

# 10. GROUP 2

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

### Learning outcomes

Candidates should be able to:

1. describe, and write equations for, the reactions of the elements with oxygen, water and dilute hydrochloric and sulfuric acids
2. describe, and write equations for, the reactions of the oxides, hydroxides and carbonates with water and dilute hydrochloric and sulfuric acids
3. describe, and write equations for, the thermal decomposition of the nitrates and carbonates, to include the trend in thermal stabilities
4. describe, and make predictions from, the trends in physical and chemical properties of the elements involved in the reactions in 10.1.1 and the compounds involved in 10.1.2, 10.1.3 and 10.1.5
5. state the variation in the solubilities of the hydroxides and sulfates

### Introduction

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Also called **alkaline earth metals**

### Properties of the elements and general trends

|                                        | Magnesium | Calcium | Strontium | Barium |
|----------------------------------------|-----------|---------|-----------|--------|
| Melting point/ $^{\circ}\text{C}$      | 649       | 839     | 769       | 729    |
| Boiling point/ $^{\circ}\text{C}$      | 1090      | 1484    | 1384      | 1637   |
| Density/ $\text{gcm}^{-3}$             | 1.74      | 1.54    | 2.60      | 3.51   |
| First IE/ $\text{kJmol}^{-1}$          | 738       | 590     | 550       | 503    |
| Second IE/ $\text{kJmol}^{-1}$         | 1451      | 1145    | 1064      | 965    |
| Atomic (metallic) radius/nm            | 0.160     | 0.174   | 0.191     | 0.198  |
| Ionic radius of $\text{M}^{2+}$ ion/nm | 0.065     | 0.094   | 0.110     | 0.134  |

Look at the metallic radii of the Group 2 elements measured in nanometers.

There are also general trends in other physical properties, such as melting point and density.

The Group 2 metals form ionic compounds. When they react, their atoms lose the two electrons from their outermost s sub-shell and form an ion with the stable electronic configuration of a noble gas. This creates a  $2+$  ion. For example, in the ionisation of a magnesium atom to a magnesium ion:

The metals act as reducing agents. Their atoms donate (give away) electrons and so they are oxidised themselves as they react to form their  $2+$  ions. The ionisation energies shown in Table show how easily the two outer electrons are removed from the Group 2 atoms.

The **metals in Group 2 get more reactive as we go down the group**. As you can see from Table, it takes less energy (i.e. it gets easier) to remove the pair of outer electrons going down Group 2. So, although the positive charge on the nucleus increases down the group:

- the greater shielding effect provided by extra inner shells of electrons, and
  - the larger distance of the outermost electrons from the nucleus outweigh the attraction of the higher nuclear charge.
- This helps to explain the increase in reactivity going down the group, as it gets easier for the atoms to form their  $2+$  ions.

1. The statements apply to the elements in Group 2.  
Which statement is correct?

- A As atomic number increases, ionic radius increases.
- B As atomic number increases, reducing ability decreases.
- C As atomic number increases, first ionisation energy increases.
- D As atomic radius increases, first ionisation energy increases.

2. Which statement explains why calcium has a higher melting point than barium?

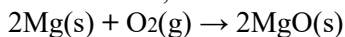
- A Calcium cations are smaller than barium cations and have a stronger attraction to the delocalised electrons.
- B The structure of calcium is partly giant molecular.
- C There are more delocalised electrons in calcium than in barium as it has lower ionisation energy.
- D There is greater repulsion between barium atoms as they have more complete electron shells than calcium atoms.

## Reaction of the elements

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### Action of oxygen

When heated, the metals catch fire and form white oxides, for example, magnesium gives MgO:



Of all the metals, magnesium catches fire most easily as it has the lowest melting point. It burns with a brilliant white light. Calcium burns with a brick-red flame, strontium with a crimson flame and barium with a green flame

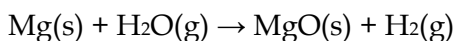
1. Oxygen reacts readily with some metals, but each Group 2 metal requires strong heating to start the reaction with oxygen.  
Suggest why strong heating is required to start these reactions. [1]

### Action of water

Magnesium reacts very slowly with cold water. However, if left long enough, the reaction will eventually form a weakly alkaline solution, and give off enough hydrogen to test:



Hot magnesium reacts vigorously with water in the form of steam. The magnesium and steam produce magnesium oxide (a white solid) and hydrogen gas:



Calcium reacts more readily than magnesium with water at room temperature:



This reaction gives off a steady stream of hydrogen gas and forms a cloudy white suspension of slightly soluble calcium hydroxide. The calcium hydroxide that does dissolve forms a solution that we call 'limewater', which makes the solution weakly alkaline.

