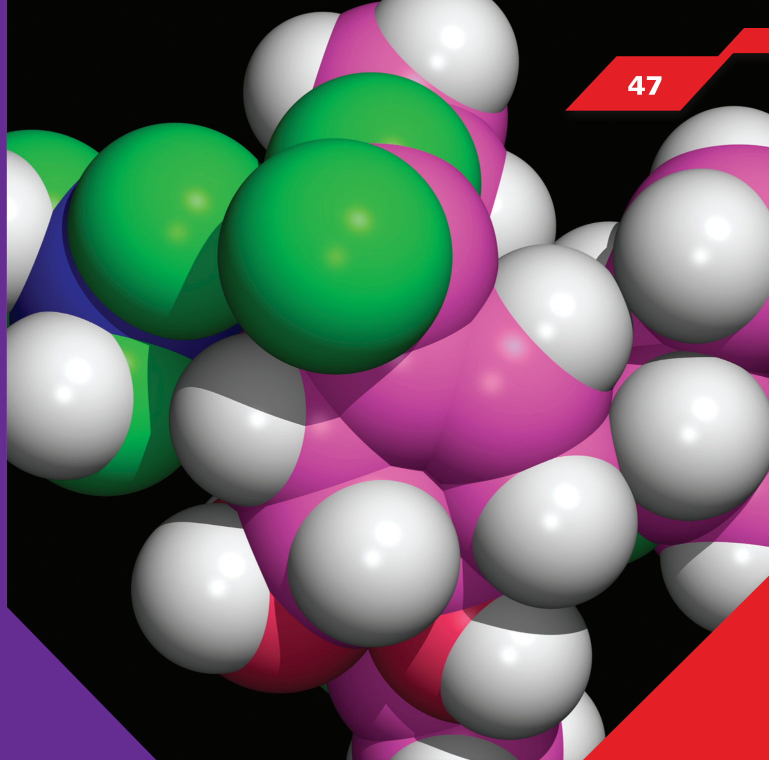


3 The periodic table

By the end of this chapter you will be able to ...

Science understanding

- describe the structure of atoms in terms of electron shells
- explain how the electronic structure of an atom determines its position in the periodic table and its properties
- investigate the chemical and physical properties of alkali metals
- predict the products of a chemical reactions between solutions of two ionic compounds

Science inquiry skills

- write and balance symbol equations to represent chemical reactions
- apply a knowledge of ionic reactions to solve chemical problems

LITERACY FOCUS

alkali metals
alkaline earth metals
atomic number
balanced equation
chemistry
compound ion
covalent bond
covalent lattice
electron shells
energy levels
halogens
ionic bond
ionic equation
ionic lattice
metallic bond
noble gases
periodic table
precipitate
transition metals
valency

Focus for learning

To understand why a leaf turns red in autumn, why diamonds are so hard or how soap gets rid of dirt you need a knowledge of chemistry. To design a synthetic fibre, a life-saving drug or a space capsule you also need an understanding of chemistry. The behaviour of atoms, molecules and ions can explain the sort of world we live in, how our bodies work, and even how we feel on a given day.

Chemists tackle the problems faced by our modern society. They may study how DNA in our bodies works, measure the amount of insecticide in drinking water, compare the protein content of meats, design a new antibiotic or analyse a moon rock.

When the weather changes in autumn, the green chlorophyll disappears from the leaves of deciduous trees and shrubs. As the green fades you begin to see the yellow and orange colours that were hidden by the green. The bright reds and purples are produced by chemical reactions in the leaves.

PROBLEM SOLVING

DHMO

Dihydrogen monoxide (DHMO) is colourless, odourless and tasteless. We use it every day, yet it kills thousands of people every year. Most of these deaths are caused when DHMO enters the lungs. Prolonged exposure to its solid form can cause loss of fingers and toes. In its gaseous state it causes deadly burns. Swallowing DHMO can cause excessive sweating and urination and possibly a bloated feeling, nausea and vomiting. We are all dependent on DHMO and its withdrawal means certain death.

DHMO is the major component of acid rain and contributes to the greenhouse effect. It causes massive erosion of our natural landscape and accelerates the corrosion and rusting of metals. It can cause electrical short circuits and is found in cancerous tumours.

DHMO is in every river, lake and reservoir in the world and large quantities are found in Antarctica. DHMO has caused millions of dollars of property damage, often associated with cyclones.

Despite these dangers, DHMO is still used as an industrial solvent and coolant, in nuclear power stations, in the production of styrofoam, as a fire retardant and in the manufacture of biological and chemical weapons. It is also the most common food additive. To make matters worse, DHMO is allowed to escape into rivers and the ocean, and nothing can be done to stop this because the practice is still legal.

The Australian government has refused to ban the production, distribution or use of DHMO owing to its importance to the national economy. In fact, the Navy is presently designing multimillion dollar devices to control and utilise it during warfare.

Use the internet to find out as much as you can about DHMO. From your research, would you support a ban on DHMO?

3.1 The periodic table

I	II											III	IV	V	VI	VII	VIII
					1 H Hydrogen												2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminium	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Caesium	56 Ba Barium	57–71	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Ti Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89–103	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium						

Transition metals

The key to an understanding of chemistry is the **periodic table**. It arranges all the elements in order according to the size of their atoms. Hydrogen is the smallest atom, with atomic number 1. The biggest atoms are at the bottom of the table, towards the right.

The periodic table groups together those elements with similar properties. Each vertical column in the table is called a *group*—a chemical family. The elements in a group are all different but they look alike and all behave in a similar way. To the left of the zigzag line in the table above are the metals and to the right of this line are the non-metals. Hydrogen is a special element. Sometimes it behaves like a metal and sometimes it behaves like a non-metal.

The metals on the left become more reactive as you go down the group, and less reactive as you go from left to right across the *periods* (the horizontal rows). So the most reactive metal of all is francium (Fr) in the bottom left-hand corner of the table. The non-metals become *less* reactive as you go down the group and *more* reactive as you go from left to right across the periods, except for the noble gases in Group VIII (see p. 50). So the most reactive non-metal is fluorine (F) in the top right-hand corner.

Alkali metals (Group I)

The metals in Group I on the left of the periodic table are the **alkali metals**. They all have similar properties. They are so reactive that they are never found in nature as elements, only as compounds. They are called alkali metals because they react with water to form alkaline solutions. For example, sodium reacts violently with water to form sodium hydroxide (an alkali) and hydrogen gas.

sodium + water → sodium hydroxide + hydrogen

INQUIRY 1 *Teacher demonstration*

You will need: pneumatic trough, scalpel, paper towel, small samples of lithium and sodium in paraffin oil, phenolphthalein

Students should wear safety glasses. Do the demonstration in a fume cupboard or behind a perspex screen.

1. Half fill the pneumatic trough with water and add a few drops of phenolphthalein.
2. Use a dry scalpel to cut a small amount of lithium—*no bigger than a rice grain*. Blot up any paraffin oil with a paper towel.
3. Carefully place the lithium in the centre of the pneumatic trough. Do not get the scalpel wet.
4. Repeat steps 1–3 for sodium. Use fresh water.
   - Which was more reactive—lithium or sodium?
   - Why did the lithium and sodium disappear?
   - Why did the water turn pink each time?

Alkaline earth metals (Group II)

These metals are not as reactive as the alkali metals. They are called **alkaline earth metals** because, when they combine with oxygen to form oxides, these oxides are alkaline. As the oxides are unreactive, the alchemists (ancient chemists) called them earths. This group contains two of the most biologically important metals: magnesium, which is found in chlorophyll in plants, and calcium, which is found in bones and teeth.

Transition metals

The metals in the middle of the periodic table are called **transition metals** because they are between Groups II and III. They are hard and have high melting points. The transition metals all have similar properties, especially those close together in the periodic table. For example, iron, nickel and cobalt, next to each other in the same horizontal period, are all magnetic. Metals near the top of the table (e.g. aluminium and zinc) are generally more reactive than those towards the bottom (e.g. silver, gold and lead).

Many of the compounds that transition metals form with non-metals are coloured. For example, copper sulfate is blue and cobalt chloride is red. These compounds are used to produce the bright colours of fireworks and to colour glass. The compounds are also responsible for the different colours of human hair.

Halogens (Group VII)

The **halogens** are very reactive non-metals on the right-hand side of the periodic table. Fluorine and chlorine are gases at room temperature, bromine is a liquid and iodine is a solid. The word *halogen* means 'salt former' because the halogens readily combine with metals to form salts. For example, chlorine reacts with sodium metal to form sodium chloride.

sodium + chlorine → sodium chloride

Noble gases (Group VIII)

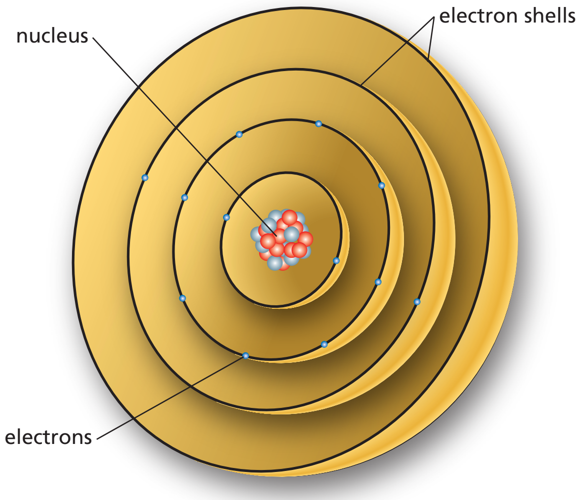
These are all colourless gases that are found in very small amounts in the atmosphere. They are called **noble gases** because they do not react with other elements, except under extreme conditions. This is because we tend to think of nobles (royalty) as having nothing to do with the common people, like us.

Helium, the lightest gas, is used to fill balloons. It is also mixed with oxygen for divers to breathe. Neon is used in neon signs and lasers because it gives a coloured light. Argon is used in light bulbs and in welding to stop hot metals from burning.

Electron shells

To make more sense of the periodic table you need to understand more about atoms. As you know, each atom has a nucleus containing protons and neutrons. This nucleus is surrounded by electrons. The number of electrons is the same as the number of protons in the nucleus—the *atomic number*. The bigger the atomic number, the bigger the atom because it has more protons in its nucleus.

The electrons are arranged in **electron shells** or *energy levels*. If you think of the nucleus of the atom as a pea, then the pea sits in the middle of a table tennis ball. This is the first shell. All this sits inside a tennis ball (the second shell), which sits inside a basketball (the third shell), which sits inside a beach ball. The electrons move rapidly around the surface of the shells. The electrons in the second shell have more energy than those in the first shell. Those in the third shell have more energy than those in the second shell, and so on.



