2.21 Ionic Bonding

100% ionic compounds do not exist but predominantly ionic compounds are formed when metals combine with non-metals.

Forming ions

Metal atoms lose electrons to form +ve ions.
Non-metal atoms gain electrons to form -ve ions.

Hydrogen is unusual in that it can form both an H^+ and H^- (hydride) ion

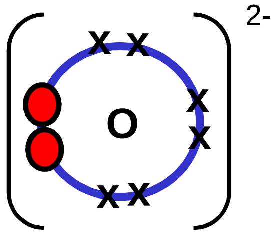
The electronic configurations of the resulting ions usually correspond to a noble gas electronic configuration.

Mg goes from $1s^2\,2s^2\,2p^6 3s^2$
to Mg^{2+} $1s^2\,2s^2\,2p^6$

The magnesium ion has a +2 charge because is has 10 (negative) electrons and 12 (positive) protons

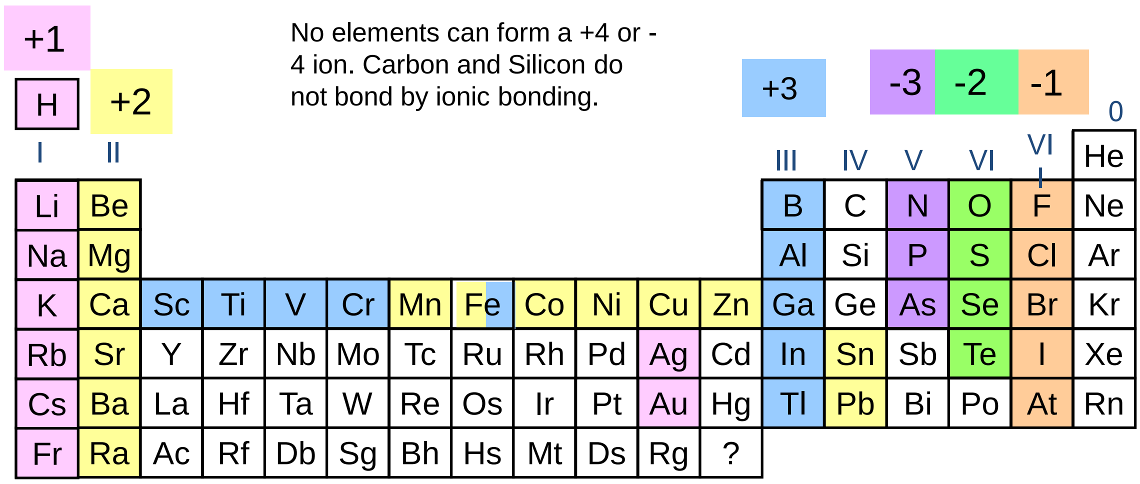
O goes from $1s^2\,2s^2\,2p^4$
to O^{2-} $1s^2\,2s^2\,2p^6$

The oxide ion has a -2 charge because is has 10 (negative) electrons and 8 (positive) protons



The diagram below shows that the main charge of some of the most common ions. The charges of the ions in group 1,2,3, and 5,6,7 can be related to their position in the periodic table, and this is how you should remember them.

No elements can form a +4 or -4 ion. Carbon and Silicon do not bond by ionic bonding.



The charge on silver (Ag^+) , gold (Au^+), lead (Pb^{2+}) and Tin (Sn^{2+}) should just be remembered

The transition metals are more complicated in that these can form different ionic charges in different compounds. To specify which charge to use we put the charge in the name in brackets, e.g. Iron (III) chloride contains iron with a +3 charge.

All the non-metal ions end in –ide and should not be confused with -ates

e.g, Li_3N is lithium nitride and contains the nitride ion N^{3-} . It should not be confused with the nitrate ion NO_3^-

Similarly don't confuse phosphide ion P^{3-} with the phosphate ion PO_4^{3-}

Compound ions

There are several compound ions you should learn the formulae and charge for. These ions have covalent bonds between the atoms in the compound ion. These ions will, however, bond ionically to metal ions.

