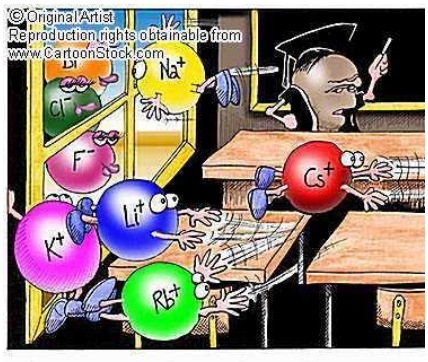


"Perhaps one of you gentlemen would mind telling me just what it is outside the window that you find so attractive..?"

Chapter 6: Chemical Bonding

Learning Objectives

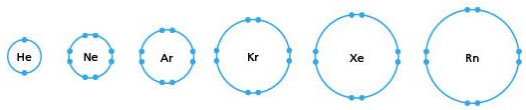
- Describe the **formation of ions** by **electron loss/gain** to obtain the electronic configuration of a noble gas.
- Describe the formation of **ionic bonds** between metals and non-metals E.g. *NaCl*
- State that ionic materials contain a **giant lattices** in which the ions are held by **electrostatic attraction**.
- Deduce the **formulae** of other ionic compounds from diagrams of their lattice structures, limited to binary compounds.
- Relate the **physical properties** of ionic compounds to their lattice structure.

Let's Recall…

- Elements in Group 0 of the periodic table is called **monatomic elements**, also known as noble gases.
- Molecules are substances that are made up of **two or more atoms** joined together chemically. E.g. Hydrogen gas (H_2)
- Compounds are substances that are made up of **two or more elements** that are chemically joined together. E.g. Water (H_2O), sodium chloride (NaCl)

Very few elements exist as individual atoms. Most of the matters in the world is made up of atoms that are chemically combined in some way. Why is that so?

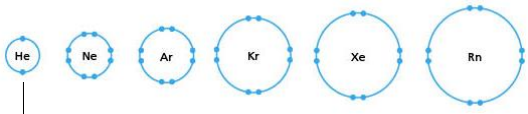
Let's take a look at the electronic configuration of noble gases.



Only the valence shells are shown.

What do they have in common?
Each noble gas has a **full valence shell.**.

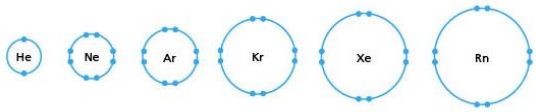
Helium atoms are unreactive because …



Helium has 2 valence electrons.

We say that it as a duplet configuration.

Other noble gas atoms are unreactive because …



Atoms of other noble gases have 8 valence electrons.

This is called an octet configuration.

- An atom is stable (or unreactive) if it has a duplet or octet configuration.
- This is known as the **noble gas configuration**.

So why are other atoms reactive?

- Atoms of elements (besides the noble gases) *do not have full shells of electrons*.
- These atoms react in order to have the noble gas structure.
- Hence atoms tend to be reactive.

How to achieve noble gas structure?

- By losing valence electrons
- By gaining valence electrons
- By sharing valence electrons

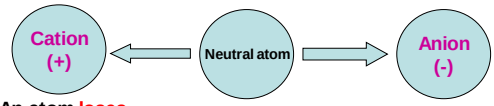
When atoms lose and gain electrons, they form ions.

Formation of Ions

Forming Ions

What is an ion?

- An ion is a **charged** particle formed from an atom or a group of atoms by the **loss** or **gain** of **electrons**.



An atom loses electrons to form a positive ion (cation).

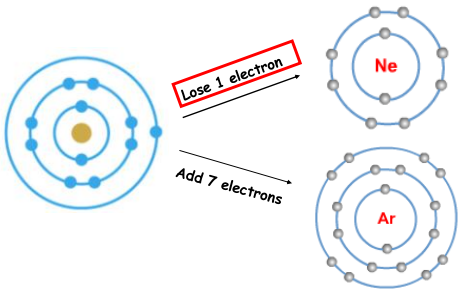
An atom gain electrons to form a negative ion (anion).

Formation of Sodium ion

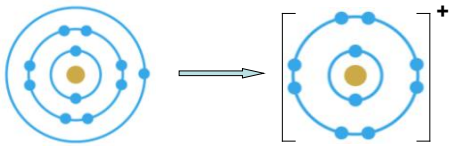
- Element: Sodium
- Chemical symbol: **Na**
- Group in Periodic Table? **Group 1**
- Electronic Configuration? **(2, 8, 1)**

Do you think sodium will gain or lose electrons to obtain the stable electronic configuration of a noble gas?