When you put a metal compound in a flame you see a flash of colour. This can be explained by saying that the energy that the electrons absorb from the flame enables them to jump to a higher energy shell for a short time. When they return to their original shell, they release their extra energy as coloured light.

Filling the shells

Electron energy levels are a bit like floors in a high-rise car park. Cars drive into the car park at ground level. Usually they fill all the parking spaces on this level before moving up to find a parking space on the next level. There are only a certain number of cars that can fit on each level. For atoms, chemists have found that:

- Electrons normally fill the energy shells in order, starting with the inner lowest energy shell.
- There is a maximum number of electrons allowed in each shell:

first shell	2
second shell	8
third shell	18
fourth shell	32

- The maximum number in the outer shell is eight. For example, the third shell can only hold 18 electrons when it is not the outer shell.

Using these rules, scientists inferred that electrons are arranged in this way for the first 20 elements.

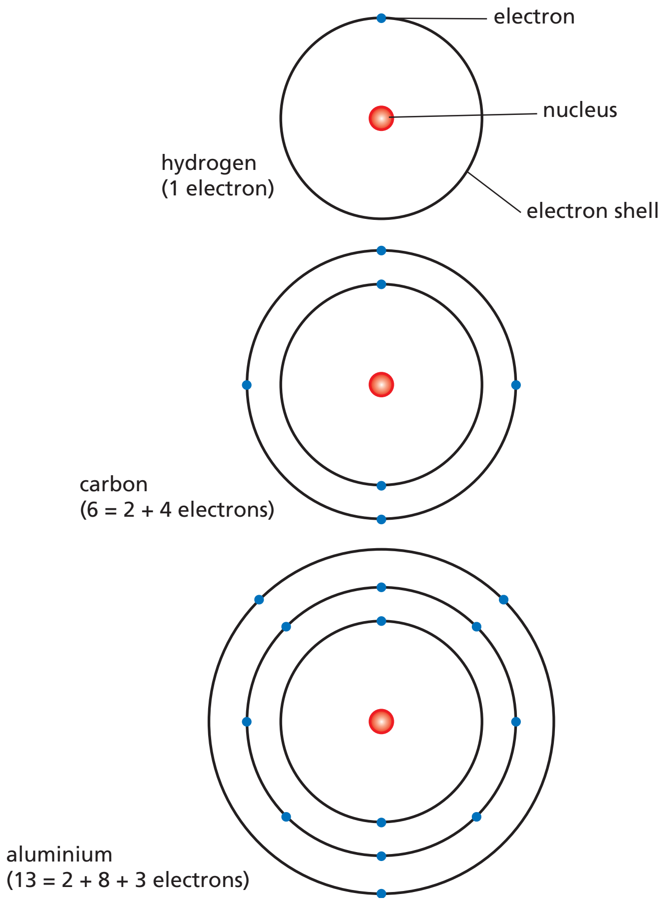
Element	Symbol	Atomic number (number of electrons)	First shell	Second shell	Third shell	Fourth shell
Hydrogen	H	1	1			
Helium	He	2	2			
Lithium	Li	3	2	1		
Beryllium	Be	4	2	2		
Boron	B	5	2	3		
Carbon	C	6	2	4		
Nitrogen	N	7	2	5		
Oxygen	O	8	2	6		
Fluorine	F	9	2	7		
Neon	Ne	10	2	8		
Sodium	Na	11	2	8	1	
Magnesium	Mg	12	2	8	2	
Aluminium	Al	13	2	8	3	
Silicon	Si	14	2	8	4	
Phosphorus	P	15	2	8	5	
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
Calcium	Ca	20	2	8	8	2

Periodic table patterns

Now you can see some interesting patterns in the periodic table. For Period 1(hydrogen and helium) the first shell is being filled. For Period 2 (lithium to neon) the second shell is being filled. For Period 3 (sodium to argon) the third shell is being filled. And so on.

Also, chemists have found that the chemical properties of an element are determined by how many electrons there are in the outer shell of its atoms. In the table on this page you will notice that lithium, sodium and potassium all have a single electron in their outer shell. This is why these elements are in Group I. They all have similar properties. You would expect the other elements in Group I to also have a single electron in their outer shell, and they do. Similarly, the Group II elements (beryllium, magnesium, calcium) all have two electrons in their outer shell, and so on until the Group VIII elements (helium, neon, argon) which have filled outer shells.

Diagrams can be used to show how the electrons are arranged in shells.



Electron shell arrangements

INQUIRY 2 Alkali metals

1 Use the table below to plot a graph of melting point against atomic number for the alkali metals. On the same graph, plot the boiling points. Write a sentence describing what patterns the graph shows.

Element	Atomic number	Melting point (°C)	Boiling point (°C)	Density (g/cm^3)
Lithium	3	180	1331	0.53
Sodium	11	98	890	0.97
Potassium	19	63	766	0.86
Rubidium	37	39	701	1.5

2 Would the alkali metals listed in the table float or sink in water? Would you say they are typical metals? Explain your answers.

3 Look at the table on the previous page. Write down the electron arrangements for lithium, sodium and potassium. How does this explain why these metals have similar properties?

Over to you

1 What does the atomic number of an element tell you?

2 Use the periodic table on page 49 to find out which element has the atomic number of:

a 6 **c** 47
b 17 **d** 88

3 Explain the difference between a period and a group in the periodic table.

4 Draw a periodic table and put in the first 20 elements. Label the following groups:

a alkali metals **d** halogens
b alkaline earth metals **e** noble gases
c transition metals

5 Use the periodic table to decide which three of the following elements have similar properties: argon, carbon, copper, gold, platinum, silver, zinc.

6 Use the periodic table to decide which element would be more reactive:

a magnesium or calcium
b sodium or magnesium
c carbon or oxygen
d fluorine or bromine

7 What are electron shells? Why are they also called energy levels?

8 Draw the electron shell arrangements for the following atoms (see diagram on p. 51).

a helium **b** oxygen **c** argon

9 Name the elements that have these electron arrangements:

a 2, 1 **c** 2, 8, 6
b 2, 5 **d** 2, 8, 8, 2

10 Name those elements in the first 20 elements that have:

a a full outer electron shell
b three electrons in their outer shell
c an outer shell needing one electron to be full

11 Which atom is represented by the electron shell diagram on page 50?

12 How many electrons are there in the outer shell of an atom of:

a magnesium? **b** silicon? **c** nitrogen?

13 What is the maximum number of electrons allowed in the outer shell of an atom?

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

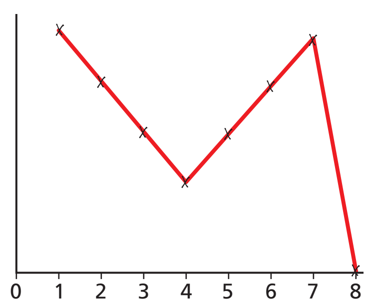
15 **a** Write a word equation for the reaction of potassium (Group I) with water.

b Suggest why you did not try this reaction in Inquiry 1 on page 49.

16 **a** If an element has two electrons in its outer shell, is it a metal or a non-metal? Explain.

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

17 The chemical reactivity of an element is related to the number of electrons in its outer electron shell. Elements with one or seven electrons in the outer shell are more reactive than those with two or six electrons. In turn, these are more reactive than elements with three or five electrons, which are more reactive than those with four. The graph below summarises this information. Copy the graph and label the two axes. Give the graph a title.



Science as a Human Endeavour

Lead—valuable resource or deadly poison?

From the age of 20 the great composer Ludwig van Beethoven had a mysterious illness that changed his personality and caused him endless suffering. He saw dozens of doctors but nobody could cure his abdominal pain, digestive trouble, depression and irritability. When he was 23 he wrote in a letter 'After my death, if Dr Schmidt is still alive, ask him in my name to discover my disease'. He died at the age of 57 and a music student kept some of his hair. This hair was eventually sold at an auction in 1994 and it was given to scientists, who bombarded it with a high-energy beam of X-rays. When this happens each atom releases energy of a particular wavelength, which allows it to be identified. They found that Beethoven's hair contained more than 60 parts per million of lead—about 100 times the normal amount. So Beethoven's illness was no longer a mystery, although where the lead came from is not known.

Beethoven composing

Lead has been used for at least 7000 years. It is easy to extract from its ore, easy to work with and resists corrosion. The Romans used it to line the aqueducts that carried their water, they drank from lead goblets, put lead compounds on their faces and added them to food and wine.

Lead pipes were widely used in plumbing. In fact, the term 'plumbing' comes from the Latin word for lead—*plumbum*. This is where the symbol for lead, Pb, comes from. The solder used to join pipes is an alloy containing 40% lead.

Lead is still widely used today, for example, in paint, car batteries, glass, ceramics, coverings for electrical cables, protective shielding against X-rays and radioactive substances, and as flashing on roofing to protect joints from rain. Up until the 1950s paint in homes could be as much as 50% lead compounds, but since 1997 it has been reduced to less than 0.1%. However, lead paint is still used to protect steel bridges against corrosion. For example, every 5 years 90 tonnes of red lead paint are used to paint the Sydney Harbour Bridge. Also, many old houses still have lead paint, perhaps under layers of newer paint. In the past, many children developed lead poisoning by chewing on the rails of lead-painted cots or on windowsills.

Up until 2002 a compound called tetraethyl lead was added to petrol to make it burn more efficiently. However, the use of this leaded petrol caused an increase in lead concentrations in the atmosphere and in roadside dust. Since leaded petrol has been phased out, these lead levels have fallen.

The element lead is not itself poisonous to humans but lead compounds, such as lead oxide, are. The metal gradually becomes coated in these compounds. Lead is also slightly soluble in water, which is why lead pipes used for water supply were a cause of lead poisoning. Once lead compounds enter your body they disrupt bodily functions and can remain in bone for 25 years. They can cause brain disorders and can affect learning in young children.

Birds and fish are also at risk from lead. Hunters use lead shot and people fishing use lead sinkers. Water birds or fish that take this lead into their bodies sicken and die. When they are eaten by predators, the lead is passed along the food chain. Alternatives such as steel shot are now being used.