Going down the group, hydrogen gas is released more and more rapidly by the reaction of the Group 2 metal with water

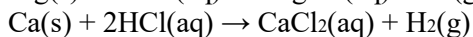
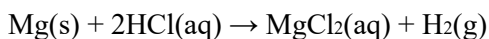
2. Write an equation for the reaction of magnesium with cold water. [1]

3. What happens when a piece of magnesium ribbon is placed in cold water?

- A A vigorous effervescence occurs.
- B Bubbles of gas form slowly on the magnesium.
- C The magnesium floats on the surface of the water and reacts quickly.
- D The magnesium glows and a white solid is produced.

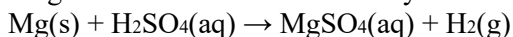
### Reaction with acids

The metals react with dilute hydrochloric acid, forming a solution of the metal chloride and giving off hydrogen gas. For example:

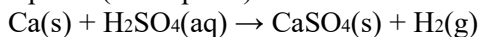


The reactions get more vigorous descending the group. You can see this by the increasing rate at which bubbles of hydrogen gas are given off.

Magnesium reacts in a similar way with dilute sulfuric acid:



However, any reaction with calcium, strontium or barium is quickly stopped by the formation of an insoluble sulfate layer on the surface of the metals. For example, you can see a slow stream of hydrogen bubbles for a short time when a pellet (small piece) of calcium metal is dropped into dilute sulfuric acid:



The calcium gets then gets completely covered by a layer sparingly soluble calcium sulfate and the bubbles of hydrogen stop rising from the metal.

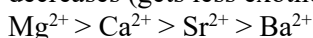
## Solubilities of the hydroxides and sulfates

The following table shows the solubility in water of some Group 2 sulfates. The solubility decreases as the radius of the metal ion increases. We can explain this variation in solubility in terms of the relative values of enthalpy change of hydration and the corresponding lattice energy.

| Compound          | Solubility / mol dm <sup>-3</sup> |
|-------------------|-----------------------------------|
| magnesium sulfate | 1.83                              |
| calcium sulfate   | $4.66 \times 10^{-2}$             |
| strontium sulfate | $7.11 \times 10^{-4}$             |
| barium sulfate    | $9.43 \times 10^{-6}$             |

### Change in hydration enthalpy down the group

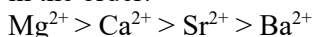
Smaller ions (with the same charge) have greater enthalpy changes in hydration so the enthalpy change of hydration decreases (gets less exothermic) in the order:



this decrease is relatively large down the group and it depends entirely on the increase in the size of the cation, as the anion is unchanged (it is the sulfate ion in every case).

### Change in lattice energy down the group

Lattice energy is greater if the ions (with the same charge) forming the lattice are small so the lattice energy decreases in the order:



the lattice energy is also inversely proportional to the sum of the radii of the anion and cation the sulfate ion is much larger than the Group 2 cations so the sulfate ion contributes a relatively greater part to the change in the lattice energy down the group so the decrease in lattice energy is relatively smaller down the group and it is determined more by the size of the large sulfate ion than the size of the cations

### The Group 2 sulfates get less soluble going down the group.

The solubility of the hydroxides changes in the opposite direction:  $\text{Mg(OH)}_2 < \text{Ca(OH)}_2 < \text{Sr(OH)}_2 < \text{Ba(OH)}_2$ . The solubility of  $\text{Mg(OH)}_2$  is about  $2 \times 10^{-4} \text{ mol dm}^{-3}$  whereas that of  $\text{Ba(OH)}_2$  is about  $0.2 \text{ mol dm}^{-3}$ .

### 3. Calcium and its compounds have a large variety of applications.

Calcium metal reacts readily with most acids.

When calcium metal is placed in dilute sulfuric acid, it reacts vigorously at first.

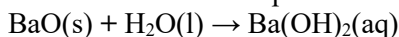
After a short time, a layer of calcium sulfate forms on the calcium metal and the reaction stops. Some of the calcium metal and dilute sulfuric acid remain unreacted.

Suggest an explanation for these observations.

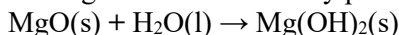
[1]

### With water

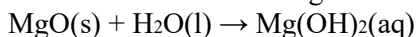
All the oxides of Group 2 elements react with water to form the hydroxides



although the reaction hardly proceeds at all with magnesium because of the insolubility of the hydroxide.



Magnesium oxide is only slightly soluble in water, and forms a weakly alkaline solution of magnesium hydroxide. A **saturated solution** of magnesium hydroxide will have a pH value of about 10:



**Saturated solution:** a solution which can dissolve no more solute at a particular temperature (in the presence of undissolved solute).

