# GROUP 2 ELEMENTS- Alkaline Earth metal

## Group 2 Elements – Alkaline Earth Metals

### Introduction and Uses

Elements from **Group 2** are used in a wide range of applications.

- **Coloured flames:** Group 2 metals produce coloured flames when heated, which makes them useful in **flares** and **fireworks**.
- **Magnesium flares:** Magnesium in powdered form is often used in flares because it burns with a bright white light.

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### Why They Are Called Alkaline Earth Metals

Group 2 elements are called **alkaline earth metals** because:

- Their **oxides** and **hydroxides** are alkaline in nature (water-soluble and basic).
- Their **oxides** are found in the earth's crust.

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### Electronic Structure

- All Group 2 elements have **two electrons in their outermost shell** (valence shell).
- These two electrons occupy the **s subshell**.
- **General electronic configuration:** $ns^2$

**Examples:**

- **Beryllium (Be):** $1s^2\ 2s^2$
- **Magnesium (Mg):** $1s^2\ 2s^2\ 2p^6\ 3s^2$
- **Calcium (Ca):** $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$

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## General Trends of Physical Properties and Chemical Reactivity

### Ion Formation and Reducing Nature

- All Group 2 metals form **ionic compounds** by donating their two outermost electrons.
- They form **2+ ions** and act as **reducing agents** (get oxidised in reactions).

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### Trend in Reactivity Down the Group

- **Reactivity increases** as we go down the group.
- This is explained by **ionization energy** trends.

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### Ionization Energy

- **Definition:** Minimum energy required to remove one mole of electrons from isolated gaseous atoms or ions.
- **Trend:** Both **first** and **second ionization energies** decrease down the group.
- **Reason:**
  - Increased **shielding effect**
  - Greater distance between nucleus and outermost electrons
- **Effect:** Easier to lose two electrons → more reactive metals.

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## Reactions of Group 2 Metals

### With Dilute Hydrochloric Acid

- Reaction produces **bubbles of hydrogen gas**.
- Rate of reaction increases down the group.
- Example:

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

### With Oxygen

- Reactivity with oxygen increases down the group.
- **Barium (Ba)** is so reactive it must be stored in oil to prevent reaction with air.

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### Trends in Atomic Radius

- **Atomic radius increases** down the group.
- **Reason:**
  - Extra electron shells are added.
  - Increased **shielding effect** reduces attraction between nucleus and valence electrons.

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### Trends in Melting Point

- **Melting point decreases** down the group.
- **Reason:**
  - Outer electrons are farther from the nucleus.
  - **Weaker attraction** between nucleus and delocalised electrons.
  - **Metallic bonds** weaken → lower melting point.

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## Table: Properties of Group 2 Elements

| Element | Metallic Radius (nm) | Atomic Number | Melting Point (°C) | Density (g/cm³) |
|---|---|---|---|---|
| Beryllium (Be) | 0.122 | 4 | 1280 | 1.85 |
| Magnesium (Mg) | 0.160 | 12 | 650 | 1.74 |
| Calcium (Ca) | 0.197 | 20 | 838 | 1.55 |
| Strontium (Sr) | 0.215 | 38 | 768 | 2.66 |
| Barium (Ba) | 0.217 | 56 | 714 | 3.56 |

## Trends in Chemical Reactivity with Oxygen, Water, and Dilute Acids

### (a) Reaction with Oxygen – Formation of Basic Oxides

- **General reaction:**
  Group 2 metals burn in air (and more rapidly in oxygen) to form **white solid oxides**.

$$2Mg\,(s) + O_2(g) \rightarrow 2MgO\,(s)$$

- **Peroxide formation:**
  Strontium and barium also form **peroxides ($MO_2$)**.
- **Example:**
  Magnesium ribbon burns with a bright white flame in a Bunsen flame.

### Solubility of Oxides

- **Beryllium oxide (BeO)** and **magnesium oxide (MgO)** are **insoluble in water**.
- Solubility of oxides **increases down the group**, producing **soluble hydroxides**.
- All oxides are **basic**, except **BeO**, which is **amphoteric**.