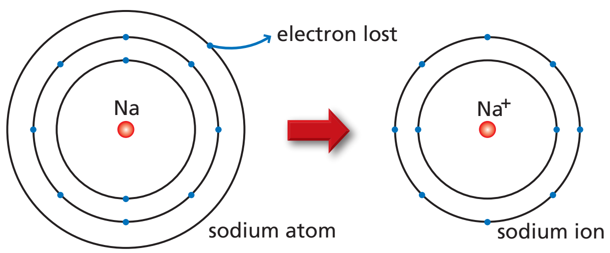
1. Why do you think the doctors 200 years ago did not know that Beethoven was suffering from lead poisoning?
2. What properties of lead make it such a useful resource?
3. If you are fishing, what precautions should you take when handling lead sinkers?
4. Should we continue to use lead or should its use be totally banned? Discuss this in a group.

3.2 Bonding

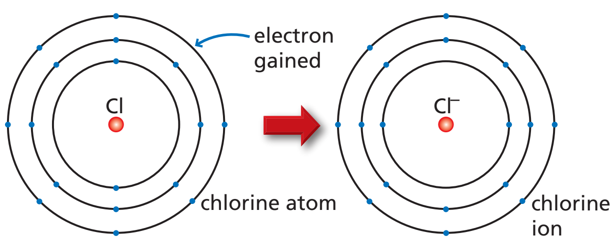
Ionic bonds

When atoms react with each other to form compounds, the electrons in their outer shells determine the type of reaction that occurs. Chemists have always been interested in the noble gases because they are so unreactive or stable. They infer they are so stable because their outer electron shell is full. All other atoms react because their electron arrangements are not as stable as those of the noble gases. Atoms can become more stable if they can get electrons to fill their outer shells.

As an example, consider a sodium atom. It has two complete shells and a single electron in its outer shell (see diagram). This is a very unstable arrangement. Sodium, therefore, has a strong tendency to lose the single electron in its outer shell so that it ends up with a full outer shell of eight electrons, like the noble gas neon. When a sodium atom loses its outer electron like this, it is no longer neutral. It becomes a positively charged ion Na^+.

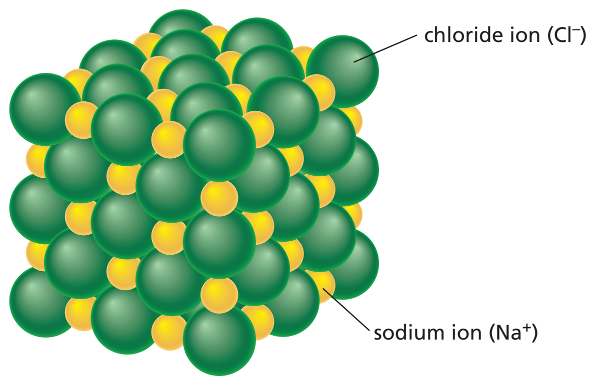


Now consider a chlorine atom. It has an outer shell with seven electrons and needs one more electron to have a full outer shell, like the noble gas argon. Chlorine, therefore, has a strong tendency to gain an electron. When this happens it becomes a negatively charged chloride ion Cl^-.



What is likely to happen when sodium and chlorine atoms come together? A sodium atom wants to lose an electron and a chlorine atom wants to gain one. So both atoms can become stable if the sodium atom gives up an electron to the chlorine atom. The 1+ charge is balanced by the 1– charge to form a neutral compound.

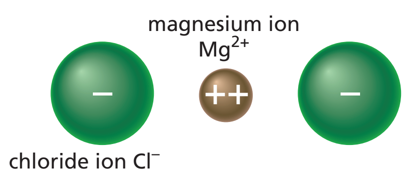
You can see what happens if you watch sodium metal burning in chlorine gas in a gas jar. The sodium burns brightly and a white solid forms on the sides of the gas jar. This solid is table salt—the compound sodium chloride (NaCl). The sodium atoms form positive ions and the chlorine atoms form negative ions. These positive and negative ions are very strongly attracted to each other and arrange themselves in a regular three-dimensional pattern, as shown below. This is called an *ionic lattice*. The force of attraction between the ions is called an **ionic bond**.



The compound sodium chloride (NaCl) consists of a lattice of positive sodium ions and negative chloride ions held together by ionic bonds.

All the elements in Group I of the periodic table behave in much the same way as sodium. When they react they tend to lose one electron to form an ion with a single positive charge. Similarly, all the elements like chlorine in Group VII tend to gain an electron to form an ion with a single negative charge.

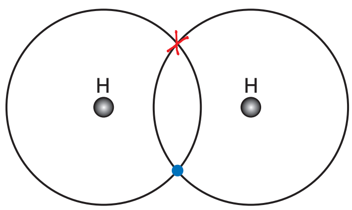
Elements in Group II tend to lose *two* electrons when they react. For example, a magnesium atom tends to lose both the electrons in its outer shell to form an ion with two positive charges Mg^{2+}. It can combine with two chloride ions to form magnesium chloride $MgCl_2$, as shown below. (Two Cl^- ions are needed to balance one Mg^{2+} ion.)



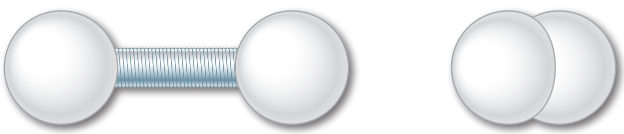
Covalent bonds

Instead of gaining or losing electrons, atoms sometimes get a stable outer shell by *sharing* electrons. This type of bonding is called **covalent bonding**. When two or more atoms share electrons a molecule is formed. The atoms in the molecule may be the same or they may be different.

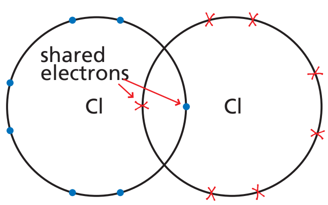
When two hydrogen atoms approach each other, both nuclei attract each other's electrons. As a result, the two atoms end up sharing the electrons. In this way they both have a full outer shell of two electrons. The electron from one atom is shown as a dot and the electron from the other atom as a cross, as shown.



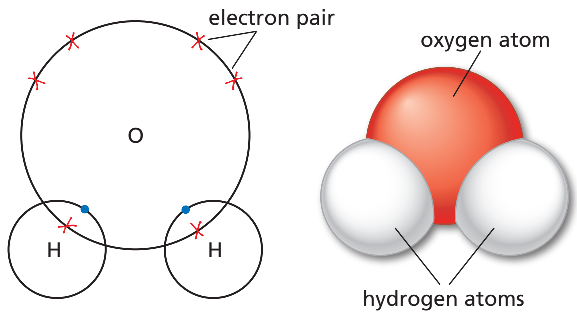
A hydrogen molecule has the formula H_2 and can be represented by H—H. The molecule can be represented as a model. In the model on the left below the spring represents the covalent bond. In the model on the right the two atoms fit together.



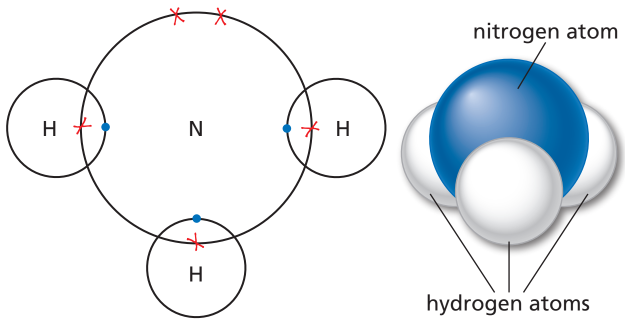
When two chlorine atoms come together to form a chlorine molecule by sharing electrons, each atom ends up with a full outer shell of eight electrons. For simplicity only the electrons in the outer shell are shown below. Chemists have found that the electrons tend to pair up.



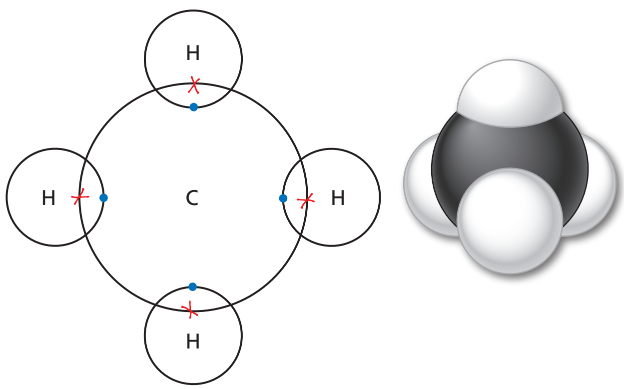
An oxygen atom has six electrons in its outer shell. So if it combines with two hydrogen atoms to form water (H_2O) it ends up with a full outer shell of eight electrons. The bent shape is the most stable and keeps all the electrons as far apart as possible, as shown below.



Nitrogen has five electrons in its outer shell so it needs to bond with three hydrogen atoms to form an ammonia molecule (NH_3). The lone pair of electrons at the top forces the molecule into the shape of a pyramid, as shown below.

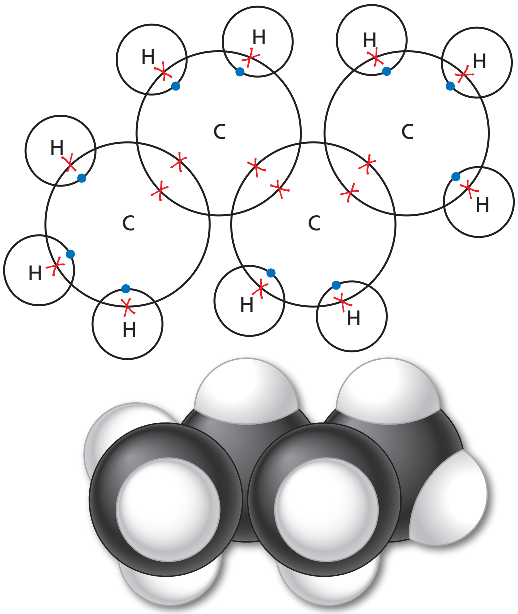


Carbon has four electrons in its outer shell so it can form four covalent bonds with hydrogen. The methane molecule formed (CH_4) has the shape of a tetrahedron, as shown below.



Carbon compounds

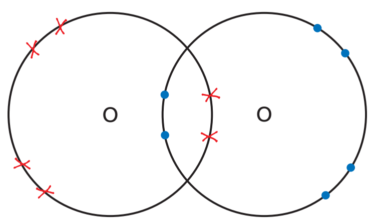
As well as bonding to hydrogen atoms, a carbon atom can also bond to other carbon atoms. Thus, each carbon atom has a complete outer shell of eight electrons. As a result, carbon can form the many complex molecules found in living things, as well as the long chains in plastics.



