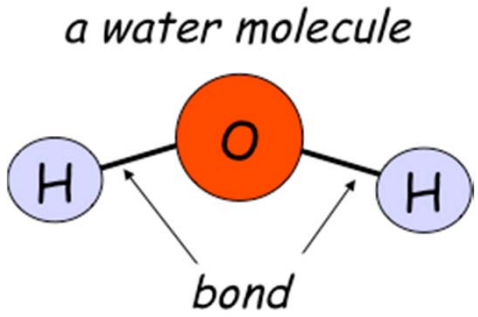
Chemical Bonds

In elements and compounds, the atoms are held together by **chemical bonds**.



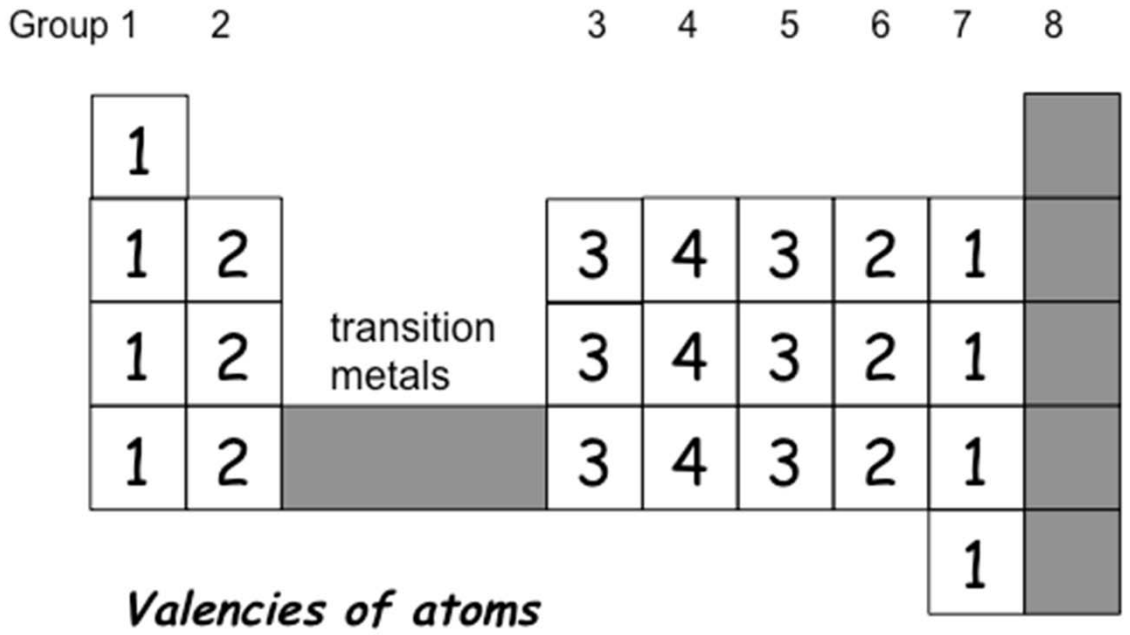
Forming a bond makes an atom **more stable**, so atoms form as many bonds are they are able to.

Bonds are made using the **outer shell** electrons of atoms, which are either **transferred** from one atom to another, or **shared** between atoms.

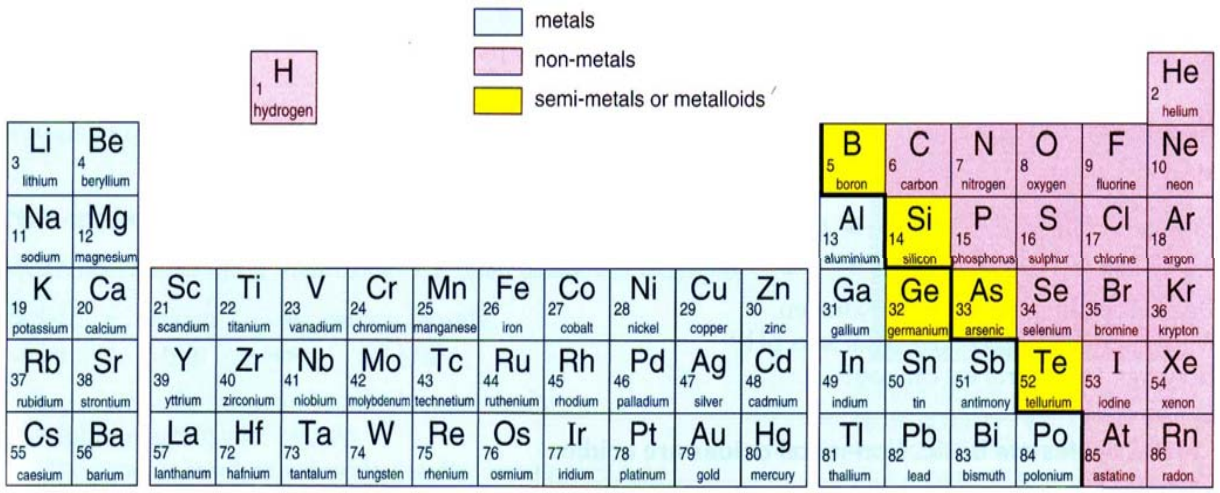
Valency

The number of electrons an atom uses for bonding is called its **valency**, and is related to the number of outer shell electrons (and the Group).

