AS Chemistry
F321: Atoms, Bonds and Groups
1.3.2 Group 2

Plymstock School

Group 2 Elements

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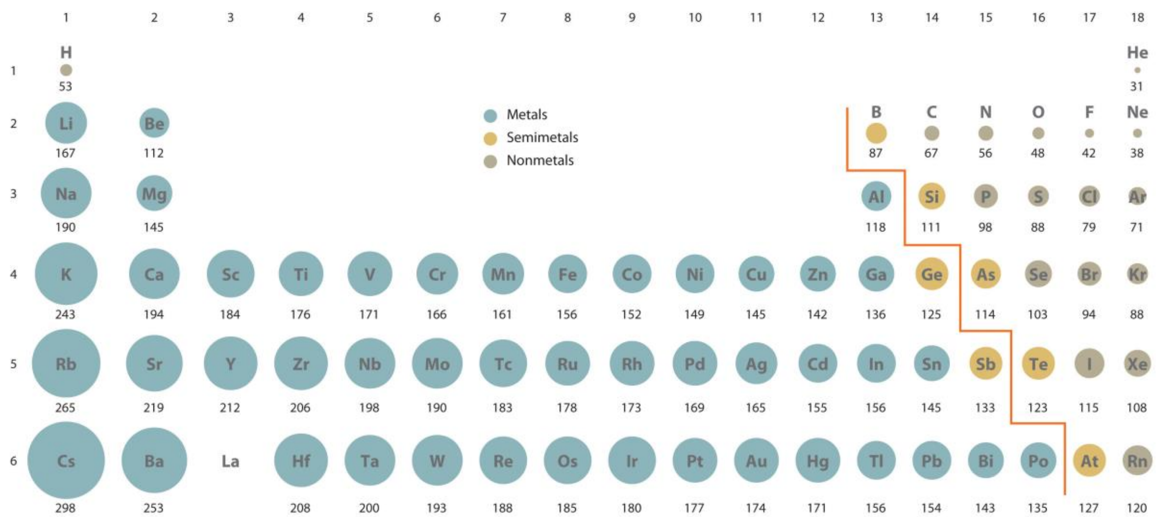


Atomic radii in picometers (pm)

Introduction.

Group 2 elements comprise:

Beryllium,	Be
Magnesium,	Mg
Calcium,	Ca
Strontium,	Sr
Barium,	Ba
Radium,	Ra

Group 2 elements show similar chemical and physical properties as they they have two electrons in their outer shell. They also belong to the s block elements as their outer electrons are in the s orbital.

Be - $1s^2$ $\mathbf{2s^2}$
Mg – $1s^2\ 2s^2\ 2p^6$ $\mathbf{3s^2}$
Ca – $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$ $\mathbf{4s^2}$
Sr - $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6$ $\mathbf{5s^2}$
Ba - $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6$ $\mathbf{6s^2}$

Properties of Group 2 elements are summarised in the following table:

Atomic number	**Element**	**Outer electronic configuration**	**Atomic radius /nm**	**Ionic radius /nm**	**Ist ionisation energy**	**Melting point /^{0}C**
4	Be	$2s^2$	0.112	0.031	900	1278
12	Mg	$3s^2$	0.160	0.065	736	650
20	Ca	$4s^2$	0.197	0.099	590	850
38	Sr	$5s^2$	0.215	0.113	548	768
56	Ba	$6s^2$	0.222	0.135	502	714
88	Ra	$7s^2$	0.220	-	510	-

Exam tip: *You will only need to consider the trends, properties and reactions of the elements Mg to Ba.*

1.3.2 (a) Redox Reactions of Group 2 Metals.

(i) The Reactions of Group 2 Elements with Oxygen.