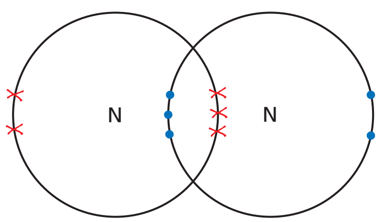
A butane molecule (C_4H_{10})

Double and triple bonds

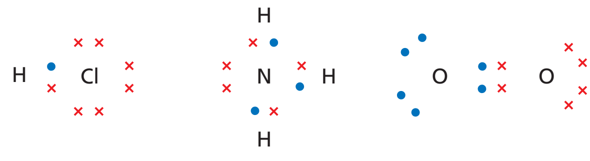
When two oxygen atoms combine they can share *two* pairs of electrons. This gives each atom a share of eight electrons in its outer shell, as shown below. Chemists say there is a *double bond*, between the two oxygen atoms.



When two nitrogen atoms combine they share *three* pairs of electrons to form a *triple bond*, as shown.



When you leave out the circles representing the outer electron shells of the atoms, you end up with *electron dot formulas*. This is a quick and neat way to show the electron arrangement of a molecule. Here are some examples.



HCl NH_3 O_2

INQUIRY 3 Molecular models

You will need: molecular models kit, Smarties (optional)

1 Use molecular models to make models of some of these molecules:

Single bonds:

hydrogen H_2	hydrogen sulfide H_2S
chlorine Cl_2	ammonia NH_3
fluorine F_2	methane CH_4
hydrogen chloride HCl	carbon tetrachloride CCl_4
water H_2O	butane C_4H_{10}

Double bonds

oxygen O_2	carbon disulfide CS_2
carbon dioxide CO_2	ethylene C_2H_4

Triple bonds

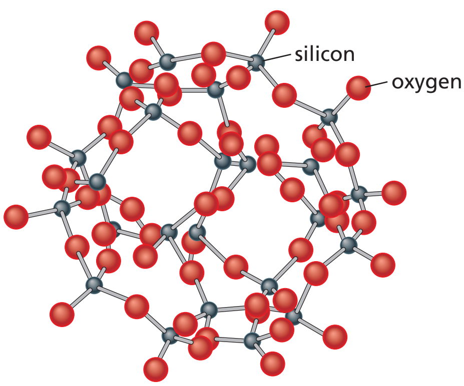
nitrogen N_2	acetylene C_2H_2

2 For each molecule you make, write down its name and formula. Also draw it in three dimensions, indicating any double or triple bonds. If possible, draw its electron dot formula.

To work out the electron dot formula you can use Smarties of different colours to represent the electrons from different atoms. You can move them around until you get the bonding pairs right.

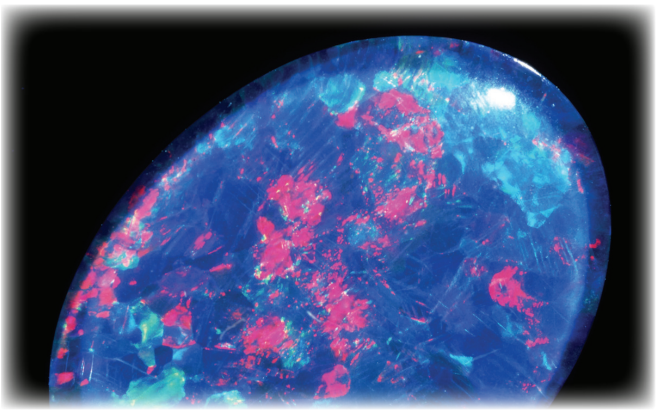
Covalent lattices

Just as ionic compounds form ionic lattices (see p. 54), some covalent elements and compounds form *covalent lattices*. For example, carbon (as diamond) and silica (silicon dioxide) form these lattices. Silicon is in the same group as carbon, with four electrons in its outer shell. Each silicon atom can therefore form four bonds with four oxygen atoms. Each oxygen atom can also bond to two silicon atoms, in a continuous three-dimensional lattice, as shown. The strong bonds throughout the structure make diamond and silica very hard, with high melting points. Because the electrons are all so tightly involved in bonding, there are no free electrons that can move through the lattice and carry an electric current. Thus, diamond and silica do not conduct electricity.



The covalent lattice of silicon dioxide (silica)

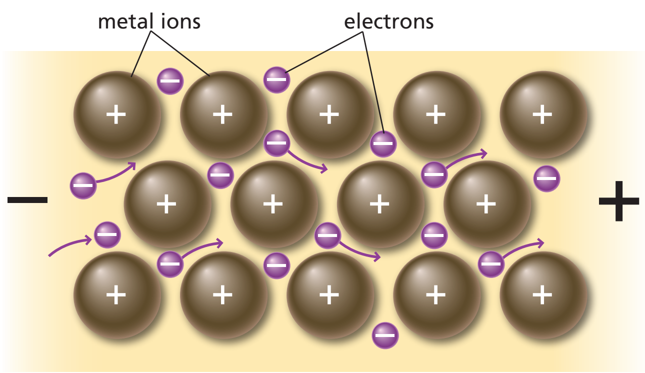
Silica makes up 87% of the Earth's crust. It forms the common mineral quartz and gems such as opal and agate. Opal contains thousands of tiny grains of silica, which scatter and bend the light hitting it, causing the beautiful colours.



Opal is considered a gem because of its beautiful colours.

Metallic bonding

The atoms in a metal are held together in a three-dimensional lattice. The electrons in their outer shells are easily lost and move freely throughout the metal without being bound to any one atom. This results in a lattice of positive ions held together by a 'sea' of electrons. This is called a **metallic bond**. When an electrical voltage such as a battery is connected to the metal, an electric current flows because the electrons are free to hop from atom to atom, as shown.



Over to you

1. Why is sodium more stable as an ion than as a neutral atom?
2. Why does magnesium always form ions with a double positive charge Mg^{2+}?
3. Use the table on page 51 to predict the type of ions formed by these elements:
   - **a** lithium
   - **b** calcium
   - **c** fluorine
   - **d** aluminium
4. **a** Give two examples of non-metals in Group VI.
   b How many extra electrons do these non-metals need to share to have a full outer electron shell?
5. **a** Draw a diagram to show what happens to the electron arrangement of lithium (see the table on page 51) when it loses an electron.
   b Draw a diagram to show what happens to the electron arrangement of fluorine when it gains an electron.
   c Predict what will happen when lithium metal burns in fluorine gas.
6. What is the difference between a single, double and triple covalent bond in terms of the number of electrons involved?
7. Describe what happens when two hydrogen atoms collide to form a molecule.

8 Why don't the noble gases form covalent bonds?

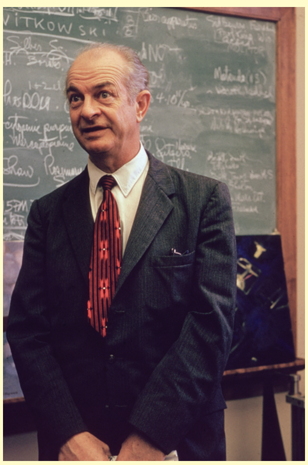
9 Use the cartoon below to explain the difference between an ionic bond and a covalent bond.

SCIENTISTS AT WORK

Linus Pauling

Linus Pauling was born in Portland, Oregon, USA in 1901. At 11 he began an insect collection and at 13 he set up a laboratory in his home.

He graduated from university with a degree in chemical engineering and began work on the structures of crystals. He used X-rays to work out how the invisible atoms in the crystals were arranged. He measured the distances and angles of the bonds in the three-dimensional structures. He realised that these bonds could be explained in terms of electrons, as you have learnt in this section.



Pauling became interested in biological molecules. For example, he studied the structure of haemoglobin, the substance in the blood that carries oxygen. He also studied DNA and in 1953 he proposed that it was made up of three chains, twisted around each other. Soon after, the British scientists Watson and Crick saw that there was a mistake in Pauling's structure. It was a double helix, not a triple helix. However, Watson and Crick had seen some X-ray photographs of DNA taken by Rosalind Franklin, which Pauling had not seen. Pauling was, however, awarded the Nobel Prize in Chemistry in 1954.

During World War II Pauling was asked to work on the Manhattan Project to develop the atomic bombs that were dropped on Hiroshima and Nagasaki in 1945. He refused because he was concerned about the dangers of atomic weapons and radiation. He showed that the radiation caused by weapons tests could cause miscarriages, stillbirths, physical and mental defects in children, and increases in cancer. In 1958 Pauling and his wife presented the United Nations with a petition signed by more than 11 000 scientists calling for an end to nuclear weapons testing. He lost many friends because of this and lost his job at the California Institute of Technology. His passport was also taken from him for 2 years, and he risked going to prison. However, public pressure led to the Partial Test Ban Treaty, signed in 1963. On the day the treaty came into force Pauling was awarded the Nobel Peace Prize, only the second person after Marie Curie to receive two Nobel Prizes.

Pauling wrote a number of books, including *No More War!*, *Vitamin C and the Common Cold* and *How to Live Longer and Feel Better.* He believed that taking very large doses of vitamin C could prevent colds and even cancer, but this has never been proven.

1 Some people thought that Pauling was guilty of treason (betraying his country). Suggest why.

2 What did Linus Pauling achieve during his life?

3 What do you think was his greatest achievement? Why?

3.3 Formulas

Covalent formulas

The chemical formula of a compound shows the symbols of the elements that have combined to make the compound. It also gives the ratio in which the atoms have joined together. For example, the formula for methane (found in natural gas) is CH_4. This means that a molecule of methane contains one carbon atom and four hydrogen atoms. The 4 is written as a subscript, slightly smaller and a little below the line.

The formulas for some common covalent compounds are listed below. You should be able to remember most of these.

hydrogen H_2	carbon monoxide CO
oxygen O_2	carbon dioxide CO_2
chlorine Cl_2	silicon dioxide SiO_2
water H_2O	sulfur dioxide SO_2
hydrogen chloride HCl	sulfur trioxide SO_3
hydrogen sulfide H_2S	methane CH_4
carbon disulfide CS_2	carbon tetrachloride CCl_4
ammonia NH_3	propane C_3H_8

You will notice that the ending of the second non-metal name changes when it forms a compound. For example, chlorine becomes chlor*ide*, sulfur becomes sulf*ide*, hydrogen becomes hydr*ide* and oxygen become ox*ide*. In carbon monoxide, each carbon atom is combined with one oxygen atom. So the *mono-* means one. Similarly *di-* means two, *tri-* means three and *tetra-* means four. Thus, dihydrogen monoxide (DHMO) indicates a compound containing two hydrogen atoms and one oxygen atom (H_2O). However, it is easier to use its common name—water. Similarly, the common name of ammonia is used instead of nitrogen trihydride, and CH_4 is called methane.

