AQA A Level Chemistry

Your notes

Group 2, the Alkaline Earth Metals

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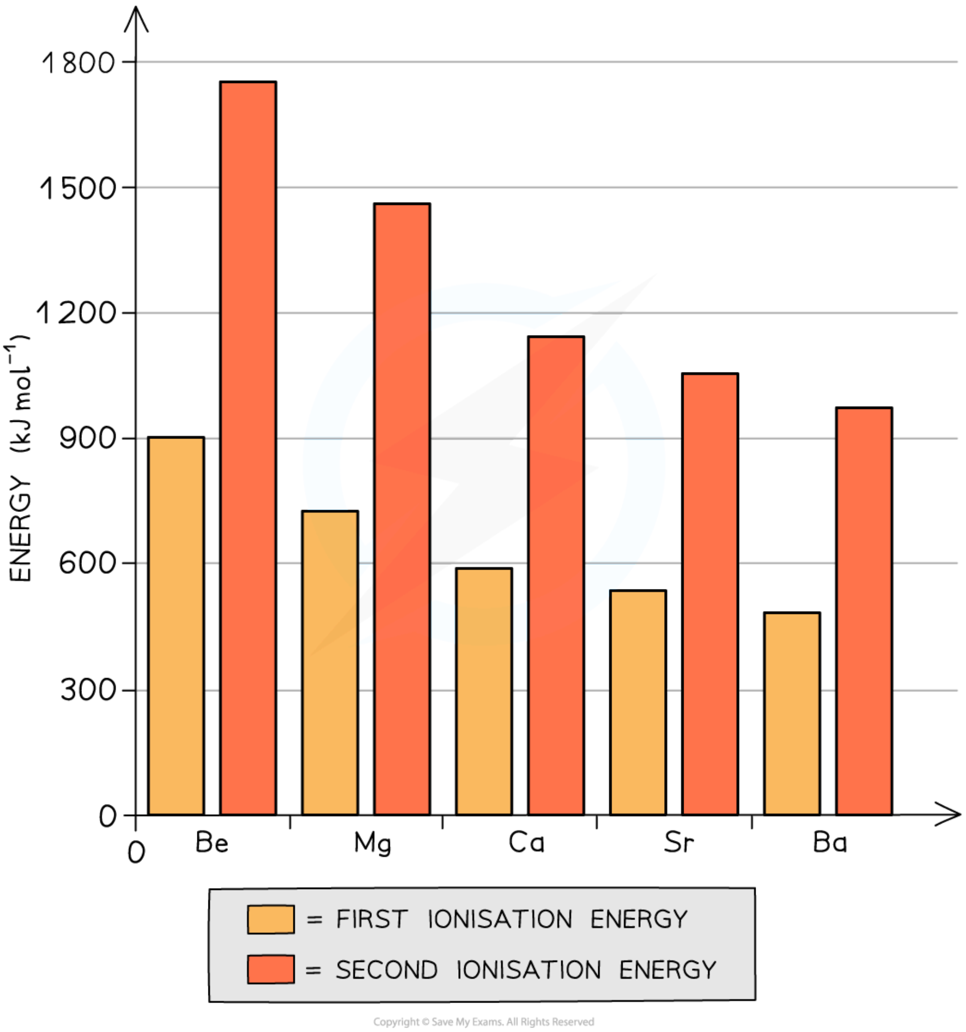
Your notes

Group 2: Trends

Chemical trends

- All elements in Group 2 (also called **alkali earth metals)** have two electrons in their **outermost principal quantum shell**
- All Group 2 metals can form **ionic compounds** in which they donate these **two outermost electrons** (so they act as **reducing agents)** to become an ion with +2 charge (so they themselves become **oxidised)**
- Going down the group, the metals become more **reactive**
- This can be explained by looking at the Group 2 ionisation energies:

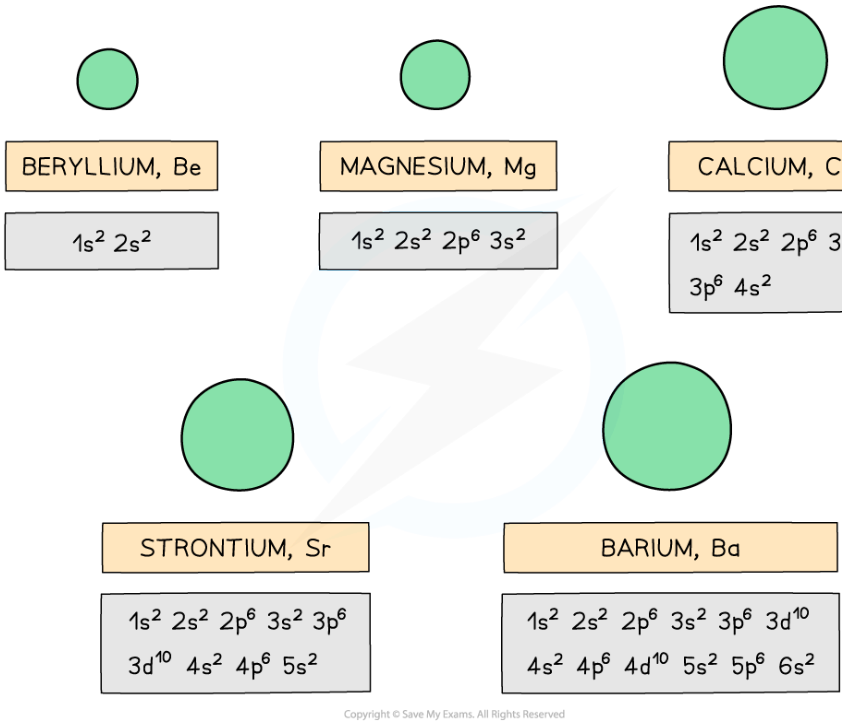


The graph shows that both the first and second ionization energies decrease going down the group

- The **first ionisation energy** is the energy needed to remove the first outer electron of an atom
- The **second ionisation energy** is the energy needed to remove the second outer electron of an atom
- The graph above shows that going down the group, it becomes easier to remove the outer two electrons of the metals
- Though the **nuclear charge** increases going down the group (because there are more protons), factors such as an **increased shielding effect** and a **larger distance** between the outermost electrons and nucleus outweigh the attraction of the higher nuclear charge
- As a result of this, the elements become more reactive going down the group as it gets easier for the atoms to lose two electrons and become 2+ ions
- This trend is shown by looking at reactions of the Group 2 metals:
  - With dilute hydrochloric acid: **bubbles** of **hydrogen gas** are given off much faster indicating that the reactions become more vigorous
  - With oxygen: the metals get more reactive with oxygen down the group (Ba is so reactive, that it must be stored in oil to prevent it from reacting with oxygen in air)

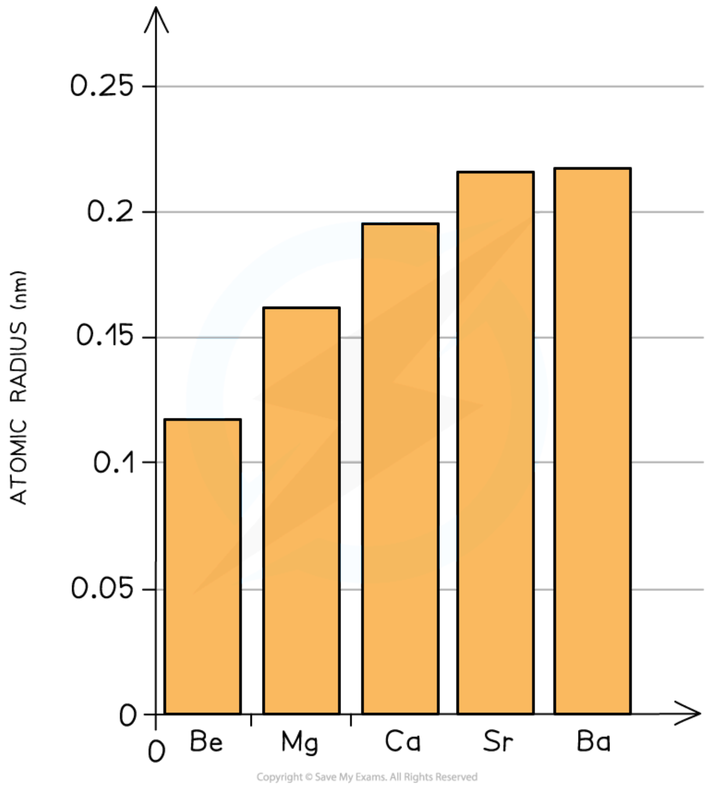
Physical trends

- Going down the group, the elements become larger as the outer two electrons occupy a new **principal quantum shell** which is further away from the nucleus



