C2 1.1 Chemical bonding

Learning objectives

- How do elements form compounds?
- How do the elements in Group 1 bond with the elements in Group 7?

You already know that we can mix two substances together without either of them changing. For example, we can mix sand and salt together and then separate them again. No change will have taken place. But in chemical reactions the situation is very different.

When the atoms of two or more elements react they make a compound.

A compound contains two or more elements which are chemically combined.

The compound formed is different from the elements and we cannot get the elements back again easily. We can also react compounds together to form other compounds. However, the reaction of elements is easier to understand as a starting point.

a What is the difference between mixing two substances and reacting them?

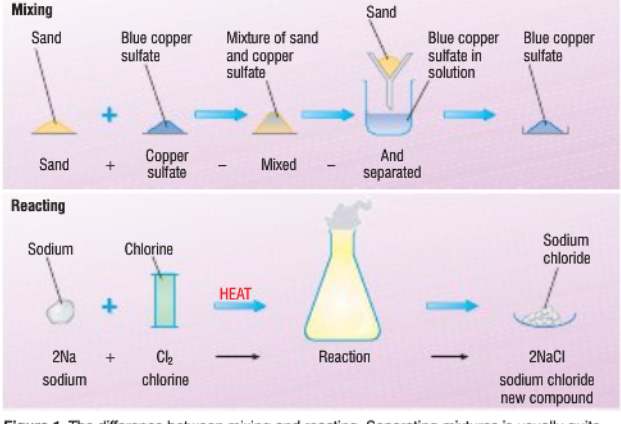


Figure 1 The difference between mixing and reacting. Separating mixtures is usually quite easy, but separating substances once they have reacted can be quite difficult. Why do atoms react?

When an atom has an arrangement of electrons like a noble gas in Group 0, it is stable and unreactive. However, most atoms do not have this electronic structure. When atoms react they take part in changes which give them a stable arrangement of electrons. They may do this by either:

- sharing electrons, which we call **covalent bonding**
- transferring electrons, which we call **ionic bonding**.

Losing electrons to form positive ions

In ionic bonding the atoms involved lose or gain electrons to form charged particles called ions. The ions have the electronic structure of a noble gas. So, for example, if sodium (2,8,1) loses one electron it is left with the stable electronic structure of neon (2,8).

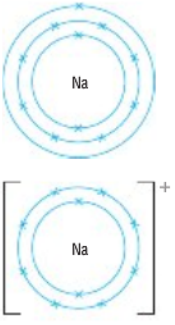


Figure 2 A positive sodium ion (Na^+) is formed when a sodium atom loses an electron during ionic bonding

However, it is also left with one more proton in its nucleus than there are electrons around the nucleus. The proton has a positive charge so the sodium atom has now become a positively charged **ion**. The sodium ion has a single positive charge. We write the formula of a sodium ion as Na^+. The electronic structure of the Na^+ ion is 2,8. This is shown in Figure 2.

Gaining electrons to form negative ions

When non-metals react with metals, the non-metal atoms gain electrons to achieve a stable noble gas structure. Chlorine, for example, has the electronic structure 2,8,7. By gaining a single electron, it gets the stable electronic structure of argon (2,8,8).

In this case there is now one more electron than there are positive protons in the nucleus. So the chlorine atom becomes a negatively charged ion. This carries a single negative charge. We write the formula of the chloride ion as Cl^-. Its electronic structure is 2,8,8. This is shown in Figure 3.

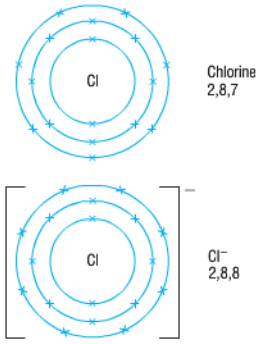


Figure 3 A negative chloride ion (Cl^-) is formed when a chlorine atom gains an electron during ionic bonding

b When atoms join together by *sharing* electrons, what type of bond is formed?

c When ions join together as a result of *gaining* or *losing* electrons, what type of bond is this?

