer shell. When two or more atoms share electrons, a molecule is formed. A chemical bond formed by the sharing of electrons is called a **covalent bond**. The compounds formed are called **covalent** or **molecular compounds**.

Non-metal atoms share electrons to form covalent molecules. These molecules can be made of more than one type of atom, or made of atoms of the same element. For example, oxygen gas consists of molecules formed when two oxygen atoms share electrons. Individual atoms of oxygen are not stable and become more stable by sharing electrons with each other.

Electron dots and dashes

It is possible to draw diagrams to show how elements share electrons to form covalent compounds. These diagrams are called **electron dot diagrams**. They show the symbol for the atom and dots for the electrons in the outer shell of atoms. The table on the right shows electron dot diagrams for some elements. Note that the electrons in the diagrams are arranged in four regions around the atom. Wherever possible, they are grouped in pairs.

When elements combine to form covalent compounds, they share electrons in order to achieve a full outer shell with eight electrons. Hydrogen has a full outer shell when it has two electrons but all the other elements in the table need eight electrons to fill the outer shell.

The table on the next page shows how some covalent compounds form. The shared electrons are called **bonding electrons**. It is also possible to draw a **structural formula**, where a dash is used to represent these shared electrons. The dash represents the covalent bond and the other electrons need not be drawn. It is also possible for double or triple covalent bonds to form. The way electrons are shared determines the ratio in which elements combine to form a covalent compound. It also determines the **chemical formula** of the compound.

eBook*plus*

Interactivity

Making molecules

In this interactivity, you will use carbon, chlorine, hydrogen, nitrogen and oxygen atoms to create the correct models of a series of chemical formulae. Instant feedback is provided.

int-0228

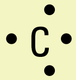
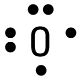
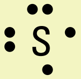
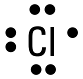
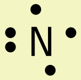
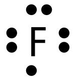
eLesson

Perkins mauve

Watch a video from *The story of science* about the first artificial dye.

eles-1774

Electron dot diagrams for some elements

Symbol	Electronic configuration	Electron dot diagram
H	1	
C	2, 4	
O	2, 6	
S	2, 8, 6	
Cl	2, 8, 7	
N	2, 5	
F	2, 7	

INVESTIGATION 5.5

Drawing electron dot diagrams

AIM To practise drawing electron dot diagrams of covalent molecules

- Draw electron dot diagrams like those in the table at left for the following covalent compounds: hydrogen fluoride (HF), methane (CH_4), phosphorus chloride (PCl_3) and hydrogen sulfide (H_2S).

DISCUSSION

1. What pattern emerges between the structural formula of the compound and the number of electrons involved in bonding?
2. State whether the covalent bonds in the compounds are single, double or triple bonds.

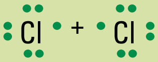
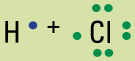
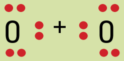
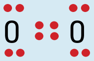
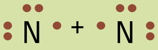
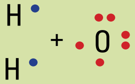
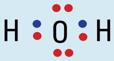
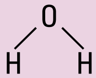
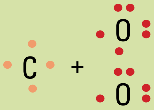
Characteristics of covalent compounds

Most covalent compounds have the following properties.

- They exist as gases, liquids or solids with low melting points because the forces of attraction between the molecules are weak.
- They generally do not conduct electricity because they are not made up of ions.
- They are usually insoluble in water.

HOW ABOUT THAT!

The electron dot diagrams shown on these pages are better known as Lewis structures, but they can also be called Lewis dot diagrams. These were developed by the American chemist Gilbert Newton Lewis, who discovered covalent bonds, as a way of notating the bonds between atoms joined together in covalent molecules. Lewis first used these diagrams in an article called 'The atom and the molecule' which was published in 1916. They are now commonly used by physical chemists.

Name and formula	Atoms	Compound	Structural formula	Explanation
Chlorine Cl_2			$Cl-Cl$ *Note:* The line represents a sharing of two electrons and is called a single covalent bond.	Each chlorine atom needs to share one electron to gain a full outer shell.
Hydrogen chloride HCl			$H-Cl$	Both the hydrogen and the chlorine atom need to share one electron to gain a full outer shell.
Oxygen O_2			$O=O$ *Note:* The double line represents a double covalent bond.	Each oxygen atom needs to share two electrons to gain a full outer shell.
Nitrogen N_2			$N\equiv N$ *Note:* The triple line represents a triple covalent bond.	Each nitrogen atom shares three electrons to gain a full outer shell.
Water H_2O				Each hydrogen atom needs one electron and the oxygen atom needs two electrons to gain a full outer shell.
Carbon dioxide CO_2			$O=C=O$	Each oxygen atom needs two electrons and the carbon atom needs four electrons to gain a full outer shell.

