GROUP 2 ELEMENTS - Beryllium to Barium

Introduction

Group I (alkali metals) and Group 2 (alkaline earths) are known as s-block elements because their valence (bonding) electrons are in s orbitals.

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Be</th>
<th>Mg</th>
<th>Ca</th>
<th>Sr</th>
<th>Ba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic configuration</td>
<td>$1s^22s^2$</td>
<td>[Ne] $3s^2$</td>
<td>[Ar] $4s^2$</td>
<td>[Kr] $5s^2$</td>
<td>[Xe] $6s^2$</td>
</tr>
</tbody>
</table>

TRENDS IN PHYSICAL PROPERTIES

Atomic Radius

Increases down each group
electrons in shells further from the nucleus

<table>
<thead>
<tr>
<th>Atomic radius / nm</th>
<th>Be</th>
<th>Mg</th>
<th>Ca</th>
<th>Sr</th>
<th>Ba</th>
</tr>
</thead>
</table>

Ionic Size

Increases down the group
nuclear charge exceeds the electronic charge

The size of a positive ions is always less than the original atom because the nuclear charge exceeds the electronic charge.

<table>
<thead>
<tr>
<th>Ionic radius / nm</th>
<th>$Be^{2+}$</th>
<th>$Mg^{2+}$</th>
<th>$Ca^{2+}$</th>
<th>$Sr^{2+}$</th>
<th>$Ba^{2+}$</th>
</tr>
</thead>
</table>

Melting Points

Decrease down each group
metallic bonding gets weaker due to increased size and lower charge density

Each atom contributes two electrons to the delocalised cloud. Melting points tend not to give a decent trend as crystalline structure affects melting points.

<table>
<thead>
<tr>
<th>Melting point / ºC</th>
<th>Be</th>
<th>Mg</th>
<th>Ca</th>
<th>Sr</th>
<th>Ba</th>
</tr>
</thead>
</table>

TRENDS IN CHEMICAL PROPERTIES

Overall

- undergo redox reactions involving the ‘loss’ of electrons to form 2+ ions
- reactivity increases down the Group due to the ease of cation formation

Reason

- ionisation energies (I.E.) decrease down the group

REMINDER

1st I.E.  The energy required to remove one mole of electrons (to infinity) from one mole of gaseous atoms to form one mole of gaseous positive ions.

e.g. $Mg(g)$ $\rightarrow$ $Mg^{+}(g)$ + $e^{-}$

2nd I.E.

e.g. $Mg^{+}(g)$ $\rightarrow$ $Mg^{2+}(g)$ + $e^{-}$
Ionisation Energy

**Decreases down the group**  **atomic size increases**

Values for Group I are low because the electron has just gone into a new level and is shielded by filled inner levels. This makes them reactive.

**Group 2 values are higher than their Group I equivalents** due to the increased nuclear charge.

<table>
<thead>
<tr>
<th></th>
<th>Be</th>
<th>Mg</th>
<th>Ca</th>
<th>Sr</th>
<th>Ba</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st I.E. / kJ mol(^{-1})</td>
<td>899</td>
<td>738</td>
<td>590</td>
<td>550</td>
<td>500</td>
</tr>
<tr>
<td>2nd I.E. / kJ mol(^{-1})</td>
<td>1800</td>
<td>1500</td>
<td>1100</td>
<td>1100</td>
<td>1000</td>
</tr>
<tr>
<td>3rd I.E. / kJ mol(^{-1})</td>
<td>14849</td>
<td>7733</td>
<td>4912</td>
<td>4120</td>
<td>3390</td>
</tr>
</tbody>
</table>

Large increase for 3rd I.E.  the electron is now being removed from a shell nearer the nucleus and there is less shielding.

### CHEMICAL PROPERTIES OF THE ELEMENTS

**Oxygen**

- **react with increasing vigour down the group**

  Mg  burns readily with a bright white flame  
  
  \[
  2\text{Mg}(s) + \text{O}_2(g) \rightarrow 2\text{MgO}(s)
  \]

  Ba  burns readily with an apple-green flame  
  
  \[
  2\text{Ba}(s) + \text{O}_2(g) \rightarrow 2\text{BaO}(s)
  \]

  In both cases  **metal is oxidised**  **oxidation No. increases from 0 to +2**  **oxygen is reduced**  **oxidation No. decreases from 0 to -2**

  \[
  \text{Mg} \rightarrow \text{Mg}^{2+} + 2\text{e}^{-}
  \]

  \[
  \text{O} + 2\text{e}^{-} \rightarrow \text{O}^{2-}
  \]

**Water**

- **react with increasing vigour down the group**

  Mg  reacts very slowly with cold water  
  
  \[
  \text{Mg}(s) + 2\text{H}_2\text{O}(l) \rightarrow \text{Mg(OH)}_2(aq) + \text{H}_2(g)
  \]

  but reacts quickly with steam  
  
  \[
  \text{Mg}(s) + \text{H}_2\text{O}(g) \rightarrow \text{MgO}(s) + \text{H}_2(g)
  \]