**The solutions formed from the reactions of the Group 2 metal oxides with water get more alkaline going down the group.**

We can explain this increase in alkalinity by looking at the solubility of the Group 2 hydroxides formed.

| Group 2 hydroxide, general formula $\text{X(OH)}_2$ | Solubility of hydroxide at 298 K<br>(mol / 100 g of water) |
|-----------------------------------------------------|------------------------------------------------------------|
| magnesium hydroxide, $\text{Mg(OH)}_2$              | $2.0 \times 10^{-5}$                                       |
| calcium hydroxide, $\text{Ca(OH)}_2$                | $1.5 \times 10^{-3}$                                       |
| strontium hydroxide, $\text{Sr(OH)}_2$              | $3.4 \times 10^{-3}$                                       |
| barium hydroxide, $\text{Ba(OH)}_2$                 | $1.5 \times 10^{-2}$                                       |

4. Group 2 metals form alkaline solutions in water.

(i) Write the equation for the reaction of calcium oxide with water.

[1]

(ii) Identify the ion that causes an aqueous solution to be alkaline.

[1]

5. Solid Ra and Ca show similar reactions with  $\text{H}_2\text{O}$ , but the reactions occur at different rates.

Separate samples, each containing a single piece of solid Ra or Ca, are added to equal volumes of cold water. Each sample contains equal numbers of moles of solid and the  $\text{H}_2\text{O}$  is in excess.

(i) Construct an equation for the reaction of Ra with  $\text{H}_2\text{O}$ .

[1]

(ii) Identify which element, Ra or Ca, reacts with  $\text{H}_2\text{O}$  at a faster rate. Suggest how the observations of each reaction would differ.

[1]

(iii) Suggest why these reactions occur at different rates.

[2]

(iv) One of the solutions is cloudy when the reaction has finished.

At the end of each reaction, universal indicator is added to each reaction mixture.

Suggest the pH values of the solutions made in both reactions. Explain your answer.

[2]

4. The oxides BaO, CaO, MgO and SrO all produce alkaline solutions when added to water. Which oxide produces the saturated solution with the highest pH?

A BaO

B CaO

C MgO

D SrO

6. Identify a single reagent that can be used to distinguish separate samples of dilute  $\text{Mg}(\text{NO}_3)_2(\text{aq})$  and dilute  $\text{Ba}(\text{NO}_3)_2(\text{aq})$ .  
Explain your answer.

[2]

5. Solutions P and Q each contain a different Group 2 ion at the same concentration. One contains  $\text{Mg}^{2+}$  and the other contains  $\text{Ba}^{2+}$ . Tests are carried out on separate  $5\text{ cm}^3$  samples of P and Q.  
test 1: add  $1\text{ cm}^3$  of  $0.1\text{ mol dm}^{-3}\text{ Na}_2\text{SO}_4(\text{aq})$   
test2: add  $1\text{ cm}^3$  of  $0.1\text{ mol dm}^{-3}\text{ NaOH}(\text{aq})$   
What are the results of these tests?

|   | results in test 1                      | results in test 2                      |
|---|----------------------------------------|----------------------------------------|
| A | more precipitate with $\text{Ba}^{2+}$ | more precipitate with $\text{Ba}^{2+}$ |
| B | more precipitate with $\text{Ba}^{2+}$ | more precipitate with $\text{Mg}^{2+}$ |
| C | more precipitate with $\text{Mg}^{2+}$ | more precipitate with $\text{Ba}^{2+}$ |
| D | more precipitate with $\text{Mg}^{2+}$ | more precipitate with $\text{Mg}^{2+}$ |

6. Equal volumes of saturated solutions of magnesium hydroxide, calcium hydroxide and strontium hydroxide are completely neutralised with dilute sulfuric acid.  
The water is gently evaporated from each of the resulting solutions, leaving the corresponding solid sulfates. These solid sulfates are completely dissolved in the minimum volume of water needed to produce saturated solutions. Which statement about the volumes of water needed to dissolve the sulfates is correct?
- A The calcium sulfate will require the greatest volume of water.  
B The magnesium sulfate will require the greatest volume of water.  
C The strontium sulfate will require the greatest volume of water.  
D They will all require the same volume of water.