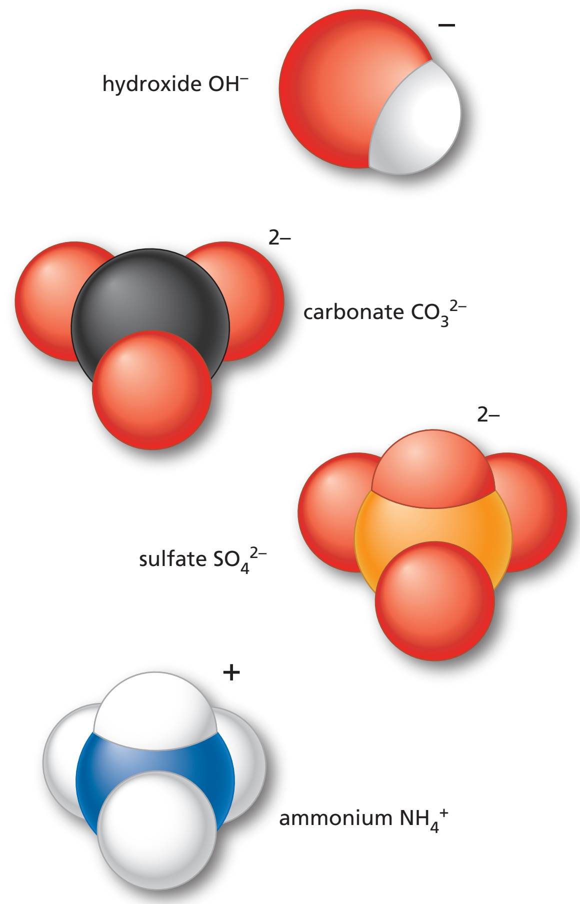
Valency

As you learnt in the previous section, the properties of an element are largely determined by the electrons in the atom's outer shell. Atoms react to fill or empty their outer shell. They do this by gaining, losing or sharing electrons with other atoms.

The number of electrons an atom normally gains, loses or shares is called its **valency** or combining power. This can be positive or negative. Metals have a positive valency because they tend to lose electrons to form positive ions. Non-metals have a negative valency because they tend to gain electrons to form negative ions.

Compound ions

Many ions are formed from single atoms, for example, Na^+ and Cl^-. However, many important ions are formed from *groups* of atoms that have an overall charge. Some of these are shown below. These are called *compound ions*. Look at the hydroxide ion. The oxygen and hydrogen are bonded together and act as a single unit with a charge of –1.



Compound ions can combine with other ions to form ionic compounds. For example, hydroxide ions OH^- can be combined with sodium ions Na^+ to form sodium hydroxide NaOH (caustic soda).

The table on the next page lists the valencies of some of the common ions, including the compound ions.

Ion	Symbol	Charge on ion (valency)
Ammonium	NH_4	1+
Hydrogen	H	1+
Potassium	K	1+
Silver	Ag	1+
Sodium	Na	1+
Calcium	Ca	2+
Copper	Cu	2+
Iron	Fe	2+ or 3+
Lead	Pb	2+
Magnesium	Mg	2+
Zinc	Zn	2+
Aluminium	Al	3+
Bromide	Br	1–
Chloride	Cl	1–
Hydrogen carbonate	HCO_3	1–
Hydroxide	OH	1–
Iodide	I	1–
Nitrate	NO_3	1–
Carbonate	CO_3	2–
Oxide	O	2–
Sulfate	SO_4	2–
Sulfide	S	2–
Phosphate	PO_4	3–

Patterns in the valencies

You will notice that metals in Group I (e.g. sodium and potassium) have a valency of 1+. Metals in Group II (e.g. calcium and magnesium) have a valency of 2+. Aluminium in Group III has a valency of 3+. Non-metals in Group VI (e.g. oxygen and sulfur) have a valency of 2–, and non-metals in Group VII (e.g. chlorine and bromine) have a valency of 1–. Transition metals such as iron have variable valencies, but most form ions with a 2+ charge.

PROBLEM SOLVING

Did you work out that DHMO is just a fancy name for plain old water? This shows how important it is to critically evaluate everything you read on the internet and elsewhere. It is very easy to agree with something without thinking about it carefully for yourself. You may want to read the description of DHMO on page 48 again. You could draw up a DHMO fact sheet and see how many signatures you can get on a petition to ban it.

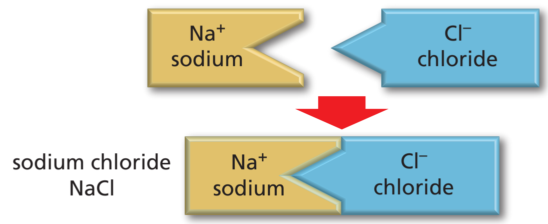
Writing formulas

Metals (positive valencies) combine with non-metals (negative valencies) to form a range of ionic compounds. When naming these compounds the metal ion is listed first, followed by the non-metal ion (e.g. sodium chlor*ide*).

INQUIRY 4 Formula cards

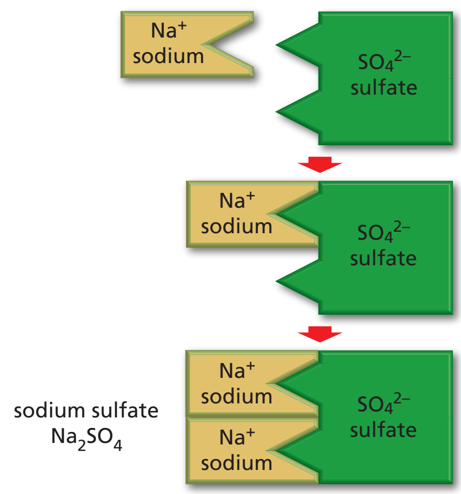
You will need: cardboard and scissors

Make cardboard cut-outs to represent various positive and negative ions. You could make them different colours.



Fit the cards together to make compounds. For example, one sodium ion fits with one chloride ion to make sodium chloride. So the formula for sodium chloride is NaCl.

Make cut-outs for sodium sulfate. This time you need two Na^+ ions to balance the double negative charge on the sulfate ion (SO_4^{2-}). So the formula for sodium sulfate is Na_2SO_4.



Make cut-outs for a range of positive and negative ions from the table on this page. Then put them together to make ionic compounds. For each compound you make write down its name and correct formula. You could have a competition to see who can make the most compounds.

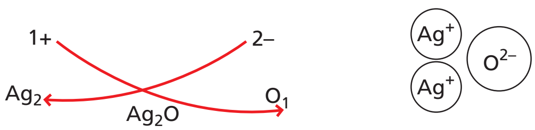
To write the formula for an ionic compound, follow these rules.

Example 1

1 Write down the symbols of the ions. Note that the positive ion (usually a metal) goes first. Write the valency above the symbols.

silver	oxide
1+	2–
Ag	O

2 Crisscross the valency to get correct subscripts. Leave out the + and – signs.

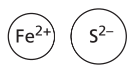


3 Write the correct formula with subscripts, leaving out the 1. Check that the charges are balanced. You need two Ag^+ ions to balance one O^{2-} ion.

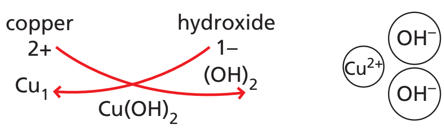
Example 2

iron sulfide FeS

Fe^{2+} balances S^{2-} $(2^+) + (2^-) = 0$.

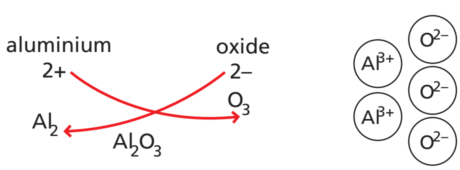


Example 3



In this example you put the compound ion in brackets to indicate that it acts as a single unit. The subscript 2 refers to everything inside the brackets. In other words, there are two oxygen atoms and two hydrogen atoms. When there is only one unit of the compound ion, the brackets are not needed, e.g. $CaCO_3$ instead of $Ca(CO_3)$.

Example 4



You need two Al^{3+} ions to balance three O^{2-} ions: $(2 \times 3+) + (3 \times 2–) = 0$.

> Formulas for common acids:
> - hydrochloric acid HCl (not hydrogen chloride)
> - sulfuric acid H_2SO_4
> - nitric acid HNO_3

Over to you

1 Write down the symbols for the following ions:
- **a** ammonium
- **b** nitrate
- **c** oxide
- **d** zinc

2 How many sodium ions (Na^+) will combine with:
- **a** a chloride ion Cl^-?
- **b** a carbonate ion CO_3^{2-}?
- **c** a phosphate ion PO_4^{3-}?

3 When carbon burns in oxygen, carbon combines with oxygen to form carbon dioxide. Name the compound formed when:
- **a** potassium burns in chlorine gas
- **b** sodium burns in air (oxygen)
- **c** silver tarnishes by reacting with sulfur in the air

4 Aluminium sulfate, used in sewage treatment and water purification, has the formula $Al_2(SO_4)_3$. How many atoms of aluminium, sulfur and oxygen are represented by this formula?

5 Copy this table and complete the formulas.

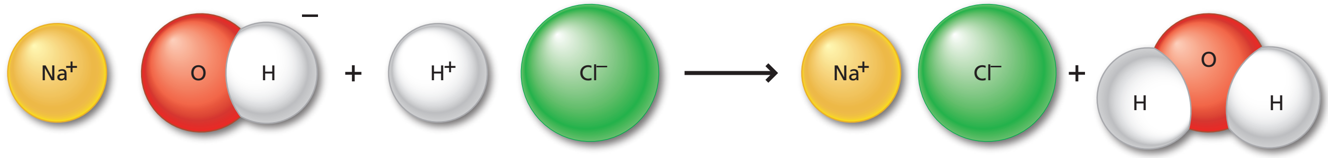
	iodide I^-	oxide O^{2-}	phosphate PO_4^{3-}
potassium K^+			
copper Cu^{2+}			
aluminium Al^{3+}			

6 Name the following compounds:
- **a** $FeCl_3$
- **b** HCl
- **c** $(NH_4)_3PO_4$
- **d** ZnI_2
- **e** $CaCO_3$
- **f** HgO
- **g** UO_2
- **h** $NaNO_3$

7 Write down the formulas for these common compounds:
- **a** ammonium sulfate (fertiliser)
- **b** calcium hydroxide (lime)
- **c** calcium phosphate (in bones)
- **d** magnesium sulfate (Epsom salts)
- **e** silver chloride (used in photographic film)
- **f** sodium hydrogen carbonate (baking soda)
- **g** sodium hydroxide (caustic soda)
- **h** zinc chloride (used in batteries)

8 The following formulas are incorrect. Correct each one and say *why* it is incorrect.
- **a** $NaCl_2$
- **b** Na_1HCO_3
- **c** $CaOH_2$
- **d** Mg_2O_2
- **e** $(NH_4)Cl$
- **f** H_2NO_3

3.4 Writing equations



$$NaOH + HCl \longrightarrow NaCl + H_2O$$

When you mix hydrochloric acid and sodium hydroxide they neutralise each other to form sodium chloride (a salt) and water. The word equation for this reaction is:

sodium hydroxide + hydrochloric acid → sodium chloride + water

Now that you know how to write chemical formulas, you can write a symbol equation like the one above.