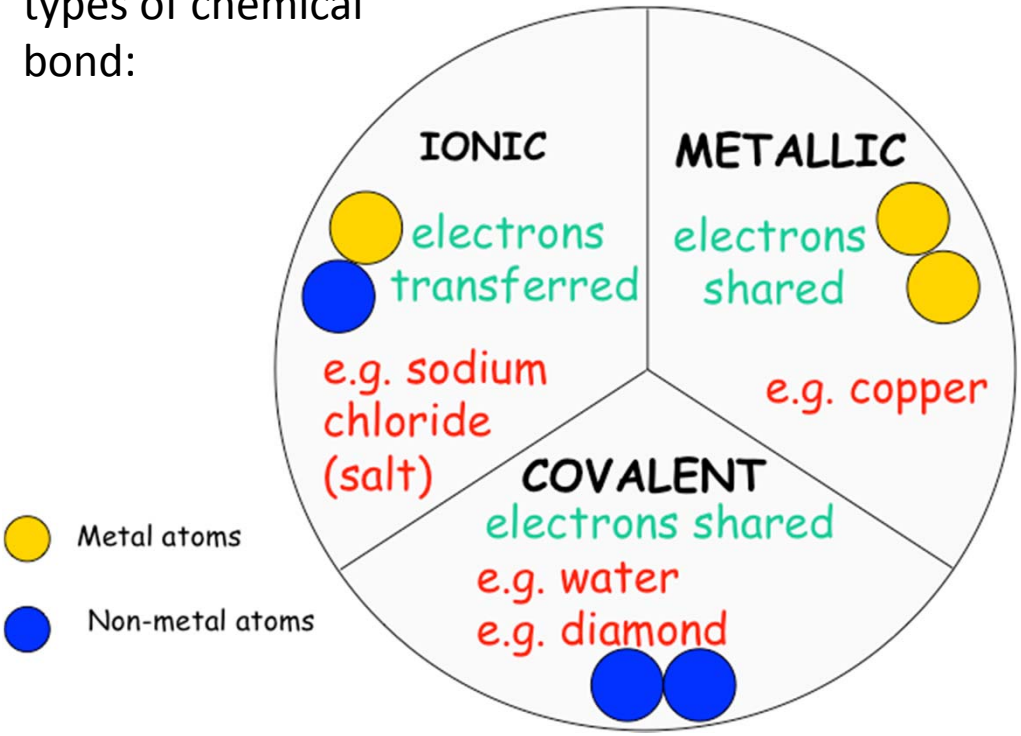
Some elements, e.g. the transition metals can have more than one different valency. A number after the name shows the valency e.g. iron(III) etc.



The **type** of chemical bond between two atoms depends on whether they are metal atoms or non-metal atoms.



There are <u>three</u> types of chemical bond:



IONIC BONDING - METAL TO NON-METAL

Metal atoms give their outer-shell electrons to non-metal atoms, and each becomes an ion.

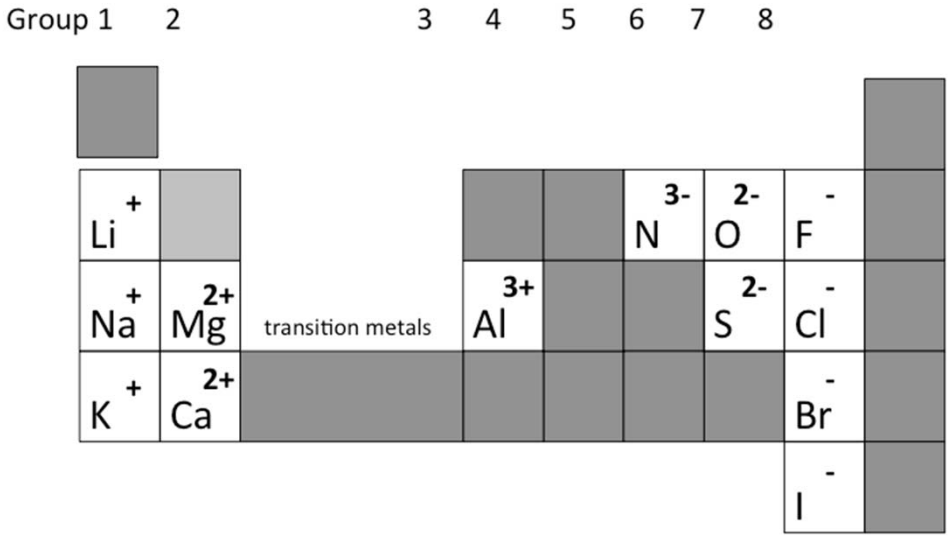
An **ion** is defined as an atom which has lost or gained electrons. The do this to become more stable, usually gaining a **full outer shell** as a result. The number of electrons an atom gains or loses to become an ion is shown by its **valency**,

An ion has a **charge.** The charge on an ion reflects the number of electrons it has gained or lost (see table below). Metals form positive ions, and non-metals form negative ions.