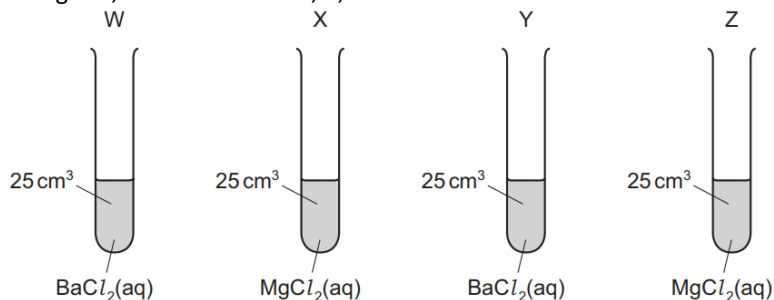
7.  $\text{NaOH}(\text{aq})$  is added to separate samples of magnesium chloride and barium chloride solutions.  $\text{H}_2\text{SO}_4(\text{aq})$  is then added slowly to each reaction mixture until in excess.  
What is observed at the **end** of the reaction sequence?

|   | $\text{MgCl}_2(\text{aq})$ | $\text{BaCl}_2(\text{aq})$ |
|---|----------------------------|----------------------------|
| A | colourless solution only   | colourless solution only   |
| B | colourless solution only   | white precipitate          |
| C | white precipitate          | colourless solution only   |
| D | white precipitate          | white precipitate          |

7. Predict what you would observe when aqueous radium chloride is added to aqueous sodium sulfate. Do **not** refer to temperature changes in your answer.

[1]

8. In the diagram, each test-tube W, X, Y and Z contains 25 cm<sup>3</sup> of a 0.1 mol dm<sup>-3</sup> solution of a salt.



To test-tubes W and X, 25 cm<sup>3</sup> of 0.1 mol dm<sup>-3</sup> NaOH(aq) is added.

To test-tubes Y and Z, 25 cm<sup>3</sup> of 0.1 mol dm<sup>-3</sup> H<sub>2</sub>SO<sub>4</sub>(aq) is added.

In which of test-tubes W and X does the liquid have the higher pH and which of test-tubes Y and Z has the greater mass of precipitate?

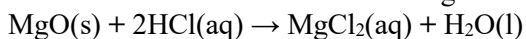
|          | higher pH | greater mass of precipitate |
|----------|-----------|-----------------------------|
| <b>A</b> | W         | Y                           |
| <b>B</b> | W         | Z                           |
| <b>C</b> | X         | Y                           |
| <b>D</b> | X         | Z                           |

8. Which row correctly describes the separate reactions of calcium and strontium with water?

|          | substance reduced    | substance oxidised   | more vigorous reaction |
|----------|----------------------|----------------------|------------------------|
| <b>A</b> | calcium or strontium | water                | calcium + water        |
| <b>B</b> | calcium or strontium | water                | strontium + water      |
| <b>C</b> | water                | calcium or strontium | calcium + water        |
| <b>D</b> | water                | calcium or strontium | strontium + water      |

### With hydrochloric acid and sulfuric acid

The oxides react with dilute acids to give salts and water.



## Reactions of the hydroxides

### With water

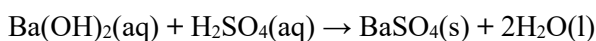
9. V and W are two compounds. Each one contains a different Group 2 element.  
A sample of each solid is added to water, shaken, and the pH of the resulting solution is measured.

| Compound | V    | W   |
|----------|------|-----|
| Ph       | 13.6 | 9.4 |

Which row could identify V and W?

|          | V                   | W                   |
|----------|---------------------|---------------------|
| <b>A</b> | BaSO <sub>4</sub>   | MgSO <sub>4</sub>   |
| <b>B</b> | MgSO <sub>4</sub>   | BaSO <sub>4</sub>   |
| <b>C</b> | Ba(OH) <sub>2</sub> | Mg(OH) <sub>2</sub> |
| <b>D</b> | Mg(OH) <sub>2</sub> | Ba(OH) <sub>2</sub> |

### With acids



9. A student titrates nitric acid with a base to form a solution containing aqueous magnesium nitrate. Identify a base that the student could use.

[1]

10. W is a solid that reacts with water to produce an alkaline solution.  
The addition of two drops of dilute  $\text{H}_2\text{SO}_4$  to this alkaline solution produces a white precipitate.  
What could be the identity of solid W?

- A magnesium hydroxide
- B magnesium oxide
- C barium oxide
- D phosphorus oxide

11. A solution contains both  $\text{Mg}^{2+}(\text{aq})$  and  $\text{Sr}^{2+}(\text{aq})$  at the same concentration.  
The solution is divided into two equal portions. Aqueous sodium hydroxide is added dropwise to one portion. Dilute sulfuric acid is added dropwise to the other portion.  
Which row is correct?

|   | precipitate seen first<br>when $\text{NaOH}(\text{aq})$ is added | precipitate seen first<br>when $\text{H}_2\text{SO}_4(\text{aq})$ is added |
|---|------------------------------------------------------------------|----------------------------------------------------------------------------|
| A | magnesium hydroxide                                              | magnesium sulfate                                                          |
| B | magnesium hydroxide                                              | strontium sulfate                                                          |
| C | strontium hydroxide                                              | magnesium sulfate                                                          |
| D | strontium hydroxide                                              | strontium sulfate                                                          |

## Reactions of the Carbonates

### With water

The Group 2 carbonates have the general formula  $\text{XCO}_3$ . The carbonates of magnesium, calcium, strontium and barium are all **insoluble in water**.