Compound ions to learn
Ammonium (NH_4^+), Carbonate (CO_3^{2-}), Sulphate (SO_4^{2-}), Nitrate (NO_3^-), hydroxide (OH^-) phosphate (PO_4^{3-})

Summary of most important ions to know

+1	+2	+3	-3	-2	-1
Group 1 Hydrogen Silver Gold **Ammonium (NH_4^+)**	Group 2 Zinc Copper (II) Iron (II) Tin Lead	Group 3 Iron (III)	Group 5 Phosphate (PO_4^{3-})	Group 6 **Carbonate (CO_3^{2-})** **Sulphate (SO_4^{2-})**	Group 7 **Nitrate (NO_3^-)** **Hydroxide (OH^-)**

How to work out the formula from the ionic charge

What is the formula of Lithium Sulphate?

1. Identify the ionic charges of the two ions

    Lithium is in group 1 so has a +1 charge, Li^+

    sulphates have a -2 charge, SO_4^{2-}

2. Combine the ions together to get a neutral compound. i.e. combine so that the total +ve charge cancels out the total –ve charge

Li^+ **Li^+** **SO_4^{2-}**

We need two lithium ions to cancel out the -2 charge on the sulphate

The formula is therefore **Li_2SO_4**

What is the formula of Calcium phosphate?

1. Identify the ionic charges of the two ions

    Calcium is in group 2 so has a +2 charge, Ca^{2+}

    Phosphates have a -3 charge, PO_4^{3-}

2. Combine the ions together to get a neutral compound. i.e. combine so that the total +ve charge cancels out the total –ve charge

We need to multiply up to get the same charge. Three calcium ions would produce +6 charge to cancel out the -6 charge on two phosphate ions

The formula is therefore **$Ca_3(PO_4)_2$**

Only use brackets when there is more than one of the compound ion in the formula.

e.g. Copper nitrate is $Cu(NO_3)_2$

Calcium hydroxide is $Ca(OH)_2$

Ammonium sulphate is $(NH_4)_2SO_4$

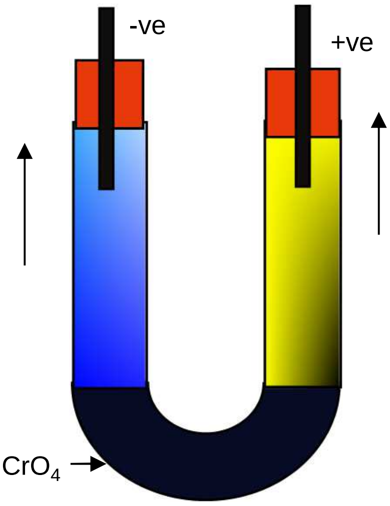
Evidence for the existence of ions

How do we know ions exist? What is the evidence for it?

Migration of ions

There are a few simple experiments that can show the migration of coloured ions.

In this experiment the $CuCrO_4$ is put at the bottom of the U-tube. The solution (or gel) above the $CuCrO_4$ is originally colourless. As the electricity is applied the colour shifts up the tubes as the two ions migrate to the electrodes



You can see a video of this demo here
https://www.youtube.com/watch?v=nQ3V6N6EzYM

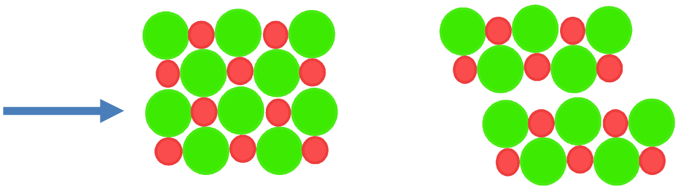
A drop of potassium Manganate solution or a small crystal of potassium mangante, which is purple, is placed on moist filter paper on a microscope slide and the ends of the slide are connected to a 24 V DC power supply. After ten minutes the purple colour of the MnO_4^- ion has migrated to the positive electrode

You can see a video of this demo here
https://www.youtube.com/watch?v=QmZPn3WMDI8

Physical properties of Ionic Compounds

The model of spherical ions strongly attracted to each other in a lattice is evidenced by the observed physical properties of ionic compounds.