The formation of covalent molecules

ACTIVITIES

REMEMBER

1 **Identify** what kinds of elements combine to form covalent compounds.

2 **Define** the term 'covalent bond'.

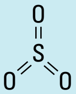
3 **Describe** what an element's electron dot diagram represents.

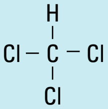
4 **Recall** what properties most covalent compounds have in common.

THINK

5 **Distinguish** between a single covalent and a triple covalent bond, in terms of the number of electrons involved.

6 For the following covalent compounds, state whether their bonds are single, double or triple covalent.

(a)  sulfur trioxide — a gas which is used to make sulfuric acid

(b) 

$$\mathrm{Cl-\overset{\displaystyle H}{\underset{\displaystyle Cl}{C}}-Cl}$$

chloroform — a liquid which was once used as an anaesthetic

(c) $H-C\equiv C-H$ acetylene — a colourless gas used in welding

7 (a) Draw electron dot diagrams to show how the following covalent compounds form: (i) Hydrogen fluoride (HF) (ii) Methane (CH_4) (iii) Phosphorus chloride (PCl_3) (iv) Hydrogen sulfide (H_2S) (v) Tetrachloromethane (CCl_4) (vi) Ammonia (NH_3) (vii) Carbon disulfide (CS_2)

(b) What pattern emerges between the structural formula of the compound and the number of electrons involved in bonding?

(c) State whether the covalent bonds in the compounds are single, double or triple bonds.

8 **Explain** why the noble gases don't form covalent compounds.

9 **Explain** why CO_2 (a compound) and O_2 (an element) are both molecules.

INVESTIGATE

10 Silicon dioxide, commonly known as silica or sand, is a hard solid covalent compound with a very high melting point. Find out about its structure.

11 Although carbon and graphite are both made up of carbon atoms, they have very different properties. **Investigate** their properties and explain why they are so different in terms of their covalent structure.

eBook*plus*

12 To find out more about atomic structure and bonding, use the **Atomic structures** weblink in your eBookPLUS.

work sheet 5.6 Covalent bonding

Finding the right formula

Most of the chemicals used in your school science laboratory are identified by both a name and a formula. Most people are able to recognise the formula of common compounds like water (H_2O) and carbon dioxide (CO_2). A chemical formula (plural 'formulae') is a shorthand way of writing the name of an element or compound. It tells us the number and type of atoms that make up an element or compound. Writing the correct formula is of paramount importance in chemistry. Most chemical problems cannot be solved without the knowledge of chemical formulae.

It's elementary

Often the formula of a substance is simply the symbol for the element. Metals such as iron and copper, which contain only one type of atom, are identified simply by the symbol for that element (e.g. Fe and Cu). Noble gases such as neon (Ne) have a similar formula.

Some non-metal elements such as hydrogen, oxygen and nitrogen exist as simple molecules. These molecules form when atoms of the same non-metal join together by covalent bonds. For example, the formula for the element hydrogen is H_2, indicating that two hydrogen atoms are joined together to make each molecule of hydrogen. A **molecular formula** is a way of describing the number and type of atoms that join to form a molecule.

Formulae of compounds

The formula of a compound shows the symbols of the elements that have combined to make the compound and the ratio in which the atoms have joined together. For example, the chemical formula for the covalent compound methane, a constituent of natural gas, is CH_4 — one carbon atom for every four hydrogen atoms. The formula for the ionic compound calcium chloride, which is used as a drying agent, is $CaCl_2$ — two chloride ions for every calcium ion.

Some common non-metal molecules and their molecular formulae

Name	Formula
Hydrogen	H_2
Nitrogen	N_2
Chlorine	Cl_2
Bromine	Br_2
Oxygen	O_2
Sulfur	S_8
Phosphorus	P_4

Valency: formulae made easy

Knowledge of the **valency** of an element is essential if we wish to write formulae correctly.

The valency of an element is equal to the number of electrons that each atom needs to gain, lose or share to fill its outer shell. For example, the chlorine atom has only seven electrons in its outer shell, which can hold eight electrons. By gaining one electron, its outer shell becomes full. Chlorine therefore has a valency of one. The magnesium atom has two electrons in its outer shell. By losing two electrons, it is left with a full outer shell. Magnesium therefore has a valency of two.

A simple guide to remembering the valency of many elements is to remember to which group in the periodic table they belong. The number of outer shell electrons allows you to work out the number of electrons required to fill the outer shell. The table below provides a simple guide to the valency of many elements.