This means that the transfer of electrons from metal to non-metal atoms results in the formation of **oppositely charged** ions.

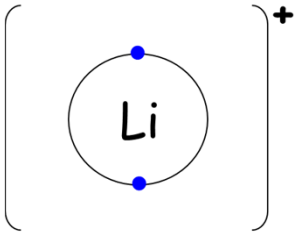
There is a **strong electrostatic attraction** between oppositely-charged ions – this is the origin of the **ionic bond** which holds the ions together.

We can work out the amount of charge an ion has from its valency, or the group it is in. We then need to give the sign of the charge – positive if electrons have been lost (metals) or negative if electrons have been gained (non-metals).

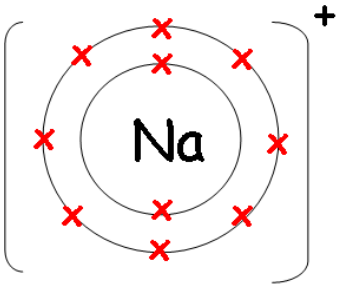


Drawing metal ions

Start by drawing the atom with its filled inner shells, but don't draw the outer shell (it is empty). Add square brackets, and the charge on the ion (same as the valency), and positive:

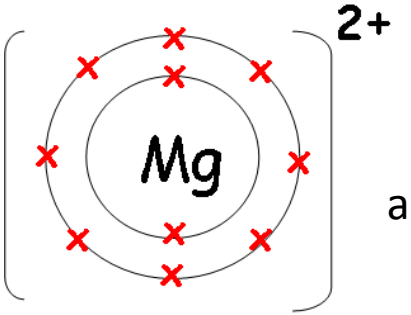


a lithium ion



a sodium ion

Na^+ $[2,8]^+$

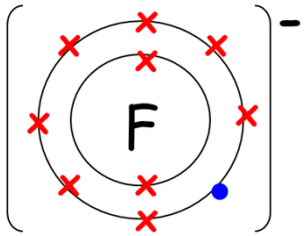


a magnesium ion

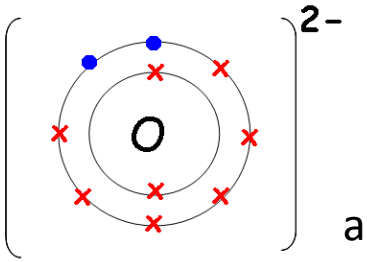
Mg^{2+} $[2,8]^{2+}$

Drawing non-metal ions

Start by drawing the atom with its filled inner shells, and its outer shell electrons (crosses). Fill the outer shell with electrons from a metal ion (dots) Add square brackets, and the charge on the ion (same as the valency), and negative:

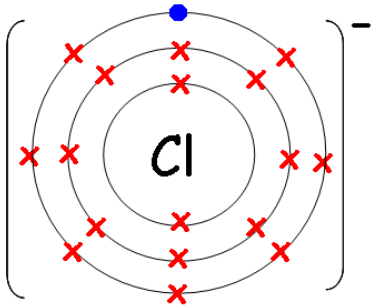


a fluoride ion



an oxide ion

O^{2-} $[2,8]^{2-}$



a chloride ion

Cl^- $[2,8,8]^-$

Note:
You can tell a negative ion, because the name of the atom has changed to have an '-ide' ending.

Some metal ions, e.g. transition metals, do not show an obvious pattern between what group they are in and their valency/charge.

Just learn these: **Silver ion Ag^+** **Zinc ion Zn^{2+}**

Some transition metals can form more than one different ion: a number in roman numerals tells us the amount of positive charge (which is the same as its valency):

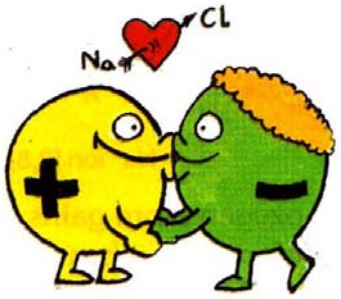
Copper(I) Cu^+ **Copper(II) Cu^{2+}**
Iron(II) Fe^{2+} **Iron(III) Fe^{3+}**

Forming ionic compounds

When we form an ionic compound, the charges have to balance; because the same number of electrons have to be given and received. This may mean different numbers of ions:

one 2+ ion and two 1- ions
one 3+ ion and three 1- ions
two 3+ ions and three 2- ions
two 1+ ions and one 2- ion etc.

Metal atoms give electrons to non-metal atoms



Opposites attract!