Your notes

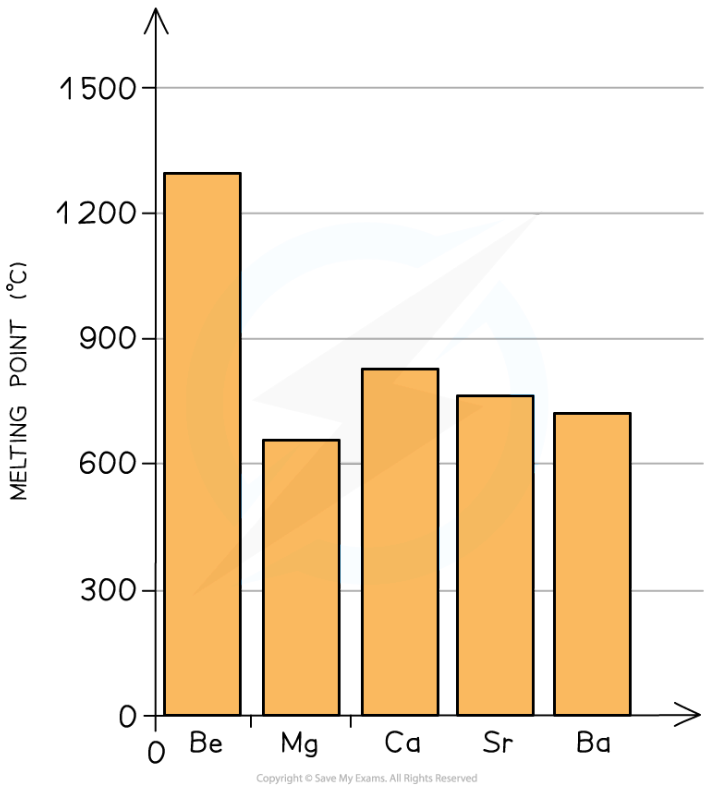
The atomic radius of the Group 2 elements increases going down the group due to the addition of an extra principal quantum shell



The graph shows a increase in atomic radius going down the group

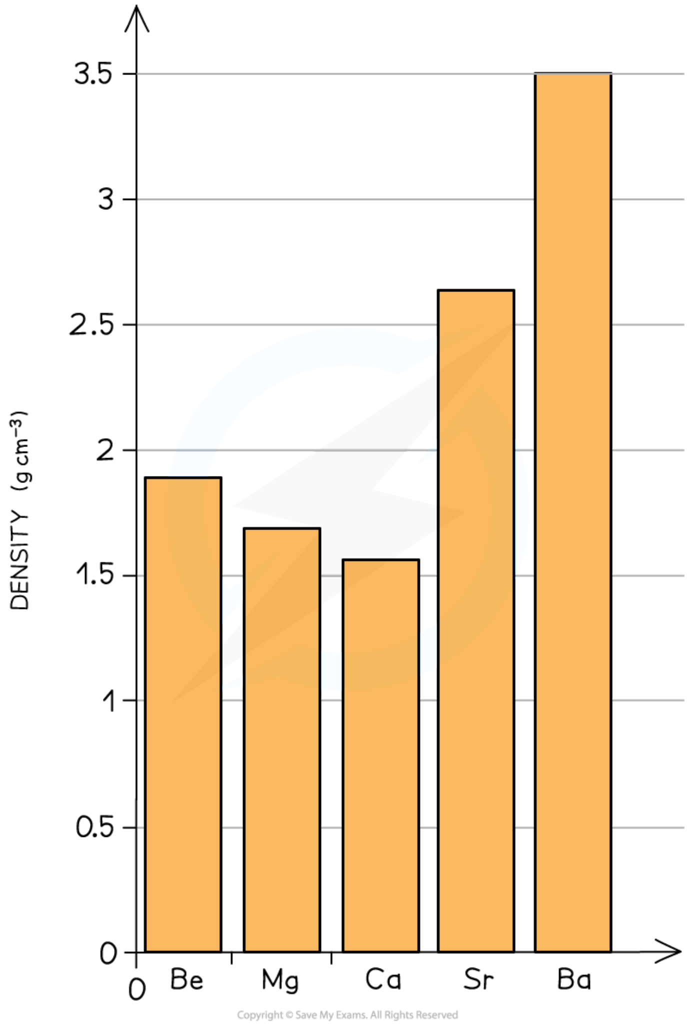
- The **melting point** of the elements decreases going down the group as the outer electrons get further away from the nucleus
- This means that the **attraction** between the **nucleus** and the **bonding electrons** decreases causing a decrease in melting point