Valency of groups in the periodic table

Group	Valency
Group 1	1
Group 2	2
Group 3	3
Group 4, group 14	4
Group 15	3
Group 16	2
Group 17	1

Writing formulae for covalent compounds

To write the formula of a non-metal compound made up of only two elements, use the valency of each element and follow the steps shown below.

Example 1

Write the formula for carbon dioxide.

Step 1 *Determine the valency of the elements involved.*

Carbon has a valency of four; oxygen a valency of two. (That is, carbon needs to share four electrons, while oxygen needs to share two electrons.)

Step 2 *Determine the ratio of atoms that need to combine so that each atom can share the same number of electrons.*

A ratio of one carbon atom to two oxygen atoms would result in both sharing four electrons.

Step 3 *Write the formula using the symbols of the elements and writing the ratios as subscripts next to the element. (The number '1' can be left out as writing the symbol for the element assumes that one atom is present.)*

The formula for carbon dioxide is CO_2.

Example 2

Write the formula for phosphorus chloride.

Step 1 *Determine the valency of the elements involved.*

Phosphorus has a valency of three; chlorine has a valency of one.

Step 2 *Determine the ratio of atoms that need to combine so that each atom can share the same number of electrons.*

A ratio of one phosphorus atom to three chlorine atoms would result in both sharing three electrons.

Step 3 *Write the formula using the symbols of the elements and writing the ratios as subscripts next to the element.*

The formula for phosphorus chloride is PCl_3.

Example 3

Write the formula for hydrogen oxide (water).

Step 1 *Determine the valency of the elements involved.*

Hydrogen has a valency of one; oxygen has a valency of two.

Step 2 *Determine the ratio of atoms that need to combine so that each element can share the same number of electrons.*

A ratio of two hydrogen atoms to one oxygen atom would result in both sharing two electrons.

Step 3 *Write the formula using the symbols of the elements and writing the ratios as subscripts next to the element.*

The formula for hydrogen oxide is H_2O.

Writing formulae for ionic compounds

The formulae for ionic compounds can be written from knowledge of the ions involved in making up the compound. In ionic compounds metal ions combine with non-metal ions. The table below and the table on page 189 list common positive and negative ions and their names.

Metal atoms usually form positive ions. The number of positive charges on the ion is called the **electrovalency** of the ion. For example, a sodium ion has one positive charge (Na^+), a calcium ion has two positive charges (Ca^{2+}) and an aluminium ion has three positive charges (Al^{3+}). Note that in the table below some of the transition metals have more than one valency (e.g. iron). The Roman numerals in brackets after iron and copper identify the valency.

Electrovalencies of some common positive ions

Number of positive charges in each element		
+1	+2	+3
Hydrogen (H^+)	Calcium (Ca^{2+})	Aluminium (Al^{3+})
Potassium (K^+)	Copper(II) (Cu^{2+})	Iron(III) (Fe^{3+})
Silver (Ag^+)	Iron(II) (Fe^{2+})	
Sodium (Na^+)	Lead (Pb^{2+})	
Ammonium (NH^{4+})	Magnesium (Mg^{2+})	
	Zinc (Zn^{2+})	

Non-metals usually form negative ions. The number of negative charges in the ion is the electrovalency of the ion. For example, chloride has one negative charge (Cl^-), oxide has two negative charges (O^{2-}) and phosphorus has three negative charges (P^{3-}). There are also some more complex negative ions called **molecular ions** or **radicals**, such as hydroxide ions (OH^-) and sulfate ions (SO_4^{2-}). These groups of atoms have an overall negative charge and are treated as a single entity. Note that the hydrogen ion, although a non-metal ion, exists as a positive ion.

Electrovalencies of some common negative ions

Number of negative charges in each element		
–1	–2	–3
Bromide (Br^-)	Carbonate (CO_3^{2-})	Phosphate (PO_4^{3-})
Chloride (Cl^-)	Oxide (O^{2-})	Nitride (N^{3-})
Hydrogen carbonate (HCO_3^-)	Sulfate (SO_4^{2-})	
Hydroxide (OH^-)	Sulfide (S^{2-})	
Iodide (I^-)		
Nitrate (NO_3^-)		

The following examples show how the formulae for ionic compounds are determined.

Example 1

Write the formula for aluminium oxide.

Step 1 *Determine the electrovalency of the ions that comprise the compound and write down their symbols.*

The symbol for the aluminium ion is Al^{3+} and the symbol for the oxide ion is O_2^-.

