HL IB Chemistry

Your notes

The Ionic Model

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Forming Ions

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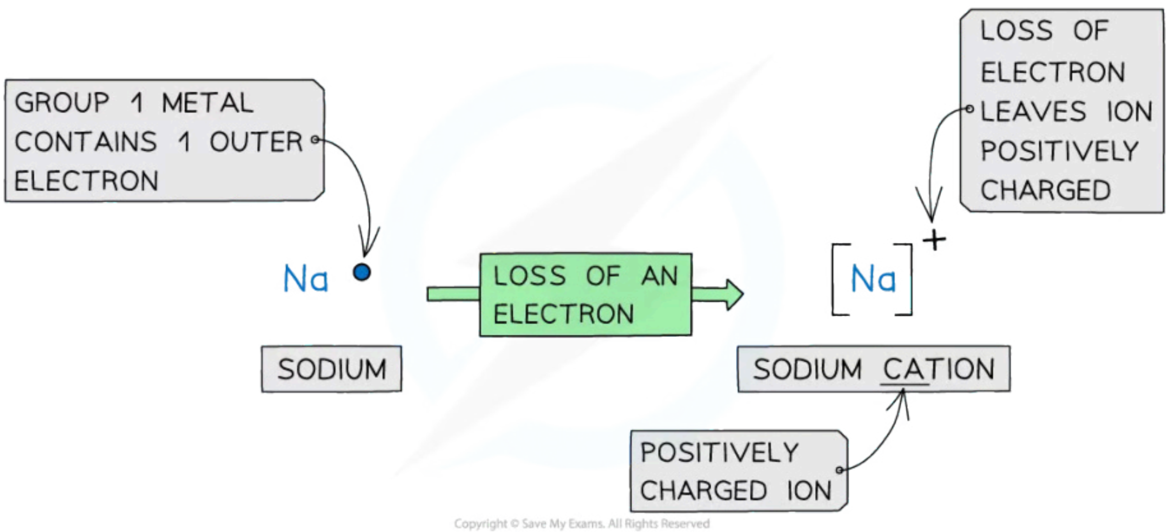
Forming Ions

How are ions formed?

- As a general rule, **metals** are on the **left** of the Periodic Table and **non-metals** are on the **right-hand** side
- **Ionic bonds** involve the **transfer** of electrons from a **metallic** element to a **non-metallic** element
- Transferring electrons usually leaves the metal and the non-metal with a **full outer shell**
- Metals **lose** electrons from their valence shell forming positively charged **cations**