- high melting points (there are strong attractive forces between the ions)
- non conductor of electricity when solid (ions are held together tightly and can not move)
- conductor of electricity when in solution or molten. (ions are free to move)
- brittle / easy to cleave apart



A little force will push the ions along and ions will be next to similar ions. There will be a force of repulsion between like ions, pushing the layers apart

Structure of Ionic Substances

An Ionic bond is the electrostatic force of attraction between oppositely charged ions in a lattice.

Electron density maps obtained through X-ray diffraction also give evidence for the existence of ions and also the structure of ionic substances

These maps show the likelihood of finding electrons in a region

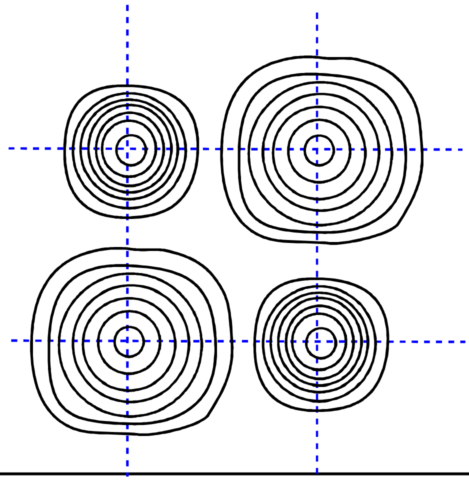
The contours are lines of equal electron density, with greater electron densities being on contours closer to the nucleus

The maps show that for NaCl

•The ions are arranged in a regular pattern.

•The chloride ions are larger than the sodium ions

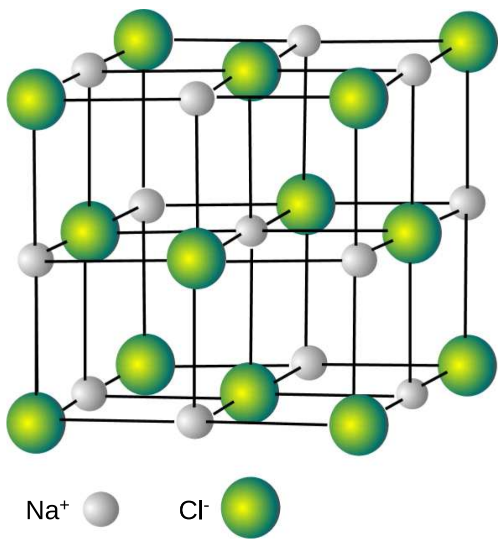
X-ray diffraction: Electron density map of NaCl



The ions are discrete or separate, because the electron density falls to zero between the ions

The electron density map does not, however, show the edge of the ion and so it is difficult to measure the radius of the ion from an electron density map

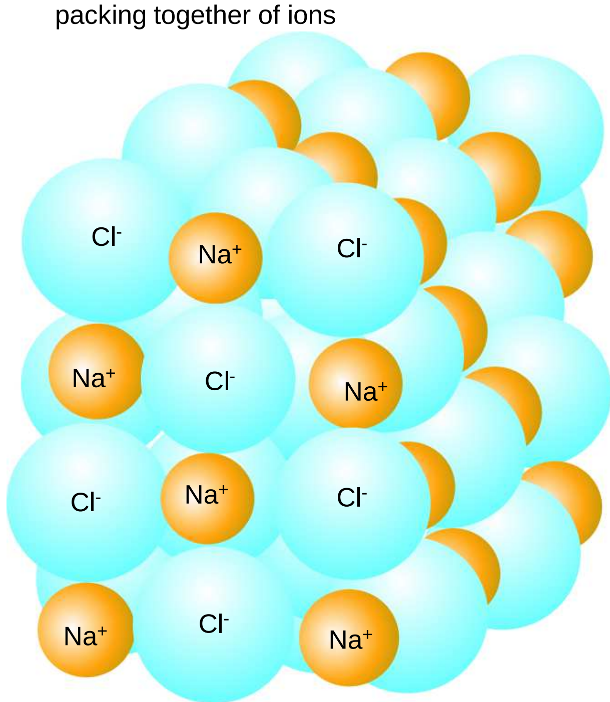
The ions in an ionic solid are arranged in a regular 3D pattern called a giant ionic lattice