Step 2 *Determine the ratio of ions required in order to achieve electrical neutrality. (Remember compounds have no overall charge.)*

The ratio of negative to positive charges for aluminium and oxide ions is 2:3. That is, it takes three negatively charged oxide ions to balance the charge of the two positively charged aluminium ions.

Step 3 *Write the formula for the compound using the numbers in the ratios as subscripts.*

The formula for the compound aluminium oxide is Al_2O_3.

Example 2

Write the formula for sodium chloride.

Step 1 *Determine the electrovalency of the ions that comprise the compound and write down their symbols.*

The symbol for the sodium ion is Na^+ and the symbol for the chloride ion is Cl^-.

Step 2 *Determine the ratio of ions required in order to achieve electrical neutrality. (Remember compounds have no overall charge.)*

The ratio of negative to positive charges for sodium and chloride ions is 1:1. That is, it takes one negatively charged chloride ion to balance the charge of the positively charged sodium ion.

Step 3 *Write the formula for the compound using the numbers in the ratios as subscripts. (Remember the number '1' does not need to be included.)*

The formula for the compound is NaCl.

Example 3

Write the formula for calcium phosphate.

Step 1 *Determine the electrovalency of the ions that comprise the compound and write down their symbols.*

The symbol for the calcium ion is Ca^{2+} and the symbol for the phosphate ion is PO_4^{3-}.

Step 2 *Determine the ratio of ions required in order to achieve electrical neutrality. (Remember compounds have no overall charge.)*

The ratio of negative to positive charges for calcium and phosphate ions is 3:2. That is, it takes two negatively charged phosphate ions to balance the charge of the three positively charged calcium ions.

Step 3 *Write the formula for the compound using the numbers in the ratios as subscripts.*

The formula for the compound calcium phosphate is $Ca_3(PO_4)_2$.

Note the use of brackets in the formula to show that more than one molecular ion is needed to balance the electrical charge.

INVESTIGATION 5.6

The ionic formula game

AIM To practise deriving chemical formulae using chemical symbols of various anions and cations

You will need:

a set of playing cards with the name and valency of each of the positive and negative ions listed in the tables on pages 188 and 189. You will need four identical cards for each ion.

- Organise a group of four students to play the card game. The aim of this game is to collect as many cards as possible by producing compounds with their correct chemical formulae.
- Shuffle the cards and then distribute them to the players.
- The dealer puts down one card.
- The rest of the players then try to produce a chemical formula using the cards they have in their hands. The first person to come up with a correct chemical formula wins the hand and keeps the cards. They are put aside until the end of the game. The dealer will decide the winner of the hand.
- The person to the left of the dealer then puts down one of their cards.
- The other players in the game now try to produce a chemical formula using the cards they have in their hands. Again, the person to come up with a correct chemical formula wins that hand and the cards are put aside until the end of the game.
- The game continues moving to the next person until no one is able to produce a chemical formula. The game stops at this point.
- Each player then counts the number of cards they have produced formulae with. The winner is the person with the most cards.

DISCUSSION

1. **Write a list of the formulae and the name of the compounds formed.**
2. **What is the best strategy to win the game?**
3. **Did you find the game useful in learning the formulae of compounds? Explain.**

ACTIVITIES

REMEMBER

1 **Define** ‘chemical formula’.

2 **Define** ‘molecular formula’.

3 **Describe** what the formula of a compound tells you about the compound.

4 Write the symbols for the following elements: sodium, hydrogen, potassium, lead, chlorine, iodine and sulfur.

5 **Identify** which elements are present in each of the following compounds.
(a) HNO_3
(b) $NaHCO_3$
(c) FeS

6 **Recall** how the valency of an element is determined.

7 **Calculate** how many chloride (Cl^-) ions would be required to combine with each of the following ions to form an ionic compound.
(a) Calcium (Ca^{2+})
(b) Aluminium (Al^{3+})
(c) Silver (Ag^+)

8 Write down the valencies for the following elements: sodium, hydrogen, lead, chlorine, iodine, magnesium and sulfur.

THINK

9 The ions listed below can combine in many different ways to form 25 different compounds. Write the formulae and names of these compounds.
Na^+ Fe^{3+} Li^+ Cu^{2+} Al^{3+} Cl^- OH^- N^{3-} O_2^- SO_4^{2-}

10 The chloride ion has the same valency as the sodium ion. However, it has a different electrovalency. **Explain** why.

11 Write a formula for each of the following:
(a) Oxygen gas
(b) Chlorine gas
(c) Lead
(d) Nitrogen oxide
(e) Zinc oxide
(f) Potassium sulfate
(g) Calcium hydroxide

12 Name the following compounds.
(a) NH_4Cl
(b) KI
(c) $Al(NO_3)_3$
(d) Fe(OH)
(e) $KHCO_3$
(f) $MgCO_3$
(g) HNO_3

13 **Explain** why group 18 is not listed in the table on page 187.