Working out the formula of an ionic compound:

1) Use the name to identify the ions present
2) Write the ions, with the correct valency underneath
3) Swap the valencies
4) Simplify if they will both divide by same number

e.g. sodium sulphide

Na^+ S^{2-}

1 2

so the formula is: Na_2S

zinc oxide

Zn^{2+} O^{2-}

2 2 *simplify!*

ZnO *not* Zn_2O_2 *!*

Work out formulae for:

- aluminium fluoride,
- magnesium chloride,
- sodium bromide,
- magnesium oxide,
- potassium oxide,
- copper(I) oxide,
- iron(III) chloride,
- zinc sulphide,
- silver oxide

Many ionic substances contain compound ions:

These are used in the same way, with brackets if there is more than one of the compound ion. Learn the formulae and the charges (which tell you the valencies).

nitrate	NO_3^-	carbonate	CO_3^{2-}
Hydroxide	OH^-	phosphate	PO_4^{3-}
sulphate	SO_4^{2-}	ammonium	NH_4^+

e.g. calcium **hydroxide**

Ca^{2+} OH^- Formula $Ca(OH)_2$

ammonium **sulphate**

NH_4^+ SO_4^{2-} Formula $(NH_4)_2SO_4$

Work out formulae for:

- potassium sulphate,
- sodium phosphate,
- ammonium bromide,
- lithium hydroxide,
- calcium carbonate,
- magnesium nitrate

Answers at the end of the topic.

We need to be able to write balanced chemical equations for any of the reactions we have met at IGCSE:

You can simply learn the equations, or you can learn how to work them out. Being able to work out the equations will help you a lot if you carry on studying Chemistry. You do need to have learnt the word equations as a starting point.

1. Write the word equation (look for clues in the question or context)
2. Underneath each named substance, write its formula if you know it, or are given it.
3. Work out the formulae for the remaining substances, using valencies
4. When all the formulae are correct, add numbers in front to balance the equation
5. Finally add state symbols (again look for clues in the question or context)

e.g. Zinc reacts with dilute hydrochloric acid. Fizzing is observed, and the gas is shown to be hydrogen when it is tested. Write the balanced chemical equation with state symbols:

Step 1: **zinc + hydrochloric acid → zinc chloride + hydrogen**

We were given three substances, and had to use our knowledge of acid reactions and making salts to work out what the salt (zinc chloride) would be in this equation.

Step 2: **Zn + HCl → zinc chloride + H_2**

Zinc and hydrogen are elements, and hydrogen is one of the elements which forms diatomic molecules (HFBrONICl) so Zn and H_2. HCl is an acid formula we should have learnt, but we could work it out using valencies if we had to. (H=1 and Cl=1 so HCl)

Step 3: $Zn + HCl \rightarrow ZnCl_2 + H_2$

We work out the formula of zinc chloride using valencies. Zn has a valency of 2 (learn this one) and Cl has a valency of 1 (in Group 7), hence $ZnCl_2$.

Step 4: $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

Balance the equation to get the same number of each atom on each side.

Step 5: $Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$

Zinc is a metal, so we know this is a solid (s) at room temperature. We are told in the question the acid is dilute, so it must be a solution in water. Our solubility rules tell us most chlorides are soluble so we expect zinc chloride to be soluble and so it will dissolve in the water present, so both the acid and the salt are (aq). We know that hydrogen is a gas, and we are told that fizzing takes place so (g) for the hydrogen.

Practice with these example reactions. You'll need to check the word equations as not all the products have been given. Answers at the end of the topic

1. Making copper nitrate by reacting copper(II) oxide with dilute nitric acid
2. Testing for sulphate ions in sodium sulphate solution using barium chloride solution
3. Testing for iron(III) ions in iron(III) chloride solution
4. Making lead(II) sulphate by precipitation from suitable aqueous solutions
5. Displacing iodine from potassium iodide solution by reacting it with chlorine water

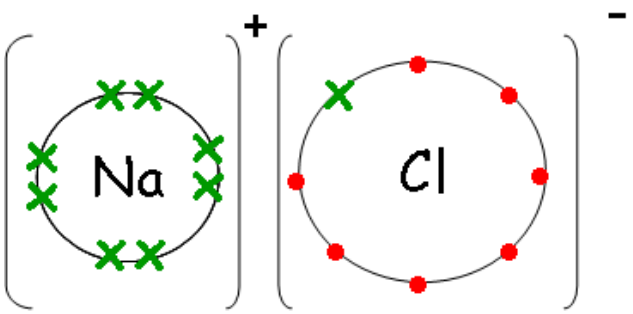
Dot and cross diagrams (ionic bonding)

Having learnt to draw individual ions and how to work out how many of each ion is in an ionic compound, we can combine these skills to draw a dot-and-cross diagram to show its ionic bonding.

We usually show **only the outer shell** electrons, because only these are involved in bonding. We can ignore the filled inner shells.

We use dots and crosses so we can see which atom the electrons came from, and which they were transferred to.