All Group 2 elements tarnish in air to form a coating of the metal oxide. They react violently in pure oxygen producing a white ionic oxide.
When these metals (M) are heated in oxygen they burn vigorously to produce a **white ionic oxide**, $M^{2+}O^{2-}$.

http://goo.gl/B8050 - Reaction of calcium in oxygen

$$\mathbf{2M(s) + O_2(g) \rightarrow 2MO(s)}$$

e.g. **$Ca(s) + O_2(g) \rightarrow 2CaO(s)$**
0 0 +2 -2

This reaction is a ***redox*** reaction where the metal loses electrons to form a positive ion – ***oxidation***. The oxygen gains electrons to form a negative ion – ***reduction***. The metal's oxidation number increases, (0 → +2), oxidation, and the oxygen's oxidation number decreases (0 → -2), reduction.

Magnesium burns with a brilliant white light (no colour). Calcium burns with a brick red flame, strontium's flame is bright red and barium has a pale green flame.

The Group 2 elements are strong reducing agents
A reducing agent is a substance which causes a species to be reduced (adds electrons)
An oxidising agent is a substance which causes a species to be oxidised (removes electrons)

Redox Equations

When magnesium is heated in air, it burns brightly to form magnesium oxide – $Mg^{2+}O^{2-}$.

$$\mathbf{2Mg(s) + O_2(g) \rightarrow 2Mg^{2+}O^{2-}(s)}$$

During this reaction each magnesium atom gives up two electrons and forms a magnesium ion

$$\mathbf{2Mg(s) \rightarrow 2Mg^{2+} + 4e^-} \qquad \textbf{OXIDATION}$$

Oxygen takes up the electrons and forms an oxide ion

$$\mathbf{O_2(g) + 4e^- \rightarrow 2O^{2-}} \qquad \textbf{REDUCTION}$$

Thus electrons are transferred from magnesium atoms to oxygen atoms. Magnesium is **oxidised** as it **loses electrons**. Oxygen, correspondingly, is **reduced** because it **gains electrons**.

Thus oxidation is loss of electrons and reduction is the gain of electrons – OIL RIG!
Another way of considering redox reactions is to look at the oxidation numbers.

The oxidation number of magnesium (element) is 0. The oxidation number of the magnesium ions is +2. Thus the oxidation number of the magnesium has increased – this is oxidation.

The oxidation number of oxygen (element) is zero. The oxidation of the oxide ions is –2. Thus the oxidation number of the oxygen has decreased – this reduction.

An increase in oxidation number is oxidation and a decrease in oxidation number is reduction.

(ii) <u>The Reactions of Group 2 Elements with Water</u>

The Group 2 elements react with water to form hydroxides with the general formula $M(OH)_2$ and hydrogen gas. The further you move down the group the more vigorous the reaction with water. Calcium, strontium and barium react with cold water and the reactivity increases from calcium to barium. In each case the metal hydroxide and hydrogen are produced. Generally:

$$\mathbf{M(s) + 2H_2O(l) \rightarrow M(OH)_2(aq) + H_2(g)}$$

$$\mathbf{Ca(s) + H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)}$$

This can be written ionically as follows:

$$\mathbf{Ca(s) + 2H_2O(l) \rightarrow Ca^{2+}(aq) + 2OH^{-}(aq) + H_2(g)}$$

The ionic equation can be written as two half equations:

$Ca \rightarrow Ca^{2+}(aq) + 2e^{-}$	**OXIDATION**
$2H_2O(l) + 2e^{-} \rightarrow 2OH^{-}(aq) + H_2(g)$	**REDUCTION**

Calcium loses electrons and it is oxidation number increases – **oxidation**.
The hydrogen in water is has an oxidation number of +1. The oxidation number of hydrogen is 0, thus it is **reduced**. Magnesium reacts very slowly with cold water but will react violently with steam.

When magnesium is heated and steam is passed over it magnesium <u>oxide </u>is formed.

$$\mathbf{Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)}$$

http://goo.gl/R8c9j. You Tube link to reaction of magnesium with steam.

The metal hydroxides show an increase in solubility as the group is descended with magnesium hydroxide being only sparingly soluble. The pH of the Group 2 hydroxide solution is pH 10-12.

1.3.2 (b) Reactivity of Group 2 Elements.