IMAGINE

14 Imagine that there was no recognised system for naming elements and compounds. **Describe** some of the problems this would lead to.

CREATE

15 **Construct** your own ionic compound formula game. It could be an improved version of the game in Investigation 5.6. However, it does not have to be a card game.

eBook*plus* work sheet 5.7 Chemical formulae

LOOKING BACK

FOCUS activity

Explain how the periodic table has been helpful to chemists of both the past and present when they are searching for new elements.

Access more details about focus activities for this chapter in your eBookPLUS.

doc-10646

1 In what part of an atom is most of its mass contained?

2 **Identify** the force that holds protons and neutrons together in an atom's nucleus.

3 (a) **Describe** the 'plum pudding' model of the atom.
  (b) How was this model different from the 'planetary' model of the atom?
  (c) Who first described the atom as being indivisible?

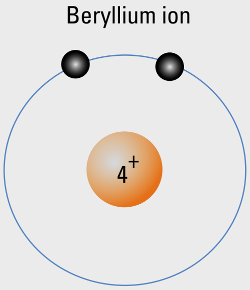
4 A neon atom has 10 protons. **Calculate**:
  (a) how many electrons there are in total in a neutral neon atom
  (b) how many electrons there are in the first shell of a neutral neon atom
  (c) how many electrons there are in the outer shell of a neutral neon atom.

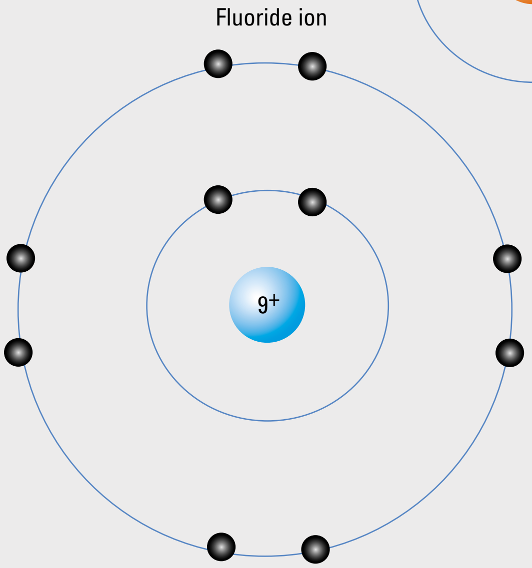
5 Draw an electron shell diagram of a neon atom.

6 **Explain** the difference between atoms, molecules and ions by drawing an example of each.

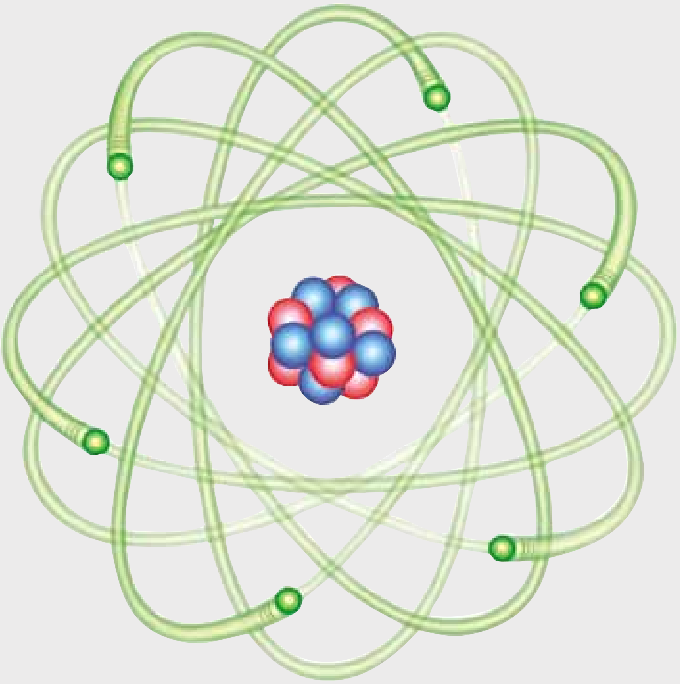
7 **Recall** the charge on:
  (a) a proton
  (b) a neutron
  (c) an electron
  (d) a sodium ion.

8 **Identify** which of the following diagrams represents a:
  (a) positive ion
  (b) negative ion.