This equation tells you how many of each kind of atom react together. Notice that the NaOH, HCl and NaCl are all ionic compounds, made up of positive and negative ions. During the reaction the ions swap partners. Look closely at the equation and you will see that there is a Na^+ ion (yellow) and a Cl^- ion (green) on both sides of the equation. Similarly, there is an oxygen atom (red) on both sides of the equation. Also, there are two hydrogen atoms (white) on the left-hand side, which both end up in the H_2O molecule on the right-hand side.

An equation like this, in which the numbers of each kind of atom are the same on both sides, is called a *balanced equation*. Equations must always be balanced because of the law of conservation of matter. Atoms cannot disappear and they cannot appear from nowhere.

To balance some equations you need to write numbers in front of the formulas. Here are three examples that show how to do this.

Equation 1

Magnesium metal reacts with hydrochloric acid to produce hydrogen gas and a solution of an ionic compound called magnesium chloride.

Step 1: Write the word equation

magnesium + hydrochloric acid → magnesium chloride + hydrogen

Step 2: Write down the formulas

You next write down the formulas of the reactants and products. For the element magnesium you simply write down its symbol Mg. It is best to remember that the formula for hydrochloric acid is HCl. For magnesium chloride you can work it out using valencies from the table on page 60. In hydrogen gas, however, the molecules are diatomic, meaning that they consist of two hydrogen atoms (H_2). Other diatomic molecules are oxygen (O_2), nitrogen (N_2) and chlorine (Cl_2).

$$\mathbf{Mg + HCl \rightarrow MgCl_2 + H2}$$

Step 3: Balance the equation

In a chemical reaction the atoms are rearranged but you end up with the same number of atoms as you started with. So the final step in writing an equation is to make sure that the numbers of atoms of each element are the same on both sides of the equation.

In this case, there is one magnesium atom on each side of the equation, so the magnesium atoms are balanced. There are two hydrogen atoms on the right-hand side but only one on the left. You can balance the hydrogen atoms by putting a 2 in front of the HCl on the left-hand side. This means two molecules of HCl.

$$\mathbf{Mg + 2HCl \rightarrow MgCl_2 + H_2}$$

The 2 refers to every atom in the molecule. So 2HCl means that there are two atoms of H and two atoms of Cl. Now the chlorine atoms are also balanced. Never change formulas to balance an equation. The balancing numbers always go in front of the formulas.

Note that the balancing numbers you use should be the smallest number possible. For example, the equation $2Mg + 4HCl \rightarrow 2MgCl_2 + 2H_2$ is balanced but can be simplified to $Mg + 2HCl \rightarrow MgCl_2 + H_2$.

Equation 2

When you add silver nitrate solution to copper chloride solution (blue) you get a **precipitate** (pre-SIP-it-ate) of white silver chloride. This is an insoluble solid that settles to the bottom of the test tube.

copper chloride + silver nitrate → silver chloride + copper nitrate

$$CuCl_2 + AgNO_3 \rightarrow AgCl + Cu(NO_3)_2$$

To balance the two Cl^- ions on the left-hand side you need to put a 2 in front of AgCl.

$$CuCl_2 + AgNO_3 \rightarrow 2AgCl + Cu(NO_3)_2$$

You then need a 2 in front of the $AgNO_3$ to balance the $Cu(NO_3)_2$ on the right-hand side.

$$CuCl_2 \quad 2AgNO_3 \rightarrow 2AgCl + Cu(NO_3)_2$$

To check the balancing you can count the numbers of atoms.

Left	Right
Cu 1	Cu 1
Cl 2	Cl 2
Ag 2	Ag 2
N 2	N 2
O 6	O 6

Equation 3

When propane (LPG) burns it reacts with the oxygen in the air to form carbon dioxide and water.

propane + oxygen → carbon dioxide + water

You need to know the formulas for propane, carbon dioxide and water.

$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$

To balance the carbon atoms you need to add a 3 in front of CO_2.

$$C_3H_8 + O_2 \rightarrow 3CO_2 + H_2O$$

To balance the hydrogens on the left-hand side you then need to add a 4 in front of H_2O.

$$C_3H_8 + O_2 \rightarrow 3CO_2 + 4H_2O$$

This makes 10 atoms of oxygen on the right-hand side. So to balance the oxygens you need to add a 5 in front of O_2 on the left-hand side.

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Left		Right	
C	3	C	3
H	8	H	4 x 2 = 8
O	5 x 2 = 10	O	(3 x 2 = 6) + 4 = 10

INQUIRY 5 Balancing Smarties

You will need: large packet of Smarties, molecular models kit (optional)

Would you believe that you can use Smarties to balance equations? Consider this equation:

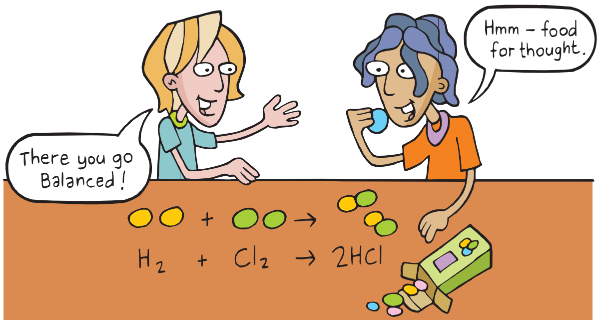
hydrogen gas + chlorine gas → hydrochloric acid

First, write the formulas for the reactants and products:

$$H_2 + Cl_2 \rightarrow HCl$$

Now use the Smarties to make models of the molecules. Decide which colours to use for the various atoms. For example, hydrogen could be represented by a pair of yellow Smarties, chlorine by a pair of green Smarties, and hydrogen chloride by a yellow–green pair. Once you have done this you will see that you will need a second yellow–green pair to balance the equation.

Try this for yourself. Before you break up the Smarties molecules, make sure you have written down the balanced equation. Don't eat the Smarties yet—you still need them.



Here are some other equations you can try to balance using Smarties.

nitrogen (N_2) + oxygen (O_2) → nitrogen dioxide (NO_2)

hydrogen (H_2) + oxygen → water

magnesium + oxygen → magnesium oxide

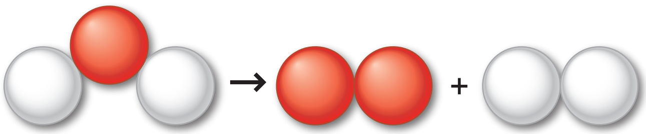
nitrogen + hydrogen → ammonia (NH_3)

If they are available you could use molecular models instead of Smarties.

Over to you

1 Why is it necessary to balance equations?

2 When electricity is passed through water it decomposes (breaks up) into hydrogen gas and oxygen gas. Kye used Smarties to make an equation for this reaction.



a Is this equation balanced? What does Kye need to do to balance it?

b Write the balanced equation.

3 Describe in your own words what happens in the reactions represented by these equations:

a $HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$

b $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$

4 Write balanced equations for these reactions between two elements to form a compound:

a potassium and iodine to form potassium iodide

b hydrogen and oxygen to form water

c carbon and hydrogen to form methane

d nitrogen and hydrogen to form ammonia

e nitrogen and oxygen to form nitrogen dioxide

5 Balance these equations. No numbers bigger than 2 are needed. (*Note:* Some equations may be balanced already.)

a $NaBr + Cl_2 \rightarrow NaCl + Br_2$

b $Ba(NO_3)_2 + H_2SO_4 \rightarrow BaSO_4 + HNO_3$

c $CaCO_3 \rightarrow CaO + CO_2$

d $H_2 + I_2 \rightarrow HI$

e $CH_4 + O_2 \rightarrow CO_2 + H_2O$

f $AgNO_3 + Cu \rightarrow Cu(NO_3)_2 + Ag$

g $NO + O_2 \rightarrow NO_2$

h $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

6 Write balanced equations for the following reactions.

a Zinc reacts with sulfuric acid (H_2SO_4) to produce zinc sulfate and hydrogen.

b Hydrogen peroxide (H_2O_2) decomposes on heating into water and oxygen.

c Sulfur dioxide burns in oxygen to produce sulfur trioxide.

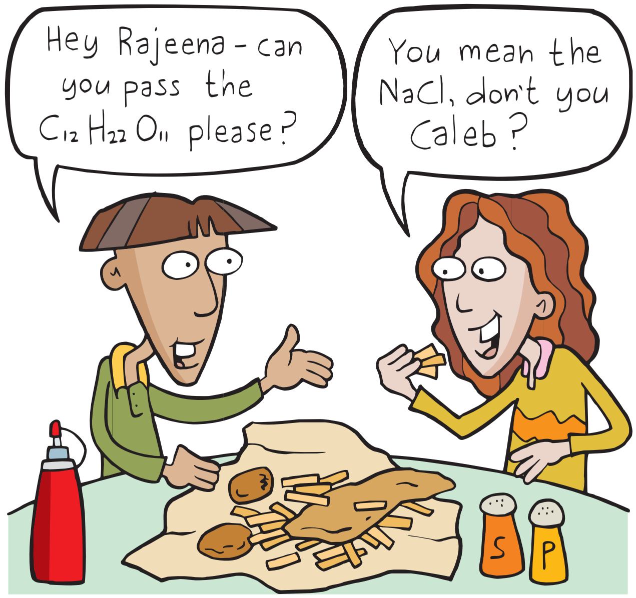
d Sodium reacts with water to produce sodium hydroxide and hydrogen (see Inquiry 1, p. 25).

e Iron reacts with the oxygen in the air to form iron oxide Fe_2O_3 (rust).

f During respiration, glucose ($C_6H_{12}O_6$) reacts with oxygen to produce carbon dioxide and water.

g When heated, table sugar ($C_{12}H_{22}O_{11}$) decomposes to carbon and water.