Your notes



The graph shows a general decrease in melting point going down the group with a slight anomaly in magnesium

- As you go down the group, the **density** of the alkali earth metals drops and then increases
- Density is also affected by the packing structure of the metals, not just the atomic radius - no trend is perfect!



The graph show the broad trend in density going down the group

Your notes

Solubility of Hydroxides & Sulfates

Group 2 hydroxides

- Going down the group, the solutions formed from the reaction of group 2 oxides with water become more **alkaline**
- When the oxides are dissolved in water, the following ionic reaction takes place:

$$O^{2-} (aq) + H_2O (l) \rightarrow 2OH^- (aq)$$

- The higher the **concentration** of OH^- ions formed, the more **alkaline** the solution
- The **alkalinity** of the solution formed can therefore be explained by the **solubility** of the Group 2 **hydroxides**

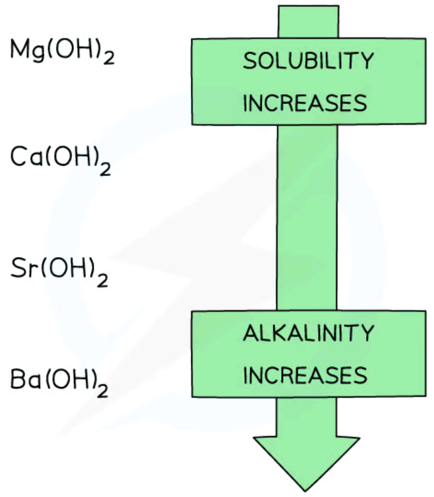
Solubility of the Group 2 Hydroxides

Group 2 hydroxide	Solubility at 298 K (mol / 100 g of water)
$Mg(OH)_2$	2.0×10^{-5}
$Ca(OH)_2$	1.5×10^{-3}
$Sr(OH)_2$	3.4×10^{-3}
$Ba(OH)_2$	1.5×10^{-2}

- The hydroxides dissolve in water as follows:

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

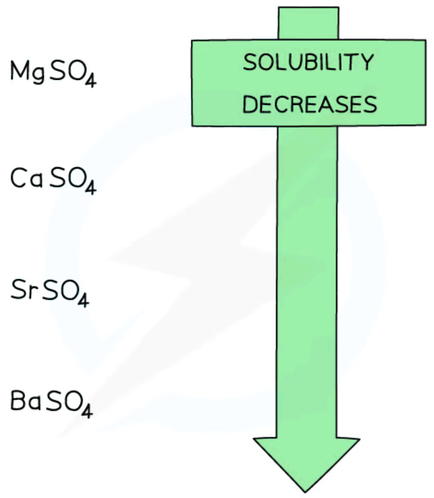
- When the metal oxides react with water, a Group 2 hydroxide is formed
- Going down the group, the **solubility** of these hydroxides **increases**
  - $Mg(OH)_2$ is **sparingly** soluble
  - $Ba(OH)_2$ is soluble
- This means that the **concentration** of OH^- ions **increases,** increasing the pH of the solution
- As a result, going down the group, the **alkalinity** of the solution formed increases when Group 2 oxides react with water



Going down the group, the solubility of the hydroxides increases which means that the solutions formed from the reactions of the Group 2 metal oxides and water become more alkaline going down the group

Group 2 sulfates

- The solubility of the Group 2 sulfates decreases going down the group



Going down the group, the solubility of the sulfates decreases

Examiner Tips and Tricks

The insolubility of barium sulfate is used to test for sulfate ions.