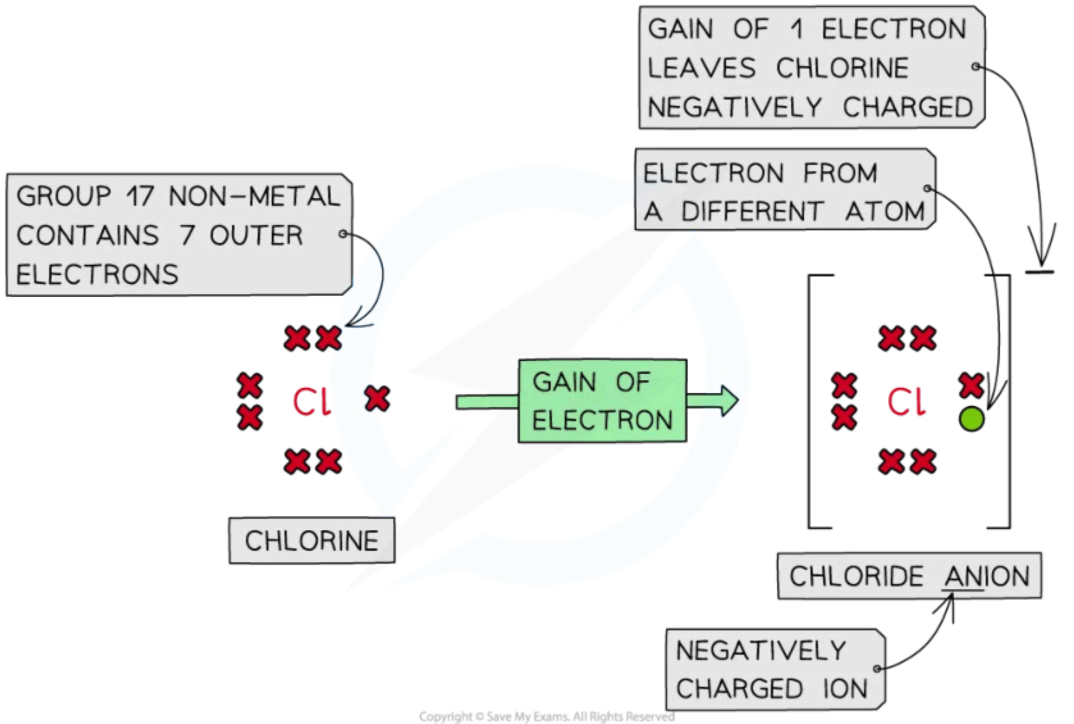
How a sodium atom forms a sodium ion



Forming cations by the removal of electrons from metals

- Non-metal atoms **gain** electrons forming negatively charged **anions**

How a chlorine atom forms a chloride ion



Forming anions by the addition of electrons to non-metals

- Once the atoms become ions, their electronic configurations are the same as a noble gas.
  - A sodium ion (Na^+) has the same electronic configuration as neon: [2,8]
  - A chloride ion (Cl^-) also has the same electronic configuration as argon: [2,8,8]

Examiner Tip

Metals usually **lose** all electrons from their outer shell to become positive ions or **cations.**

You can make use of the groups on the periodic table to work out how many electrons an atom is likely to lose or gain by looking at the **group** an atom belongs to.

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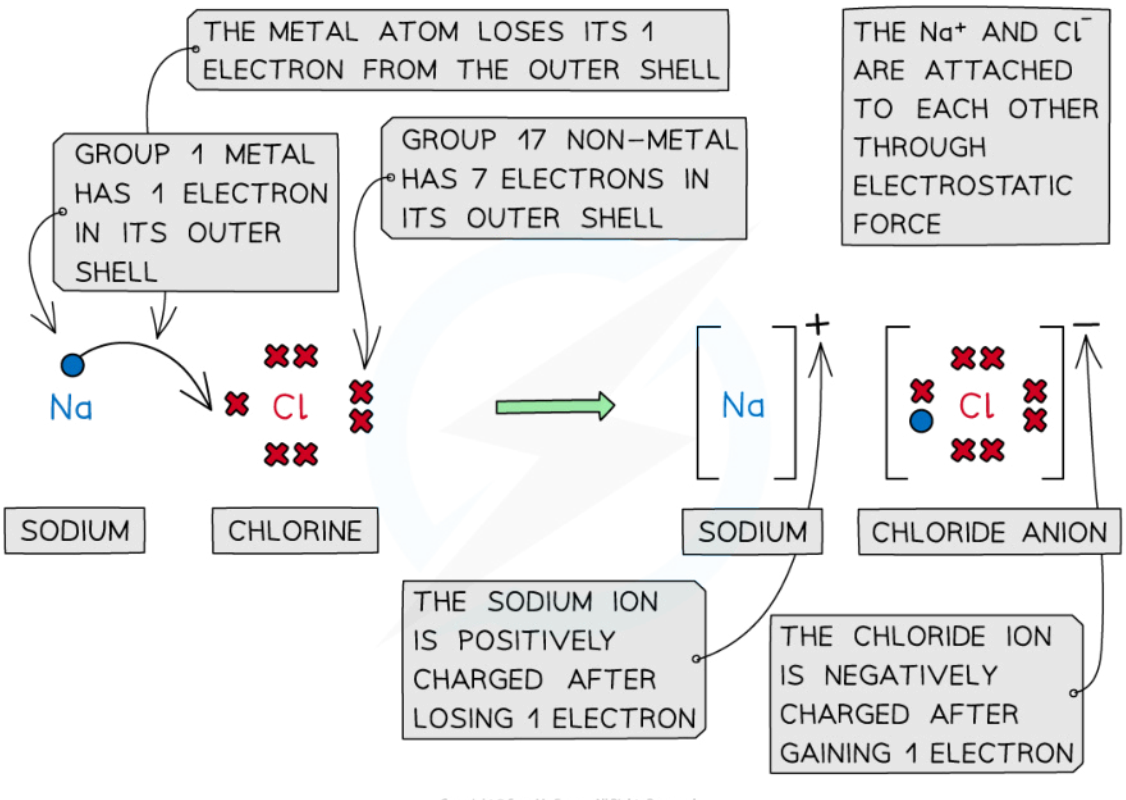
Binary Ionic Compounds