12. In which list are all three compounds soluble in water?

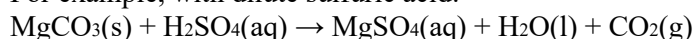
- A barium chloride, calcium carbonate, magnesium hydroxide
- B barium hydroxide, calcium hydroxide, strontium carbonate
- C barium chloride, barium hydroxide, magnesium sulfate
- D barium sulfate, calcium sulfate, magnesium hydroxide

13. L and M are both compounds of Group 2 elements.  
L and M are both soluble in water.  
When solutions of L and M are mixed, a white precipitate is formed.  
What could be L and M?

- A barium chloride and magnesium sulfate
- B barium sulfate and magnesium chloride
- C barium nitrate and magnesium chloride
- D barium carbonate and magnesium nitrate

### With acids

However, the carbonates all react in dilute acid, forming a salt and water and giving off carbon dioxide gas.  
For example, with dilute sulfuric acid:



The magnesium sulfate salt formed in the reaction above is soluble in water. This remains in aqueous solution, and no solid carbonate will remain in excess dilute sulfuric acid.

However, the sulfates of the other Group 2 elements are much less soluble than magnesium sulfate.

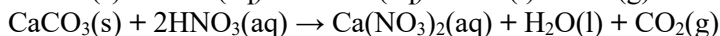
Remember the decreasing trend in the solubility of the sulfates. So, the sulfates of calcium, strontium and barium tend to form as an insoluble sulfate layer on their solid carbonates. This stops any further reaction after the initial effervescence (bubbling) of carbon dioxide gas is seen.

For example:



The reactions of the Group 2 carbonates with dilute hydrochloric acid will all form soluble chloride salts, water and carbon dioxide gas.

For example:



10. A sample of  $\text{MgCO}_3(\text{s})$  is distinguished from a sample of  $\text{Mg}(\text{OH})_2(\text{s})$  by adding a small amount of each solid to  $\text{HCl}(\text{aq})$ .

State one similarity and one difference in these two reactions.

[2]

11. Separate samples of  $\text{Na}_2\text{CO}_3$  and  $\text{NaHCO}_3$  react with  $\text{HCl}(\text{aq})$  to produce the same products, as shown in Table

| reaction | equation                                                                                           | $\Delta H/\text{kJ mol}^{-1}$ |
|----------|----------------------------------------------------------------------------------------------------|-------------------------------|
| 1        | $\text{Na}_2\text{CO}_3 + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$ | $\Delta H_1$                  |
| 2        | $\text{NaHCO}_3 + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$           | $\Delta H_2 = +27.2$          |

The value for  $\Delta H_1$  is determined by experiment using the following method.

- $50.0 \text{ cm}^3$  of  $2.00 \text{ mol dm}^{-3} \text{ HCl}(\text{aq})$  is added to a polystyrene cup.
- The initial temperature of the acid is recorded as  $19.6^\circ\text{C}$ .
- $0.0400 \text{ mol}$  of  $\text{Na}_2\text{CO}_3$  is added and the mixture is stirred.
- All the solid  $\text{Na}_2\text{CO}_3$  disappears and a colourless solution is produced.

The maximum temperature recorded during the reaction is  $26.2^\circ\text{C}$ .

Describe **one** other observation that shows the reaction is complete.

[1]

14. Separate samples, each of mass  $1.0 \text{ g}$ , of the compounds listed are treated with an excess of dilute acid.  
Which compound releases the largest amount of  $\text{CO}_2$ ?

A  $1.0 \text{ g CaCO}_3$

B  $1.0 \text{ g Li}_2\text{CO}_3$

C  $1.0 \text{ g MgCO}_3$

D  $1.0 \text{ g Na}_2\text{CO}_3$

15. A  $3.7 \text{ g}$  sample of copper(II) carbonate is added to  $25 \text{ cm}^3$  of  $2.0 \text{ mol dm}^{-3}$  hydrochloric acid.  
Which volume of gas is produced at room conditions?