Your notes

Addition of HCl (aq) followed by $BaCl_2$ (aq) **OR** HNO_3 (aq) followed by $BaNO_3$ (aq) will form a white precipitate of barium sulfate if sulfate ions are present.

The acid removes other anions (e.g. carbonate) that could also form white precipitates, ensuring the test is specific to sulfate.

Your notes

Worked Example

Predicting properties of radium

Radium (Ra) is a radioactive element found below barium at the bottom of group 2.

Applying your knowledge of the Group 2 elements, predict:

1. The formula of the ion formed by Ra.
2. The formulae of its oxide and hydroxide
3. Its first ionisation energy
4. Its reactivity compared with barium
5. The relative pH of its saturated hydroxide solution compared with a saturated solution of calcium hydroxide
6. The solubility of its sulfate compared to strontium sulfate
7. The equation for the reaction of its solid oxide with dilute hydrochloric acid
8. What would you expect to see if you mixed radium hydroxide solution with dilute sulfuric acid?

Answers:

1. The formula of the ion formed by Ra.
   - Since, Ra is in Group 2, it will form an ion with +2 charge to give Ra^{2+}
2. The formulae of its oxide and hydroxide.
   - The group 2 oxides and hydroxides have general formula XO and $X(OH)_2$ respectively where X is the Group 2 element.
   - Therefore, radium oxide is RaO and radium hydroxide is $Ra(OH)_2$
3. Its first ionisation energy.
   - Radium is below barium so its atomic radius is larger than the atomic radius of barium.
   - This means that radium's outermost electrons are even further away and are therefore even more easily removed than barium's outermost electron pair.
   - The first ionization energy is between 450–480 kJ mol^{-1}
4. Its reactivity compared with barium.
   - Radium's outermost electrons are even further away than in barium and are therefore more easily removed making radium more reactive than barium.
5. The relative pH of its saturated hydroxide solution compared with a saturated solution of calcium hydroxide.
   - The Group 2 hydroxides become more soluble going down the group.
   - Radium hydroxide will therefore be more soluble than calcium hydroxide. Since more hydroxide ions will be present in solution, the pH should be higher than the pH of calcium hydroxide

6. The solubility of its sulfate compared to strontium sulfate.
   - The Group 2 sulfates become less soluble going down the group.
   - Radium sulfate will therefore be less soluble than strontium sulfate.
7. The equation for the reaction of its solid oxide with dilute hydrochloric acid.
   - The general equation for the reaction of group 2 oxides with dilute hydrochloric acid is:
     - **$XO (s) + 2HCl (aq) \rightarrow XCl_2 (aq) + H_2O (l)$**
   - The reaction of radium oxide with dilute hydrochloric acid is therefore:
     - **$RaO (s) + 2HCl (aq) \rightarrow RaCl_2 (aq) + H_2O (l)$**
8. What would you expect to see if you mixed radium hydroxide solution with dilute sulfuric acid?

- Radium sulfate will be formed in this reaction, however the solubility of Group 2 sulfates decreases going down the group, therefore a white precipitate of radium sulfate will be formed in this reaction

Your notes

Reactions of Group 2

- The group 2 elements react with oxygen, water and dilute acids

Group 2 Reactions – Observations

	Reaction with oxygen	Reaction with water	Reaction with dilute HCl	Reaction with dilute H_2SO_4
Mg	Burns easily Bright white light	Vigorous reaction with steam, no reaction with water	Reacts vigorously	Reacts vigorously
Ca	Difficult to ignite Red flame	Reacts moderately, forms a hydroxide	Reacts vigorously	Reaction slowed by the formation of a sparingly soluble sulfate layer on the metal, stopping hydrogen bubbles from rising
Sr	Difficult to ignite Red flame	Reacts rapidly, forms a hydroxide	Reacts vigorously	Reaction is quickly stopped by the formation of an insoluble sulfate layer on the metal
Ba	Difficult to ignite Green flame	Reacts rapidly, forms a hydroxide	Reacts vigorously	Reaction is quickly stopped by the formation of an insoluble sulfate layer on the metal

