

Group 2

AS

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Read first: **Atomic structure**, **The Periodic Table: chemical periodicity**

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What you need to know

By the end of this topic you should be able to do the following for the Group 2 metals magnesium, calcium, strontium and barium (Mg to Ba) and their compounds:

1. **The elements' reactions.** Describe, and write equations for, how the metals react with oxygen, with water (and steam, for magnesium), and with dilute hydrochloric acid and dilute sulfuric acid.
2. **The compounds' reactions.** Describe, and write equations for, how the oxides, hydroxides and carbonates react with water and with dilute hydrochloric and sulfuric acids.
3. **Thermal decomposition.** Describe, and write equations for, what happens when the nitrates and the carbonates are heated, and state how their thermal stability changes down the group.
4. **Trends and predictions.** Describe the trends down the group in the physical and chemical properties of the elements and of the compounds above, and use them to predict how another member (such as radium, below barium) or an unknown compound behaves.
5. **Solubility.** State how the solubility of the hydroxides and of the sulfates changes down the group.

At AS you **state and use** the thermal stability trend; explaining it in terms of the size and charge density of the ion comes in the A Level part of the course. Beryllium is not in the outcomes, although a multiple-choice question may give you facts about it to compare.

Understand it

Four reactive metals with the same outer shell

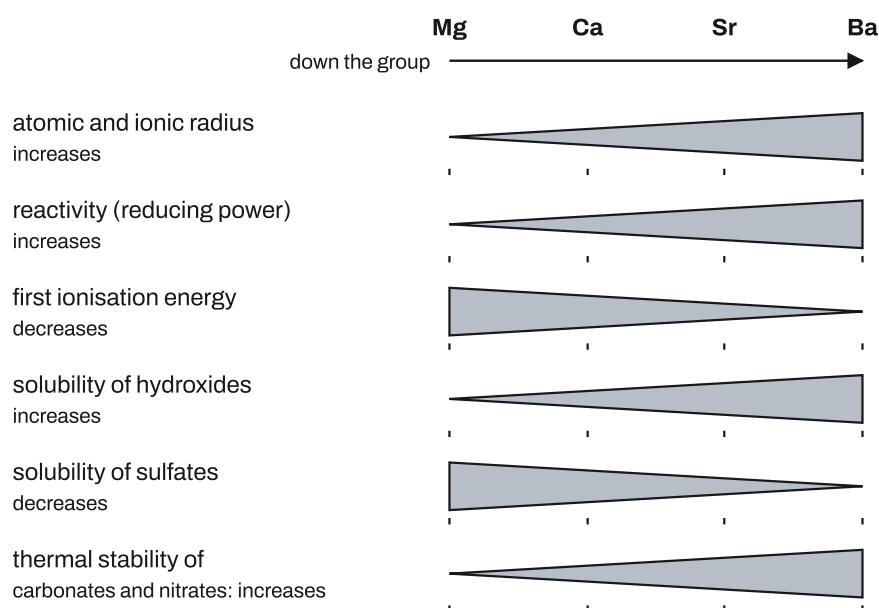
Every Group 2 atom has two electrons in its outer s orbital: magnesium $[\text{Ne}]3s^2$, calcium $[\text{Ar}]4s^2$, and so on. In every reaction in this topic the metal loses those two electrons and becomes an M^{2+} ion, so all its compounds have the formulas MO , $\text{M}(\text{OH})_2$, MCO_3 , $\text{M}(\text{NO}_3)_2$, MSO_4 and MCl_2 . The metal is always **oxidised** (its oxidation number goes from 0 to +2), so the metal is a **reducing agent**. Its compounds are white solids, and their solutions are colourless.

Going down the group each atom has one more shell of electrons, so:

	Mg	Ca	Sr	Ba
metallic (atomic) radius / nm	0.160	0.197	0.215	0.217
ionic radius of M^{2+} / nm	0.065	0.099	0.113	0.135
first ionisation energy / kJ mol^{-1}	736	590	548	502

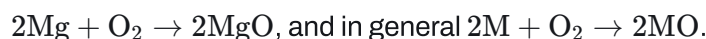
The outer electrons are further from the nucleus and better shielded, so less energy is needed to remove them. The metal gives away its electrons more easily, so it is a **stronger reducing agent** and **more reactive** down the group: barium fizzes rapidly in cold water, magnesium hardly reacts with it.

Melting point falls down the group. The metals have metallic bonding, and a smaller ion (Mg^{2+}) is closer to the sea of delocalised electrons, so it attracts them more strongly than a larger ion (Ba^{2+}) with the same charge.

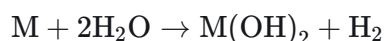


The elements with oxygen, water and acids

Oxygen. All four burn in air or oxygen to form the white oxide, MO . Magnesium burns with a very bright white flame and leaves white magnesium oxide powder.



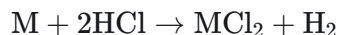
Water. The metal pushes hydrogen out of water and forms the hydroxide:



- **Magnesium** reacts only very slowly with cold water: a few bubbles slowly form on the ribbon over hours. With **steam** it reacts quickly and glows, giving magnesium **oxide**, not the hydroxide: $\text{Mg} + \text{H}_2\text{O} \rightarrow \text{MgO} + \text{H}_2$.
- **Calcium** fizzes steadily in cold water, and the liquid turns cloudy because calcium hydroxide is only slightly soluble.
- **Strontium** and **barium** react faster still, with rapid effervescence, and the metal disappears quickly.