9 The diagram below represents a model of a neutral atom.
  (a) **Recall** which two types of particle make up the nucleus of the atom.
  (b) **Identify** the particles shown orbiting the nucleus in the atom.
  (c) What features of an atom are not very well represented by this particular model?
  (d) **Identify** the element that this diagram represents.



10 Write the atomic number and mass number of the following atoms and then calculate the number of protons, neutrons and electrons they have.

(a) $^{28}_{14}\text{Si}$ (b) $^{52}_{24}\text{Cr}$ (c) $^{197}_{79}\text{Au}$ (d) $^{206}_{82}\text{Pb}$ (e) $^{242}_{94}\text{Pu}$

11 Use the $^{A}_{Z}E$ convention to write the symbols for the following elements:
  (a) Helium
  (b) Molybdenum
  (c) Meitnerium

12 The periodic table is a classification of all the known elements. **Describe** what information is given by the group and period numbers on the periodic table.

13 **Recall** the group of elements in the periodic table that the neon used in lighting belongs to.

14 As you move down the groups in the periodic table, **describe** how the reactivity changes for:
  (a) metals
  (b) non-metals.

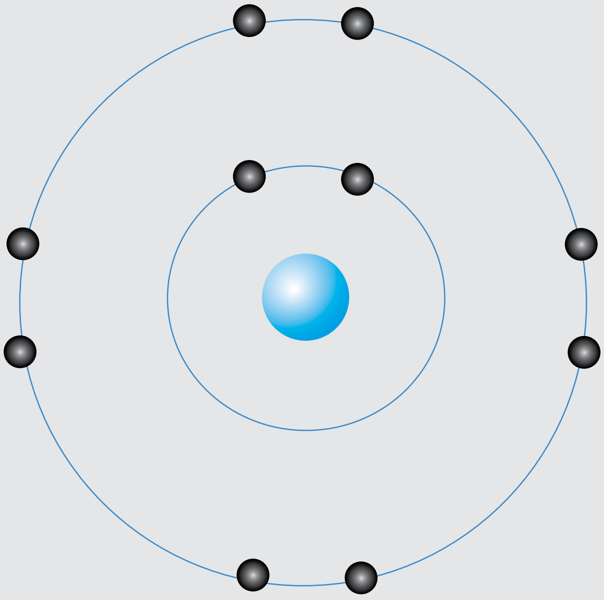
15 As you move across the periodic table, **describe** what changes occur in:
  (a) atomic number
  (b) mass number
  (c) melting point
  (d) metallic character.

16 Although they look very different from each other and have very different uses, arsenic, germanium and silicon belong to the group of elements known as metalloids. **Explain** how metalloids differ from all of the other elements in the periodic table.

17 Write the electron arrangements for the following atoms: helium, silicon, argon, potassium, phosphorus.

18 All atoms of the element magnesium have twelve protons. Eighty per cent of those atoms have twelve neutrons.
(a) State the atomic number of magnesium.
(b) What is the mass number of most magnesium atoms?
(c) How many electrons orbit a neutral magnesium atom?
(d) **Explain** why all magnesium atoms don't have the same mass number.

19 The electron shell diagram below has its first two shells filled. It could represent a neutral atom, a positive ion or a negative ion. **Identify** the names and symbols of the atom or ion if it represents:
(a) a neutral atom (identify one)
(b) a positive ion (identify two possibilities)
(c) a negative ion (identify two possibilities).



20 Use diagrams to show how the following ionic compounds form.
(a) Lithium fluoride (LiF)
(b) Sodium oxide (Na_2O)

21 Use diagrams to show how the following covalent compounds form.
(a) Hydrogen chloride (HCl)
(b) Ammonia (NH_3)

22 **Compare** the properties of ionic and covalent compounds.

23 Write formulae for the following substances:
(a) Oxygen gas
(b) Carbon dioxide gas
(c) Aluminium oxide
(d) Sodium fluoride
(e) Calcium carbonate
(f) Zinc chloride
(g) Iron (III) sulfide
(h) Sulfur dioxide
(i) Carbon
(j) Lead

TEST YOURSELF

1 Every element in the periodic table has an atomic number. The atomic number of an element refers to the number of
A electrons in its outermost shell.
B electrons in all of its shells.
C neutrons in its nucleus.
D protons in its outermost shell. (1 mark)

2 An aluminium atom has 13 protons in its nucleus. On the periodic table, aluminium is in
A group 2, period 2.
B group 3, period 3.
C group 4, period 3.
D group 3, period 2. (1 mark)

3 An atom with two electron shells and six electrons in the outermost shell is
A magnesium.
B calcium.
C nitrogen.
D oxygen. (1 mark)

4 A molecular bond in which atoms share electrons is called a(n)
A ionic bond.
B covalent bond
C metallic bond.
D aqueous bond. (1 mark)

5 There have been many occasions in chemistry when a new substance has been discovered quite by accident. Such a substance was discovered in the 1930s when chemists opened a gas tank. Imagine their surprise when, instead of finding a gas, they found a white solid. The chemists investigated the solid and found it
- did not conduct electricity
- was very slippery to touch
- was tough and didn't shatter
- softened at 320°C
- did not dissolve in water.