Reactions with water and oxygen

- The reaction of group 2 metals with oxygen follows the following general equation:

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

Where M is any metal in group 2

Remember than Sr and Ba **also** form a peroxide, MO_2

- The reaction of all metals with water follows the following general equation:
  - Except for, Be which does not react with water

$$M\ (s) + 2H_2O\ (l) \rightarrow M(OH)_2\ (s) + H_2\ (g)$$

Group 2 Metals reacting with Water and with Oxygen – Equations

	Reaction with oxygen	Reaction with water
Mg	$2Mg (s) + O_2 (g) \rightarrow 2MgO (s)$	$Mg (s) + H_2O (g) \rightarrow MgO (s) + H_2 (g)$
Ca	$2 Ca (s) + O_2 (g) \rightarrow 2CaO (s)$	$Ca (s) + 2H_2O (l) \rightarrow Ca(OH)_2 (s) + H_2 (g)$
Sr	$2Sr (s) + O_2 (g) \rightarrow 2SrO (s)$ $Sr (s) + O_2 (g) \rightarrow SrO_2 (s)$	$Sr (s) + 2H_2O (l) \rightarrow Sr(OH)_2 (aq) + H_2 (g)$
Ba	$2Ba (s) + O_2 (g) \rightarrow 2BaO (s)$ $Ba (s) + O_2 (g) \rightarrow BaO_2 (s)$	$Ba (s) + 2H_2O (l) \rightarrow Ba(OH)_2 (aq) + H_2 (g)$

- Magnesium reacts **extremely slowly** with cold water:

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

- The solution formed is **weakly alkaline** (pH 9–10) as **magnesium hydroxide** is only **slightly soluble**
- However, when magnesium is **heated in steam**, it reacts **vigorously** with steam to make magnesium oxide and hydrogen gas:

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

Reactions of Group 2 metals with acid

- The Group 2 metals will react with dilute acids to form **colourless solutions of metal salts**
    - For example, they will form colourless solutions of metal chlorides if reacted with hydrochloric acid
- When metals react with an acid, the by-product of this reaction is hydrogen gas

Group 2 Reactions with Dilute Acids – Equations

	Reaction with dilute HCl	Reaction with dilute H_2SO_4
Mg	$Mg (s) + 2HCl (aq) \rightarrow MgCl_2 (aq)\ H_2 (g)$	$Mg (s) + H_2SO_4 (aq) \rightarrow MgSO_4 (aq) + H_2 (g)$
Ca	$Ca (s) + 2HCl (aq) \rightarrow CaCl_2 (aq)\ H_2 (g)$	$Ca (s) + H_2SO_4 (aq) \rightarrow CaSO_4 (aq) + H_2 (g)$
Sr	$Sr (s) + 2HCl (aq) \rightarrow SrCl_2 (aq)\ H_2 (g)$	$Sr (s) + H_2SO_4 (aq) \rightarrow SrSO_4 (s) + H_2 (g)$
Ba	$Ba (s) + 2HCl (aq) \rightarrow BaCl_2 (aq)\ H_2 (g)$	$Ba (s) + H_2SO_4 (aq) \rightarrow BaSO_4 (s) + H_2 (g)$

- When some of Group 2 metals react with sulfuric acid rather than hydrochloric, an insoluble sulfate forms

Your notes

- Going down the group, the Group 2 sulfates become less and less soluble
    - Calcium sulfate is sparingly soluble, but strontium sulfate and barium sulfate are insoluble
- The reaction of the metals with dilute HCl follows the following general equation:

$$M\ (s) + 2HCl\ (aq) \rightarrow MCl_2\ (aq) + H_2\ (g)$$

- The reaction of the metals with dilute H_2SO_4 follows the following general equation:

$$M\ (s) + H_2SO_4\ (aq) \rightarrow MSO_4\ (aq) + H_2\ (g)$$

Remember that $SrSO_4$ and $BaSO_4$ are insoluble

Examiner Tips and Tricks

Learn the general equation for the reaction with water and for magnesium with steam. You could be asked or reactions of the oxides and hydroxides with acids.

