Cambridge (CIE) A Level Chemistry

Your notes

Similarities & Trends in the Properties of the Group 2 Metals, Magnesium to Barium, & Their Compounds

Contents

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Reactions of the Group 2 Elements

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

Reaction of Group 2 elements table

Group 2 element	Reaction with oxygen	Reaction with water	Reaction with dilute HCl	Reaction with dilute H_2SO_4
Mg	Burns easily Bright white flame	Vigorous reaction with steam Very slow reaction with water	Reacts vigorously	Reacts vigorously
Ca	Difficult to ignite Red flame	Reacts moderately Hydroxide formed	Reacts vigorously	Reaction is slowed by the formation of a sparingly soluble sulfate layer which coats the metal surface stopping hydrogen bubbles from rising
Sr	Difficult to ignite Red flame	Reacts rapidly Hydroxide formed	Reacts vigorously	Reaction is quickly stopped by the formation of an insoluble sulfate layer on the metal surface
Ba	Difficult to ignite Green flame	Reacts vigorously Hydroxide formed	Reacts vigorously	Reaction is quickly stopped by the formation of an insoluble sulfate layer on the metal surface

Group 2 reactions with oxygen & water chemical equations

Group 2 element	Reaction with oxygen	Reaction with water
Mg	$2Mg\,(s) + O_2\,(g) \rightarrow 2MgO\,(s)$	$Mg\,(s) + H_2O\,(l) \rightarrow Mg(OH)_2\,(s) + H_2\,(g)$ *
Ca	$2Ca\,(s) + O_2\,(g) \rightarrow 2CaO\,(s)$	$Ca\,(s) + 2H_2O\,(l) \rightarrow Ca(OH)_2\,(s) + H_2\,(g)$

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	$2Ba(s) + O_2(g) \rightarrow 2BaO(s)$ $Ba(s) + O_2(g) \rightarrow BaO_2(s)$	$Ba(s) + 2H_2O(l) \rightarrow Ba(OH)_2(aq) + H_2(g)$

*Mg reacts with steam: $Mg(s) + 2H_2O(g) \rightarrow MgO(s) + H_2(g)$

Group 2 reactions with dilute hydrochloric acid & dilute sulfuric acid chemical equations

Group 2 element	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	$Ca(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2(g)$	$Ca(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + H_2(g)$
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	$Ba(s) + 2HCl(aq) \rightarrow BaCl_2(aq) + H_2(g)$	$Ba(s) + H_2SO_4(aq) \rightarrow BaSO_4(s) + H_2(g)$

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

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

- Where M is any metal in Group 2
  - Remember that Sr and Ba **also** form MO_2
- The reaction of all metals with water follows the following general equation:

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

- The exceptions to this general equation are:
  - Be which does not react with water
  - Mg which forms MgO (s) and H_2 (g)
- The reaction of all metals with dilute HCl follows the following general equation:

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

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

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

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- Remember that $CaSO_4$, $SrSO_4$ and $BaSO_4$ are insoluble

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Examiner Tips and Tricks

Learn the general equation for the reaction with oxygen, water and dilute HCl / H_2SO_4 and the exceptions instead of memorizing the entire table!

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Reactions of 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 with water to form **alkaline** solutions which generally get more **alkaline** going down the group
  - This happens because the hydroxides that form become more soluble as you move down the group
  - This means that more hydroxide ions, OH^-, dissociate into the solution causing the pH to increase

Group 2 oxide reactions with the water table

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	$BaO\,(s) + H_2O\,(l) \rightarrow Ba(OH)_2\,(aq)$	

- Remember that:

oxide + water → hydroxide

- And that calcium hydroxide is also called **limewater**

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


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Group 2 reactions with dilute acids table

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

Reactions of Group 2 oxides with acid

- Group 2 sulfates also form when a Group 2 oxide is reacted with an 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 → salt + water

metal oxide + dilute sulfuric acid → sulfate + water

Reactions of Group 2 hydroxides

- The Group 2 metal hydroxides form **colourless solutions of metal chlorides** 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 table