In this reaction the metal is oxidised and water is reduced (the H in water goes from +1 to 0 in H_2).

Dilute hydrochloric acid. Every Group 2 metal fizzes, gives hydrogen and dissolves to a colourless solution of the chloride, faster down the group:

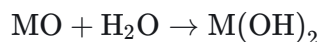


Dilute sulfuric acid. The equation is the same kind, $\text{M} + \text{H}_2\text{SO}_4 \rightarrow \text{MSO}_4 + \text{H}_2$. Magnesium sulfate is soluble, so magnesium dissolves completely. Calcium, strontium and barium sulfates are sparingly soluble or insoluble, so a layer of sulfate forms on the metal's surface. It stops the acid reaching the metal, and the reaction slows and stops with metal left over, even though the metal is more reactive than magnesium.

Oxides, hydroxides and carbonates with water and acids

These are all **bases**, so with acids they give a salt and water; a carbonate gives carbon dioxide as well.

Oxides with water give the hydroxide, with no gas:



Calcium oxide reacts vigorously and gives out heat. Magnesium oxide reacts only slightly, because magnesium hydroxide is almost insoluble.

Hydroxides with water simply dissolve a little, giving hydroxide ions, so the solution is alkaline. How alkaline depends on how much dissolves (next section): a saturated solution of magnesium hydroxide has a pH of about 9–10, calcium hydroxide (limewater) about 12, and barium hydroxide about 13–14.

With dilute hydrochloric acid every one reacts and the white solid disappears, giving a colourless solution of the chloride:

- oxide: $\text{MO} + 2\text{HCl} \rightarrow \text{MCl}_2 + \text{H}_2\text{O}$
- hydroxide: $\text{M}(\text{OH})_2 + 2\text{HCl} \rightarrow \text{MCl}_2 + 2\text{H}_2\text{O}$
- carbonate: $\text{MCO}_3 + 2\text{HCl} \rightarrow \text{MCl}_2 + \text{H}_2\text{O} + \text{CO}_2$, with **effervescence** as well

Only the carbonate fizzes. That is the way to tell magnesium carbonate from magnesium oxide or hydroxide with acid.

With dilute sulfuric acid the equations are similar:

- $\text{MO} + \text{H}_2\text{SO}_4 \rightarrow \text{MSO}_4 + \text{H}_2\text{O}$
- $\text{M}(\text{OH})_2 + \text{H}_2\text{SO}_4 \rightarrow \text{MSO}_4 + 2\text{H}_2\text{O}$
- $\text{MCO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{MSO}_4 + \text{H}_2\text{O} + \text{CO}_2$

For magnesium the solid dissolves to a colourless solution. For barium (and less so strontium and calcium) the insoluble sulfate forms instead: with barium hydroxide solution you see a **white precipitate** of barium sulfate, and a lump of barium carbonate soon stops fizzing because a sulfate coat covers it.

Carbonates with water. The Group 2 carbonates are insoluble and do not react with water on its own. Water containing dissolved carbon dioxide slowly dissolves calcium carbonate as soluble calcium hydrogencarbonate, $\text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{Ca}(\text{HCO}_3)_2$.

Limewater. Carbon dioxide turns limewater milky because insoluble calcium carbonate forms: $\text{Ca}(\text{OH})_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}$. Barium hydroxide solution does the same, giving barium carbonate.

These reactions explain everyday uses you may meet in a question. Calcium hydroxide (slaked lime), calcium oxide (lime) and calcium carbonate (limestone) are bases, so farmers spread them on acidic soil to **raise** its pH; calcium hydroxide is made from calcium carbonate by heating it to calcium oxide and then adding water. Barium sulfate is so insoluble that it can be swallowed safely for X-ray images of the gut, whereas soluble barium compounds are toxic.

Solubility of the hydroxides and sulfates

The two trends go in **opposite directions**:

- **Hydroxides become more soluble down the group.** $\text{Mg}(\text{OH})_2$ is almost insoluble, $\text{Ca}(\text{OH})_2$ is slightly soluble, $\text{Ba}(\text{OH})_2$ dissolves well. So a saturated solution has more OH^- ions, and a **higher pH**, down the group.
- **Sulfates become less soluble down the group.** MgSO_4 is soluble, CaSO_4 is sparingly soluble, BaSO_4 is insoluble.

So when you mix solutions:

- Adding OH^- (for example sodium hydroxide) to a solution of Mg^{2+} gives a white precipitate of magnesium hydroxide; with Ba^{2+} there is none. $\text{Mg}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Mg}(\text{OH})_2(\text{s})$
- Adding SO_4^{2-} (dilute sulfuric acid or any soluble sulfate) to a solution of Ba^{2+} gives a white precipitate of barium sulfate; with Mg^{2+} there is none. $\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})$

This is why aqueous barium ions are the test for sulfate ions: add dilute nitric or hydrochloric acid and then barium chloride or barium nitrate solution. A white precipitate that does not dissolve in the acid shows sulfate.

The carbonates of all four are insoluble, so adding a carbonate solution to any of their ions gives a white precipitate of the carbonate, for example $\text{MgCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{MgCO}_3(\text{s}) + 2\text{NaCl}(\text{aq})$. Their nitrates and chlorides are all soluble.

Heating the carbonates and nitrates

Both kinds of compound break down on strong heating to leave the white oxide. This is **thermal decomposition**.