To add or to lose electrons?



Formation of Sodium ion (Cont'd)



- It is **easier** for sodium to **lose 1 electron** than to gain 7 electrons to achieve the noble gas structure.
- Hence, it become **Sodium ion (Na^+)**.

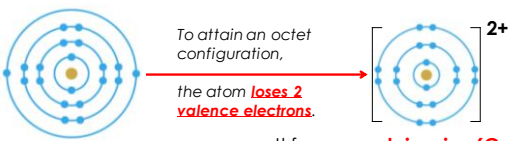
	Sodium atom	Sodium ion
No. of protons	11	11
No. of electrons	11	10
No. of neutrons	12	12

Why sodium ion is written as Na^+?

Answer: There are 11 protons but 10 electrons. Since there are more protons than electron, the sodium ion formed has 1 positive charge.

Formation of Calcium ion

- Element: Calcium
- Chemical symbol: Ca
- Group in Periodic Table? Group II
- Electronic Configuration? (2, 8, 8, 2)



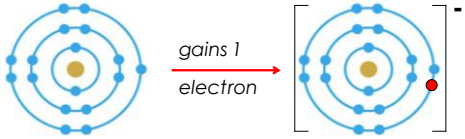
It forms a **calcium ion (Ca^{2+})**.

Formation of Chloride ion

- Element: Chlorine
- Chemical symbol: Cl
- Group in the periodic table? Group 7
- Electronic configuration? (2, 8, 7)

Do you think chlorine will gain or lose electrons to obtain the stable electronic configuration of a noble gas?

Formation of Chloride Ion



- It is **easier** for chlorine to **gain one electron** than to lose all 7 electrons to achieve the noble gas structure.
- Hence, it becomes **chloride ion (Cl^-).**

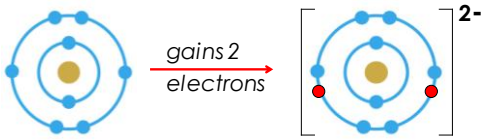
	Chlorine atom	Chloride ion
No. of protons	17	17
No. of electrons	17	18
No. of neutrons	18	18

Why chloride ion is written as Cl^-?

Answer: there are 17 protons but 18 electrons. Since there are more electrons than protons, the chloride ion has 1 negative charge.

Formation of oxide ion

- Element: Oxygen
- Chemical symbol: O
- Group in Periodic Table? Group 6



It gains two electrons to form an oxide ion (O^{2-}).

Common Ions and Their Charges

Charge on ion	Name of cation	Formula of cation
+1	Ammonium	NH_4^+
	Hydrogen	H^+
	Potassium	K^+
	Silver	Ag^+
	Sodium	Na^+
+2	Calcium	Ca^{2+}
	Copper(II)	Cu^{2+}
	Magnesium	Mg^{2+}
	Zinc	Zn^{2+}
	Iron(II)	Fe^{2+}
+3	Iron(III)	Fe^{3+}
	Aluminium	Al^{3+}

- **Cations are usually ions of metals.**
- **H^+ and NH_4^+ are some exceptions.**

- **Some metals form more than 1 type of ion e.g. iron forms Fe^{2+} and Fe^{3+}.**

Common Ions and Their Charges

Charge on ion	Name of anion	Formula of anion
-1	Bromide	Br^-
	Chloride	Cl^-
	Hydroxide	OH^-
	Nitrate	NO_3^-
-2	Carbonate	CO_3^{2-}
	Oxide	O^{2-}
	Sulphate	SO_4^{2-}

Polyatomic ions is a group of atoms that carries a charge.

Conclusion

- Elements that do not have fully filled outermost shells will tend to either **lose or gain electrons** in order to obtain the stable electronic configuration of the noble gases. Thus, they formed ions.
- Atom that loses electrons → **positively** charged ion (**cations**)
- Atom that gains electrons → **negatively** charged ion (**anions**)

- **Metals will lose electrons; non-metals will gain electrons**

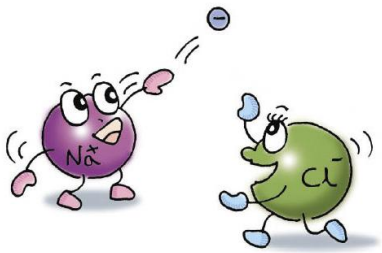
Ionic Bonding

Table Salt (aka sodium chloride)

Ionic Bond

- Between **metals** and **non-metals**.
- When ionic bonding occurs, metallic atoms will lose electrons to non-metallic atoms.
- The compound formed is called **Ionic compounds**.
- Use '**dot-and-cross**' diagram to represent the formation of ionic compounds.