The overall trend, for the reactivity of Group 2 metals with water, is an *increase down the group*. The outer electrons are easier to remove as they are further from the nucleus and there is more shielding resulting in a lower nuclear attraction.

The Reaction of Magnesium with Hydrochloric Acid

Generally, a reactive metal will react with hydrochloric acid to form a metal salt (metal chloride) and hydrogen gas i.e.

$$\text{Metal} + \text{Hydrochloric Acid} \rightarrow \text{Metal Chloride} + \text{Hydrogen}$$

Magnesium reacts vigorously (and exothermically) with hydrochloric acid to form magnesium chloride and hydrogen.

$$\boxed{\mathbf{Mg(s) + 2HCl \rightarrow MgCl_2(aq) + H_2(g)}}$$

Ionically $$\mathbf{Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)}$$

This reaction can be written as two half equations:

$$\mathbf{Mg(s) \rightarrow Mg^{2+}(aq) + 2e^-}$$

$$\mathbf{2H^+(aq) + 2e^- \rightarrow H_2(g)}$$

From these it can be seen that the magnesium is oxidised – produces electrons and its oxidation number increases. The hydrogen ions are reduced – electrons received and the oxidation number decreases.

The Reaction of Magnesium Oxide with Hydrochloric Acid

Like the Group 2 oxides magnesium oxide is basic – it reacts with acids to form a metal salt and water.

$$\boxed{\mathbf{MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)}}$$

The above reaction is not a redox reaction are there is no change in the oxidation states of the elements.

The Reaction of Magnesium Carbonate with Hydrochloric Acid

When a metal carbonate reacts with an acid a metal salt is formed, carbon dioxide gas is liberated and water is also formed.

Metal Carbonate + Acid $\rightarrow$ Metal Salt + Carbon Dioxide + Water

When magnesium carbonate reacts with hydrochloric acid magnesium carbonate is produced along with carbon dioxide and water.

$$\boxed{MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + CO_2(g) + H_2O(l)}$$

Acid	**Metal Salt suffix**	**Example**
Hydrochloric Acid	-chloride	$CaCl_2$
Sulfuric Acid	-sulfate	$CaSO_4$
Nitric Acid	-nitrate	$Ca(NO_3)_2$
Phosphoric Acid	-phosphate	$Ca_3(PO_4)_2$

1.3.2 (c) Group 2 Oxides and Hydroxides.

The Group 2 oxides react with water to form a solution of the metal hydroxide.

$$\boxed{MgO(s) + H_2O(l) \rightarrow Mg(OH)_2(aq)}$$

The Group 2 hydroxides dissolve in water to form alkaline solutions.

$$Ca(OH)_2(s) + (aq) \rightarrow Ca^{2+}(aq) + 2OH^-(aq)$$

Solubility.

The solubility of the hydroxides ***increase down the group*** causing the solutions to be more alkaline. $Mg(OH)_2$ is slightly soluble in water. This results in a solution with a dilute concentration of $OH^-(aq)$. $Ba(OH)_2$ is much more soluble in water than $Mg(OH)_2$ resulting in a greater $OH^-(aq)$ concentration. The solubility increases down the group due to:

- the metal ions get larger so charge density decreases
- get a lower attraction between the OH^- ions and larger 2+ ions
- the ions will split away from each other more easily
- there will be a greater concentration of OH^- ions in water

	Be	Mg	Ca	Sr	Ba
Reactivity with water	None	Reacts	Reacts	Reacts	Reacts
Solubility of hydroxide with water	Insoluble	Sparingly soluble	Slightly soluble	Quite soluble	Very soluble

Table of solubility of Group 2 elements in water

1.3.2 (d) Thermal Decomposition of Group 2 Carbonates.

The carbonates of Group 2:

- All have the formula MCO_3
- Are insoluble in water
- React with dilute acids
- Decompose on heating to give the oxide and carbon dioxide – **thermal decomposition**

$$\boxed{CaCO_3(s) \rightarrow CaO(s) + CO_2(g)}$$

The carbonates become more stable down the group and are more difficult to decompose –thermal stability of the Group 2 carbonates increases down the group.