### Amphoteric Nature of BeO

- **Reacts with acids:**

$$BeO\,(s) + 2HCl\,(aq) \rightarrow BeCl_2(aq) + H_2O$$

- **Reacts with bases:**

$$BeO\ (s) + 2NaOH\ (aq) \rightarrow Na_2BeO_2(aq) + H_2O\ (l)$$

**Reactivity Trend with Oxygen**

- Reactivity **increases down the group** because larger atoms lose outer electrons more easily.
- Barium is so reactive it must be stored under oil.

**Covalent Character of BeO**

- $Be^{2+}$ has a small ionic radius and high **polarizing power**.
- It strongly polarises the oxide ion, creating **covalent bonds**.

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**Flame Test for Group 2 Metals**

The flame colours are due to excitation of **2+ ions**.

| Metal | Flame Colour |
|---|---|
| Calcium | Brick red |
| Strontium | Scarlet / Red |
| Barium | Apple green |

**Procedure:**

1. Clean nichrome wire with concentrated HCl.
2. Dip into the salt sample.
3. Place in a **non-luminous** Bunsen flame.

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**(b) Reaction with Water**

**General Trends**

- **Beryllium (Be):** No reaction due to protective BeO layer.
- **Magnesium (Mg):** No reaction with cold water; burns in steam:

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

- **Calcium (Ca):** Reacts with cold water:

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

- Forms cloudy white suspension of slightly soluble $Ca(OH)_2$.
- Solution becomes **weakly alkaline**.

- **Reactivity increases down the group** – hydrogen gas is produced faster.

**General Equation (except Be and Mg):**

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

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**(c) Reaction with Dilute Acids**

- **General redox reaction:**

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

- Reactions become **more vigorous and exothermic** down the group.

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**(d) Reaction of Group 2 Oxides with Acids**

- Group 2 oxides are **basic** and neutralise acids to form salts and water.

**Examples:**

1. Magnesium oxide with sulfuric acid:

$$MgO\,(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O\,(l)$$

2. Calcium oxide with hydrochloric acid:

$$CaO\,(s) + 2HCl\,(aq) \rightarrow CaCl_2(aq) + H_2O\,(l)$$

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**Uses of Products**

- **Magnesium sulfate ($MgSO_4$):**
  - Short-term relief of constipation.
  - Soaking solution for minor sprains, bruises, muscle aches, and joint stiffness.
- **Calcium chloride ($CaCl_2$):**
  - Solidifying agent in paint production.
  - Coagulant in rubber manufacturing.

## Comparison of Reactivity of Group 1 and Group 2 Elements

### Dependence on Ionization Energy

- **Reactivity** of metals is inversely related to their **ionization energy**:
  - **Lower ionization energy → Higher reactivity**
- **Alkaline earth metals (Group 2)** have **higher ionization energies** compared to **alkali metals (Group 1)**.
- Reason:
  - Group 2 atoms are **smaller** in size.
  - Stronger **nuclear attraction** on valence electrons.

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### Reactivity Trend

- **Group 1 elements** are **more reactive** than **Group 2 elements** in the same period.
- This is due to the **lower ionization energy** of Group 1 metals compared to Group 2 metals.

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### Reaction with Water

- **Alkali metals (Group 1):**
  - React **very vigorously** with water.
  - Reaction produces enough heat to ignite the evolved **hydrogen gas**.
  - Example:

$$2Na\,(s) + 2H2O\,(l) \rightarrow 2NaOH\,(aq) + H_2(g)$$

- **Alkaline earth metals (Group 2):**
  - React **slowly** with water.
  - Example:

$$Ca\,(s) + 2H_2O\,(l) \rightarrow Ca(OH)_2$$

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### Reducing Power

- **Group 1 metals** are **stronger reducing agents** than Group 2 metals.
- Reason:
  - **Lower ionization energy** makes it easier for Group 1 metals to lose electrons.

# Uses of Group 2 Compounds

## 1. Use of Limestone in Industry

Limestone is mainly **calcium carbonate ($CaCO_3$)**.
Many forms of limestone are used as **building stones**.