A  $0.60 \text{ dm}^3$

B  $0.72 \text{ dm}^3$

C  $1.20 \text{ dm}^3$

D  $2.40 \text{ dm}^3$

16. The carbonate of an s-block element is reacted with an excess of hydrochloric acid.  
 $0.833 \text{ g}$  of the carbonate releases  $200 \text{ cm}^3$  of gas, measured under room conditions.  
What is the identity of the metal carbonate?

A  $\text{Na}_2\text{CO}_3$ B  $\text{K}_2\text{CO}_3$ C  $\text{MgCO}_3$ D  $\text{CaCO}_3$ 

17. A solid, X, was placed in an excess of the liquid Y.  
A colourless gas was given off and a white precipitate was seen. The precipitate was not X.  
What could be the identities of X and Y?

|   | X               | Y                              |
|---|-----------------|--------------------------------|
| A | $\text{BaCO}_3$ | $\text{H}_2\text{O}$           |
| B | Ca              | dilute $\text{H}_2\text{SO}_4$ |
| C | Mg              | dilute $\text{H}_2\text{SO}_4$ |
| D | $\text{SrCO}_3$ | dilute $\text{HCl}$            |

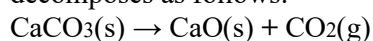
18. Compound Z is insoluble in water but soluble at low pH.  
What could be compound Z?
- A barium carbonate  
B barium chloride  
C barium hydroxide  
D barium sulfate
19. A mixture contains magnesium carbonate and barium carbonate only. A sample of the mixture is dissolved in nitric acid to produce a solution.  
How could this solution be processed into a magnesium compound and a separate barium compound?
- A Add  $\text{HCl}(\text{aq})$ , filter off the solid barium chloride.  
B Add  $\text{HCl}(\text{aq})$ , filter off the solid magnesium chloride.  
C Add  $\text{H}_2\text{SO}_4(\text{aq})$ , filter off the solid barium sulfate.  
D Add  $\text{H}_2\text{SO}_4(\text{aq})$ , filter off the solid magnesium sulfate
20. Q is a Group 2 metal.  
An excess of  $\text{QCO}_3(\text{s})$  is added to  $\text{H}_2\text{SO}_4(\text{aq})$  followed by filtration. A sample of  $\text{QSO}_4$  is then obtained by evaporation of the filtrate.  
What could be the identity of Q?
- A barium, calcium or magnesium  
B barium or calcium only  
C calcium only  
D calcium or magnesium only

## Thermal decomposition of the nitrates and carbonates

### Thermal decomposition: the breakdown of the compound by heat into two or more different substances

#### Carbonates

The carbonates decompose on heating to give the oxide and carbon dioxide. For example, calcium carbonate decomposes as follows:



Going down the group, the carbonates become more stable to heat: magnesium carbonate decomposes at  $500^\circ\text{C}$ , so can be decomposed in the heat of a Bunsen flame, but barium carbonate needs a temperature of over  $1000^\circ\text{C}$  before much carbon dioxide is produced.

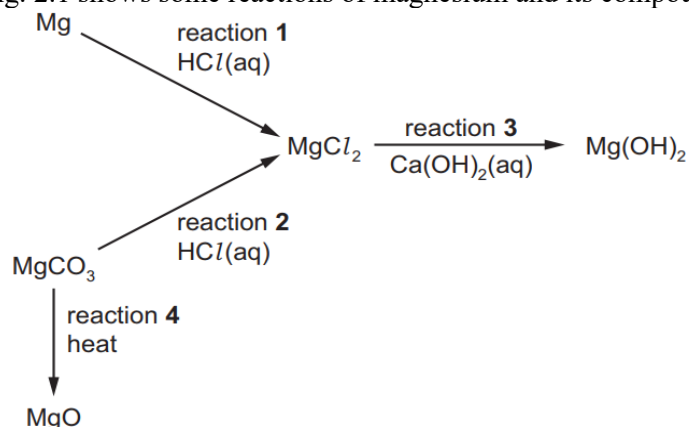
12. Calcium oxide can be made from calcium carbonate in a single-step reaction.  
Identify the type of reaction that occurs.

[1]

13. Emissions of  $\text{SO}_2$  from coal-fired power stations can be reduced by mixing the coal with powdered limestone. Limestone is heated to form  $\text{CaO}$  in reaction 1. This then reacts with  $\text{SO}_2$  and  $\text{O}_2$  to form  $\text{CaSO}_4$  in reaction 2.
- reaction 1:  $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$
- reaction 2:  $\text{CaO}(\text{s}) + \text{SO}_2(\text{g}) + 1/2\text{O}_2(\text{g}) \rightarrow \text{CaSO}_4(\text{s})$
- State the type of reaction occurring in reaction 1. [1]

14. Write equations for the following reactions: the thermal decomposition of sodium carbonate, forming sodium oxide and carbon dioxide. [1]

