Group 2

Reactions of the Group 2 metals and their oxides, hydroxides and carbonates, the thermal stability of nitrates and carbonates, and the solubility of hydroxides and sulfates.

10.1 Similarities and trends in the properties of the Group 2 metals, magnesium to barium, and their compounds

Group 2 metals have two outer electrons and form M^{2+} ions. Reactivity **increases down the group**, because the first and second ionisation energies fall (a larger radius, more shielding).

Reactions of the elements

- **With oxygen:** $2Mg + O_2 \rightarrow 2MgO$. Barium also forms a peroxide, but only the oxides are required.
- **With water:** $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$ (very slow with cold water; Mg reacts rapidly with steam to give MgO). $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$, and Sr and Ba react more vigorously.
- **With dilute acids:** $Mg + 2HCl \rightarrow MgCl_2 + H_2$ and $Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$. With sulfuric acid the reaction of Ba stops quickly because $BaSO_4$ is insoluble and coats the metal.

Reactions of the oxides, hydroxides and carbonates

- **Oxides:** $MgO + H_2O \rightarrow Mg(OH)_2$ (slight), $CaO + H_2O \rightarrow Ca(OH)_2$; they react with acids: $MgO + 2HCl \rightarrow MgCl_2 + H_2O$.
- **Hydroxides** are bases, and become more soluble and more strongly basic down the group (the pH of the saturated solution increases).
- **Carbonates** react with dilute acid: $MgCO_3 + 2HCl \rightarrow MgCl_2 + H_2O + CO_2$. They are insoluble in water.

Thermal decomposition

$MCO_3 \rightarrow MO + CO_2$ $\quad$ $2M(NO_3)_2 \rightarrow 2MO + 4NO_2 + O_2$

The nitrates also give brown fumes of NO_2 and oxygen. Thermal stability **increases down the group**: it takes a higher temperature to decompose $BaCO_3$ than $MgCO_3$. This is explained in the A Level chapter on Group 2, in terms of the polarisation of the anion.

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Solubility

- **Hydroxides:** solubility **increases** down the group. $Mg(OH)_2$ is almost insoluble; $Ba(OH)_2$ is soluble.
- **Sulfates:** solubility **decreases** down the group. $MgSO_4$ is soluble, $BaSO_4$ is insoluble.

Test for sulfate ions: add dilute HCl (to remove carbonates) then aqueous barium chloride or nitrate. A white precipitate of $BaSO_4$ shows sulfate. $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$**.**

TRY IT

Predict what happens when $Sr(OH)_2$ solution is shaken with dilute sulfuric acid.

A white precipitate of $SrSO_4$ forms (sulfates become less soluble down the group): $Sr(OH)_2 + H_2SO_4 \rightarrow SrSO_4 + 2H_2O$.

Linking the electron configuration to reactivity

The Group 2 metals have an outer ns^2 configuration and typically lose two electrons. Down the group, greater nuclear charge is outweighed by increased distance and shielding for the outer electrons, so the first two ionisation energies generally fall. This helps explain more vigorous reaction with water. Distinguish losing electrons more easily from attracting extra electrons more strongly: these metals act as reducing agents.

Surface conditions matter. Magnesium's oxide layer and the slow cold-water reaction can make it appear unreactive under one set of conditions, while steam gives a much faster reaction. With cold water, the hydroxide product is appropriate; with steam, write the oxide. Do not interchange the two equations simply because both release hydrogen.

Worked example: $Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$ balances steam reaction. For calcium in cold water, $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$. Bubbling is evidence of gas evolution; a white cloudy mixture can arise from sparingly soluble hydroxide. State the gas test if identification is requested: hydrogen gives a squeaky pop with a lighted splint.

TRY IT

Why can barium cease reacting visibly with dilute sulfuric acid even though it is more reactive than magnesium?

Answer: Insoluble $BaSO_4$ can form a surface coating that restricts acid contact with the metal. The observed reaction is limited by the coating, not evidence that barium has become intrinsically less willing

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to lose electrons.