The simplest example would be a compound with a 1+ and a 1- ion in it, e.g. sodium chloride:



Name: sodium chloride
Formula: NaCl

How to draw ionic dot and cross diagrams

1. Work out the formula of the compound (see earlier)

2. Draw the outline of the dot-cross diagram
   - correct number of ions, from formula
   - correct charges on ions

3. Put in the outer shell electrons for negative ions
   - add the electrons transferred from the positive ion to get full outer shells

4. Give the positive ion a full outer shell (an empty outer shell is also allowed).

Practice:

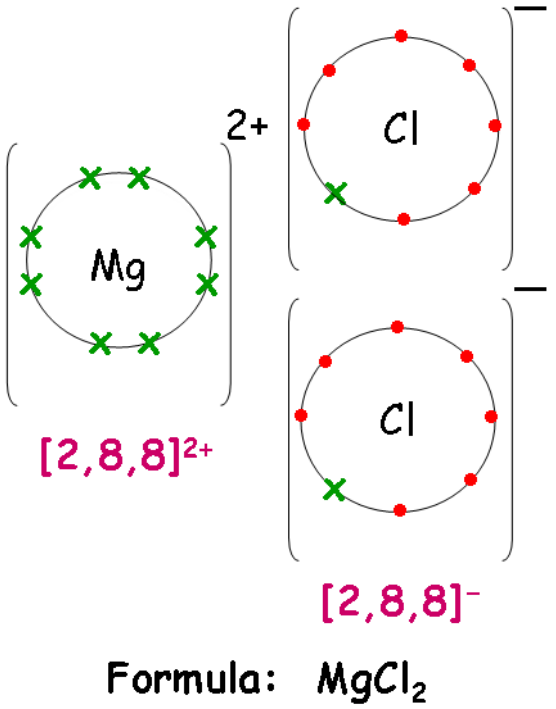
Using the example for magnesium chloride, draw dot and cross diagrams to show the ionic bonding in:

sodium oxide

magnesium oxide

calcium chloride

… answers at the end of the topic.

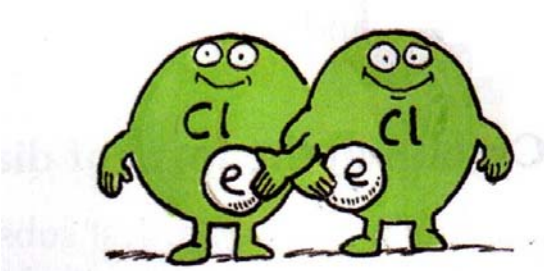


Covalent bonding - non-metal to non-metal

Many of the substances which make up our natural world are made only from **non-metal atoms.** **e.g.** H_2O CH_4 O_2 CO_2 $C_6H_{12}O_6$

Non-metal atoms form bonds with other non-metal atoms by **sharing pairs of electrons** – this is called **covalent** bonding.

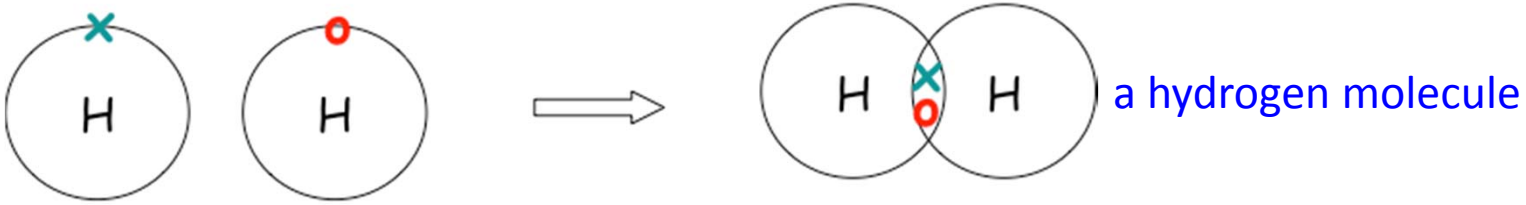
Each non-metal atom forms as many bonds as it can (to become more stable) until the outer shell is full.



Chlorine atoms share a pair of electrons in a covalent bond

Dot and cross diagrams (covalent bonds)

Hydrogen atoms have a valency of 1, so each can share one electron to form one bond.



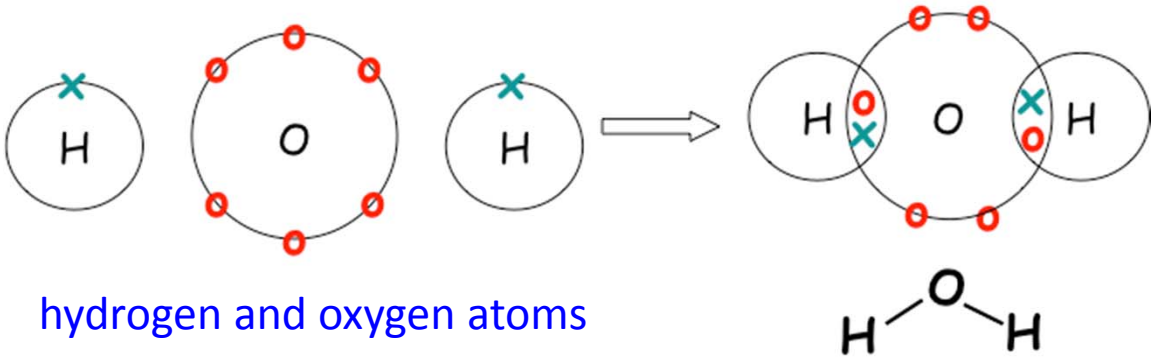
The **shared pair** of electrons, one from each atom, is a **covalent bond**. We draw the shared pair as one dot and one cross in the overlap between the two outer shells.