Carbonates give off carbon dioxide:

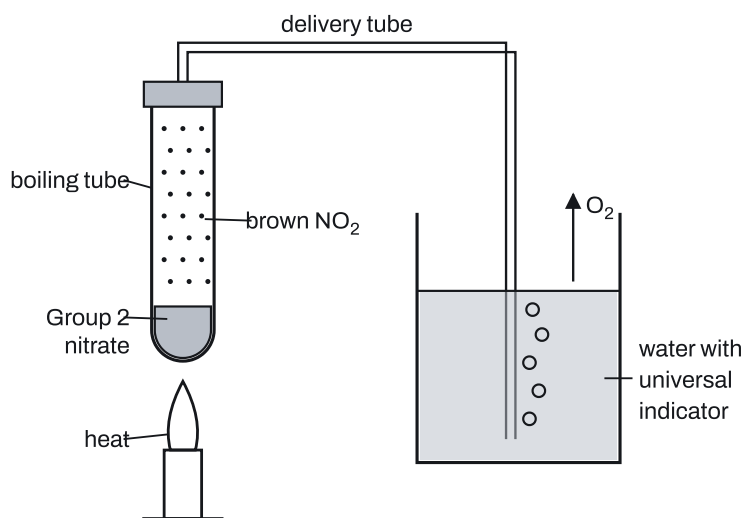


The white solid looks unchanged, so the evidence is the gas (it turns limewater milky) and the loss in mass.

Nitrates give off nitrogen dioxide and oxygen:



You see **brown fumes** of nitrogen dioxide, a **glowing splint relights** in the gas (oxygen), and a white solid (the oxide) is left. So 1 mol of nitrate gives $2 + \frac{1}{2} = 2.5$ mol of gas; 1 mol of carbonate gives 1 mol. The products are the oxide, NO_2 and O_2 only: never the metal, NO , N_2 or N_2O . A **hydrated** nitrate gives off steam as well.



NO_2 dissolves: the indicator turns red (pH about 2).

O_2 bubbles out: it relights a glowing splint.

Nitrogen dioxide is an acidic gas. If the gases bubble through water with universal indicator, the indicator turns from green to red (pH about 2), and the oxygen passes through and can be collected. The less stable the nitrate, the sooner this colour change happens.

Thermal stability increases down the group for both carbonates and nitrates. Magnesium carbonate decomposes easily in a Bunsen flame; barium carbonate needs a much higher temperature. So down the group:

- a higher temperature is needed to decompose the compound;
- at the same temperature it decomposes more slowly (less gas per minute).

A double carbonate such as $\text{BaCa}(\text{CO}_3)_2$ behaves as a mixture: its calcium carbonate part decomposes first, at a lower temperature than its barium carbonate part.

Predicting other members

Use the same trends to predict an element or compound you have not studied. Radium, below barium, should react with cold water even faster than barium, its hydroxide should be the most soluble and its sulfate the least soluble, its nitrate and carbonate should need the highest temperatures to decompose, and it should have the lowest ionisation energy. Its equations follow the same pattern: $\text{Ra} + 2\text{H}_2\text{O} \rightarrow \text{Ra}(\text{OH})_2 + \text{H}_2$ and $2\text{Ra}(\text{NO}_3)_2 \rightarrow 2\text{RaO} + 4\text{NO}_2 + \text{O}_2$.

Key facts and formulas

"Given" means it is printed in the 9701 Data Booklet or on the paper's Periodic Table. "Learn it" means you must remember it. The Data Booklet does not print equations, observations, pH values or solubility trends.

Formula	Status
Relative atomic masses: Mg 24.3, Ca 40.1, Sr 87.6, Ba 137.3, C 12.0, N 14.0, O 16.0	Given
Molar volume of a gas = $24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions	Given
Atomic and ionic radii; first ionisation energies	Given
With oxygen: $2\text{M} + \text{O}_2 \rightarrow 2\text{MO}$	Learn it
With water: $\text{M} + 2\text{H}_2\text{O} \rightarrow \text{M}(\text{OH})_2 + \text{H}_2$; Mg with steam: $\text{Mg} + \text{H}_2\text{O} \rightarrow \text{MgO} + \text{H}_2$	Learn it
With acid: $\text{M} + 2\text{HCl} \rightarrow \text{MCl}_2 + \text{H}_2$	Learn it
Oxide with water: $\text{MO} + \text{H}_2\text{O} \rightarrow \text{M}(\text{OH})_2$ (no hydrogen)	Learn it
Carbonate with acid: $\text{MCO}_3 + 2\text{HCl} \rightarrow \text{MCl}_2 + \text{H}_2\text{O} + \text{CO}_2$	Learn it
Carbonate on heating: $\text{MCO}_3 \rightarrow \text{MO} + \text{CO}_2$ (1 mol gas per mol)	Learn it
Nitrate on heating: $2\text{M}(\text{NO}_3)_2 \rightarrow 2\text{MO} + 4\text{NO}_2 + \text{O}_2$ (2.5 mol gas per mol)	Learn it
Down the group: reactivity and reducing power $\uparrow$, first ionisation energy $\downarrow$, radius $\uparrow$, melting point $\downarrow$	Learn it
Down the group: hydroxide solubility $\uparrow$ (pH of saturated solution $\uparrow$), sulfate solubility $\downarrow$	Learn it
Down the group: thermal stability of carbonates and nitrates $\uparrow$	Learn it
All Group 2 carbonates are insoluble; all nitrates and chlorides are soluble	Learn it
$n = \frac{m}{M_r}$; gas volume = $n \times 24.0 \text{ dm}^3$	Learn it

Formula masses you will use often: $\text{Mg}(\text{NO}_3)_2$ 148.3, $\text{Ca}(\text{NO}_3)_2$ 164.1, $\text{Sr}(\text{NO}_3)_2$ 211.6, $\text{Ba}(\text{NO}_3)_2$ 261.3; MgCO_3 84.3, CaCO_3 100.1; oxides MgO 40.3, CaO 56.1, SrO 103.6, BaO 153.3.

