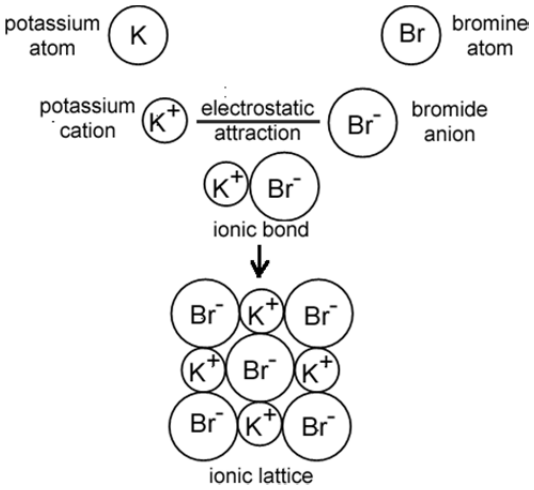
CHEM1001 Worksheet 3: Ionic and Covalent Bonding

Model 1: Ionic Bonding



The compounds formed by metals and non-metals contain *ionic* bonds. Metal atoms lose electrons to form cations. Non-metal atoms gain electrons to form anions. The interactions between cations and anions are *ionic* and are often called *ionic bonds.* Simply, it is the coming together of opposite charges in a strict ratio based on *electrostatic attraction.*

Ionic compounds form *extended ionic lattices* which contain an 'infinite' networks of ionic bonds.

Cations *lose* electrons so that they have an empty outer shell: Group 1 metals lose 1 electron, Group 2 metals lose 2 electrons and Group 13 metals lose 3 electrons.

Anions *gain* electrons so that they have a full outer shell: Group 17 non-metals gain 1 electron, Group 16 non-metals gain 2 electrons and Group 15 non-metal gain 3 electrons. Gain or loss of more than 3 electrons requires considerable energy and rarely occurs. This limits the combinations of elements that can form ionic compounds.

Critical thinking questions

1. What charge will a group 2 cation have?

2. What charge will a group 16 anion have?

3. What charge will a group 15 anion have?

Ionic compounds form in strict ratios of anions to cations to gain overall neutrality. For example, Ca^{2+} and Cl^- will form an ionic lattice in the ratio 1 : 2 ($1 \times 2 + 2 \times (-1) = 0$). The resulting ionic compound has the formula $CaCl_2$ and is calcium chloride. Notice that the *cation is given first* in the formula and name.

4. Predict the ions formed for each of the elements below.
   iodine, sodium, oxygen, aluminium, nitrogen, sulfur, bromine, magnesium

5. Form as many ionic compounds as you can from this list and write down the formula of each.

Some ions contain groups of atoms. These are called *polyatomic ions*. The groups of atoms in a polyatomic ion tend to stay together in reactions. Some of the most common are listed opposite. Polyatomic ions can form compounds with each other and with atomic ions. Examples include:

- calcium nitrate: $Ca(NO_3)_2$
- calcium sulfate: $CaSO_4$
- ammonium chloride: NH_4Cl

Polyatomic ion
hydroxide: OH^-
sulfate: SO_4^{2-}
carbonate: CO_3^{2-}
nitrate: NO_3^-
phosphate: PO_4^{3-}
ammonium: NH_4^+

Note: Two NO_3^- ions are needed to balance the charge of Ca^{2+}, just as in $CaCl_2$. To show this, brackets are placed around the polyatomic ion with the two outside the bracket. In the other examples, only one polyatomic ion is required and no brackets are used.

6. Write down the formulae of the following ionic compounds. (*Hint*: remember to put the cation first, to balance the charges and to use bracket if required around a polyatomic ion.)

(i) sodium hydroxide

(ii) sodium nitrate

(iii) sodium sulfate

(iv) sodium phosphate

(v) magnesium hydroxide

(vi) magnesium nitrate

(vii) ammonium hydroxide

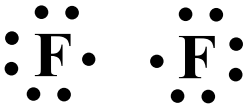
(viii) ammonium sulfate

Model 2: Covalent bonding

The interaction between two non-metals is *covalent*. Two (or more) non-metals form *covalent bonds*. In a *covalent bond*, two atoms *share* their electrons, in order for each to gain a noble gas configuration. For most of the atoms you come across, this will mean having 8 electrons in the valence shell – the octet rule.