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

- Remember that:

metal hydroxide + dilute acid → salt + water

metal 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
- When reacted with sulfuric acid, the carbonates of Ca, Sr and Ba form an **insoluble sulfate layer** on their surface which **stops** any further reaction after the initial bubbling (**effervescence) of carbon dioxide gas** is seen

Group 2 carbonate reactions with dilute acids

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

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$BaCO_3$	$BaCO_3(s) + 2HCl(aq) \rightarrow BaCl_2(aq) + H_2O(l) + CO_2(g)$	$BaCO_3(s) + H_2SO_4(aq) \rightarrow BaSO_4(s) + H_2O(l) + CO_2(g)$

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- Remember that:

metal carbonate + dilute hydrochloric acid → salt + water + carbon dioxide

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

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Thermal Decomposition of Group 2 Nitrates & Carbonates

Thermal decomposition is the breakdown of a compound into two or more different substances using **heat**

Thermal decomposition of carbonates

- The Group 2 carbonates break down (**decompose**) when they are heated to form the **metal oxide** and give off **carbon dioxide gas**
- The general equation for the decomposition of Group 2 carbonates is:

$$XCO_3\,(s) \xrightarrow{HEAT} XO\,(s) + CO_2\,(g)$$

X = Group 2 element

- Going **down** the group, more heat is needed to break down the carbonates

$$MgCO_3\,(s) \xrightarrow{HEAT} MgO\,(s) + CO_2\,(g)$$

Thermal decomposition of nitrates

- Group 2 nitrates also undergo thermal decomposition
- Group 2 nitrates decompose to form the metal oxide, nitrogen dioxide gas and oxygen gas
- The general equation for the decomposition of Group 2 nitrates is:

$$X(NO_3)_2\,(s) \xrightarrow{HEAT} XO\,(s) + 2NO_2\,(g) + \tfrac{1}{2}O_2\,(g)$$

OR

$$2X(NO_3)_2\,(s) \xrightarrow{HEAT} 2XO\,(s) + 4NO_2\,(g) + O_2\,(g)$$

X = Group 2 element

- Nitrogen dioxide gas is observed as **brown fumes** and is toxic
  - This is often seen as brown fumes when heating Group 2 nitrates in test tube reactions
- An example of this reaction is:

$$2Ca(NO_3)_2\,(s) \xrightarrow{HEAT} 2CaO\,(s) + 4NO_2\,(g) + O_2\,(g)$$

Trend in thermal stabilities

- Going **down** Group 2, more heat is needed to break down the carbonate and nitrate ions
- The thermal stability of the Group 2 carbonates and nitrates therefore **increases** down the group
  - The smaller positive ions at the top of the groups will polarise the anions more than the larger ions at the bottom of the group
    - The small positive ion attracts the delocalised electrons in the carbonate ion towards itself
    - The higher the charge and the smaller the ion the higher the polarising power
  - The more polarised they are, the more likely they are to thermally decompose as the bonds in the carbonate and nitrate ions become weaker