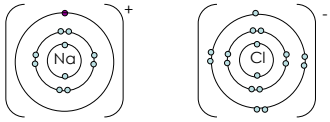
Ionic Bonding: Transfer of Electrons

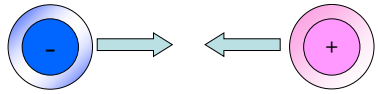


Formation of Ionic Compound

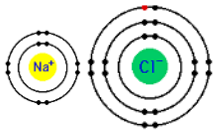
- Step 1
  Formation of positive ions
  (this involves the metals)
- Step 2
  Formation of negative ions
  (this involves the non-metals)
- Step 3
  Formation of ionic bonds

Example: Sodium Chloride

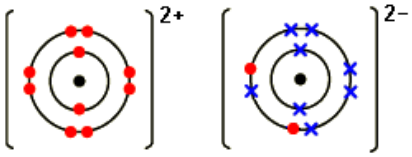




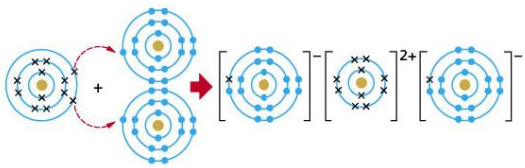
- Na^+ ion and Cl^- ion are attracted to each other by **electrostatic attraction** to form NaCl in a **three-dimensional arrangement.**.
- This electrostatic attraction is known as **ionic bonds**.

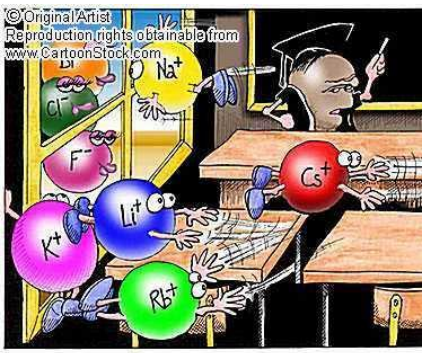


Example: Magnesium oxide



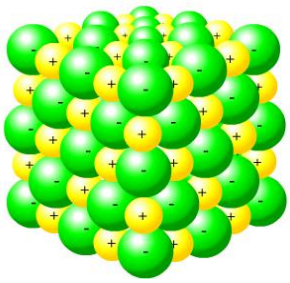
Exercise: Magnesium chloride



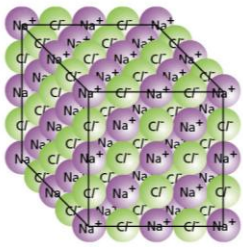


"Perhaps one of you gentlemen would mind telling me just what it is outside the window that you find so attractive..?"

3-Dimensional Arrangement of ionic compound



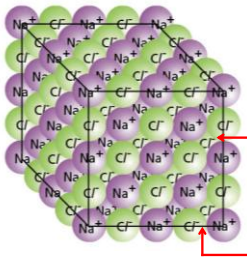
Structure of Ionic Compounds



Ionic compounds form giant ionic structures.

Such structures are also known as
giant lattice structure or
crystal lattice.

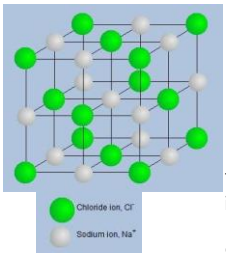
Example: Sodium chloride



In a lattice, millions of sodium and chloride ions are arranged in an orderly manner.

These ions are held in place by ionic bonds throughout the entire lattice.

Example: Sodium chloride



Each *sodium* ion is surrounded by 6 *chloride* ions.
Each *chloride* ion is surrounded by 6 *sodium* ions.

The ratio of sodium ions to chloride ions is 1 : 1.
Hence, the formula of sodium chloride is **NaCl**.

NaCl is the **formula unit** of sodium chloride.

http://www.avogadro.co.uk/structure/chemstruc/ionic/g-ionic.htm

Writing Formula of Ionic Compounds

– the "criss-cross" method.

Example 1: Sodium chloride

Na^+ Cl^-

Na_1 Cl_1

We are only interested in the oxidation numbers NOT the charges.

We cross the oxidation numbers ONLY.