The sticks in this diagram are there to help show the arrangements of the ions. They do not represent the ionic bonds.

Ionic bonding is between ions and all their surrounding oppositely charged ions. Each sodium ion in this structure is surrounded and equally attracted by six chloride ions. The ionic bond is the attraction between all these ions

Space filling model of the ions showing the packing together of ions



This is a more realistic representation of the arrangement of sodium ions (Na^+) and chloride ions (Cl^-) in the ionic compound sodium chloride.

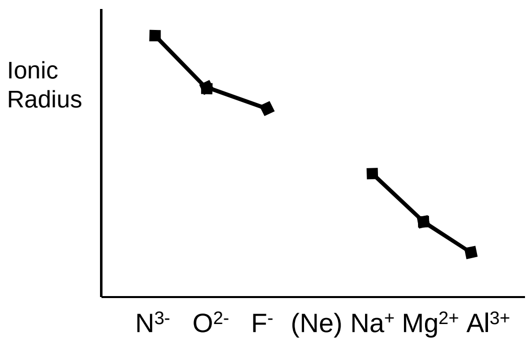
Not all ionic substances have the same arrangement of ions in their lattices.

Ionic Radii

Positive ions are smaller compared to their atoms because it has one less shell of electrons and the ratio of protons to electrons has increased so there is greater net force on remaining electrons holding them more closely.

The negative ions formed from groups five to seven are larger than the corresponding atoms.

The negative ion has more electrons than the corresponding atom but the same number of protons. So the pull of the nucleus is shared over more electrons and the attraction per electron is less, making the ion bigger.



N^{3-} O^{2-} F^- and Na^+ Mg^{2+} Al^{3+} all have the same electronic structure (of the noble gas Ne)

There are increasing numbers of protons from N to F and then Na to Al but the same number of electrons. The effective nuclear attraction per electron therefore increases and ions get smaller

Within a group the size of the Ionic radii increases going down the group. This is because as one goes down the group the ions have more shells of electrons.

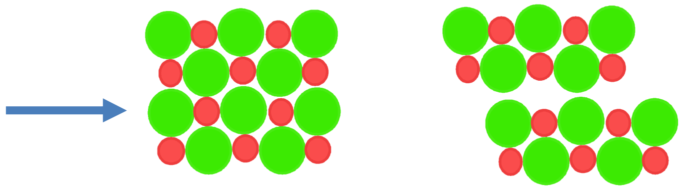
Strength of Ionic bonding in lattices

It is actually not easy to define what 'one' ionic bond is. We generally measure the strength of ionic bonding by the energy needed to form **one mole** of an ionic lattice from its gaseous ions (called the lattice enthalpy of formation) rather than trying to measure the strength of 'one' bond. You can find more on lattice enthalpy in chapter 3.15 Born Haber cyles

Ionic bonding is stronger and the melting points are higher when **the ions are smaller** and/ or have **higher charges.** This is because the ions form stronger attractions when they have higher charges and can get closer to each other.
So MgO has a higher melting point than NaCl because the ions involved (Mg^{2+} & O^{2-}) are smaller and have higher charges than those in NaCl (Na^+ & Cl^-)

Typical Physical properties of Ionic Compounds

•High melting points - There are strong electrostatic attractive forces between the oppositely charged ions in the lattice
•Non conductor of electricity when solid- The ions are held together tightly in the lattice and can not move so no charge is conducted
•Good conductor of electricity when in solution or molten – The ions are free to move when in solution and molten. Charge can be carried
•brittle / easy to cleave apart



A little force will push the ions along and then ions will be next to ions of the same charge. There will be a force of repulsion between ions of the same charge, pushing the layers apart

- They are **usually** soluble in aqueous solvents.