The negatively-charged electrons of the shared pair attract the positively-charged nuclei of the two atoms, holding them together **strongly** by **electrostatic attraction**.

An oxygen atom has a valency of 2, so it shares two of its electrons to form two covalent bonds.

Hydrogen atoms have a valency of 1, so they can only share one electron and form one bond.

This is why we have two hydrogen atoms and one oxygen atom in a water molecule, which we show by overlapping each of the hydrogen atoms' outer shells with the oxygen atom, and drawing a shared pair of electrons in each overlap. This leaves four unshared electrons in the outer shell of the oxygen atom.



hydrogen and oxygen atoms

a water molecule

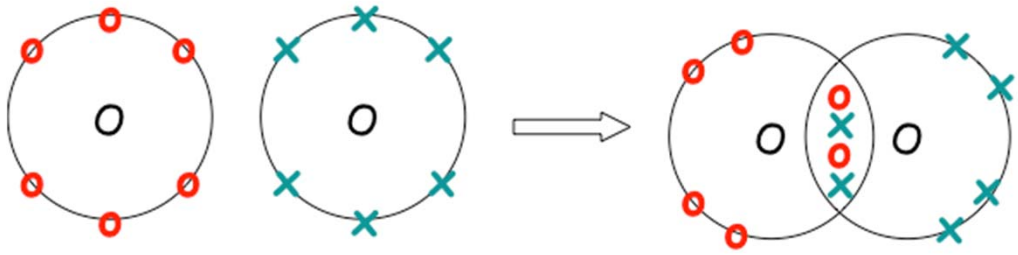
Practice:

Draw dot and cross diagrams for these molecules: (answers at the end of the topic)

Hydrogen chloride	HCl
Chlorine	Cl_2
Methane	CH_4
Ammonia	NH_3
Ethane	C_2H_6

An oxygen atom can share two electrons with another oxygen atom, however, making two covalent bonds between the SAME two atoms – a **double bond.**

This is why the formula for oxygen molecules is $\mathbf{O_2}$



two oxygen atoms

O=O

an oxygen molecule

Practice:

Draw dot and cross diagrams for these molecules:

Carbon dioxide	CO_2
Ethene	C_2H_4

It is also possible to have a triple bond, with three shared pairs of electrons. See if you can draw a dot-and-cross diagram for:

Nitrogen	N_2

Working out the formula of covalent compounds:

1) Use the name to identify the atoms present
2) Write the valency for each
3) Swap the valencies
4) Simplify if they will both divide by same number

e.g. Carbon dioxide

C **O**

4 2 *(swap to give C_2O_4 and simplify because both will divide by 2)*

so the formula is: **CO_2**

Work out the formula for a molecule made from each of the following pairs of atoms:

i) carbon and chlorine
ii) phosphorus and hydrogen
iii) sulphur and oxygen
iv) sulphur and hydrogen

… answers at the end of the topic

Metallic bonding - metal to metal

Atomic-resolution microscope images show us that metal atoms are arranged in regular layers.

A metal consists of layers of **positively charged metal ions**, which have given up their outer shell electrons to form a 'sea' of free, **delocalised** electrons (which have a negative charge).

Strong **electrostatic attractions** hold the electrons and the metal ions together in a **metallic bond**.