Binary Ionic Compounds

What is a binary ionic compound?

- A **binary ionic compound** is composed of ions of two different elements
  - They consist of a **metal cation** and a **non-metal anion**
- For example, sodium and chlorine react together to form the binary ionic compound, sodium chloride

Sodium and chlorine atoms react to form sodium chloride



Cations and anions bond together using strong electrostatic forces, which require a lot of energy to overcome

What is ionic bonding?

- One definition of **ionic bonding** is:

  'the force of attraction between oppositely charged species / ions'

- **Cations** and **anions** are oppositely charged and therefore attracted to each other

- **Electrostatic attractions** are formed between the oppositely charged ions to form **ionic compounds**
- This form of attraction is very **strong** and requires a lot of energy to overcome
  - This causes high melting points in ionic compounds

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Naming Ionic Compounds

Nomenclature of binary ionic compounds

- **Binary ionic compounds** are named with the cation first, followed by the anion
  - The anion adopts the suffix "ide"
- For example, when sodium reacts with iodine:
  - The name of the binary ionic compound starts with the metal, sodium
  - The name of the binary ionic compound ends with the nonmetal, including the "ide" suffix
    - Iod**ine** becomes iod**ide**
  - So, the binary ionic compound formed when sodium reacts with iodine is sodium iodide

Worked example

Give the IUPAC names of the binary ionic compounds formed in the following reactions:

1. Lithium + sulfur
2. Calcium + nitrogen
3. Sodium + hydrogen

Answer 1:

- The metal is lithium
- The nonmetal is sulfur, which becomes sulfide when it is bonded to a metal
- Therefore, the name of the binary ionic compound is lithium sulfide

Answer 2:

- The metal is calcium
- The nonmetal is nitrogen, which becomes nitride when it is bonded to a metal
- Therefore, the name of the binary ionic compound is calcium nitride

Answer 3:

- The metal is sodium
- The nonmetal is hydrogen, which becomes hydride when it is bonded to a metal
- Therefore, the name of the binary ionic compound is sodium hydride

- The following is a list of binary ionic compounds, because they contain a metal cation and a nonmetal anion:
  - Lithium fluoride
  - Sodium chloride
  - Potassium bromide
  - Magnesium sulfide
  - Calcium oxide

What is the charge of an ionic compound?

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- **Ionic compounds** are formed from a **metal** and a **non-metal** bonded together
- Ionic compounds are electrically neutral; the positive charges equal the negative charges
- This means that the overall charge of an ionic compound is 0
  - They are neutral