How to do it

In the Paper 1 and Paper 2 questions we have tagged for this topic (104 questions, 2021–2025), the types came up this often. 33 of the 104 questions mix more than one type, so the counts add up to 157.

Question type	Questions
Solubility of hydroxides and sulfates: state and use the trend	31
Thermal decomposition: equations, products, observations	28
Thermal stability down the group	20
Calculations from thermal decomposition	18
Reactions of oxides, hydroxides and carbonates with water and acids	17

Question type	Questions
Reactions of the elements with oxygen, water and acids	16
Identify, tell apart or separate substances from test results	9
Choose the correct statement across several trends	8
Uses of Group 2 compounds	7
Physical trends: radius, melting point, reducing power	3

1. Solubility of hydroxides and sulfates (31 questions)

- Write the trend the question needs.** Hydroxides: solubility **increases** down the group. Sulfates: solubility **decreases** down the group. A 1-mark "state the variation" wants exactly that sentence, with "down the group".
- Turn it into what is asked:**
 - pH:** more soluble hydroxide means more OH^- in a saturated solution, so a higher pH. BaO or $\text{Ba}(\text{OH})_2$ gives the highest pH (about 13–14); MgO or $\text{Mg}(\text{OH})_2$ the lowest (about 9–10). All are above 7.
 - Which precipitate:** with OH^- the least soluble hydroxide ($\text{Mg}(\text{OH})_2$) precipitates first or most; with SO_4^{2-} the least soluble sulfate (BaSO_4) precipitates first or most.
- Name the precipitate and its colour:** "white precipitate of barium sulfate".

Variations you will meet:

- Two soluble salts that give a precipitate when mixed.** Look for a swap that makes BaSO_4 (or CaSO_4) or $\text{Mg}(\text{OH})_2$: for example $\text{BaCl}_2(\text{aq})$ and $\text{MgSO}_4(\text{aq})$.
- A table of solubility data** for calcium and an unknown element. If the unknown's hydroxide is more soluble than calcium's, it is below calcium, so its sulfate must be less soluble and its carbonate must decompose at a higher temperature. Check all three columns move the right way.
- Equal amounts in a stoichiometry question**, such as equal moles of BaCl_2 and MgCl_2 each mixed with H_2SO_4 : only the barium tube gives a precipitate; with NaOH only the magnesium tube does, so the barium tube keeps its OH^- and has the higher pH.
- Why calcium stops reacting with dilute sulfuric acid:** calcium sulfate is only sparingly soluble and coats the metal. The answer is about the sulfate's solubility, not about calcium being less reactive.
- Why calcium hydroxide solution can precipitate $\text{Mg}(\text{OH})_2$ from MgCl_2 but not $\text{Ba}(\text{OH})_2$ from BaCl_2 :** barium hydroxide is soluble.

2. Thermal decomposition: equations, products, observations (28 questions)

- Decide carbonate or nitrate.**
- Write the products:** carbonate $\rightarrow$ oxide + CO_2 ; nitrate $\rightarrow$ oxide + NO_2 + O_2 .
- Balance.** Carbonates are always 1 : 1 : 1. Nitrates are 2 : 2 : 4 : 1, or 1 : 1 : 2 : $\frac{1}{2}$.
- Observations if asked:** nitrate: brown gas, glowing splint relights, white solid left; carbonate: gas turns limewater milky, white solid left, loss in mass.

Variations you will meet:

- **Pick the correct equation.** Several options may balance in atoms; the right one has only MO, NO₂ and O₂. Reject any with the metal, M₂O, NO, N₂ or N₂O.
- **Identify the gas** from what it does: brown and acidic (NO₂, turns indicator red); relights a glowing splint (O₂); turns limewater milky (CO₂). NO₂ is also the gas that reacts with unburned hydrocarbons to form PAN, so the compound that gives it is a nitrate such as Ca(NO₃)₂.
- **Mixtures:** list the products of each compound, then count the different ones. For a mixture of CaCO₃ and Ca(NO₃)₂ the products are CaO, CO₂, NO₂ and O₂: four different substances.
- **Double carbonates**, such as SrMg(CO₃)₂: write both oxides and two CO₂: $\text{SrMg}(\text{CO}_3)_2 \rightarrow \text{SrO} + \text{MgO} + 2\text{CO}_2$.
- **Hydrated nitrate:** add steam (H₂O) to the products.
- **Telling solids apart by heating**, such as MgO, MgCO₃ and Mg(NO₃)₂: the oxide does not change; the carbonate loses mass with a colourless gas; the nitrate gives brown fumes.
- **"State the type of reaction":** thermal decomposition.

3. Thermal stability down the group (20 questions)

1. **State the trend:** thermal stability of the carbonates (or nitrates) **increases** down the group.
2. **Apply it:** the compound higher up the group decomposes **first**, at a **lower** temperature, or **faster** at the same temperature.

For example, heating Ca(NO₃)₂ and Sr(NO₃)₂ in identical tubes: calcium nitrate is less stable, so its NO₂ turns the indicator red sooner.