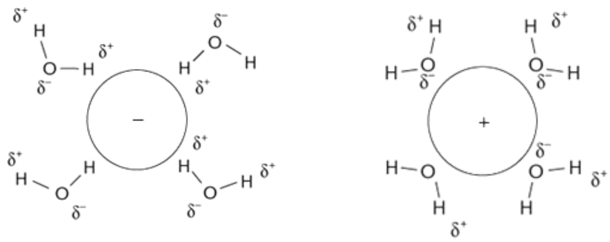
Solubility of a solute in a solvent is a complicated balance of energy required to break bonds in the solute and solvent against energy given out making new bonds between the solute and solvent.

Ionic substances dissolving in water

When an ionic lattice dissolves in water it involves breaking up the bonds in the lattice and forming new bonds between the metal ions and water molecules.

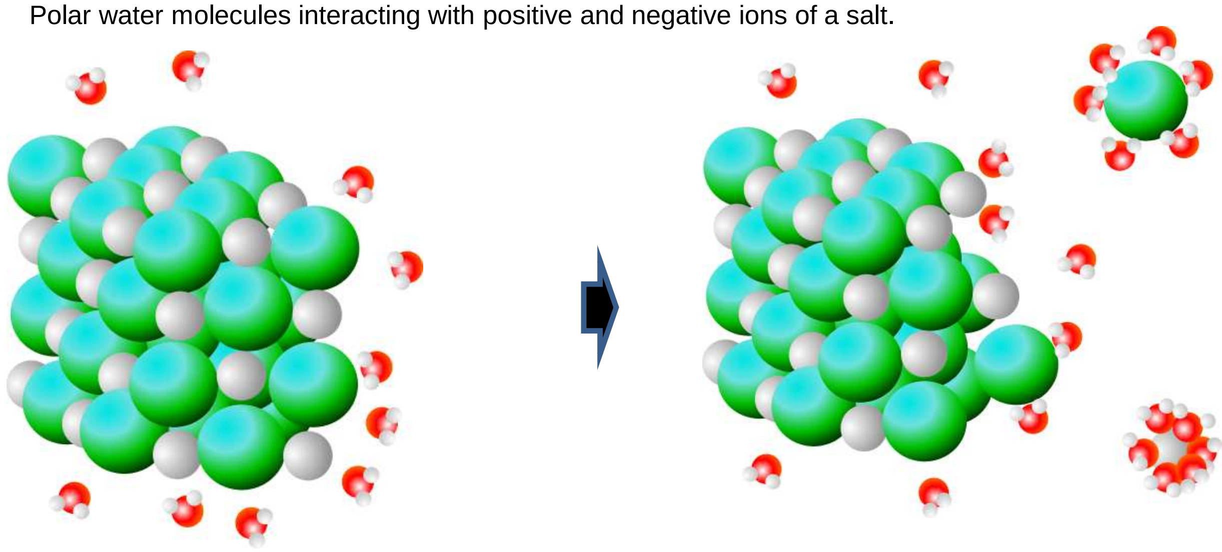
The **negative** ions are attracted to the **δ^+ hydrogens** on the **polar water** molecules and the positive ions are attracted to the δ^- oxygen on the polar water molecules.

hydration of the ions



The higher the **charge density** the greater the hydration enthalpy (e.g. **smaller ions** or **ions with larger charges**) as the ions attract the water molecules more strongly.

Polar water molecules interacting with positive and negative ions of a salt.



•Ionic compounds that are insoluble in water have stronger attractions to each other than to water.

There is more detail on the energy changes in this process in chapter 3.17 enthalpies of Solution