Representing ionic bonding

Metal atoms, which need to lose electrons, react with non-metal atoms, which need to gain electrons. So when sodium reacts with chlorine, each sodium atom loses an electron and each chlorine atom gains that electron. They both form stable ions. The electrostatic attraction between the oppositely charged Na^+ ions and Cl^- ions is called ionic bonding.

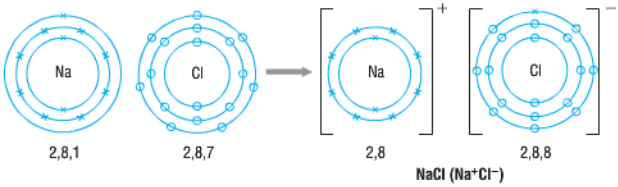


Figure 4 The formation of sodium chloride (NaCl) – an example of ion formation by transferring an electron

We can show what happens in a diagram. The electrons of one atom are represented by dots, and the electrons of the other atom are represented by crosses. This is shown in Figure 4.

Summary questions

1 Copy and complete using the words below:

covalent difficult compound gaining ionic losing new noble

When two elements react together they make a ..... substance called a ..... . It is ..... to separate the elements after the reaction. Some atoms react by sharing electrons. We call this ..... bonding. Other atoms react by ..... or ..... electrons. We call this ..... bonding. When atoms react in this way they get the electronic structure of a ..... gas.

2 Draw diagrams to show the ions that would be formed when the following atoms are involved in ionic bonding. For each one, state how many electrons have been lost or gained and show the charge on the ions formed.

a aluminium (Al) **b** fluorine (F) **c** potassium (K) **d** oxygen (O)

Key points

- Elements react together to form compounds by gaining or losing electrons or by sharing electrons.
- The elements in Group 1 react with the elements in Group 7. As they react, atoms of Group 1 elements can each lose one electron to gain the stable electronic structure of a noble gas. This electron can be given to an atom from Group 7, which then also achieves the stable electronic structure of a noble gas.

C2 1.2 Ionic bonding

Learning objectives

- How are ionic compounds held together?
- Which elements, other than those in Groups 1 and 7, form ions?

You have seen how positive and negative ions form during some reactions. Ionic compounds are usually formed when metals react with non-metals.

The ions formed are held next to each other by very strong forces of attraction between the oppositely charged ions. This electrostatic force of attraction, which acts in all directions, is called **ionic bonding**.

The ionic bonds between the charged particles result in an arrangement of ions that we call a **giant structure** (or a **giant lattice**). If we could stand among the ions they would seem to go on in all directions forever.

The force exerted by an ion on the other ions in the lattice acts equally in all directions. This is why the ions in a giant structure are held so strongly together.

The giant structure of ionic compounds is very regular. This is because the ions all pack together neatly, like marbles in a box.

a What name do we give to the arrangement of ions in an ionic compound?
b What holds the ions together in this structure?

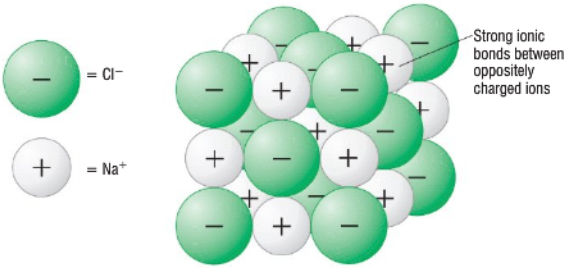


Figure 1 Part of the giant ionic lattice (3-D network) of sodium and chloride ions in sodium chloride

Sometimes the atoms reacting need to gain or lose two electrons to gain a stable noble gas structure. An example is when magnesium (2,8,2) reacts with oxygen (2,6). When these two elements react they form magnesium oxide (MgO). This is made up of magnesium ions with a double positive charge (Mg^{2+}) and oxide ions with a double negative charge (O^{2-}).

We can represent the atoms and ions involved in forming ionic bonds by **dot and cross diagrams**. In these diagrams we only show the electrons in the outermost shell of each atom or ion. This makes them quicker to draw than the diagrams on the previous page. Figure 2 on the next page shows an example.