7 Choose two of the equations from question 6 and draw diagrams of the atoms, molecules and ions to show what is happening.



8 Each of the following equations is incorrect. First check the formulas. Then rewrite the equations correctly and balance them.

a $H + Cl \rightarrow HCl$

b $Cu + O_2 \rightarrow CuO_2$

c $H_2 + F_2 \rightarrow HF + HF$

d $Pb(NO_3)_2 + NaI \rightarrow PbI + Na(NO_3)_2$

e $K + H_2O \rightarrow KOH + H_2$

9 Balance these equations. (The formulas are correct.) You may need to use the numbers 2, 3, 4 or 6.

a $C + Fe_2O_3 \rightarrow Fe + CO$

b $C_2H_4 + O_2 \rightarrow CO_2 + H_2O$

c $HCl + O_2 \rightarrow Cl_2 + H_2O$

d $Al + HCl \rightarrow AlCl_3 + H_2$

e $(NH_4)_2CO_3 + Fe_2(SO_4)_3 \rightarrow Fe_2(CO_3)_3 + (NH_4)_2SO_4$

f $Pb_3O_4 \rightarrow PbO + O_2$

g $KClO_3 \rightarrow KCl + O_2$

h $CH_4 + Cl_2 \rightarrow CCl_4 + HCl$

i $Pb(NO_3)_2 \rightarrow PbO + NO_2 + O_2$

3.5 Predicting precipitates

A colourful precipitate

When you mix lead nitrate and potassium iodide (both colourless solutions), an amazing thing happens. An eye-catching yellow solid is formed (see photograph), which settles to the bottom of the beaker as a precipitate. You can explain what has happened from what you have learnt in this chapter.

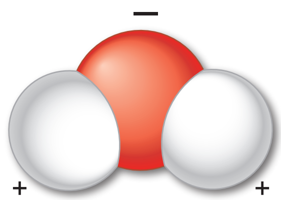
Lead nitrate and potassium iodide are both ionic compounds. When they dissolve in water the ionic lattice is broken up. The ions separate and move freely throughout the solution. Lead nitrate $Pb(NO_3)_2$ breaks up to form a lead ion with a double positive charge and two nitrate ions with a single positive charge.

$$Pb(NO_3)_2 \rightarrow Pb^{2+} + 2NO_3^-$$

In the same way, the potassium iodide KI breaks up into K^+ ions and I^- ions.

When the two solutions are mixed, the four ions also mix—a bit like the different coloured Smarties in a box. The ions are constantly moving and bump into each other. The positive ions are attracted by the negative ions and repelled by other positive ions. This means that the Pb^{2+} ions are attracted to the I^- ions as well as to the NO_3^- ions. The K^+ ions are attracted to the NO_3^- ions as well as to the I^- ions. So there is the possibility that the ions could change partners.

The ions are also attracted to the water molecules. This is because the hydrogen and oxygen in the molecule do not share their electrons equally. The oxygen is greedier for electrons than hydrogen is. As a result, the oxygen atom has a slight negative charge and the hydrogen atoms have a slight positive charge, as shown. This is why water dissolves so many different ionic compounds. It interacts with ions, breaking them apart.



Changing partners

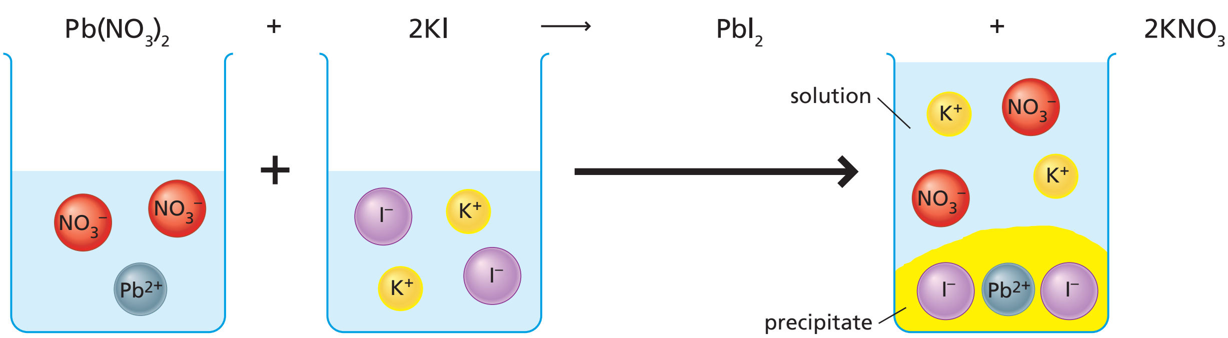
Look at the diagram below showing what happens when you mix lead nitrate and potassium iodide solutions. The ionic compound lead iodide is insoluble in water and forms a precipitate. This is because lead ions are more strongly attracted to iodide ions than they are to nitrate ions or to water molecules. These ions join together to form solid lead iodide. The potassium and nitrate ions are left in the clear solution.

Notice that each Pb^{2+} ion combines with two I^- ions to form PbI_2. Hence, there is a 2 in front of the KI so that there are the same numbers of ions on both sides of the equation.

The equation can be written more simply by showing only the ions that form the precipitate. The ions that do not take part in the reaction are left out. This is called an *ionic equation*.

$$Pb^{2+} + 2I^- \rightarrow PbI_2$$

lead nitrate solution + potassium iodide solution ⟶ lead iodide precipitate + potassium nitrate solution



Solubilities of ionic compounds

Using what you have learnt on the previous page, it is possible to predict whether a precipitate will be formed when two ionic solutions are mixed. If a soluble compound is formed, it will remain in solution. If the compound is insoluble, it will form a precipitate.

1 All ionic compounds containing sodium, potassium, ammonium or nitrate ions are soluble in water. For example, $NaCl$, K_2SO_4, NH_4Cl and $AgNO_3$ are all soluble.

2 Compounds containing chloride, bromide or iodide ions are soluble, except when they contain Ag^+, Pb^{2+}, Cu^+ or Hg^{2+} ions. For example, $MgCl_2$, $NaBr$ and KI are soluble but $AgCl$, PbI_2, CuI and $HgBr_2$ are not.

3 Compounds containing sulfate ions are soluble, except for $CaSO_4$, $BaSO_4$ and $PbSO_4$. For example, Na_2SO_4 and $(NH_4)_2SO_4$ are soluble.

4 Compounds containing carbonate ions are generally insoluble, unless they contain Na^+, K^+ or NH_4^+ ions. For example, $PbCO_3$ is insoluble, but Na_2CO_3 is soluble.

5 Compounds containing hydroxide ions are generally insoluble unless they contain Na^+, K^+ or NH_4^+ ions. For example, $Cu(OH)_2$ is insoluble but $NaOH$ and NH_4OH are soluble.

6 Some compounds are *slightly* soluble, for example, $Ca(OH)_2$, $PbCl_2$, $CaSO_4$ and Ag_2SO_4.

INVESTIGATION

1 Predicting and mixing

Aim

To predict whether a precipitate will form when pairs of ionic solutions are mixed, then to test these predictions.

Risk assessment and planning

The solutions you will be using are toxic, especially lead compounds. For this reason you should wear gloves at all times, and wash your hands when you are finished.

The leftover solutions must not be washed down the sink. They must be placed in a clearly marked waste bottle for proper disposal.

Apparatus

- 0.1 M solutions of the following:
  ammonium carbonate $(NH_4)_2CO_3$
  barium chloride $BaCl_2$
  copper sulfate $CuSO_4$
  lead nitrate $Pb(NO_3)_2$
  potassium iodide KI
  sodium hydroxide $NaOH$

- 2 test tube racks
- white tile and black tile (optional)
- 15 test tubes
- marking pen

Method

Part A: Making your predictions

1 There are six solutions and you will be mixing them two at a time. How many different combinations are there? Write them in your notebook, leaving a space to record your prediction and observation. Number each pair.

2 Look at your first pair of solutions (e.g. ammonium carbonate and barium chloride). The ions can swap partners, as shown on the previous page.

ammonium carbonate + barium chloride
⟶ barium carbonate ⟶ + ⟶ ammonium chloride

According to the solubility generalisations above, barium carbonate is insoluble, so you would predict a precipitate.

Consider each pair in this way and record your predictions.

Part B: Testing your predictions

1 Number the test tubes to match your solution pairs from Part A.

2 Mix your first pair of solutions. To do this, add 10 drops of the first solution to a test tube, then 10 drops of the second. If necessary, hold a black or white tile behind the test tube to make it easier to see any precipitate.

Record your observation next to your prediction.

3 Repeat for all the different combinations of solutions.

Results

Check how many of your predictions were correct. If your prediction is wrong, either do the prediction again or mix the two solutions again.

INVESTIGATION

1 *continued*

Part C: Solving problems

Use what you have learnt in this practical to solve one or more of these problems. Work out what tests you could do to solve the problem using the solutions from Part B, then carry out your tests. Make sure you use the same safety precautions as you did in Part B.

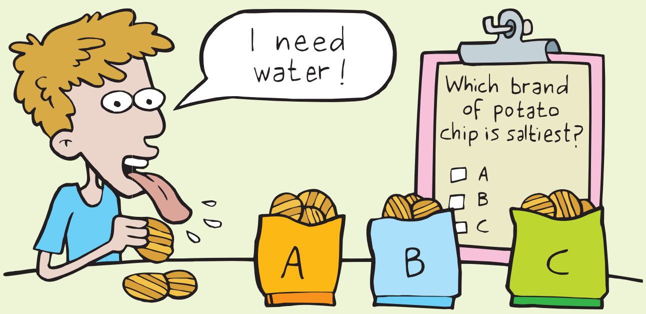
1 You are given three containers labelled A, B and C. The solutions are copper sulfate, sodium chloride and water. Your problem is to work out which is which by adding any of the solutions you used in Part A. For example, copper sulfate reacts with sodium hydroxide to give an insoluble blue precipitate, but nothing happens with sodium chloride.

2 Imagine you are an investigator called out to investigate a suspected poisoning. In the victim's bathroom are three bottles containing colourless liquids. Someone has pulled all the labels off the containers. You test the solutions and find them to be lead acetate (a poison), magnesium sulfate (Epsom salts) and sodium chloride (table salt). The pathologist has given you a sample of fluid from the stomach of the victim. Your problem is to test this sample to see if it contains the poison lead acetate. In other words, how can you test for lead acetate?

3 You have colourless solutions of four different sodium salts—sodium carbonate, sodium chloride, sodium nitrate and sodium sulfate. How can you work out which is which?