When a metal ion is placed near the carbonate ion (CO_3^{2-}) is caused it be become polarised (the negative charge moves to the side of the molecule nearer the metal ion). The smaller the +2 ion the greater the amount of polarisation. This weakens the bond between the oxygen and the carbon and when heat is applied the bond breaks easier if the amount of polarisation is greater.

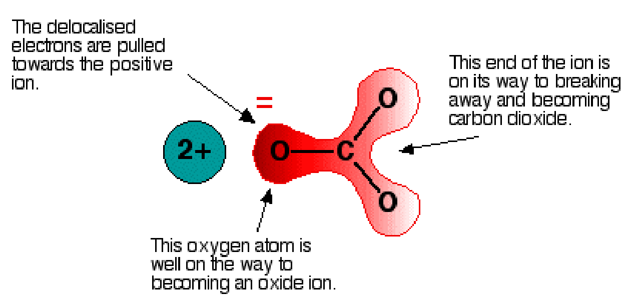
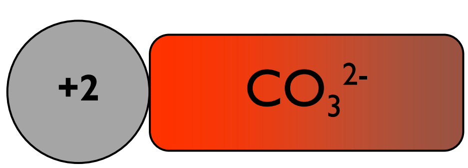


Image taken from Chemguide.co.uk

CO_3^{2-} becomes heavily polarized causing the C-O bond to break forming the metal oxide.

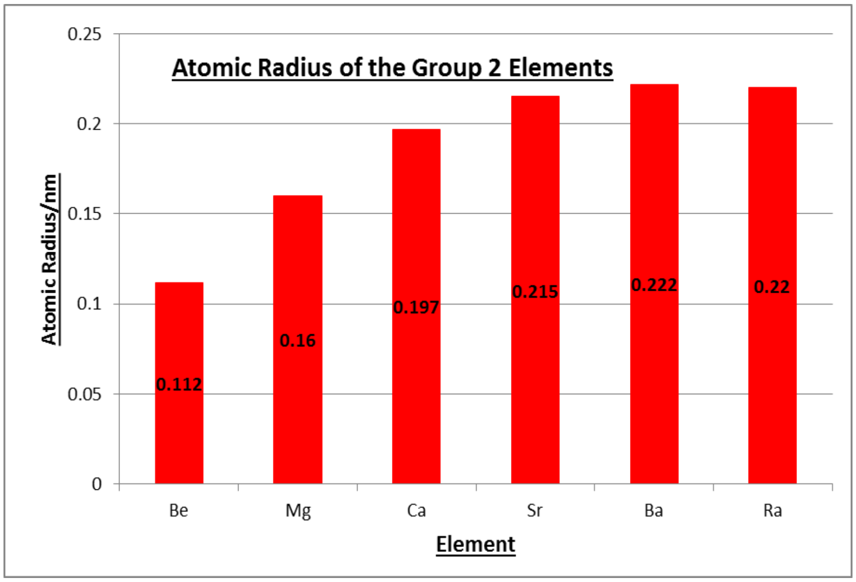


Small amount of polarization of the CO_3^{2-} by the large metal ion C-O more difficult to break so required more energy (heat).

1.3.2 (e) Chemical and Physical Properties.

Atomic Radii.