Variations you will meet:

- **"Which decomposes first?"** (for example in barytocalcite, BaCa(CO₃)₂): name the compound higher in the group **and** give the trend as the reason, as one answer.
- **"Which needs the highest temperature?"** among magnesium, calcium and radium nitrates: radium, the lowest in the group.
- **Don't mix up the trends.** A question about stability wants stability; some candidates answer with the solubility of the hydroxides.
- **Data tables:** a larger decomposition temperature of the carbonate means an element lower in the group.

4. Calculations from thermal decomposition (18 questions)

1. **Write the balanced equation** (per mole of compound): $\text{MCO}_3 \rightarrow \text{MO} + \text{CO}_2$ or $\text{M}(\text{NO}_3)_2 \rightarrow \text{MO} + 2\text{NO}_2 + \frac{1}{2}\text{O}_2$.
2. **Moles of the compound:** $n = \frac{m}{M_r}$.
3. **Use the ratio** to get moles of what is asked: gas (1 or 2.5 times), O₂ ($\frac{1}{2}$ times), NO₂ (2 times), oxide (1 times).
4. **Convert:** mass = $n \times M_r$; gas volume = $n \times 24.0 \text{ dm}^3$ at room conditions.

For example, 0.010 mol of $\text{Mg}(\text{NO}_3)_2$ gives 0.025 mol of gas, $0.025 \times 24.0 = 0.600 \text{ dm}^3 = 600 \text{ cm}^3$.

Variations you will meet:

- **Identify the metal from the mass lost or left.** Moles of residue (oxide) = moles of the compound. Either work out the fraction left, $\frac{M_r(\text{MO})}{M_r(\text{M}(\text{NO}_3)_2)}$, for each metal and match it, or call the metal's A_r x and solve $\frac{m_{\text{nitrate}}}{x + 124.0} = \frac{m_{\text{oxide}}}{x + 16.0}$. For a carbonate use $x + 60.0$ and $x + 16.0$.
- **Most gas per gram.** Gas per gram = $\frac{\text{mol gas per mol}}{M_r}$. Nitrates beat carbonates (2.5 against 1 mol), and a lighter compound beats a heavier one, so of Ca and Ba nitrates and carbonates, $\text{Ca}(\text{NO}_3)_2$ gives most.
- **Greatest percentage loss in mass** = $\frac{\text{mass of gas}}{\text{mass of compound}} \times 100$: again the lightest nitrate wins.
- **Mass ratio of NO_2 to O_2 :** $\frac{2 \times 46.0}{0.5 \times 32.0} = 5.75$, the same for every Group 2 nitrate.
- **Comparing volumes:** equal moles of a nitrate give 2.5 times the gas volume of the carbonate.
- **Double-carbonate minerals** as fire retardants: the best is the one giving the most CO_2 per gram, so work out $\frac{\text{mol CO}_2}{M_r}$ for each.

5. Reactions of oxides, hydroxides and carbonates with water and acids (17 questions)

1. **Classify the reaction:** oxide or hydroxide + acid $\rightarrow$ salt + water; carbonate + acid $\rightarrow$ salt + water + CO_2 ; oxide + water $\rightarrow$ hydroxide.
2. **Write the formulas** from M^{2+} : chloride MCl_2 , sulfate MSO_4 , nitrate $\text{M}(\text{NO}_3)_2$, ethanoate $\text{M}(\text{CH}_3\text{COO})_2$.
3. **Balance**, and add state symbols if asked (a precipitate is (s), dissolved ions (aq)).
4. **Observations:** the white solid dissolves (disappears) to a colourless solution; a carbonate also effervesces. With sulfuric acid and Ca, Sr or Ba, expect a white solid (the sulfate) to remain or form.

Variations you will meet:

- **An oxide with water makes no hydrogen.** $\text{BaO} + \text{H}_2\text{O} \rightarrow \text{Ba}(\text{OH})_2$ only. Hydrogen comes from the metal with water.
- **Precipitating a carbonate:** $\text{MgCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{MgCO}_3(\text{s}) + 2\text{NaCl}(\text{aq})$, one mark for the balanced formulas and one for the state symbols.
- **Reactant for a step in a scheme**, such as turning $\text{Ba}(\text{OH})_2(\text{aq})$ into $\text{BaCO}_3(\text{s})$: carbon dioxide, $\text{Ba}(\text{OH})_2 + \text{CO}_2 \rightarrow \text{BaCO}_3 + \text{H}_2\text{O}$.
- **Making a pure salt:** for an insoluble sulfate, mix a soluble barium compound with dilute sulfuric acid, then filter, wash and dry. For a soluble salt, add an excess of the insoluble oxide or carbonate to the acid, filter off the excess, then evaporate the filtrate. That only works if the new salt is soluble: magnesium carbonate with sulfuric acid gives soluble MgSO_4 , but with calcium or barium the insoluble sulfate stays on the filter paper with the excess carbonate.

6. Reactions of the elements with oxygen, water and acids (16 questions)

1. **Write the equation:** with oxygen $2M + O_2 \rightarrow 2MO$; with water $M + 2H_2O \rightarrow M(OH)_2 + H_2$ (magnesium with steam gives MgO); with acid, salt + H_2 .
2. **Describe what you see**, using the trend: magnesium in cold water forms bubbles slowly; calcium fizzes steadily and goes cloudy; barium fizzes rapidly and disappears quickly. Magnesium burns with a bright white flame to a white powder.
3. **Explain a difference in reactivity** by ionisation energy: down the group the outer electrons are further from the nucleus and more shielded, so they are lost more easily and the metal is a stronger reducing agent.