→ Ionic formula of sodium chloride is **NaCl**.

Writing Formula of Ionic Compounds

– the "criss-cross" method.

Example 2: Magnesium chloride

Mg^{2+} Cl^-

Mg_1 Cl_2

The oxidation number of magnesium ion is 2. Therefore, the number 2 is crossed over to Cl.

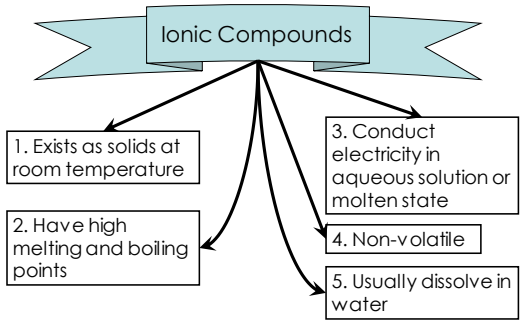
The oxidation number of chloride ion is 1, and it is crossed over to Mg.

We ignore the number if it is 1.

→ Ionic formula of magnesium chloride is **$MgCl_2$**.

Properties of Ionic Compounds

Properties of Ionic Compounds



1. Exists as solids at room temperature

- The lattice of an ionic compound is held together by **strong ionic bonds between the ions**.
- A **large amount of energy** is needed to **overcome** these strong bonds and to change an ionic compound from solid to liquid state.

2. Have high melting and boiling points

- The **ions** in ionic compounds are held together by **strong ionic bonds**.
- **A lot of energy** is used to **overcome** the **strong electrostatic forces** that are holding the ions together.

3. Conduct electricity in aqueous solution or molten state

- The ions can move about in **molten** and in **aqueous** solution because the giant lattice structure has broken down. **Electricity is conducted when ions move around freely**.
- In **solid** state, the **ions cannot move around freely** because they are held strongly together by the electrostatic force in a giant lattice structure.

4. Non-volatile

- A volatile substance is one that **evaporates easily**.
- An ionic compound **does not** evaporate easily because of the **strong electrostatic forces** holding the ions together.

5. Usually dissolve in water

5. Usually dissolve in water

- Ionic compounds are usually **soluble in water** but **insoluble in organic solvent** (i.e. other than water).
- The water molecules can **separate** the positive ions from the negative ions, causing them to dissolve.

Exercise

- Draw a "dot and cross" diagram to show the bonding for the following compounds., Write down the formula of the compounds as well.
  (a) Between aluminium and chlorine
  (b) Between lithium and oxygen
  (c) Between calcium and nitrogen

Covalent Bonding

Learning Objectives

- Define that covalent bonding is the sharing of electrons between non-metals.
- Illustrate covalent bonding using "dot and cross" diagrams.
- Predict the arrangement of the electrons in other covalent molecules.
- Describe the physical properties of covalent compound with relation to its structure.

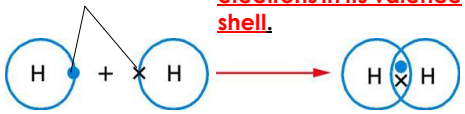
Covalent Bond

- Covalent bond is the bond that is formed when atoms **share** their valence electrons.
- Covalent bonding occurs between **non-metals**.
- When atoms combine by sharing their valence electrons, **molecules** are formed.

Example: Hydrogen

A hydrogen atom has **1 valence electron**.

Two hydrogen atoms **share** a pair of electrons so that **each atom has 2 electrons in its valence shell.**



As a result, both have a **stable duplet configuration.**

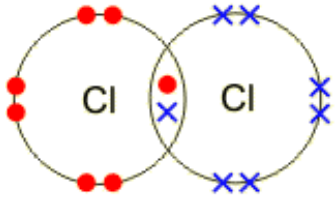
Example: Hydrogen

The *sharing of 2 electrons* forms a **single covalent bond**.

'Dot and cross' diagram	Structural formula	Molecular formula	Model
H × • H	H – H	H_2	

A single covalent bond or a **single bond** is represented by a single line '–' in the structural formula.

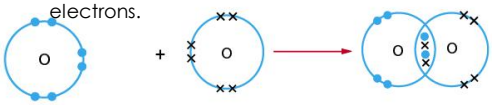
Exercise: Chlorine



Example: Oxygen

An oxygen atom has **6** valence electrons.

It needs 2 more electrons to form a stable octet structure.



Each oxygen atom **shares two of its electrons** with another oxygen atom.