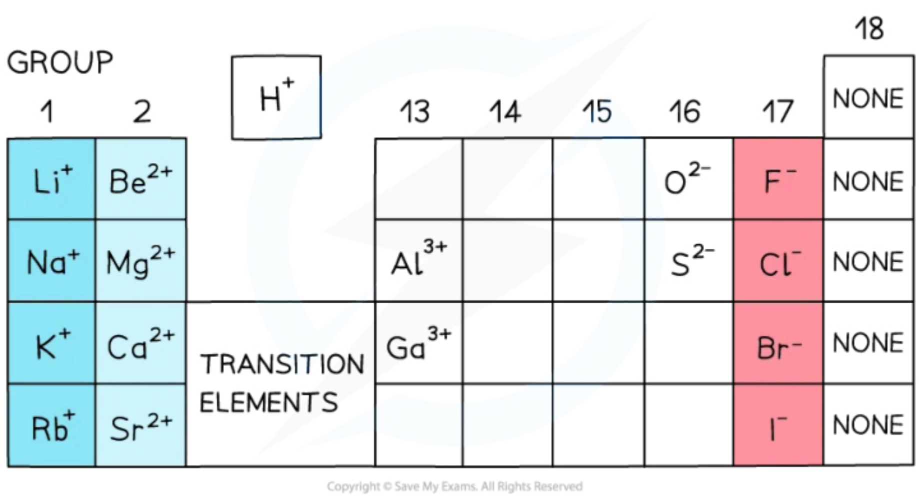
Charges on positive metal ions

- All metals form **positive** ions
  - There are some non-metal positive ions such as ammonium, NH_4^+, and hydrogen, H^+
- The **metals** in Group 1, Group 2 and Group 13 have a charge of 1+ and 2+ and 3+ respectively
- The charge on the ions of the **transition elements can vary** which is why **Roman numerals** are often used to indicate their charge
  - This is known as **Stock notation** after the German chemist Alfred Stock
- **Roman numerals** are used in some compounds formed from transition elements to show the **charge** (or **oxidation state**) of metal ions
  - Eg. in copper(II) oxide, the copper ion has a charge of 2+ whereas in copper(I) nitrate, the copper has a charge of 1+

Charges on negative nonmetal ions

- The **non-metals** in groups 15 to 17 have a negative charge and the suffix 'ide'
  - Eg. nitride, chloride, bromide, iodide
- Elements in group 17 gain 1 electron so have a 1– charge, eg. Br^-
- Elements in group 16 gain 2 electrons so have a 2– charge, eg. O^{2-}
- Elements in group 15 gain 3 electrons so have a 3– charge, eg. N^{3-}

Common charges of elements on the Periodic Table



The charges of simple ions depend on their position in the Periodic Table

What are polyatomic ions?

- **Polyatomic ions** are sometimes called **compound negative ions**

- They are ions that are made up of more than one type of atom
  - There are generally negative ions, although there are some positive ones such as the ammonium ion
- There are seven polyatomic ions you need to know for IB Chemistry:

Formulae of Polyatomic Ions Table

Ion	Formula and charge
Ammonium	NH_4^+
Hydroxide	OH^-
Nitrate	NO_3^-
Hydrogencarbonate	HCO_3^-
Carbonate	CO_3^{2-}
Sulfate	SO_4^{2-}
Phosphate	PO_4^{3-}

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Worked example

Determine the formulae of the following ionic compounds:

1. Magnesium chloride
2. Aluminium oxide
3. Ammonium sulfate

Answer 1: Magnesium chloride

- Magnesium is in Group 2 so has a charge of 2+
- Chlorine is in Group 17 so has a charge of 1–
- Each magnesium atom needs two chlorine atoms to balance the charges
- So, the formula is $\mathbf{MgCl_2}$

Answer 2: Aluminium oxide

- Aluminium is in Group 13 so the ion has a charge of 3+
- Oxygen is in Group 16 so has a charge of 2–
- The charges need to be equal, which means that 2 aluminium atoms require 3 oxygen atoms to balance electronically
- So, the formula is $\mathbf{Al_2O_3}$

Answer 3: Ammonium sulfate

- Ammonium is a polyatomic ion with a charge of 1+
- Sulfate is a polyatomic ion and has a charge of 2–
- To balance the charges, 2 ammonium ions are needed for each sulfate ion
- **Careful:** The polyatomic ion needs to be placed in a bracket if more than 1 is needed
- So, the formula of ammonium sulfate is $(NH_4)_2SO_4$

Examiner Tip

Remember: Polyatomic ions are ions that contain more than one type of element, such as OH^- .