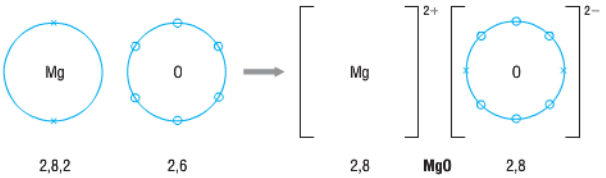


Figure 2 When magnesium oxide (MgO) is formed, the reacting magnesium atoms lose two electrons and the oxygen atoms gain two electrons

Another example of an ionic compound is calcium chloride. Each calcium atom (2,8,8,2) needs to lose two electrons but each chlorine atom (2,8,7) needs to gain only one electron. This means that two chlorine atoms react with every one calcium atom to form calcium chloride. So the formula of calcium chloride is $CaCl_2$.

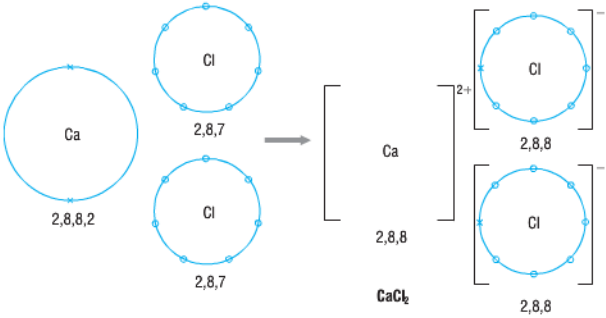


Figure 3 The formation of calcium chloride ($CaCl_2$)

Summary questions

1 a Copy and complete the table:

Atomic number	Atom	Electronic structure of atom	Ion	Electronic structure of ion
8	O			$[2,8]^{2-}$
19		2,8,8,1	K^+	
17	Cl		Cl^-	
20		2,8,8,2		

b Explain why potassium chloride is KCl but potassium oxide is K_2O.
c Explain why calcium oxide is CaO but calcium chloride is $CaCl_2$.

2 Draw dot and cross diagrams to show how you would expect the following elements to form ions together:
a lithium and chlorine
b calcium and oxygen
c aluminium and fluorine.

Did you know ...?

The structure of ionic lattices is investigated by passing X-rays through them.

Key points

- Ionic compounds are held together by strong forces of attraction between the oppositely charged ions. This is called ionic bonding.
- Besides the elements in Groups 1 and 7, other elements that can form ionic compounds include those from Groups 2 and 6.

C2 1.3 Formulae of ionic compounds

Learning objectives

- How can we write the formula of an ionic compound, given its ions?

In this chapter we have seen how three different ionic compounds are formed. You should understand how atoms turn to ions when sodium chloride, magnesium oxide and calcium chloride are formed from their elements.

The overall charge on any ionic compound is zero. The compounds are neutral. Therefore we do not have to draw dot and cross diagrams to work out each ionic formula. As long as we know or are given the charge on the ions in a compound we can work out its formula.

a What is the overall charge on an ionic compound?

If we look at the three examples above, we can see how the charges on the ions in a compound cancel out:

Ionic compound	Ratio of ions in compound	Formula of compound
sodium chloride	$Na^+ : Cl^-$ 1 : 1	NaCl
magnesium oxide	$Mg^{2+} : O^{2-}$ 1 : 1	MgO
calcium chloride	$Ca^{2+} : Cl^-$ 1 : 2	$CaCl_2$

b What is the formula of magnesium chloride?

We can work out the formula of some ions given a copy of the periodic table. Remember that in your exams you will have a Data Sheet which includes a periodic table and a table showing the charges of common ions.

Groups of metals

- The atoms of Group 1 elements form 1+ ions, e.g. Li^+.
- The atoms of Group 2 elements form 2+ ions, e.g. Ca^{2+}.

Groups of non-metals

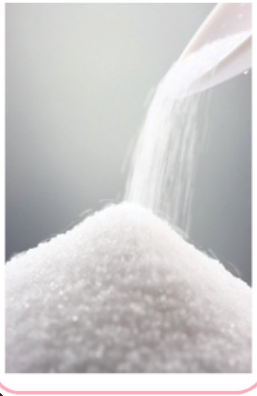
- The atoms of Group 7 elements form 1− ions, e.g. F^-.
- The atoms of Group 6 elements form 2− ions, e.g. S^{2-}.