Example: Oxygen

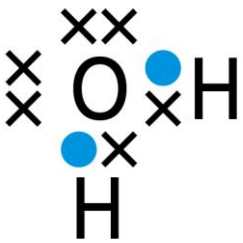
4 electrons are shared between 2 oxygen atoms.

Such a bond is called **a double covalent bond**.

'Dot and cross' diagram	Structural formula	Molecular formula	Model
	O=O	O_2	

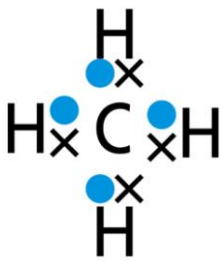
A **double bond** is represented by '=' in a structural formula.

Exercise: Water (H_2O)



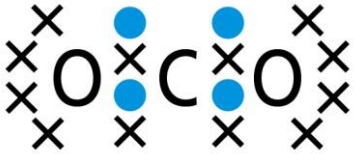
Showing outermost electrons only

Exercise: Methane (CH_4)



Showing outermost electrons only

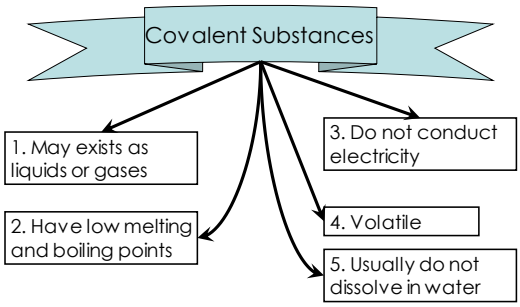
Exercise: CO_2



Showing outermost electrons only

Properties of Covalent Substances

Properties of Covalent Substances



1. May exists as liquids or gases

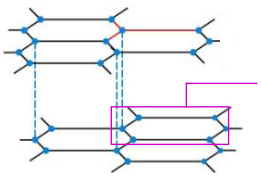
As the intermolecular forces (forces between the molecules) are **weak**, the molecules are **not held together tightly** compared to particles in a solid, hence, they are **free to move**.

2. Have low melting and boiling points

Their molecules are held together by **weak intermolecular forces** (forces between molecules). **Less heat energy** is needed to overcome these forces.

- Exception: Graphite

Why does graphite have high melting and boiling points?



In graphite, the bonds *within* each layer are strong and difficult to break.

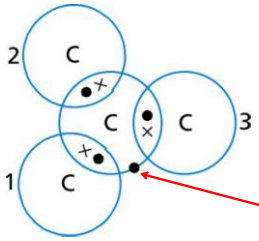
Hence, graphite has high melting and boiling points.

3. Do not conduct electricity

A covalent compounds consists of **neutral molecules**. They **do not** have **ions** which can move about to conduct electricity.

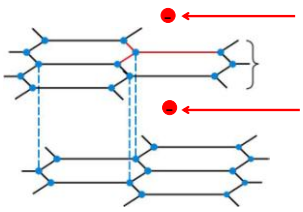
However, there are exception. Graphite is a good conductor of electricity.

Why is graphite able to conduct electricity?



In graphite, each carbon atom has **1 valence electron that is not used to form covalent bonds**.

Why is graphite able to conduct electricity?



There are **delocalised electrons**. These electrons can move along the layers from one carbon atom to the next when graphite is connected to a battery.

Hence, graphite is a good conductor of electricity.

4. Volatile

Most covalent compounds have **low boiling point**, hence, they are volatile and evaporate easily.

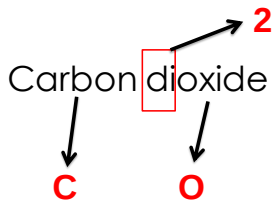
5. Usually do not dissolve in water

- Most covalent molecules are **insoluble in water** and **soluble in organic solvent**.

Chemical Formula of Covalent Substances

Prefix	Subscript
Mono-	1
Di-	2
Tri-	3
Tetra-	4

What is the chemical formula of carbon dioxide?



The chemical formula of carbon dioxide is **CO_2**.

What is the chemical formula of dinitrogen monoxide?

Dinitrogen monoxide

The chemical formula is **N_2O**.

What is the chemical formula of dinitrogen tetroxide?

dinitrogen tetroxide

The chemical formula is **N_2O_4**.

Predicting ionic and covalent compounds

Which of the following compounds would you expect to be ionic compounds and which are covalent compounds?

(a) BaF_2 ionic compound
(b) SF_4 covalent compound
(c) PH_3 covalent compound
(d) CH_3OH covalent compound