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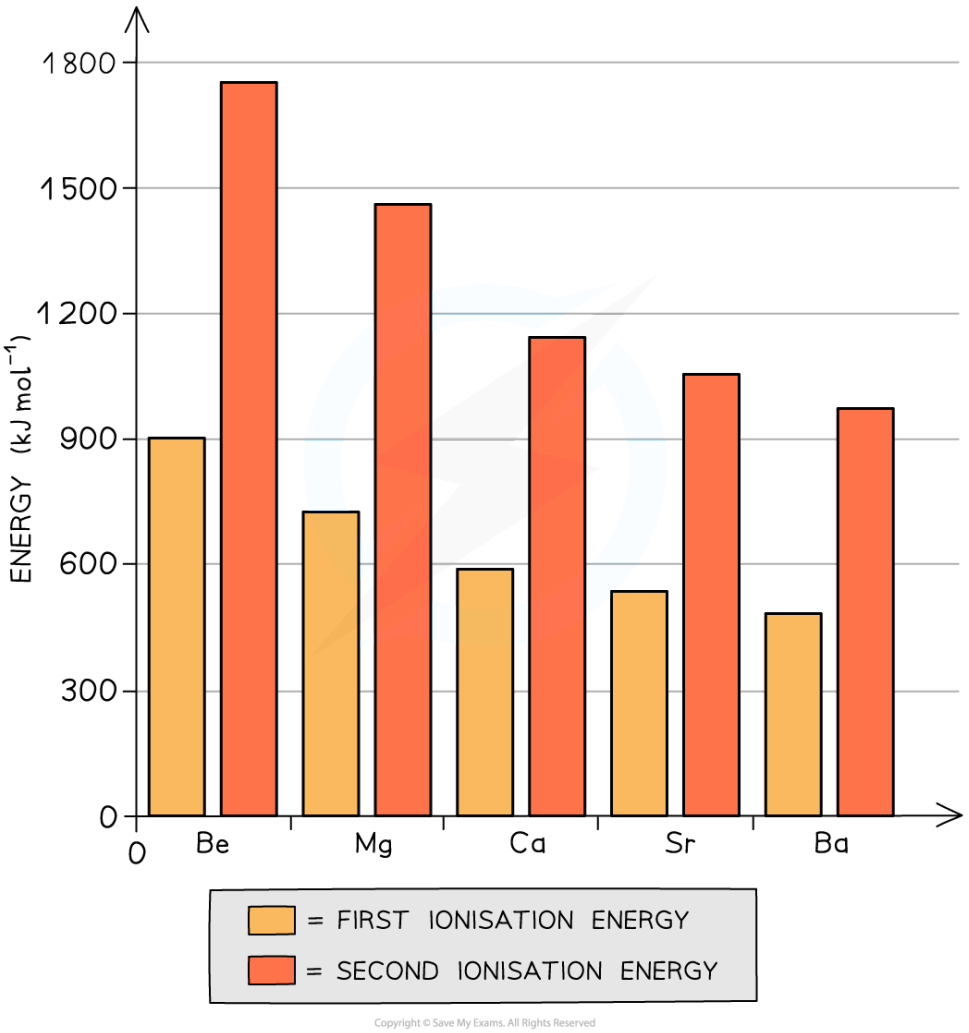
Physical & Chemical Trends in Group 2

Chemical trends

- All elements in Group 2 (also called **alkali earth metals)** have the 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:

Graph of the first and second ionisation energies of the Group 2 elements



The graph shows that both the first and second ionisation energies decrease going down the table

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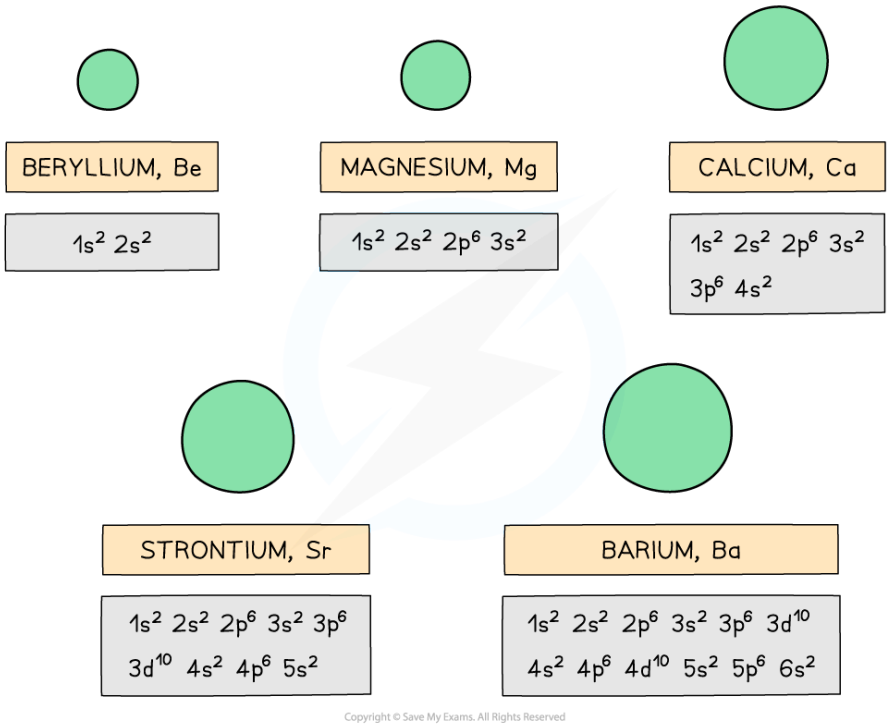
- The **first ionisation energy** is the energy needed to remove the first outer electron of an atom
- The **second ionisation energy** is the energy needed to remove the second outer electron of an atom
- The graph above shows that going down the group, it becomes easier to remove the outer two electrons of the metals
- Though the **nuclear charge** on the nucleus 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 the nucleus outweigh the attraction of the higher nuclear charge
- 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 the 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