Variations you will meet:

- **Radium versus calcium with water:** radium reacts faster, so more bubbles per second and the solid disappears sooner. The pH at the end is higher for radium (its hydroxide is more soluble); the calcium mixture may be cloudy because calcium hydroxide is only slightly soluble.
- **Which substance is oxidised and which reduced:** the metal is oxidised, water (its hydrogen) is reduced.
- **Why burning magnesium reacts fast with cold water:** it is at a high temperature, so far more collisions have energy above the activation energy.
- **Compound J from magnesium and steam** is MgO : white, basic, $M_r = 40.3$, and almost insoluble in water.

7. Identify, tell apart or separate substances (9 questions)

1. **List every clue** and what it tells you: fizzes in water $\rightarrow$ a reactive metal (gas is H_2); alkaline solution $\rightarrow$ oxide, hydroxide or metal; white precipitate with dilute $H_2SO_4 \rightarrow Ba^{2+}$ (or Sr^{2+} , Ca^{2+}), never Mg^{2+} ; brown gas on heating $\rightarrow$ a nitrate.
2. **Put the elements in order** using each trend, then fit the letters.
3. **Check your answer against every clue.**

Variations you will meet:

- **One reagent to tell two solutions apart**, such as $Mg(NO_3)_2$ and $Ba(NO_3)_2$: dilute sulfuric acid (white precipitate with barium only, because $BaSO_4$ is insoluble and $MgSO_4$ soluble), or sodium hydroxide (white precipitate with magnesium only, because $Mg(OH)_2$ is insoluble). Give the reagent **and** the reason.
- **Identify an anion** by its precipitate: a white precipitate with $Sr(NO_3)_2$ or Ba^{2+} that does not react with dilute nitric acid is a sulfate; a carbonate precipitate would fizz and dissolve in the acid.
- **Separate two metals from a solution of their nitrates:** add dilute sulfuric acid and filter off solid barium sulfate; magnesium stays in solution as $MgSO_4$.
- **A mixture of an oxide and a sulfate shaken with water:** the soluble parts pass through the filter. Test the residue and the filtrate using the solubility rules.

8. Choose the correct statement across several trends (8 questions)

1. **Go through the statements one at a time** and test each against the summary diagram: radius ↑, ionisation energy ↓, reactivity and reducing power ↑, hydroxide solubility ↑, sulfate solubility ↓, thermal stability ↑.
2. **Watch the direction words:** "less stable", "lower decomposition temperature" and "faster" must all be checked against which element is higher in the group.

For example: "strontium is a stronger reducing agent than magnesium" is true; "strontium hydroxide is more soluble than barium hydroxide" is false. A question asking which property **decreases** from magnesium to barium wants the solubility of the sulfates (or the ionisation energy).

Variations you will meet:

- **Radium or another member you have not studied:** extend each trend one step further.
- **Beryllium compared with magnesium:** the question gives you the facts; spot the one that is different, such as beryllium chloride fuming (giving HCl) in water while magnesium chloride just dissolves.
- **Counting gas from reactions with acid:** one mole of any Group 2 carbonate gives one mole of CO_2 with excess acid, so magnesium and barium carbonate give the same amount.

9. Uses of Group 2 compounds (7 questions)

1. **Match the use to the chemistry:** acidic soil or water needs a base; an X-ray meal needs something insoluble; a sulfate test needs an insoluble barium salt.
2. **Check the direction:** a base **raises** the pH of soil; an acid lowers it.

Variations you will meet:

- **Treating soil:** calcium hydroxide, calcium carbonate and dolomite, $\text{CaMg}(\text{CO}_3)_2$, all raise the pH. The carbonates are less soluble than calcium hydroxide, and one mole of dolomite neutralises twice as much acid as one mole of calcium carbonate (it contains two carbonate ions).
- **Water treatment:** calcium hydroxide added to water containing carbonate or hydrogencarbonate ions precipitates calcium carbonate.
- **Ammonium salts** are acidic, so they would not raise the pH of soil.
- **Barium sulfate**, not magnesium sulfate, is the insoluble one; barium hydroxide is soluble and toxic, so it is never used as an antacid.

10. Physical trends (3 questions)

1. **Ionic radius increases down the group** because each ion has an extra shell of electrons (2 marks: the trend and the extra shell).
2. **Melting point decreases down the group:** the cations get larger with the same 2+ charge, so they attract the delocalised electrons less strongly and the metallic bonding is weaker.

3. **Across a period**, compare as in the periodic table topic: barium's ion is smaller than caesium's and has double the charge, so barium has the higher melting point.

Worked examples

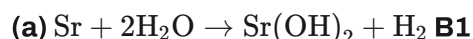
The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
 - **A1** accuracy mark: for a correct answer; it needs the M mark before it.
 - **B1** mark for a correct result on its own, with no method needed.
-

Example 1

Strontium, Sr, is in Group 2 between calcium and barium.

- (a) Write an equation for the reaction of strontium with cold water, and give **two** observations. **[3]**
- (b) Suggest the pH of the solution formed, and explain how it compares with the pH of the mixture formed when magnesium is left in cold water. **[2]**
- (c) Write an equation for the reaction of strontium carbonate with dilute hydrochloric acid, and state what you would observe. **[2]**
- (d) Strontium oxide is added to dilute sulfuric acid. Write an equation for the reaction. **[1]**

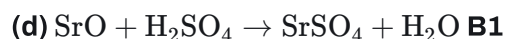


Rapid effervescence (bubbles of gas) **B1**; the metal disappears quickly **B1** (or: a colourless solution forms).