15. Fig. 2.1 shows some reactions of magnesium and its compounds.



- (i) Identify the other products of reactions 1 and 2. [1]
- (ii) Reaction 3 is used to form a precipitate of  $\text{Mg}(\text{OH})_2$  from  $\text{MgCl}_2(\text{aq})$ . State why  $\text{Ca}(\text{OH})_2(\text{aq})$  would **not** form a precipitate of  $\text{Ba}(\text{OH})_2$  from  $\text{BaCl}_2(\text{aq})$ . [2]
- (iii) State the type of reaction that occurs in reaction 4. [1]
16. Solid ethanedioic acid reacts with aqueous calcium ions to make a precipitate of calcium ethanedioate,  $\text{CaC}_2\text{O}_4$ .  $\text{CaC}_2\text{O}_4$  breaks down when heated to form calcium oxide, carbon dioxide and carbon monoxide.
- (i) Construct an equation to represent the reaction of  $\text{CaC}_2\text{O}_4$  when heated. Include state symbols. [2]
- (ii) Identify the type of reaction which occurs when  $\text{CaC}_2\text{O}_4$  is heated. [1]
- (iii) Identify another compound containing calcium ions which will also produce carbon dioxide and calcium oxide when it is heated. [1]

21. Which statement comparing magnesium and barium, or their compounds, is correct?

- A Magnesium reacts with dilute hydrochloric acid more rapidly than barium does.
- B One mole of magnesium carbonate gives off a greater amount of gas when it reacts with an excess of dilute hydrochloric acid than one mole of barium carbonate does.
- C The solubility of magnesium sulfate in water is greater than the solubility of barium sulfate in water.
- D Magnesium carbonate undergoes thermal decomposition **less** readily than barium carbonate does.

22. What are the trends in the stated properties as Group 2 is descended from magnesium to barium?

|   | Decomposition temperature of the carbonate | first ionisation energy |
|---|--------------------------------------------|-------------------------|
| A | decreases                                  | increases               |
| B | decreases                                  | Decreases               |
| C | Increases                                  | Increases               |
| D | increases                                  | decreases               |

23. The table compares calcium with barium and calcium carbonate with barium carbonate. Which row is correct?

|   | reactivity of the element with water | thermal stability of the metal carbonate |
|---|--------------------------------------|------------------------------------------|
| A | barium is more reactive              | barium carbonate is more stable          |
| B | barium is more reactive              | calcium carbonate is more stable         |
| C | calcium is more reactive             | barium carbonate is more stable          |
| D | calcium is more reactive             | calcium carbonate is more stable         |

24. Samples of magnesium carbonate,  $\text{MgCO}_3$ , are placed in crucibles R and S. The sample in crucible R is heated until there is no further loss in mass, and then allowed to cool. The sample in crucible S is left unheated. Dilute hydrochloric acid is then added to both crucibles. On adding the dilute hydrochloric acid, which observations are correct?

|   | R               | S               |
|---|-----------------|-----------------|
| A | gas produced    | gas produced    |
| B | gas produced    | no gas produced |
| C | no gas produced | gas produced    |
| D | no gas produced | no gas produced |

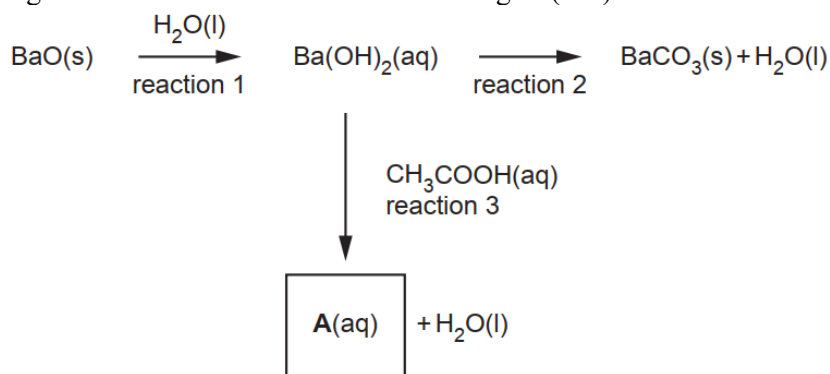
25. Which property shows an increase from calcium to barium going down Group 2?