The accidently discovered substance was most likely made up of
A small molecules where the atoms share electrons.
B large molecules where the atoms share electrons.
C a network of atoms that share electrons with the atoms around them.
D metal ions and electrons in a metal lattice.
E a lattice of positive and negative ions. (3 marks)
Justify your choice with a full explanation.
(This unexpected discovery is, today, used to make many things, including the surfaces of skis and frypans.)

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work sheets
5.8 Chemistry — the inside story: puzzles
5.9 Chemistry — the inside story: summary

STUDY CHECKLIST

ATOMIC THEORY

- ☐ **describe** the features and location of protons, neutrons and electrons in an atom **5.1**
- ☐ **define** the terms 'ion', 'electron cloud' and 'molecule' **5.1, 5.2, 5.3**
- ☐ **distinguish** between atomic mass and atomic number **5.2, 5.3**
- ☐ **describe** the way in which electrons are arranged around the nucleus **5.1, 5.2, 5.3**

ELEMENTS AND COMPOUNDS

- ☐ **describe** some relationships between elements using the periodic table **5.3**
- ☐ **compare** the shell arrangements and properties within atoms in different groups in the periodic table **5.4**
- ☐ **distinguish** between elements and compounds **5.5**
- ☐ **define** the term 'valency' **5.7**
- ☐ **identify** features of specific families of elements **5.3**
- ☐ **explain** how compounds are named **5.5, 5.6, 5.7**

BONDS BETWEEN ATOMS

- ☐ **distinguish** between ionic and covalent bonds **5.6, 5.7**
- ☐ **identify** which compounds are more likely to have one form of bond rather than another **5.6, 5.7**
- ☐ **compare** and **contrast** characteristics of ionic and covalent compounds **5.5, 5.6**
- ☐ **recall** how electron dot diagrams can be used to represent bonds **5.4, 5.5**

HISTORY OF SCIENCE

- ☐ **discuss** how the model of an atom's structure has changed over the last two thousand years **5.1, 5.3**

SUMMARY

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Digital documents

Individual pathways

Activity 5.1	**Activity 5.2**	**Activity 5.3**
Revising chemistry	Investigating chemistry	Investigating chemistry further
doc-10647	doc-10648	doc-10649

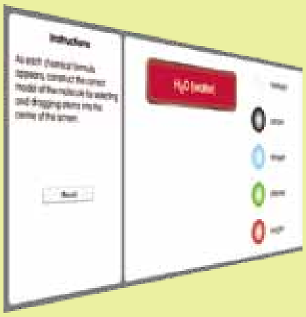
Interactivities

It's elementary! revelation game
In this revelation game, you must identify common elements from their symbols to reveal the full periodic table. You must answer quickly to complete the game in time.

Searchlight ID: int-0229

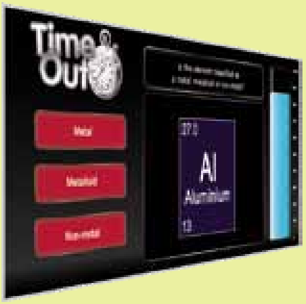
Making molecules
In this interactivity, you will use carbon, chlorine, hydrogen, nitrogen and oxygen atoms to create the correct models of a series of chemical formulae. Instant feedback is provided.

Searchlight ID: int-0228



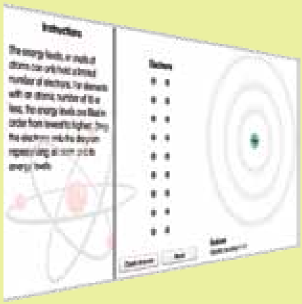
Time Out 'Periodic Table'
In this exciting interactivity, test your ability to classify elements from the periodic table before time runs out.

Searchlight ID: int-0758



Shell-shocked?
This interactivity challenges you to create a model of the electron shell of an atom and indicate its energy levels.

Searchlight ID: int-0676



Pass the salt
Use this interactivity to test your knowledge on what it means to be ionic.