Group 2: Oxides, Hydroxides & Carbonates

Reactions of group 2 oxides with water

- All group 2 oxides are **basic**, except for BeO which is **amphoteric** (it can act both as an acid and base)
- Group 2 oxides react water to form **alkaline** solutions which get more **alkaline** going down the group

Group 2 Oxides reacting with Water

Group 2 oxide	Reaction with water	Observations
MgO	$MgO\ (s) + H_2O\ (l) \rightarrow Mg(OH)_2\ (s)$	MgO is only slightly soluble in water, therefore a weakly alkaline solution (pH 10.0) is formed
CaO	$CaO\ (s) + H_2O\ (l) \rightarrow Ca(OH)_2\ (s)$	A vigorous reaction which releases a lot of energy, causing some of the water to boil off as the solid lump seems to expand and open (pH 11.0)
SrO	$SrO\ (s) + H_2O\ (l) \rightarrow Sr(OH)_2\ (aq)$	
BaO	$BaO\ (s) + H_2O\ (l) \rightarrow Ba(OH)_2\ (aq)$	

Your notes

Your notes

- Remember that:

oxide + water → hydroxide

- You should know that calcium hydroxide, when in solution, is also called **limewater**

Reactions of Group 2 oxides with acid

- Group 2 sulfates also form when a group 2 oxide is reacted with sulfuric acid
- The **insoluble sulfates** form at the **surface** of the oxide, which means that the solid oxide beneath it can't react with the acid
- This can be prevented to an extent by using the oxide in **powder** form and **stirring**, in which case neutralisation can take place
- Remember that:

metal oxide + dilute hydrochloric acid → metal chloride + water

metal oxide + dilute sulfuric acid → metal sulfate + water

Reactions of group 2 hydroxides

- The group 2 metal hydroxides form **colourless solutions of metal salts** when they react with a dilute acid
- The sulfates decrease in **solubility** going down the group (barium sulfate is an insoluble white precipitate)

Group 2 Hydroxide Reactions with Dilute Acids

Group 2 hydroxide	Reaction with dilute HCl	Reaction with dilute H_2SO_4
$Mg(OH)_2$	$Mg(OH)_2$ (s) + 2HCl (aq) → $MgCl_2$ (aq) + $2H_2O$ (l)	$Mg(OH)_2$ (s) + H_2SO_4 (aq) → $MgSO_4$ (aq) + $2H_2O$ (l)
$Ca(OH)_2$	$Ca(OH)_2$ (s) + 2HCl (aq) → $CaCl_2$ (aq) + $2H_2O$ (l)	$Ca(OH)_2$ (s) + H_2SO_4 (aq) → $CaSO_4$ (aq) + $2H_2O$ (l)
$Sr(OH)_2$	$Sr(OH)_2$ (s) + 2HCl (aq) → $SrCl_2$ (aq) + $2H_2O$ (l)	$Sr(OH)_2$ (s) + H_2SO_4 (aq) → $SrSO_4$ (s) + $2H_2O$ (l)
$Ba(OH)_2$	$Ba(OH)_2$ (s) + 2HCl (aq) → $BaCl_2$ (aq) + $2H_2O$ (l)	$Ba(OH)_2$ (s) + H_2SO_4 (aq) → $BaSO_4$ (s) + $2H_2O$ (l)

- Remember that:

hydroxide + dilute hydrochloric acid → chloride + water

hydroxide + dilute sulfuric acid → sulfate + water

Reactions of group 2 carbonates

- All group 2 carbonates (except for **$BeCO_3$**) are **insoluble in water**
- All group 2 carbonates will form **soluble chloride salts,** water and carbon dioxide gas when reacted with dilute hydrochloric acid
- The carbonates of Ca, Sr and Ba form as an **insoluble sulfate layer** on their solid carbonates which **stops** any further reaction after the initial bubbling (**effervescence)** of carbon dioxide gas is seen