(b) pH about 13. **B1** Strontium hydroxide is much more soluble than magnesium hydroxide (solubility of the hydroxides increases down the group), so there are more hydroxide ions in solution and the pH is higher. **B1**



Effervescence, and the white solid dissolves to a colourless solution. **B1**



Example 2

A student heats 3.00 g of anhydrous calcium nitrate, $\text{Ca}(\text{NO}_3)_2$, until there is no further change in mass.

- (a) Write an equation for the reaction. **[1]**
- (b) Give **two** observations. **[2]**

(c) Calculate the mass of solid left. **[2]**

(d) Calculate the total volume of gas produced, measured at room conditions. **[2]**

(e) The experiment is repeated with 3.00 g of barium nitrate. State and explain **two** differences you would expect. **[2]**



(b) Brown fumes (gas) given off **B1**; a glowing splint held in the gas relights (or: a white solid remains) **B1**.

(c) $M_r(\text{Ca}(\text{NO}_3)_2) = 40.1 + 2(14.0 + 3 \times 16.0) = 164.1$

$$n = \frac{3.00}{164.1} = 0.01828 \text{ mol } \mathbf{M1}$$

1 mol of nitrate leaves 1 mol of CaO ($M_r = 56.1$): mass = $0.01828 \times 56.1 = 1.03 \text{ g}$ **A1**

(d) Each mole of nitrate gives $2 + \frac{1}{2} = 2.5$ mol of gas: $2.5 \times 0.01828 = 0.04570 \text{ mol}$ **M1**

Volume = $0.04570 \times 24.0 = 1.10 \text{ dm}^3$ **A1**

(e) A higher temperature is needed (or it decomposes more slowly), because thermal stability of the nitrates increases down the group. **B1**

Less gas is produced: barium nitrate has a larger M_r (261.3), so 3.00 g is fewer moles (0.01148 mol, giving 0.689 dm^3 of gas). **B1**

Example 3

A 5.00 g sample of an anhydrous Group 2 nitrate, $\text{X}(\text{NO}_3)_2$, is heated strongly until its mass stops changing. The solid residue, XO, has a mass of 2.93 g. Identify X. Show your working. **[3]**

1 mol of $\text{X}(\text{NO}_3)_2$ gives 1 mol of XO, so the amounts are equal. Let the A_r of X be x : $M_r(\text{X}(\text{NO}_3)_2) = x + 124.0$ and $M_r(\text{XO}) = x + 16.0$. **M1**

$$\frac{5.00}{x + 124.0} = \frac{2.93}{x + 16.0}$$

$5.00x + 80.0 = 2.93x + 363.32$, so $2.07x = 283.32$ and $x = 136.9$ **M1**

The nearest Group 2 element is barium, $A_r = 137.3$: X is **barium**. **A1**

(Check: $\frac{153.3}{261.3} \times 5.00 = 2.93 \text{ g}$)

Example 4

E is one of the Group 2 metals magnesium, calcium, strontium or barium.

- A saturated solution of the hydroxide of E has a higher pH than a saturated solution of magnesium hydroxide.

- The nitrate of E decomposes at a lower temperature than strontium nitrate.

(a) Identify E. Explain how each piece of information helps. **[2]**

(b) Write an equation for the thermal decomposition of the carbonate of E. **[1]**

(c) Calculate the volume of gas, measured at room conditions, produced when 2.50 g of the carbonate of E is completely decomposed. **[2]**

(d) A small lump of E is dropped into an excess of dilute sulfuric acid. It fizzes at first, but the reaction soon stops with metal left over. Explain why. **[2]**

(a) Hydroxide solubility increases down the group, so a higher pH than magnesium hydroxide means E is below magnesium. Thermal stability increases down the group, so a less stable nitrate than strontium's means E is above strontium. **M1**

E is **calcium**. **A1**

(b) $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$ **B1**

(c) $M_r(\text{CaCO}_3) = 100.1$, so $n = \frac{2.50}{100.1} = 0.02498$ mol, and 1 mol of carbonate gives 1 mol of CO_2 . **M1**

Volume = $0.02498 \times 24.0 = 0.599 \text{ dm}^3$ **A1**

(d) $\text{Ca} + \text{H}_2\text{SO}_4 \rightarrow \text{CaSO}_4 + \text{H}_2$. Calcium sulfate is only sparingly soluble **B1**, so it forms a layer on the surface of the calcium that stops the acid reaching the metal. **B1**

Common mistakes

- **Mixing up the two solubility trends.** Hydroxides get **more** soluble down the group, sulfates **less**. Picture barium: $\text{Ba}(\text{OH})_2$ dissolves, BaSO_4 is the white precipitate.
- **Answering about the wrong property.** Examiners regularly see answers about the solubility of hydroxides when the question asked about thermal stability, or comparisons with sodium hydroxide when it asked about Group 2. Underline the property in the question.
- **Wrong products for a nitrate.** The products are the oxide, NO_2 and O_2 . Writing the metal (as for some other metal nitrates), or NO , loses the mark. Check the equation balances: 2 : 2 : 4 : 1.
- **Hydrogen from an oxide.** $\text{BaO} + \text{H}_2\text{O}$ gives only $\text{Ba}(\text{OH})_2$. Only the metal releases hydrogen.
- **Magnesium and steam.** The product is magnesium **oxide**, not the hydroxide.
- **Leaving out state symbols** when the question asks for them, especially "(s)" on a precipitate.
- **Vague observations.** "A reaction happens" or "it gets hot" earns nothing, and some questions say not to mention temperature. Say what you see: bubbles or effervescence, a solid disappearing, a white precipitate, brown fumes, a colour change of the indicator.
- **Precipitate or residue?** A solid left in a flask after a reaction is not a "precipitate"; a precipitate forms when two solutions are mixed.