Searchlight ID: int-0675

projects*plus*

The mystery metal

SEARCHLIGHT ID: PRO-0113

Scenario

Your eccentric aunt loves combing through junk shops in search of overlooked treasures, and every time you spend a day with her she'll make you go into one grubby store smelling of mangy mink coats after another. One day during the school holidays, you are wandering idly in one of these old junk shops while your aunt haggles for an old vase with the owner. You find a lump of metal in a drawer of an old dresser. The shopkeeper says that you can keep it and you put it in your pocket. Occasionally over the next few days you wonder what the metal is. Is it something valuable like platinum, or useful like aluminium? Or is it just an old lump of lead? By the end of the holidays, you've forgotten all about the lump of mystery metal.

When you get back to school, your science teacher announces that everyone in your class is to enter a competition that the Australian Chemistry Teachers' Association is running. The competition needs you to write an online 'Choose your own adventure' story that has a chemistry theme. You and your friends are scratching your heads trying to come up with an idea when, suddenly, you remember that lump of mystery metal you found in the junk shop. Maybe you could use that as the theme for your competition entry . . .

Your task

Either on your own or as part of a group, you will develop a 'Choose your own adventure' (CYOA) story exploring the identification of the mystery metal. You will then create a series of interconnected PowerPoint screens that can be uploaded. A player starting at the first screen will advance through a storyline according to the choices they make at each screen. The choices will relate to various chemical and physical characteristics of the metal. The right sequence of choices will eventually lead to the correct identification of the mystery metal.

Process

- Open the ProjectsPLUS application for this chapter located in your eBookPLUS. Watch the introductory video lesson and then click the 'Start Project' button to set up your project group. You can complete this project individually or invite other members of your class to form a group. Save your settings and the project will be launched.

MEDIA CENTRE

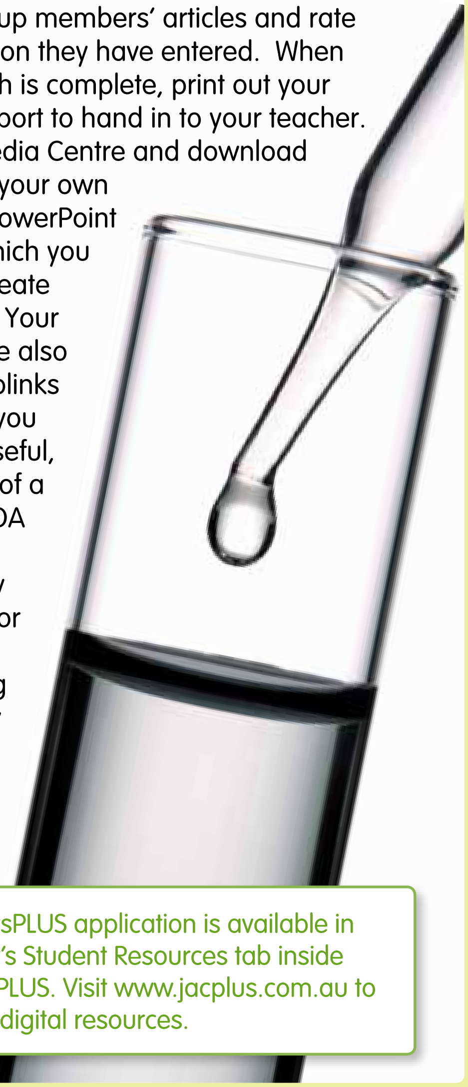
Your Media Centre contains:

- a sample rule book
- a selection of useful weblinks
- a selection of images
- an assessment rubric.

SUGGESTED SOFTWARE

- ProjectsPLUS
- Word or other word-processing software
- PowerPoint
- Internet access

- Navigate to your Research Forum. Here you will find a number of different headings under which you will organise your research. You may delete those topics that you will not be considering or add your own topics if you find your research going in a different direction.
- Start your research. Make notes of information that you think will be relevant to your project, such as what different metals look like and how metals that look similar can be distinguished from one another. Enter your findings as articles under your topic headings in the Research Forum. You should each find at least three sources (other than the textbook, and at least one offline such as a book or encyclopaedia) to help you discover extra information about the chemistry of metals. You can view and comment on other group members' articles and rate the information they have entered. When your research is complete, print out your Research Report to hand in to your teacher.
- Visit your Media Centre and download the 'Choose your own adventure' PowerPoint template, which you will use to create your project. Your Media Centre also includes weblinks to sites that you might find useful, an example of a scientific CYOA and images that you may find helpful for your project.
- Start creating your Mystery Metal CYOA.



Your ProjectsPLUS application is available in this chapter's Student Resources tab inside your eBookPLUS. Visit www.jacplus.com.au to locate your digital resources.