Group 2 Carbonates reacting with Dilute Acids

Group 2 carbonate	Reaction with dilute HCl	Reaction with dilute H_2SO_4
$MgCO_3$	$MgCO_3$ (s) + 2HCl (aq) → $MgCl_2$ (aq) + H_2O (l) + CO_2 (g)	$MgCO_3$ (s) + H_2SO_4 (aq) → $MgSO_4$ (aq) + H_2O (l) + CO_2 (g)
$CaCO_3$	$CaCO_3$ (s) + 2HCl (aq) → $CaCl_2$ (aq) + H_2O (l) + CO_2 (g)	$CaCO_3$ (s) + H_2SO_4 (aq) → $CaSO_4$ (aq) + H_2O (l) + CO_2 (g)
$SrCO_3$	$SrCO_3$ (s) + 2HCl (aq) → $SrCl_2$ (aq) + H_2O (l) + CO_2 (g)	$SrCO_3$ (s) + H_2SO_4 (aq) → $SrSO_4$ (s) + H_2O (l) + CO_2 (g)
$BaCO_3$	$BaCO_3$ (s) + 2HCl (aq) → $BaCl_2$ (aq) + H_2O (l) + CO_2 (g)	$BaCO_3$ (s) + H_2SO_4 (aq) → $BaSO_4$ (s) + H_2O (l) + CO_2 (g)

- Remember that:

carbonate + dilute hydrochloric acid → chloride + water + carbon dioxide

carbonate + dilute sulfuric acid → sulfate + water + carbon dioxide

Uses of Group 2

Uses of Calcium

- Three different calcium compounds are used commonly in agriculture, construction and iron extraction:
  - **Limestone** - this is impure calcium carbonate
  - **Quicklime** - this is calcium oxide, formed by the thermal decomposition of calcium carbonate
  - **Slaked lime** - this is calcium hydroxide formed when water is added to quicklime
    - $Ca(OH)_2 (s) + 2H^+ (aq) \rightarrow Ca^{2+} (aq) + 2H_2O (l)$
- All three materials are used in **agriculture** to raise the pH of the soil
- Over time, the soil becomes more **acidic** while the **optimum pH** for many crops to grow is at around 6–6.5
- The compounds are all bases and react with the acids in the soil and raise the pH of the soil
- Calcium carbonate is more commonly used in **agricultural lime** as it is **cheaper** and **safer** to handle
  - However, due to calcium carbonate being largely insoluble, it acts more slowly than calcium hydroxide
- Calcium compounds are also used to remove sulfur dioxide from flue gases in a process known as **sulfur scrubbing**

Uses of Barium

- Barium is used in medicine in the form of barium sulfate, $BaSO_4$
- A barium meal or barium swallow containing $BaSO_4$ is given to a patient who needs an X-ray on their intestines
- Barium absorbs X-rays which means the gut shows up white on the image
- Barium is toxic though can be used in this form because
  - Barium sulfate is insoluble so is not absorbed into the blood
  - The barium meal or swallow is only a small amount for the patient to ingest
- Barium chloride or barium nitrate solution can be used in the test for sulfate ions, SO_4^{2-}

Uses of Magnesium

- Magnesium hydroxide, $Mg(OH)_2$, is partially soluble in water and is used in suspension (known as 'milk of magnesia') to neutralise excess acid in the stomach and treat constipation

$$Mg(OH)_2\,(s) + 2HCl\,(aq) \rightarrow MgCl_2\,(aq) + 2H_2O\,(l)$$

- It is safe to use as the magnesium hydroxide is only partially soluble making the solution only slightly alkaline (pH $\cong$ 10) due to the low OH^- concentration
- Magnesium is also used in the extraction of titanium from its ore, TiO_2
- TiO_2 is heated in a stream of chlorine, in the presence of coke, to produce $TiCl_4$

$$TiO_2\,(s) + 2C\,(s) + 2Cl_2\,(g) \rightarrow TiCl_4\,(g) + 2CO\,(g)$$

- The titanium is extracted from its chloride by **reduction** with magnesium (sodium can also be used)

$$TiCl_4\,(g) + 2Mg\,(l) \rightarrow Ti\,(s) + 2MgCl_2\,(l)$$

Your notes