If more than one polyatomic ion is needed in a chemical formula, then it is placed inside a bracket with the number of them outside the bracket, e.g. $Ca(NO_3)_2$.

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Ionic Lattices

Ionic Lattices

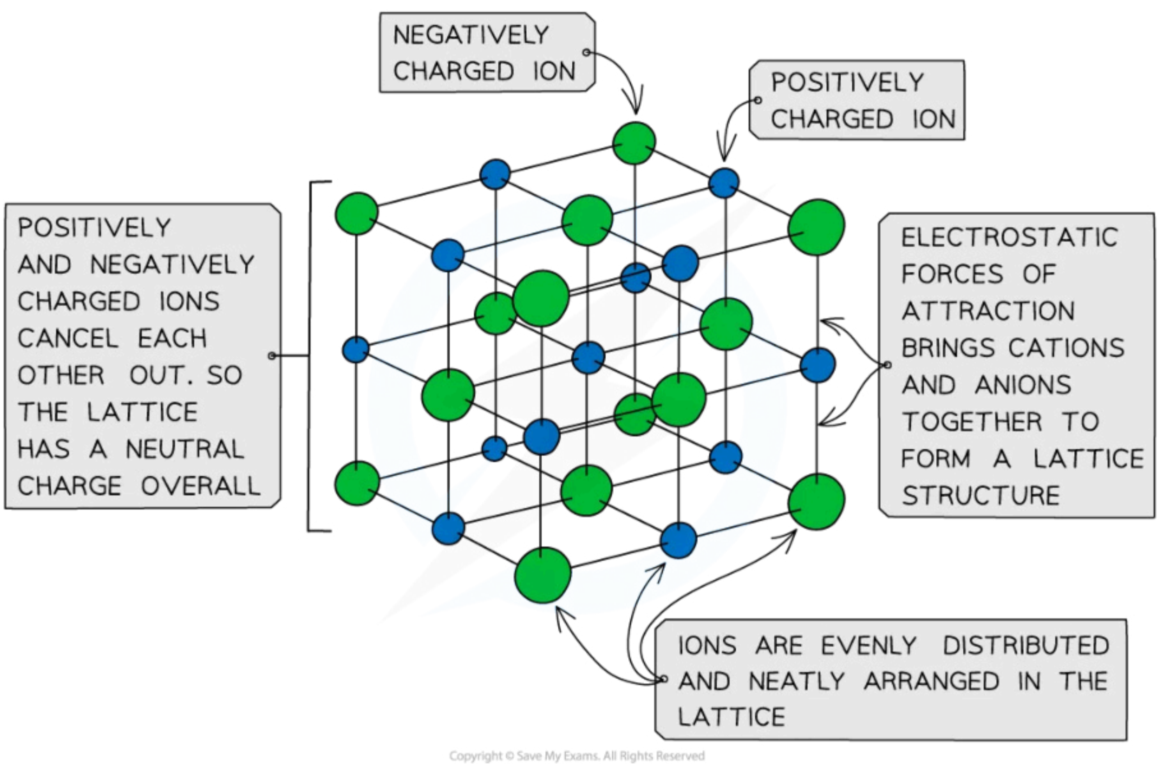
What is an ionic lattice?

- The ions form a **lattice structure**, known as an ionic lattice
  - This is an evenly distributed **crystalline** structure
- Ions in a lattice are arranged in a **regular repeating pattern** so that positive charges cancel out negative charges
- Therefore, the final lattice is overall electrically **neutral**

What forces hold together an ionic lattice?