- Shaped into blocks and fixed with mortar.
- Traditional mortar: lime + sand.
- Modern mortar: cement + sand (cement is made from lime).

**Marble:** Another form of calcium carbonate, used for expensive tiles and decorative work.

### Manufacture of Cement

The first stage in the manufacture of cement is the roasting of limestone in a lime kiln. At high temperatures in the kiln, calcium carbonate decomposes to form calcium oxide also called lime or quick lime.

$$CaCO_3 \xrightarrow{Heat} CaO\ (lime) + CO_2$$

The calcium oxide made in the lime kiln goes on to be roasted with clay to make cement.

Cement can be mixed with sand and small pieces of rock to make concrete, the most widely used building material in the world. Its tensile strength can be improved by letting the concrete set with iron rods running through it.

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## 2. Use of Slaked Lime in Agriculture

Slaked lime is **calcium hydroxide ($Ca(OH)_2$)**.

- **Purpose:** To increase the **pH of acidic soils** by neutralisation.
- **Reaction:**

$$Ca(OH)_{2(s)} + 2H^+(aq) \rightarrow Ca^{2+}(aq) + 2H_2O(l)$$

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## 3. Use of Group 2 Compounds in Medicine

### (a) Barium Sulphate ($BaSO_4$)

- Absorbs X-rays strongly → used in diagnosing stomach and intestinal disorders.
- Insoluble, so it is safe and not absorbed into the bloodstream.

### (b) Antacids

- Purpose: Neutralise excess stomach acid (HCl) in acid indigestion.
- Common examples:
  - Calcium carbonate ($CaCO_3$) → used in Gaviscon, Rennies.
  - Magnesium carbonate ($MgCO_3$)
  - Milk of Magnesia → suspension of magnesium hydroxide ($Mg(OH)_2$) in water.

**Reactions:**

1. With calcium carbonate:

$$CaCO_{3(s)} + 2HCl(aq) \rightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O(l)$$

With magnesium hydroxide:

$$Mg(OH)_{2(s)} + 2HCl(aq) \rightarrow MgCl_{2(aq)} + 2H_2O(l)$$

## Thermal Decomposition of Group 2 Carbonates and Nitrates

## Definition

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

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### 1. Decomposition of Group 2 Carbonates

- When heated, **Group 2 carbonates** break down into the **metal oxide** and **carbon dioxide** gas.

**Example:**

$$MgCO_3 \xrightarrow{Heat} MgO + CO_{2(g)}$$

- **Trend:** The temperature required for decomposition **increases down the group**.

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### 2. Decomposition of Group 2 Nitrates

- **Group 2 nitrates** decompose on heating to form:
  - **Metal oxide**
  - **Nitrogen dioxide ($NO_2$)** – a toxic brown gas
  - **Oxygen gas ($O_2$)**

**Example:**

$$2Ca(NO3)2(s) \xrightarrow{Heat} 2CaO(s) + 4NO2(g) + O2(g)$$

- **Observation:** Brown fumes of nitrogen dioxide are seen.
- **Trend:** Higher temperatures are needed for decomposition **down the group**.

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## 3. Trend in Thermal Stability

- **Thermal stability** of Group 2 carbonates and nitrates **increases down the group**.
- This means:

$$BaCO_3 > SrCO_3 > CaCO_3 > MgCO_3$$

$$Ba(NO_3)_2 > Sr(NO_3)_2 > Ca(NO_3)_2 > Mg(NO_3)_2$$

- **Reason:** Larger cations down the group have less polarising power.

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## 4. Enthalpy Change of Decomposition for Group 2 Carbonates

| Carbonate | Decomposition Temperature (°C) | ΔH (kJ mol⁻¹) |
|---|---|---|
| Magnesium carbonate | 540 | +117 |
| Calcium carbonate | 900 | +176 |
| Strontium carbonate | 1280 | +238 |
| Barium carbonate | 1360 | +268 |

- **Interpretation:**
  - More positive ΔH → more energy needed → greater stability.