- **Thinking calcium is less reactive than magnesium** because it stops fizzing in sulfuric acid. It stops because calcium sulfate coats it.
- **Using 1 mol of gas per mol of nitrate.** A nitrate gives 2.5 mol of gas (2 of NO_2 and $\frac{1}{2}$ of O_2).
- **pH below 7 for a Group 2 hydroxide.** Every Group 2 oxide or hydroxide solution is alkaline; give a number above 7 and name the ion responsible (OH^-).

How to get the marks

- **"State the variation" or "state the trend"** is 1 mark for the direction and "down the group", for example "the solubility of the sulfates decreases down the group". No explanation is needed.
- **"Identify ... and explain"** in a two-part answer: the mark usually needs both, such as " CaCO_3 , because thermal stability of the carbonates increases down the group".
- **Equations** must be balanced with correct formulas. $\frac{1}{2}\text{O}_2$ is fine: $\text{Ca}(\text{NO}_3)_2 \rightarrow \text{CaO} + 2\text{NO}_2 + \frac{1}{2}\text{O}_2$ earns the same mark as the doubled equation. "Construct an equation" for an unfamiliar compound (radium, a double carbonate) means use the pattern you know.
- **State symbols** are often a separate mark: precipitates (s), solutions (aq), gases (g).
- **Observations** must be things you can see, hear or smell, and each counts once: effervescence, solid dissolves or disappears, white precipitate, brown gas, glowing splint relights, limewater milky, indicator turns red.
- **"Suggest"** means apply the trends to something new, such as radium. A sensible answer following the trend earns the mark.
- **Calculations in multiple choice:** write the equation first, work out moles, and use the Data Booklet A_r values and 24.0 dm^3 . Several wrong options match common slips (1 mol of gas per nitrate, forgetting the $\frac{1}{2}$, using the wrong M_r).
- **Explaining reactivity:** say "ionisation energy decreases down the group", then why (outer electrons further from the nucleus, more shielding, weaker attraction), then "so electrons are lost more easily".
- **Reagent tests:** name the reagent, give the observation for **each** substance, and link it to a solubility.

Quick check

1. Write an equation for the thermal decomposition of barium nitrate.
2. 0.0250 mol of magnesium carbonate is completely decomposed. Calculate the volume of gas produced at room conditions (in cm^3) and the mass of solid left.
3. 14.83 g of anhydrous magnesium nitrate is completely decomposed. Calculate the mass of oxygen produced and the mass of nitrogen dioxide produced.
4. Calculate the percentage loss in mass when calcium carbonate is completely decomposed, and when barium carbonate is. Which loses the larger percentage?
5. A white strontium compound, X, is heated strongly. A brown gas is given off, a glowing splint relights in the gases, and a white solid, Y, is left. Identify X and Y and write an equation for the reaction. Then suggest how the pH of the mixture formed when Y is shaken with water compares with that formed by magnesium oxide,

and explain why.

Answers

- $2\text{Ba}(\text{NO}_3)_2 \rightarrow 2\text{BaO} + 4\text{NO}_2 + \text{O}_2$
- $\text{MgCO}_3 \rightarrow \text{MgO} + \text{CO}_2$, so 0.0250 mol of CO_2 : $0.0250 \times 24\,000 = 600\text{ cm}^3$. Solid left: 0.0250 mol of $\text{MgO} = 0.0250 \times 40.3 = 1.01\text{ g}$.
- $M_r = 24.3 + 2(14.0 + 48.0) = 148.3$, so $n = \frac{14.83}{148.3} = 0.100\text{ mol}$. Oxygen: $0.100 \times \frac{1}{2} = 0.0500\text{ mol} = 0.0500 \times 32.0 = 1.60\text{ g}$. Nitrogen dioxide: $0.200\text{ mol} = 0.200 \times 46.0 = 9.20\text{ g}$.
- CaCO_3 (M_r 100.1) loses 44.0 g of CO_2 per mole: $\frac{44.0}{100.1} \times 100 = 44.0\%$. BaCO_3 (M_r 197.3): $\frac{44.0}{197.3} \times 100 = 22.3\%$. Calcium carbonate loses the larger percentage, because it is lighter and each mole still loses one mole of CO_2 .
- The brown gas (NO_2) and oxygen show X is a nitrate: X is strontium nitrate and Y is strontium oxide.
 $2\text{Sr}(\text{NO}_3)_2 \rightarrow 2\text{SrO} + 4\text{NO}_2 + \text{O}_2$. Y reacts with water to give strontium hydroxide, $\text{SrO} + \text{H}_2\text{O} \rightarrow \text{Sr}(\text{OH})_2$. Its pH is higher (about 13, against about 9–10) because strontium hydroxide is much more soluble than magnesium hydroxide, so there are more OH^- ions in solution.

Past questions to try

- 9701/22/F/M/25 Q2**: observations with acid, the reaction of strontium with water and the sulfate trend (part (d)).
- 9701/13/O/N/23 Q21**: identifying the metal from the mass lost when its nitrate is heated.
- 9701/23/O/N/23 Q2**: barium hydroxide reactions, the hydroxide trend and a double carbonate.
- 9701/11/M/J/23 Q23**: which precipitate forms first with sodium hydroxide and with sulfuric acid.