- The ionic lattice consists of alternating cations and anions
  - Cations are positively charged ions and anions are negatively charged ions
- Therefore, there are strong electrostatic forces of attraction between the oppositely charged ions
  - **Remember:** This is one possible definition of ionic bonding

Giant ionic lattice structure diagram



Ionic solids are arranged in lattice structures

Lattice Enthalpy

- The **lattice dissociation enthalpy** ($\Delta H_{latt}^{\ominus}$) is defined as the standard enthalpy change that occurs on the formation of 1 mole of **gaseous ions** from the solid lattice
- Since this is always an endothermic process, the enthalpy change will always have a **positive** value
- The $\Delta H_{latt}^{\ominus}$ is always **endothermic** as energy is always required to **break** any bonds between the ions in the lattice

$$NaCl\ (s) \rightarrow Na^{+}\ (g) + Cl^{-}\ (g) \quad \Delta H_{lat}^{\ominus} = +790\ kJ\ mol^{-1}$$

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Properties of Ionic Compounds

- Different types of **structure** and **bonding** have different effects on the **physical properties** of substances such as their **melting** and **boiling points**, **electrical conductivity** and **solubility**

Ionic bonding & giant ionic lattice structures

- Ionic compounds are **strong**
  - The **strong electrostatic forces** in ionic compounds keep the ions held strongly together
- They are **brittle** as ionic crystals can split apart
- Ionic compounds have **high melting** and **boiling points**
  - The strong electrostatic forces between the ions in the lattice act in all directions and keep them strongly together
  - Melting and boiling points increase with the charge density of the ions due to the **greater electrostatic attraction** of charges
  - $Mg^{2+}O^{2-}$ has a higher melting point than $Na^{+}Cl^{-}$
- Ionic compounds are **not volatile**
  - Volatility refers to the vapourisation of a chemical
  - Large amounts of energy are required to overcome the strong electrostatic forces of attraction, which means that ionic compounds are not volatile
- Ionic compounds are **soluble** in water as they can form **ion-dipole bonds**
- Ionic compounds only **conduct electricity** when **molten** or **in solution**
  - When molten or in solution, the ions can freely move around and conduct electricity
  - As a solid, the ions are in a fixed position and unable to move around

Table comparing the characteristics of giant ionic lattices with other structure types

	Giant ionic	Giant metallic	Simple covalent	Giant covalent
Melting / boiling point	High	Moderately high to high	Low	Very high
Electrical conductivity	Only when molten or in solution	When solid or liquid	Do not conduct electricity	Do not conduct electricity (except **graphite**)
Solubility	Soluble	Insoluble but some may react	Usually insoluble unless they are polar	Insoluble
Hardness	Hard, brittle	Hard, malleable	Soft	Very hard (**diamond and silica**) or soft (**graphite**)

Physical state at room temperature	Solid	Solid	Solid, liquid or gas	Solid
Forces	Electrostatic attraction between ions	Delocalised electrons attracting positive ions	Weak intermolecular forces and covalent bonds within a molecule	Electrons in covalent bonds between atoms
Particles	Ions	Positive ions in a sea of electrons	Small molecules	Atoms
Examples	NaCl	Copper	Br_2	Graphite, silicon(IV) oxide

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Worked example

The table below shows the physical properties of substances **X**, **Y** and **Z**.

Substance	Melting point (°C)	Electrical conductivity when molten	Solubility in water
X	839	Good	Soluble
Y	95	Very poor	Almost insoluble
Z	1389	Good	Insoluble

Which one of the following statements about **X**, **Y** and **Z** is completely true?

Statement 1: X has a giant ionic structure, **Y** has a giant molecular structure, **Z** is a metal

Statement 2: X is a metal, **Y** has a simple molecular structure, **Z** has a giant molecular structure

Statement 3: X is a metal, **Y** has a simple molecular structure, **Z** has a giant ionic structure

Statement 4: X has a giant ionic structure, **Y** has a simple molecular structure, **Z** is a metal

Answer:

- Compound **X** has a relatively high melting point, is soluble in water and conducts electricity when molten
  - This suggests that **X** has a giant ionic structure
- Compound **Y** has a low melting point which suggests that little energy is needed to break the lattice
  - This suggests that **Y** is a simple molecular structure
  - This is further supported by its low electrical conductivity and it being almost insoluble in water
- Compound **Z** has a very high melting point, which is characteristic of either metallic, giant ionic lattices or giant covalent / molecular lattices
  - However since it is insoluble in water, compound **Z** must be a metal
- Therefore, the correct answer is **Statement 4**