Distinguishing three acid reactions

Metal plus dilute non-oxidising acid gives hydrogen; oxide or hydroxide plus acid gives water; carbonate plus acid gives carbon dioxide and water. Write the reaction class first, then the specific salt formula. A Group 2 metal always contributes a 2+ ion, but chloride and sulfate require different formula ratios.

Worked example: 0.0100 mol $CaCO_3$ requires 0.0200 mol HCl but only 0.0100 mol H_2SO_4 for complete acid–carbonate neutralisation. Both cases can release 0.0100 mol CO_2, assuming no insoluble layer prevents completion. The acid's number of available protons sets the mole ratio.

For hydroxides, distinguish **solubility** from **extent of dissociation of the dissolved portion**. A sparingly soluble hydroxide can produce a lower-pH saturated solution because fewer hydroxide ions enter solution. This need not mean the dissolved portion behaves like a molecular weak base. Saturated-solution pH is also not a measure of how much undissolved solid remains.

> **TRY IT**
>
> Complete and balance $CaO + HNO_3 \rightarrow$ products, then compare it with the calcium carbonate reaction.

Answer: $CaO + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$. The carbonate gives the same nitrate salt plus CO_2 and water. Oxide neutralisation does not release carbon dioxide because no carbon is present.

Thermal decomposition: observations and stoichiometry

Heating a carbonate releases carbon dioxide, detectable by turning limewater milky. Heating a nitrate gives brown nitrogen dioxide and oxygen, with the oxide remaining. Oxygen relights a glowing splint. The gas mixture is not adequately described by "a brown gas"; identify both products when asked.

Worked example: 0.0200 mol $Mg(NO_3)_2$ decomposes completely. From $2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$, it produces 0.0400 mol NO_2 and 0.0100 mol O_2, a total of 0.0500 mol gas. It leaves 0.0200 mol MgO. Count each coefficient; one mole of nitrate salt does not give one mole of every product.

Compare decomposition temperatures using the same anion and controlled conditions. A higher temperature needed for significant decomposition indicates greater thermal stability, not necessarily a higher melting point. The explanation through cation polarising power is developed in **A Level Group 2**.

> **TRY IT**
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> What mass remains when 10.0 g $CaCO_3$ ($M_r = 100$) decomposes completely to CaO ($M_r = 56.0$)?

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Answer: 0.100 mol carbonate gives 0.100 mol oxide, or **5.60 g**. The remaining 4.40 g leaves as carbon dioxide in an open heating experiment.

Using precipitation trends in qualitative analysis

The downward decrease in sulfate solubility makes barium ions a useful sulfate test reagent. Acidification with dilute HCl removes carbonate interference, which would otherwise also give a white barium precipitate. Add the acid before the barium reagent and avoid sulfuric acid, which would introduce the ion being tested. A white precipitate alone is not diagnostic unless the sequence controls possible interferences.

For a fair comparison of sulfate solubility, use comparable ion concentrations, volumes and temperature. Absence of visible precipitate in a very dilute sample does not prove the ions cannot form a sparingly soluble salt. Conversely, a large precipitate does not mean a different oxidation state has formed: precipitation is not necessarily redox.

> **TRY IT**
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> Why is sulfuric acid unsuitable for acidifying a sample before adding barium chloride to test for sulfate?

Answer: It supplies sulfate ions itself, causing $BaSO_4$ to form whether or not the original sample contained sulfate. The test would no longer identify the sample's original composition.

Chapter check: use the correct product for cold water versus steam, distinguish surface passivation from intrinsic reactivity, and connect ion ratios to quantitative calculations.

References and further reading

Scope follows section 10 of the **Cambridge 9701 syllabus for 2025–2027**. **Chemguide's Cambridge topic index** links to alternative explanations. The worked exercises and added diagrams are original teaching examples; numerical examples are illustrative unless a specific source is identified.

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