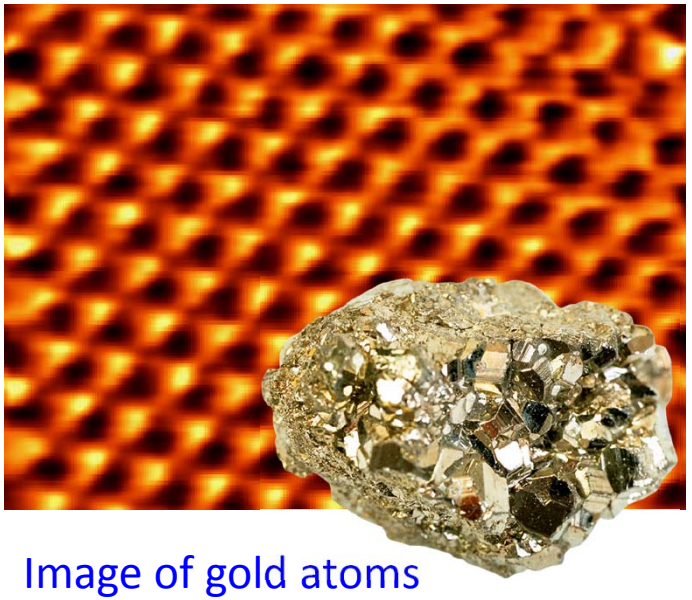
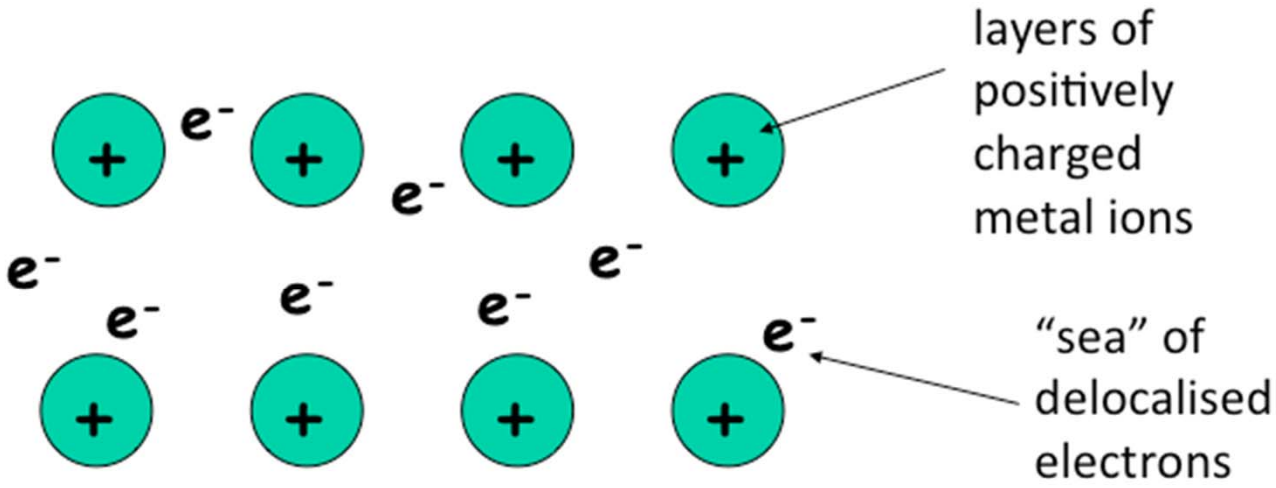


Image of gold atoms
Scale: atoms are about a millionth of a millimetre apart



A diagram to show metallic bonding in any metal

Answers

Work out formula for:

- aluminium fluoride, AlF_3
- magnesium chloride, $MgCl_2$
- sodium bromide, $NaBr$
- magnesium oxide, MgO
- potassium oxide, K_2O
- copper(I) oxide, Cu_2O
- iron(III) chloride, $FeCl_3$
- zinc sulphide, ZnS
- silver oxide Ag_2O

Work out formula for:

- potassium sulphate, K_2SO_4
- sodium phosphate, Na_3PO_4
- ammonium bromide, NH_4Br
- lithium hydroxide, $Li(OH)_2$
- calcium carbonate, $CaCO_3$
- magnesium nitrate $Mg(NO_3)_2$

Practice with these example reactions. You'll need to check the word equations as not all the products have been given.

Making copper nitrate by reacting copper(II) oxide with dilute nitric acid

$CuO(s) + 2HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + H_2O(l)$

Testing for sulphate ions in sodium sulphate solution using barium chloride solution

$Na_2SO_4(aq) + BaCl_2(aq) \rightarrow BaSO_4(s) + 2NaCl(aq)$

Testing for iron(III) ions in iron(III) chloride solution

$FeCl_3(aq) + 3NaOH(aq) \rightarrow Fe(OH)_3(s) + 3NaCl(aq)$

Making lead(II) sulphate by precipitation from suitable aqueous solutions

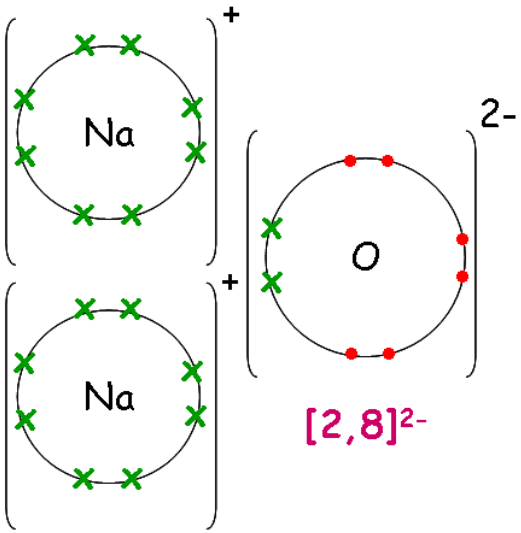
e.g. $Pb(NO_3)_2(aq) + K_2SO_4(aq) \rightarrow PbSO_4(s) + 2KNO_3(aq)$

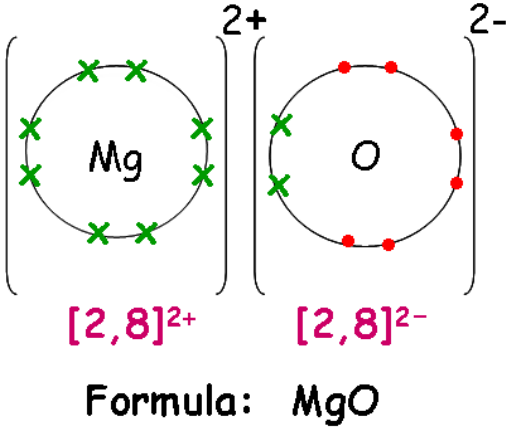
Displacing iodine from potassium iodide solution by reacting it with chlorine water