The names of compounds of transition metals contain the charge on their ions in brackets in roman numerals. This is because they can form ions carrying different sizes of positive charge. For example, iron can form 2+ and 3+ ions. So the name iron(III) oxide tells us that the iron is present as Fe^{3+} ions in this compound.

c What is the formula of lithium sulfide?
d What is the formula of iron(III) oxide?

Did you know ...?

Common salt is sodium chloride. In just 58.5 g of salt there are over 600 000 000 000 000 000 000 000 ions of Na^+ and the same number of Cl^- ions.



More complicated ions

Some ions are made up of more than one element. When you studied limestone, you learned that the formula of calcium carbonate is $CaCO_3$. It contains calcium ions, Ca^{2+}, and carbonate ions, CO_3^{2-}. The carbonate ions contain carbon and oxygen. However, the rule about cancelling out charges still applies as in one-element ions. Calcium carbonate is $CaCO_3$ as the 2+ and 2− ions in the ionic compound cancel out in the ratio 1 : 1.

Two-element ions you might come across are shown in the table below:

Name of ion	Formula of ion	Example of compound
hydroxide	OH^-	calcium hydroxide, $Ca(OH)_2$
nitrate	NO_3^-	magnesium nitrate, $Mg(NO_3)_2$
carbonate	CO_3^{2-}	sodium carbonate, Na_2CO_3
sulfate	SO_4^{2-}	calcium sulfate, $CaSO_4$

Notice how the formula of a compound containing a two-element ion sometimes contains brackets. To write calcium hydroxide as $CaOH_2$ would be misleading. It would tell us the ratio of Ca : O : H ions was 1 : 1 : 2. However, as there are twice as many hydroxide ions as calcium ions, the ratio should be 1 : 2 : 2. This is why we write the formula as $Ca(OH)_2$.

e What is the formula of calcium nitrate?

Figure 1 Haematite is an ore of iron. It is mined (as here) and used as a source of iron(III) oxide for the blast furnace in the extraction of iron.

AQA Examiner's tip

When naming compounds we use the ending –ide for simple non-metal ions such as oxide or sulfide. However, we use –ate for ions that include oxygen, such as sulfate, nitrate and carbonate.

AQA Examiner's tip

You do not have to learn the charges on ions – they are on the data sheet.

Think of each symbol as a single atom and the formula of each ion as a single ion. Small numbers multiply only the symbol they follow.

Brackets are needed when there is more than one type of atom in the ion being multiplied.

Summary questions

1 Using the charges on the ions given on this spread, give the formula of:
- **a** calcium oxide
- **b** lithium oxide
- **c** magnesium chloride

2 Draw a table with K^+, Mg^{2+} and Fe^{3+} down the side and Br^-, OH^-, NO_3^- and SO_4^{2-} across the top. Then fill in the formula of the compound in each cell of the table.

3 **a** The formula of strontium nitrate is $Sr(NO_3)_2$. What is the charge on a strontium ion?
b The formula of aluminium sulfate is $Al_2(SO_4)_3$. What is the charge on an aluminium ion?

Key points

- The charges on the ions in an ionic compound always cancel each other out.
- The formula of an ionic compound shows the ratio of ions present in the compound.
- Sometimes we need brackets to show the ratio of ions in a compound, e.g. magnesium hydroxide, $Mg(OH)_2$.

C2 1.4 Covalent bonding (k)

Learning objectives

- How are covalent bonds formed?
- What types of substance have covalent bonds?

Figure 1 Most of the molecules in substances which make up living things are held together by covalent bonds between non-metal atoms

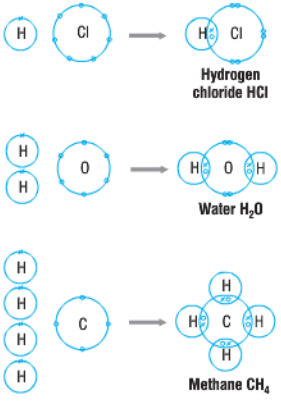


Figure 3 The principles of covalent bonding remain the same however many atoms are involved

Reactions between metals and non-metals usually result in ionic bonding. However, many, many compounds are formed in a very different way. When non-metals react together their atoms share pairs of electrons to form molecules. We call this **covalent bonding**.