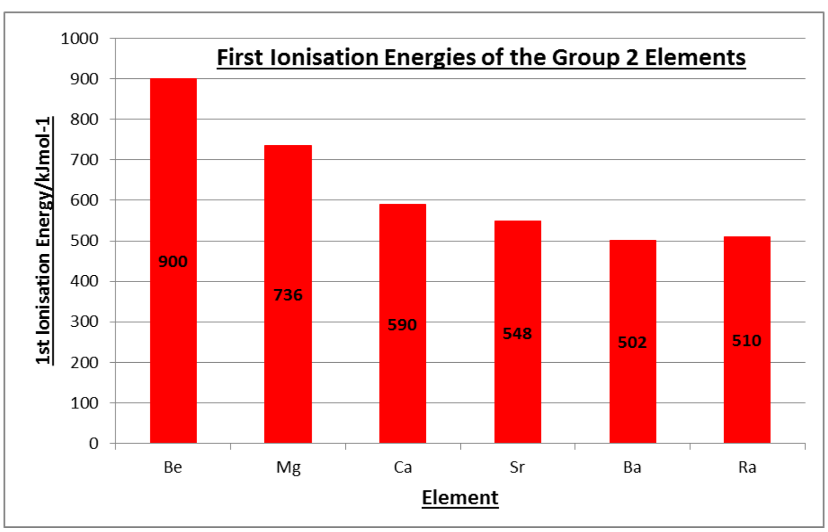
In moving down Group 2 there is an additional quantum shell of electrons for each element. The effect of this is that the outer electrons are increasingly shielded from the attraction of the nucleus so the overall nuclear attraction on the outermost electrons is less resulting in an increase in atomic radius.



First Ionisation Energy.

$Mg(g) \rightarrow Mg^{+}(g) + e^{-}$ Equation or the first ionisation energy of magnesium.

As the atomic radius increases, the outermost electrons move further away from the nucleus in addition to the shielding increases down the Group. Thus the attraction of the outer electrons to the nucleus decreases (decrease in nuclear attraction).
It is therefore becomes increasingly easier to remove the outer electrons as shown by the graph of first ionisation energies below:



The first ionisation energy is the energy required to remove one electron from each atom in one mole of gaseous atoms to form one mole of gaseous 1+ ions.

Electronegativity.

Electronegativity measures the pull of an atom of an element on the electrons in a chemical bond (covalent). The stronger its pulling power the higher its electronegativity.

Electronegativity **increases** from **left to right** across a **period**. As the nuclear charge increases from one element to the next across the period the extra electrons go in to the same shell. Thus there is, in effect a greater pull on electrons which are the same distance away.

Electronegativity **decreases down a group**. As a group is descended the outer shell of electrons gets further from the positive nucleus so the pull on these electrons gets less from one element to the next. The most electronegative element is fluorine (4.0), followed by oxygen (3.5), then nitrogen and chlorine (3.0).

Uses of Group 2 Hydroxides.

Calcium hydroxide, $Ca(OH)_2$ is used by farmers to neutralise acidity while magnesium hydroxide, $Mg(OH)_2$ commonly called milk of magnesia is used to neutralise excess stomach acid in indigestion remedies.

Summary.

- First ionisation energy decreases down the Group
- Reactivity increases down the Group
- Atomic radii increases down the Group
- Alkalinity increases down the Group
- Solubility increases down the Group
- Ease of thermal decomposition decreases down the Group. Stability of the carbonate increases down the group.
- Electronegativity decreases down the group.

Additional Background Information.

The Atypical Behaviour of Beryllium.

As for any group in the Periodic Table the Group 2 atoms get larger. So do their ions. The ions have a charge of +2 when the atoms lose the two outermost-level electrons, leaving this level empty.
The two electrons of the Be^{2+} ion occupy the first energy level only so the ion is very small. Ions such as this, small and highly charged, have a high charge density and the charge density of the Be^{2+} ion is very high indeed. As a consequence of this the properties of beryllium and its compounds are not typical of the other Group 2 elements.

The Reaction of Limewater with Carbon Dioxide

When carbon dioxide is bubbled into limewater the solution turns cloudy or milky. This is because insoluble calcium carbonate is formed.

$$\mathbf{Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)}$$

If more carbon dioxide (excess) is bubbled through the solution above the cloudiness disappears to form a clear solution of calcium hydrogen carbonate.

$$\mathbf{CaCO_3(s) + H_2O(l) + CO_2(g) \rightarrow Ca(HCO_3)_2(aq)}$$

Calcium hydrogen carbonate causes temporary hardness in water. A hard water is one which does not form a lather easily. Temporary hardness means that it can be removed by boiling.

$$\mathbf{Ca(HCO_3)_2(aq) \rightarrow CaCO_3(s) + CO_2(g) + H_2O(l)}$$