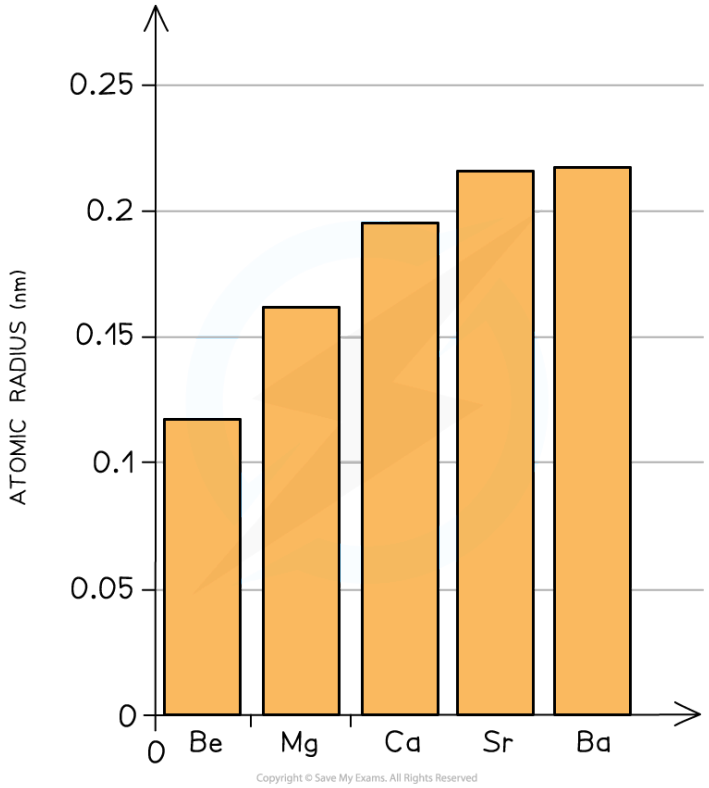
- Going down the group, the elements become larger as the outer two electrons occupy a new **principal quantum shell** which is further away from the nucleus

The atomic radius of the Group 2 elements



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

Graph of the atomic radius descending Group 2



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

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- 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