Simple molecules (k)

The atoms of non-metals generally need to gain electrons to achieve stable outer energy levels. When they react together neither atom can give away electrons. So they get the electronic structure of a noble gas by sharing electrons. The atoms in the molecules are then held together by the shared pairs of electrons. We call these strong bonds between the atoms covalent bonds.

a What is the bond called when two atoms share a pair of electrons?

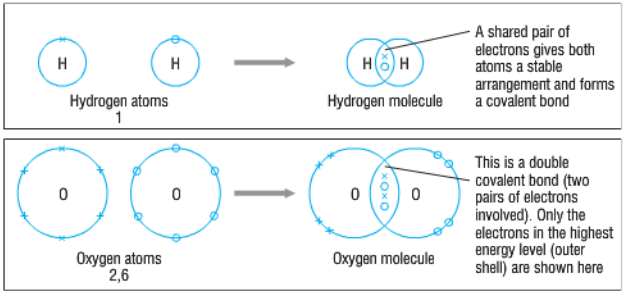


Figure 2 Atoms of hydrogen and oxygen join together to form stable molecules. The atoms in H_2 and O_2 molecules are held together by strong covalent bonds.

Sometimes in covalent bonding each atom brings the same number of electrons to share. But this is not always the case. Sometimes the atoms of one element will need several electrons, while the other element only needs one more electron for each atom to get a stable arrangement. In this case, more atoms become involved in forming the molecule.

We can represent the covalent bonds in substances such as water, ammonia and methane in a number of ways. Each way represents the same thing. The method chosen depends on what we want to show.

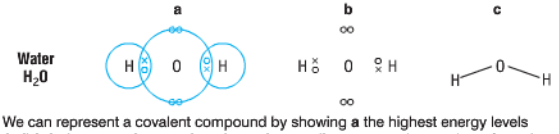


Figure 4 We can represent a covalent compound by showing **a** the highest energy levels (or outer shells), **b** the outer electrons in a dot and cross diagram or **c** the number of covalent bonds

Giant covalent structures

Many substances containing covalent bonds consist of small molecules, for example, H_2O. However, some covalently bonded substances are very different. They have giant structures where huge numbers of atoms are held together by a network of covalent bonds. These are sometimes referred to as macromolecules.

Diamond has a giant covalent structure. In diamond, each carbon atom forms four covalent bonds with its neighbours. This results in a rigid giant covalent lattice.

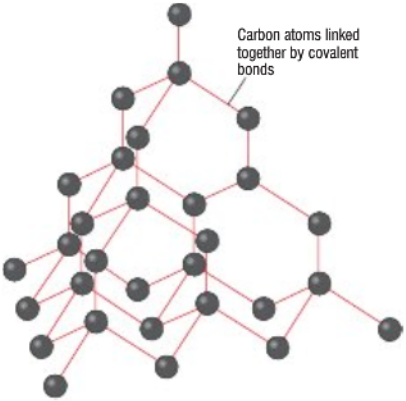


Figure 5 Part of the giant covalent structure of diamond

Figure 6 Diamonds owe their hardness to the way the carbon atoms are arranged in a giant covalent structure

Silicon dioxide (silica) is another substance with a giant covalent structure.

b What do we call the structure of a substance held together by a network of covalent bonds?

Summary questions

1 Copy and complete using the words below:

covalent *giant* *molecules* *macromolecules* *shared*

When non-metal atoms react together they make ..... bonds. The atoms in these bonds are held together by ..... electrons. Most substances held together by covalent bonds consist of ....., but some have ..... covalent structures, sometimes called ..... .

2 Draw diagrams, showing all the electrons, to represent the covalent bonding between the following atoms.
- **a** two hydrogen atoms
- **b** two chlorine atoms
- **c** a hydrogen atom and a fluorine atom

3 Draw dot and cross diagrams to show the covalent bonds when:
- **a** a nitrogen atom bonds with three hydrogen atoms
- **b** a carbon atom bonds with two oxygen atoms.

Key points

- Covalent bonds are formed when atoms share pairs of electrons.
- Many substances containing covalent bonds consist of simple molecules, but some have giant covalent structures.