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## 5. Explanation – Ion Polarisation Theory

- **Carbonate ion ($CO_3^{2-}$)** has a large ionic radius, making it easy to **polarise**.
- **Smaller, highly charged cations** (like $Mg^{2+}$) have strong polarising power, distorting the carbonate ion and weakening the C–O bond.
- **Trend down the group:**
  - Cation size increases:

$$Mg^{2+} < Ca^{2+} < Sr^{2+} < Ba^{2+}$$

- Polarising power decreases.
- Less distortion → more stable carbonate → higher decomposition temperature.

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**Summary of Stability Order:**

- **Carbonates:**

$$BaCO_3 > SrCO_3 > CaCO_3 > MgCO_3$$

- **Nitrates:**

$$Ba(NO_3)_2 > Sr(NO_3)_2 > Ca(NO_3)_2 > Mg(NO_3)_2$$

## Trends in Solubility of Group 2 Hydroxides and Sulphates

### (a) Solubility of Hydroxides of Group 2 Elements

The solubility of hydroxides **increases** as we move down Group 2, with **barium hydroxide** being highly soluble in water.

**Order of solubility:**

$$Mg(OH)_2 < Ca(OH)_2 < Sr(OH)_2 < Ba(OH)_2$$

**Table 5.3 – Solubility in water at 298 K**

| Group 2 hydroxide | Solubility ($mol$ / $100\ g\ water$) |
|---|---|
| $Mg(OH)_2$ | $2 \times 10^{-5}$ |
| $Ca(OH)_2$ | $1.5 \times 10^{-3}$ |
| $Sr(OH)_2$ | $3.4 \times 10^{-3}$ |
| $Ba(OH)_2$ | $1.5 \times 10^{-2}$ |

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### (b) Change in Hydration Enthalpy Down the Group

- Hydration enthalpy is **directly proportional** to ionic charge and **inversely proportional** to ionic size.
- Smaller ions have a **more exothermic** hydration enthalpy.
- As we go down the group, **cation size increases**, so hydration enthalpy becomes **less exothermic**:

$$Mg^{2+} > Ca^{2+} > Sr^{2+} > Ba^{2+}$$

- This decrease is **small** compared to the change in lattice energy, since the anion ($OH^-$) remains the same.

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## (c) Change in Lattice Energy Down the Group

- Lattice energy is greater for **smaller ions** (with the same charge).
- As cation size increases, **lattice energy decreases** in the order:

$$Mg^{2+} > Ca^{2+} > Sr^{2+} > Ba^{2+}$$

- The lattice energy is also inversely proportional to the sum of the radii of the anion and cation.
- The decrease in lattice energy down the group is **large**, mainly due to the increase in cation size ($OH^-$ size remains constant).

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## (d) Enthalpy of Solution and Solubility

- High solubility is linked to a **more negative (exothermic)** enthalpy of solution.
- Down the group:
  - **Lattice energy decreases** by a relatively large amount.
  - **Hydration enthalpy decreases** by a smaller amount.
  - Result: **Enthalpy of solution becomes more negative**, increasing solubility.
- A compound is **likely soluble** if its enthalpy of solution is negative or only slightly positive.

**Conclusion:**
The greater decrease in lattice energy compared to hydration enthalpy causes **Group 2 hydroxides** to become more soluble down the group.



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## (e) Solubility of Sulphates of Group 2 Elements

The solubility of sulphates **decreases** as we go down the group, with **barium sulphate** being almost insoluble in water.

**Order of solubility:**

$$MgSO_4 > CaSO_4 > SrSO_4 > BaSO_4$$

This is due to:

When we move down the group, both the lattice dissociation enthalpy and hydration enthalpy decrease. The hydration enthalpy decreases more than the lattice dissociation enthalpy. So, the enthalpy of the solution becomes more endothermic.