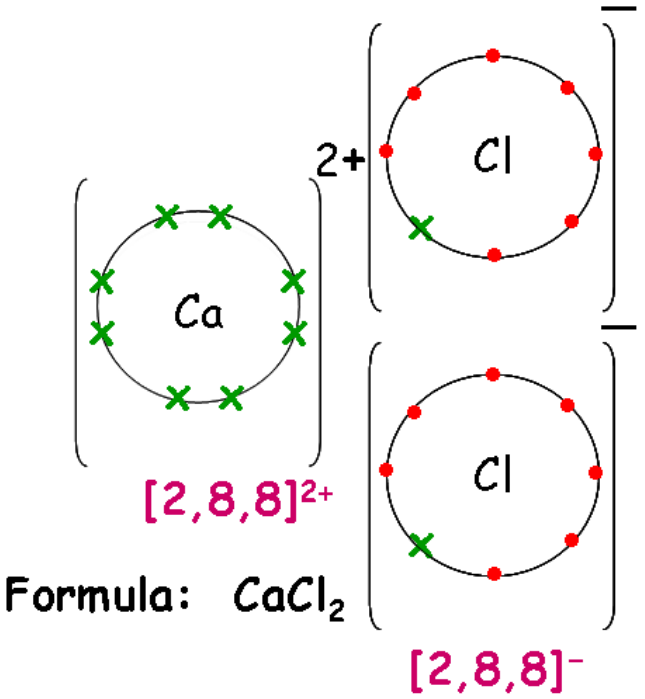
$2KI(aq) + Cl_2(aq) \rightarrow 2KCl(aq) + I_2(aq)$

Using the example for magnesium chloride, draw dot and cross diagrams to show the ionic bonding in:

sodium oxide
magnesium oxide
calcium chloride

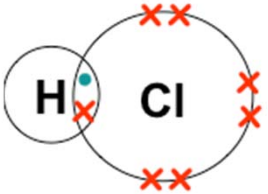


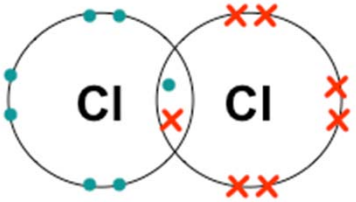


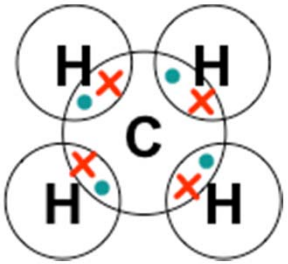


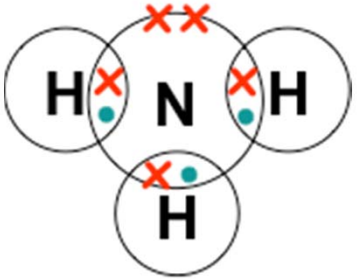
Draw dot and cross diagrams for these molecules:

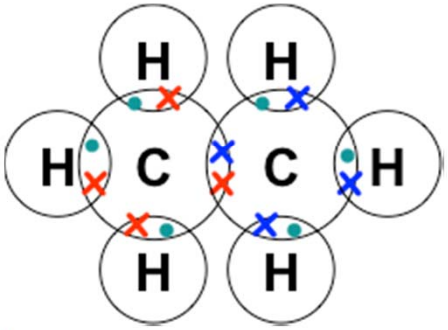
Hydrogen chloride	HCl
Chlorine	Cl_2
Methane	CH_4
Ammonia	NH_3
Ethane	C_2H_6





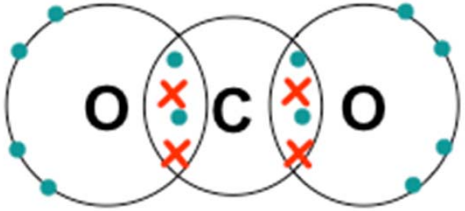


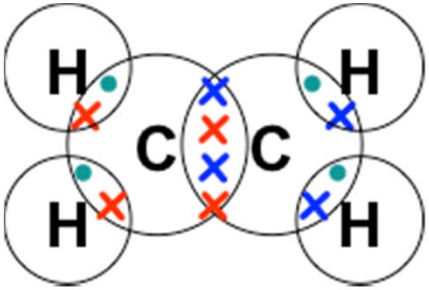


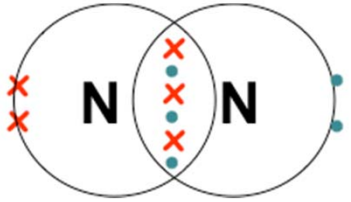


Draw dot and cross diagrams for these molecules:

Carbon dioxide	CO_2
Ethene	C_2H_4
Nitrogen	N_2







Work out the formula for a molecule made from each of the following pairs of atoms:

i)	carbon and chlorine	CCl_4
ii)	phosphorus and hydrogen	PH_3
iii)	sulphur and oxygen	SO_2
iv)	hydrogen and sulphur	H_2S