4 Imagine you have been captured by terrorists. They are holding you in an abandoned laboratory that was once used to manufacture poisons. You are dying of thirst and the terrorists have given you two containers—one containing water and the other a poisonous substance called mercury nitrate. How can you use the chemicals in the laboratory to identify which container is safe to drink?

5 Design an experiment to test which brand of potato chips is the saltiest, using one of the solutions from Part A.



Over to you

1 Use the solubility generalisations on the previous page to classify the following compounds as soluble or insoluble:

aluminium hydroxide	lead carbonate
ammonium bromide	mercury chloride
barium carbonate	potassium hydroxide
chromium nitrate	silver nitrate
gold sulfate	zinc chloride

2 Write equations like the one on page 65 to describe what happens when the following ionic compounds dissolve in water:

a copper sulfate $CuSO_4$
b sodium carbonate Na_2CO_3
c aluminium chloride $AlCl_3$
d ammonium sulfate $(NH_4)_2SO_4$

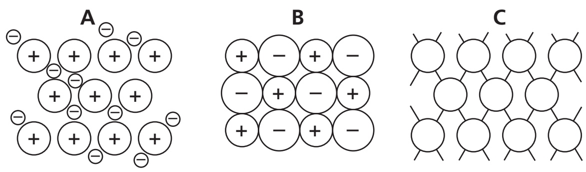
3 What precipitate is formed when the following solutions are mixed?

a silver nitrate and sodium chloride
b copper sulfate and ammonium hydroxide
c calcium nitrate and lithium carbonate
d barium nitrate and sodium sulfate

4 **a** You want to make some copper carbonate. What two solutions could you mix to do this?
b Write a balanced equation for the reaction.
c Write an ionic equation showing how the copper carbonate is formed.

THINKING SKILLS ?

1 Look at the three diagrams below. Which one represents an ionic lattice, which is a covalent lattice and which is a metallic lattice? Explain your answers.

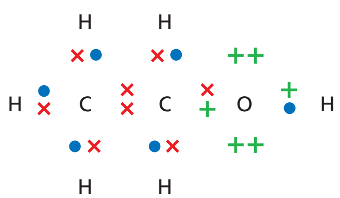


2 A metal M forms many different compounds. For example, it forms an oxide with the formula M_2O_3. Given this information, which of the following formulas are correct?

a M_2SO_4 **c** M_2Br_3 **e** $M(OH)_3$

b $M_2(NO_3)_3$ **d** MPO_3 **f** M_3S_2

3 The diagram shows the electron arrangement in a molecule of ethanol (alcohol).



a What is the formula for ethanol?

b What do each of the three types of symbols (×, • and +) represent?

c Which type of bonding is present in this molecule?

d How many bonds does each carbon atom form?

4 Why do oxygen and hydrogen exist as diatomic molecules (O_2 and H_2) but helium exists as single atoms?

5 Which type of bonding would you expect to find in the following substances (covalent, ionic or metallic)?

a sodium
b sulfur dioxide
c chlorine
d aluminium
e silicon dioxide
f sodium nitrate
g lithium oxide
h nitrogen dioxide
i silver chloride

6 Elements X and Y form two different compounds with carbon. Their formulas are CX_4 and CY_2.

a Predict the formula of a compound of X and Y. Explain how you worked it out.

b If carbon forms a compound with both X and Y, what would its formula be?

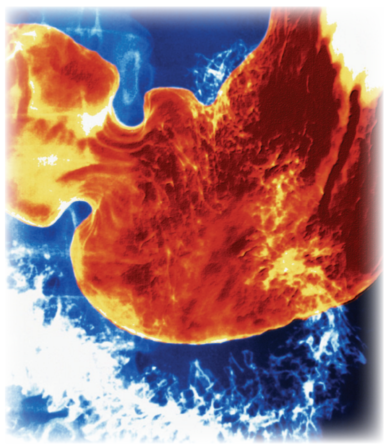
7 Predict what shapes you would expect the following molecules to have. Draw them.

a Br_2 **c** PCl_3 **e** CCl_4

b H_2S **d** HF

8 A salt solution conducts electricity but a sugar solution ($C_{12}H_{22}O_{11}$) does not. Use what you have learnt in this chapter to explain the difference.

9 A person with a problem in their digestive tract may be asked to swallow a porridge containing a very insoluble substance called barium sulfate. X-rays cannot pass through this substance and any problem in the digestive tract can be identified.



a Suppose the hospital does not have any barium sulfate. Which two compounds could they mix to make it?

b Suggest why no toxic barium ions are absorbed into the patient's bloodstream.

10 Imagine you are an electron in the outer shell of a sodium atom in a piece of sodium. Describe your experience as the sodium is burnt in a gas jar of chlorine gas.

11 Felicia wants to learn the names of the first 10 or 20 elements in the periodic table. Design a jingle to help her remember them. (A jingle is a sentence or rhyme to help you remember facts; for example, **M**y **V**ery **E**ducated **M**other **J**ust **S**erved **U**s **N**achos for the planets in the solar system.)

Knowing and Understanding

Copy and complete these statements using the words on the right to make a summary of this chapter.

1 The periodic table arranges the elements in order according to the size of their ______. Elements with similar properties are in the same vertical column or ______.

2 The metals are on the left and in the middle of the periodic table, with the ______ on the right.

3 The electrons surrounding the nucleus of an atom are arranged in ______ or energy levels. The number of electrons in the ______ shell determines the chemical ______ of the element.

4 Metals tend to lose electrons to form ______ ions, and non-metals tend to ______ electrons to form negative ions. These positive and negative ions combine to form ______ compounds.

5 When atoms share electrons they form a ______ bond. For example, two oxygen atoms combine to form a ______ with the formula O_2.

6 Metals consist of a lattice of positive ions held together by a 'sea' of ______. This is called a metallic ______.

7 The ______ of an atom is the number of electrons it gains, loses or ______ with other atoms.

8 Chemical equations must be ______, with the same number of each type of atom on each side of the equation.

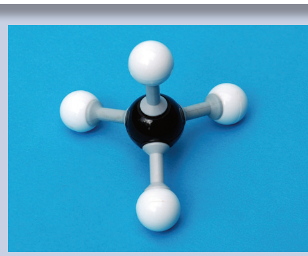
atoms
balanced
bond
covalent
electrons
gain
group
ionic
molecule
non-metals
outer
positive
properties
shares
shells
valency

Self-management

Chemical riddles

1 Use the clues next to each set of blanks to fill in the missing word. Now transfer the corresponding letters to the numbered blanks at the bottom to give the answer to the riddle.

2 As a group, make up your own chemical riddle based on this chapter. Check through the chapter for important words and use the riddle on the right as a model. Check carefully that you have all the right letters, then try it out on another group.



_ _ _ _ _ _
1 2 3 4 5 6
This atom normally forms four covalent bonds.

_ _ _ _ _ _ _
7 8 9 10 11 12 13
This man won two Nobel Prizes.

_ _ _ _ _
14 15 16 17 18
Number of electrons that atoms like to have in their outer shell.

_ _ _ _
19 20 21 22
A heavy poisonous metal in Group IV.

You sit at one of these on a regular basis.

_ _ _ _ _ _ _ _   _ _ _ _ _
7 20 3 11 5 22 15 1   18 8 4 19 14

Checkpoint

1 Which one of the following substances is an ionic compound?

A copper **C** calcium carbonate
B water **D** carbon dioxide

2 Covalent compounds usually form when:

A non-metals react together
B metals react together
C metals and non-metals react together
D ions are present

3 Which one of the following is the correct formula for the ionic compound calcium iodide?

A CaI_2 **B** CaI **C** Ca_2I_2 **D** $Ca(I)_2$

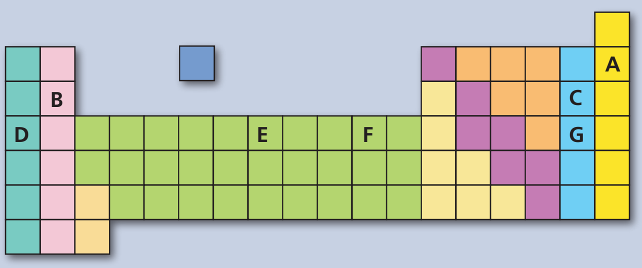
4 When hydrochloric acid is added to zinc, hydrogen is produced and zinc chloride is left in solution. Which one of the following is the correctly balanced equation for this reaction?

A $Zn + HCl \rightarrow ZnCl_2 + H_2$
B $Zn + HCl \rightarrow ZnCl + H$
C $Zn + 2HCl \rightarrow ZnCl_2 + H_2$
D $2Zn + 2HCl \rightarrow 2ZnCl_2 + H_2$

5 The formula for magnesium sulfate (Epsom salts) is $MgSO_4$.

a How many different elements are there in magnesium sulfate?
b Which ions are formed when magnesium sulfate dissolves in water?
c Is magnesium sulfate an ionic or a covalent compound? Explain.

6 This question refers to the outline of the periodic table below. The letters in the table are not the symbols for the elements.



a Which two elements would you expect to have very similar chemical properties? Why?
b Name two elements that are in the same period. Explain your answer.
c Which element is an alkaline earth metal?
d Which element is a very unreactive gas?
e Which two elements are transition metals?
f Which element reacts violently with water?
g Which element has only one electron in its outer shell?
h Name two elements that are likely to react with each other?

7 The table gives the solubility (shown by a tick) of some ionic compounds in water. Use the table to work out which of the following generalisations are true.

Ions	potassium	sodium	calcium	lead
nitrate	✓	✓	✓	✓
chloride	✓	✓	✓	✗
sulfate	✓	✓	✗	✗
carbonate	✓	✓	✗	✗

a All carbonates are soluble.
b All compounds are soluble when they contain nitrate ions.
c All calcium compounds are insoluble.
d Lead compounds are insoluble except for lead nitrate.
e Calcium sulfate often forms a precipitate.

8 Calcium chloride and sodium hydroxide react to form calcium hydroxide and sodium chloride.

a Write a word equation for this reaction.
b Write an equation using the formulas for each substance.
c Add numbers in front of the formulas if necessary to balance the equation.

9 Lead nitrate solution $Pb(NO_3)_2$ is mixed with sodium carbonate Na_2CO_3.

a Which ions would be in the mixture?
b Would a precipitate be formed? Explain.
c Write a balanced equation for the reaction you predict.

10 These diagrams represent the electrons in the outer shells of carbon and hydrogen. Use them to explain how covalent bonds are formed to hold a molecule of methane (CH_4) together.
Draw an electron dot formula.