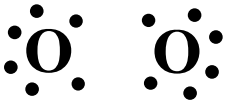
For some elements in period 3 and below, most notably S and P, this rule can be broken. Compounds of these elements will be discussed later.

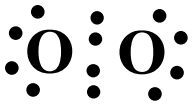
each F atom has 7 valence electrons so require 1 more to reach 8



each F atom shares 1 of its electrons to reach 8

each O atom has 6 valence electrons so require 2 more to reach 8



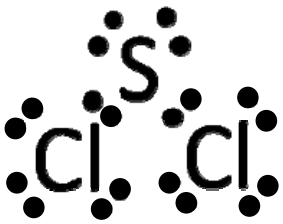


each O atom shares 2 of its electrons to reach 8

Critical thinking questions

1. Label the bonding (shared) and non-bonding (unshared) electron pairs in F_2 and O_2 on the diagram.

When the non-metals are not in the same group, one atom shares electrons with several other atoms. Consider the formula of a compound containing sulfur and chlorine.



- sulfur: 6 valence electrons so needs 2 to reach 8
- chlorine: 7 valence electrons, needs 1 to reach 8

To achieve 8 electrons on each atom, S bonds to two Cl atoms to form SCl_2 or sulfur dichloride. The atom on the left in the Periodic Table (S) is given first and the prefix "di" shows there are 2 Cl atoms.

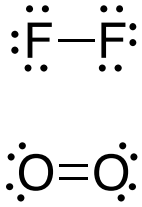
2. How many electrons do the elements below need to form an isoelectronic configuration with a noble gas?

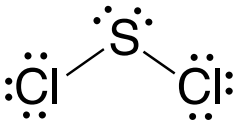
hydrogen, carbon, nitrogen, oxygen, fluorine, silicon, phosphorus, sulfur, chlorine

3. Each covalent bond leads to each atom involved gaining 1 electron to its total. How many bonds do the elements below need to form an isoelectronic configuration with a noble gas?

hydrogen, carbon, nitrogen, oxygen, fluorine, silicon, phosphorus, sulfur, chlorine

In chemical structures, sticks are used to represent covalent bonds: a single stick represents sharing of 2 electrons and a single bond, 2 sticks represents sharing of 4 electrons and a double bond and 3 sticks represents sharing of 6 electrons and a triple bond. Lone pairs are shown as dots. The chemical structures of F_2, O_2 and SCl_2 are shown opposite.



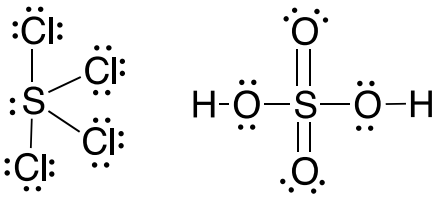


4. What is the total number of valence electrons around each atom in F_2, O_2 and SCl_2?

5. Show the bonding in the following molecules and include any lone pairs. (*Hint*: remember from Q3, H can only form a single bond, C needs to form 4 bonds, etc. Elements can bond to themselves and can use single, double or triple bonds.)

NH_3	N_2H_4
N_2H_2	CH_3NH_2
CH_3CN	CH_2O

Elements in the third period and below are able to fit more than 8 electrons in their valence shell. Although many of their molecules do obey the octet rule, some exceed it, particularly when they are surrounded by O, F or Cl atoms. Two examples are shown opposite.



6. What is the total number of valence electrons around the S atoms in SCl_4 and H_2SO_4?

7. In SCl_4, sulfur has 6 valence electrons and Cl has 7 valence electrons.
   (a) What is the total number of valence electrons available to form all of the bonds and lone pairs?

   (b) Count up the number of electrons in bonds and in lone pairs. Does it match your answer to (a)?

8. Show the bonding in the following molecules and include any lone pairs. (*Hint*: remember that the number of bonds that O needs to make and that you can only use the electrons that are available).

SO_3	SO_2

Model 3: Ionic or Covalent?

Ionic bonding requires a metal and a non-metal. Covalent bonding occurs between non-metals.

Critical thinking questions

1. Predict whether the bonding in the **oxides** following elements will be covalent or ionic:

   (a) sodium (b) magnesium (c) aluminium

   (d) silicon (e) phosphorus (f) sulfur

2. Write down the formula of each oxide.