**Table – Solubility in Water of Group 2 Sulphates at 298 K**

| $Compound$ | $Solubility(moldm^{-3})$ |
|---|---|
| $MgSO_4$ | 1.83 |
| $CaSO_4$ | $4.66 \times 10^{-2}$ |
| $SrSO_4$ | $7.11 \times 10^{-3}$ |
| $BaSO_4$ | $9.43 \times 10^{-6}$ |

## Complexes of the Alkaline Earth Metals

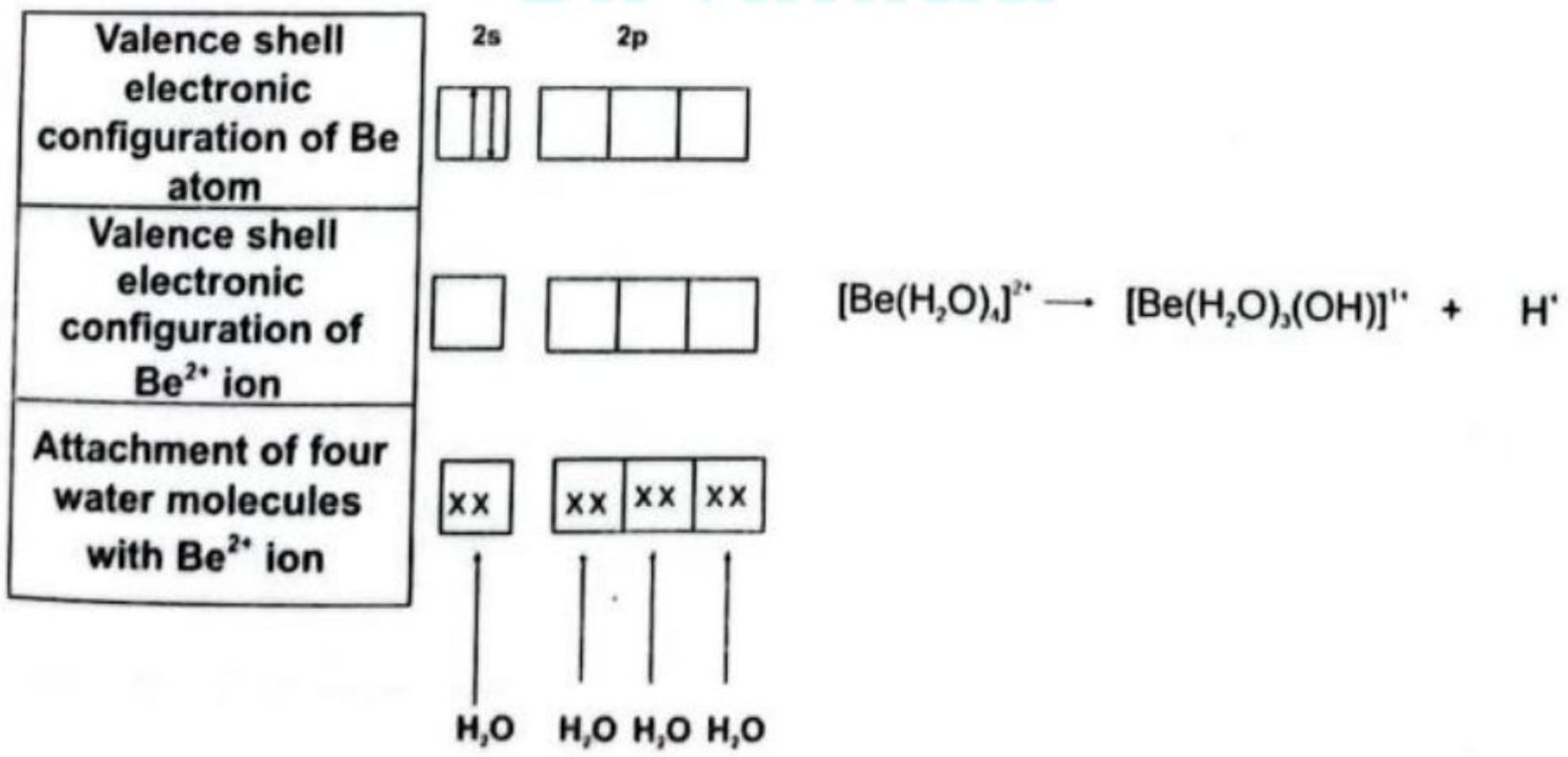
Group 2 elements usually form ionic compounds containing the **$M^{2+}$ ion**. They are more reactive towards Group 5 elements and show a greater tendency to form complexes with Lewis bases than alkali metals. This is because they have a **+2 charge** and **smaller ionic radii**, giving them stronger attraction for electron donors.