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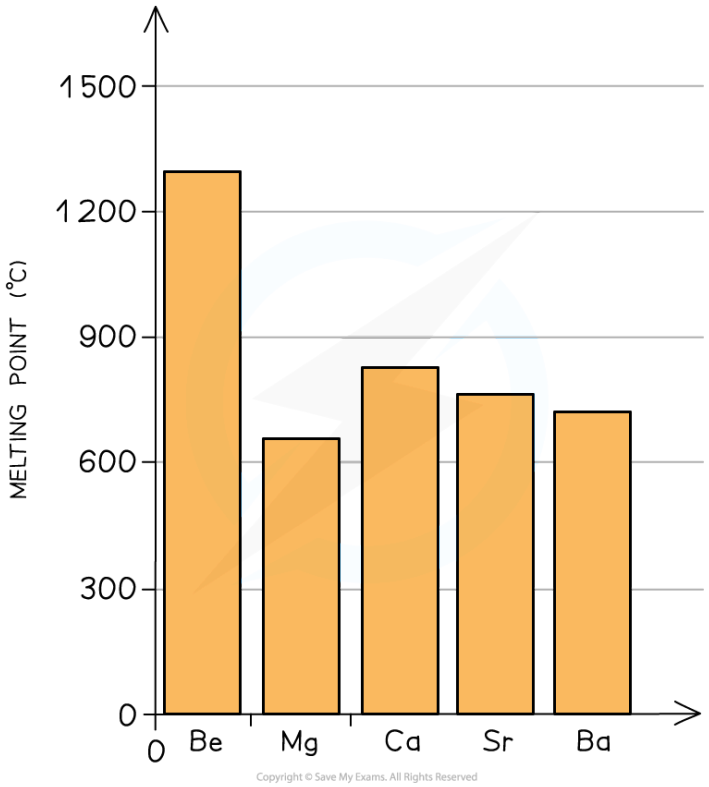
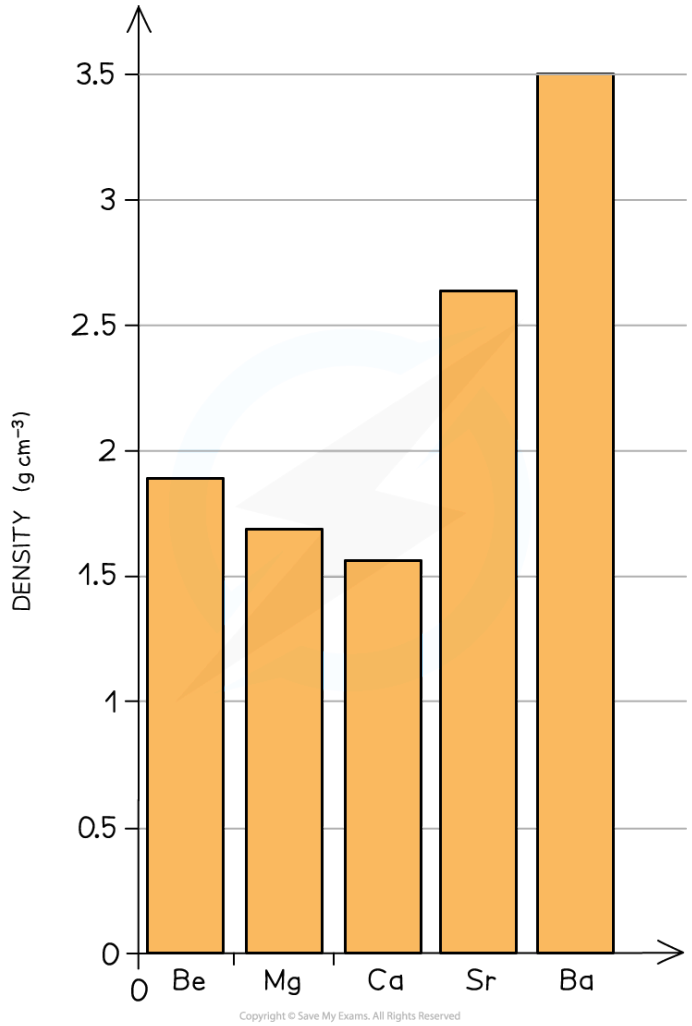
Graph of the melting points descending Group 2



The graph shows a general decrease in melting point going down the group

- As you go down the group, the **density** of the alkali earth metals increases

Graph of the density descending Group 2



The graph shows an overall increase in density going down the group

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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 radium.
2. The formula radium's oxide and hydroxide.
3. The first ionisation energy of radium.
4. The reactivity of radium compared to barium.
5. The relative pH of a saturated radium hydroxide solution compared with a saturated calcium hydroxide solution.
6. The solubility of radium sulfate compared with strontium sulfate.
7. The equation for the reaction of solid radium oxide with dilute hydrochloric acid.

8. What you would expect to see if you mixed radium hydroxide solution with dilute sulfuric acid.

Answer

- **Answer 1:**
  - Since Ra is in Group 2, it will form an ion with a +2 charge to give Ra^{2+}
- **Answer 2:**
  - The Group 2 oxides and hydroxides have the general formula XO and $X(OH)_2$ respectively, where X is the Group 2 element
  - Therefore, radium oxide is RaO and radium hydroxide is $Ra(OH)_2$
- **Answer 3:**
  - 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 ionisation energy is between 450 - 480 kJ mol^{-1}
- **Answer 4:**
  - Radium's outermost electrons are even further away than in barium and are therefore more easily removed, making radium more reactive than barium
- **Answer 5:**
  - The Group 2 hydroxides become more soluble going down the group
  - Radium hydroxide will therefore be more soluble than calcium hydroxide
- **Answer 6:**
  - The Group 2 sulfates become less soluble going down the group
  - Radium sulfate will therefore be less soluble than strontium sulfate
- **Answer 7:**
  - The general equation for the reaction of Group 2 oxides with dilute hydrochloric acid is:

$$\mathbf{XO\,(s) + 2HCl\,(aq) \rightarrow XCl_2\,(aq) + H_2O\,(l)}$$

- where X is the Group 2 element
  - The reaction of radium oxide with dilute hydrochloric acid is therefore:

$$\mathbf{RaO\,(s) + 2HCl\,(aq) \rightarrow RaCl_2\,(aq) + H_2O\,(l)}$$

- **Answer 8:**
  - 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

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Trends in Solubility of Group 2 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 formed solution can therefore be explained by the **solubility** of the Group 2 **hydroxides**

Solubility of the Group 2 hydroxides table

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

- The hydroxides dissolve in water as follows:

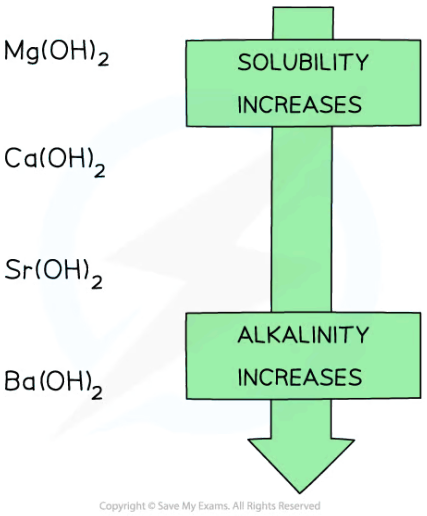
$$X(OH)_2(aq) \rightarrow X^{2+}(aq) + 2OH^-(aq)$$

- Where X is the Group 2 element
- When the metal oxides react with water, a Group 2 hydroxide is formed:

$$XO(s) + H_2O(l) \rightarrow X(OH)_2(aq)$$

- Going down the group, the **solubility** of these hydroxides **increases**
- 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

The solubility of the Group 2 hydroxides



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

Group 2 sulfate	Solubility at 298 K (mol / 100 g of water)
$MgSO_4$	Highly soluble
$CaSO_4$	1.2×10^{-3}
$SrSO_4$	7.6×10^{-4}
$BaSO_4$	1.0×10^{-4} (insoluble)

- The sulfates dissolve in water as follows:

$$XSO_4\,(s) \rightarrow X^{2+}\,(aq) + SO_4^{2-}\,(aq)$$

- Where X is the Group 2 element
- When the metal oxides react with sulfuric acid, a Group 2 sulfate is formed:

$$XO\,(s) + H_2SO_4\,(aq) \rightarrow XSO_4\,(aq) + H_2O\,(l)$$

- Going down the group, the **solubility** of these sulfates **decreases**

The solubility of the Group 2 sulfates

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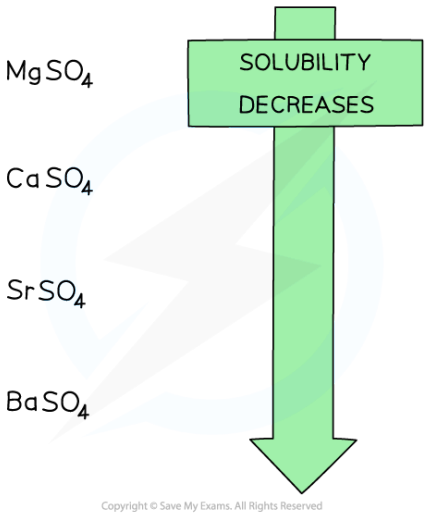

Going down the group, the solubility of the sulfates decreases

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Examiner Tips and Tricks

You only need to be able to state the variation in the solubilities of the hydroxides and sulfates for this topic.

Enthalpy of Hydration: Ionic Charge & Radius in the A level course gives more detail on the solubility of Group 2 sulfates.