  Ba  react with vigourously with cold water  
  
  \[
  \text{Ba}(s) + 2\text{H}_2\text{O}(l) \rightarrow \text{Ba(OH)}_2(aq) + \text{H}_2(g)
  \]
Dilute acid
- react with increasing vigour down the group to produce hydrogen + a salt
- reactions are more vigorous than with water

\[
\begin{align*}
\text{e.g. } & \quad \text{Mg(s)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{MgSO}_4(\text{aq}) + \text{H}_2(\text{g}) \\
& \quad \text{Mg(s)} + 2\text{HCl}(\text{aq}) \rightarrow \text{MgCl}_2(\text{aq}) + \text{H}_2(\text{g}) \\
\text{ionically } & \quad \text{Mg(s)} + 2\text{H}^+(\text{aq}) \rightarrow \text{Mg}^{2+}(\text{aq}) + \text{H}_2(\text{g})
\end{align*}
\]

OXIDES OF GROUP 2 ELEMENTS

Properties
- ionic solids; EXC. beryllium oxide which has covalent character

\[
\begin{align*}
\text{BeO} & \quad \text{beryllium oxide} \\
\text{MgO} & \quad \text{magnesium oxide} \\
\text{CaO} & \quad \text{calcium oxide} \\
\text{SrO} & \quad \text{strontium oxide} \\
\text{BaO} & \quad \text{barium oxide}
\end{align*}
\]

Reaction with water
Most Group 2 oxides react with water to produce the hydroxide

\[
\begin{align*}
\text{e.g. } & \quad \text{CaO(s)} + \text{H}_2\text{O(l)} \rightarrow \text{Ca(OH)}_2(\text{s})
\end{align*}
\]

<table>
<thead>
<tr>
<th>Reactivity with water</th>
<th>NONE</th>
<th>reacts</th>
<th>reacts</th>
<th>reacts</th>
<th>reacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solubility of hydroxide g/100cm$^3$ of water</td>
<td>insoluble</td>
<td>sparingly</td>
<td>slightly</td>
<td>quite</td>
<td>very</td>
</tr>
<tr>
<td>approx. pH of 0.1M solution</td>
<td>-</td>
<td>10.4</td>
<td>12.5</td>
<td>13.0</td>
<td>13.1</td>
</tr>
</tbody>
</table>

Hydroxides
- basic strength also increases down group
  - this is because the solubility increases
  - the metal ions get larger so charge density decreases
  - there is a lower attraction between the OH$^-$ ions and larger dipositive ions
  - the ions will split away from each other more easily
  - there will be a greater concentration of OH$^-$ ions in water

Uses
- \(\text{Ca(OH)}_2\) used in agriculture to neutralise acid soils
  \[
  \text{Ca(OH)}_2(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Ca}^{2+}(\text{aq}) + 2\text{H}_2\text{O(l)}
  \]
- \(\text{Mg(OH)}_2\) used in toothpaste and indigestion tablets as an antacid
  \[
  \text{Mg(OH)}_2(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{H}_2\text{O(l)}
  \]
  - both the above are weak alkalis and not as caustic as sodium hydroxide
CARBONATES OF GROUP 2 ELEMENTS

**Properties**
- insoluble in water
- undergo thermal decomposition to oxide and carbon dioxide
  
  e.g.  \[ \text{MgCO}_3(s) \rightarrow \text{MgO}(s) + \text{CO}_2(g) \]
- ease of decomposition decreases down the group

<table>
<thead>
<tr>
<th>Solubility (g/100cm(^3) of water)</th>
<th>MgCO(_3)</th>
<th>CaCO(_3)</th>
<th>SrCO(_3)</th>
<th>BaCO(_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition temperature / °C</td>
<td>400</td>
<td>980</td>
<td>1280</td>
<td>1360</td>
</tr>
</tbody>
</table>

SULFATES OF GROUP 2 ELEMENTS

**Sulphates**
- white crystalline solids
- solubility in water decreases down the Group

<table>
<thead>
<tr>
<th>Salt</th>
<th>Ionic radius (M(^{2+})) / nm</th>
<th>Hydration Enthalpy (M(^{2+})) / kJ mol(^{-1})</th>
<th>Solubility moles/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgSO(_4)</td>
<td>0.064</td>
<td>-1891</td>
<td>3600 \times 10(^{-4})</td>
</tr>
<tr>
<td>CaSO(_4)</td>
<td>0.094</td>
<td>-1562</td>
<td>11 \times 10(^{-4})</td>
</tr>
<tr>
<td>SrSO(_4)</td>
<td>0.110</td>
<td>-1413</td>
<td>0.62 \times 10(^{-4})</td>
</tr>
<tr>
<td>BaSO(_4)</td>
<td>0.134</td>
<td>-1273</td>
<td>0.009 \times 10(^{-4})</td>
</tr>
</tbody>
</table>

- there is little change in the lattice enthalpy   BUT
- as the cation gets larger the hydration enthalpy gets much smaller
- a larger cation has a lower charge density so is less attracted to water

**Test for sulfates**
- **barium sulfate’s high insolubility** is the basis for a laboratory **test for sulfates**

  **Method**
  - make up a solution of the compound to be tested
  - acidify it with dilute hydrochloric (or nitric) acid *
  - add a few drops of **barium chloride solution**
  - **white precipitate of barium sulfate** conforms presence of sulfate ion

  \[ \text{Ba}^{2+}(aq) + \text{SO}_4^{2-}(aq) \rightarrow \text{BaSO}_4(s) \]

* adding acid prevents precipitation of other insoluble ions such as carbonate

**Q.1** How is the high insolubility of barium sulfate made use of in hospitals?