### Trend in Complex Formation

The tendency to form complexes is greatest for **$Be^{2+}$** and decreases sharply down the group as the ionic radius increases. The high **charge-to-radius ratio** of $Be^{2+}$ gives it strong polarizing power, allowing it to distort the electron clouds of ligands and form stable complexes.

### Beryllium as a Lewis Acid

Beryllium chemistry is dominated by complex formation. In water, $Be^{2+}$ salts produce acidic solutions containing the tetrahedral **$[Be(H_2O)_4]^{2+}$** ion. The strong polarization of coordinated water molecules weakens O–H bonds, releasing $H^+$ ions and increasing acidity. Heavier Group 2 cations like $Ba^{2+}$ have lower charge density and form less stable complexes.




**Complex Formation in Beryllium and Other Alkaline Earth Metals**

In the presence of a strong base, **beryllium and its salts** form the tetrahedral hydroxo complex **$[Be(OH)_4]^{2-}$**, showing that **beryllium oxide is amphoteric**. Beryllium also forms a very stable tetrahedral fluoride complex **$[BeF_4]^{2-}$** (and related species such as **$[BeF_3]^-$**). These properties are due to the **small size** and **high charge density** of the $Be^{2+}$ ion.
Beryllium halides act as **Lewis acids** by forming adducts with Lewis bases.

### Complexes of Heavier Group 2 Metals

Heavier alkaline earth metals form fewer complexes, usually with a coordination number of **six or higher**. Complex formation is most significant for the smaller cations like **$Mg^{2+}$** and **$Ca^{2+}$**. For example, in aqueous solution, $Mg^{2+}$ exists as the octahedral complex **$[Mg(H_2O)_6]^{2+}$**, where magnesium uses one 3s, three 3p, and two 3d orbitals in its outer shell to achieve a coordination number of six.

## Extraction and Purification of Group 2 Elements and Compounds

Group 2 elements (alkaline earth metals) include **beryllium, magnesium, calcium, strontium, barium, and radium**. Their extraction and purification methods vary depending on the element's chemical properties, but generally involve ore preparation, thermal decomposition, reduction, and electrolysis.

### 1. Extraction

- **Ore Preparation:**
  Group 2 metals occur in minerals such as **carbonates, sulfates, oxides, and silicates**. The ores are mined, crushed, and ground into a fine powder for processing.
- **Roasting:**
  Carbonates decompose on heating to form metal oxides and $CO_2$.
  Example:

$$MgCO_3 \xrightarrow{Heat} MgO + CO_2$$

- **Reduction:**
  - **Magnesium:** Extracted by electrolysis of molten magnesium oxide.
  - **Calcium & Strontium:** Obtained by reducing their halides with sodium or magnesium.

### 2. Electrolysis (Purification)

- Pure metals are obtained by electrolyzing **molten chlorides or oxides**.
- Electrolysis may also be used for **final purification**.
- **Beryllium:** Initially produced by reducing beryllium chloride.
- **Radium:** Extracted from radium chloride through multiple separation steps due to its radioactivity.

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### Examples of Extraction and Purification

- **Beryllium:**
  - **Extraction:** From **beryl ore** ($Be_3Al_2(SiO_3)_6$) by acid digestion and solvent extraction.
  - **Purification:** Convert $Be(OH)_2$ to **$BeF_2$**, then reduce with magnesium to obtain high-purity metal.
- **Magnesium:**
  - **Extraction:** By electrolysis of molten $MgCl_2$ (from seawater or brines).
  - **Purification:** Fractional distillation or vacuum distillation.

## For More Information:

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