- A the ease of decomposition of the carbonates
- B the solubility of the hydroxides
- C the solubility of the sulfates
- D the volume of hydrogen given off when 1 g of the metal reacts with water

26. Which row gives correct comparisons between the solubilities of calcium hydroxide and barium hydroxide and the thermal stabilities of calcium carbonate and barium carbonate?

|   | solubility        |                  | thermal stability |                  |
|---|-------------------|------------------|-------------------|------------------|
|   | calcium hydroxide | barium hydroxide | calcium carbonate | barium carbonate |
| A | higher            | lower            | higher            | lower            |
| B | higher            | lower            | lower             | higher           |
| C | lower             | higher           | higher            | lower            |
| D | lower             | higher           | lower             | higher           |

17. Barium hydroxide,  $\text{Ba}(\text{OH})_2$ , is a strong base used in inorganic and organic reactions. Fig. 2.1 shows a reaction scheme involving  $\text{Ba}(\text{OH})_2$ .

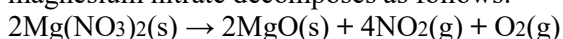


**Fig. 2.1**

- (a) (i) State the variation in solubilities of group 2 hydroxides. [1]
- (ii) State what is observed in reaction 1. [1]
- (iii) Suggest a reactant for reaction 2. [1]
- (iv) Identify A. [1]
- (v)  $\text{Ba}(\text{OH})_2$  is made by the reaction of Ba with water. Write an equation for this reaction. [1]
- (b) The mineral barytocalcite contains both  $\text{BaCO}_3$  and  $\text{CaCO}_3$ . Both compounds decompose on heating.
- (i) State which compound decomposes first when barytocalcite is heated. Explain your answer. [1]
- (ii) Construct an equation for the complete thermal decomposition of barytocalcite. The formula of barytocalcite is  $\text{BaCa}(\text{CO}_3)_2$ . [1]

### Nitrates

The nitrates also decompose on heating, to give the oxide, nitrogen dioxide (**a brown gas**) and oxygen. For example, magnesium nitrate decomposes as follows:



Like the carbonates, a higher temperature is needed to decompose the nitrates of the metals at the bottom of the group compared to those at the top, although all can be decomposed using a Bunsen burner.

**Both for carbonates and nitrates, a higher temperature is needed to thermally decompose as group 2 is descended.**

18. Write the equation for the thermal decomposition of calcium nitrate. [1]

19. Write an equation for the decomposition of magnesium nitrate. [1]

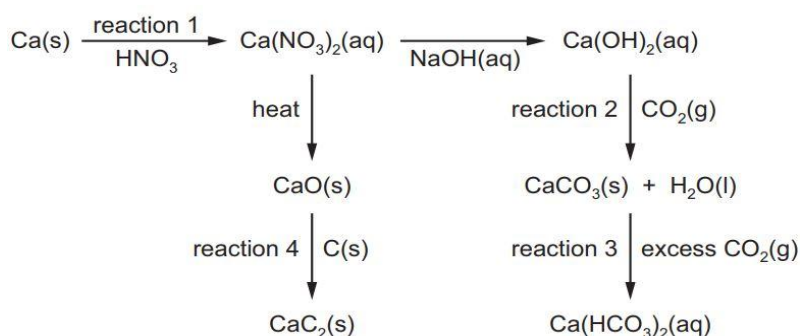
20. State how the thermal stability of Group 2 nitrates changes down the group. [1]

21. Suggest which of the Group 2 nitrates, calcium, magnesium or radium, requires the highest temperature to decompose. Explain your answer. [1]

22. **Z** is a salt that contains a Period 4 element from Group 2. When **Z** is heated brown gas forms.  
Identify the formula of **Z** and use it to write an equation for the reaction. [1]

23. Aluminium nitrate is a white soluble salt. On heating aluminium nitrate, thermal decomposition occurs and a brown gas is seen.  
State the formula of the salt of another element in Period 3 which also decomposes on heating to produce a brown gas. [1]

24. The reaction scheme shows some reactions of calcium.



(i) Reaction 1 produces  $\text{Ca(NO}_3)_2$  and one other product.  
Identify the other product. [1]

(ii) Construct an equation for the thermal decomposition of  $\text{Ca(NO}_3)_2\text{(s)}$ . [1]

(iii) State the trend in the thermal stability of the Group 2 nitrates down the group. [1]

(iv) In reaction 3, excess  $\text{CO}_2$  is bubbled through water containing  $\text{CaCO}_3$ . A solution of  $\text{Ca(HCO}_3)_2\text{(aq)}$  forms.  
Construct an equation for reaction 3. [1]

(v) Describe how  $\text{Ca(OH)}_2$  is used in agriculture. [1]

25. Separate 1.0g samples of three different magnesium salts are tested in order to identify the anion present in each sample.

Explain how the action of heat is used to identify which sample is:

- $\text{MgCO}_3$
- $\text{Mg}(\text{NO}_3)_2$
- $\text{MgO}$ .

[3]

26. Group 2 nitrates decompose on heating to form oxides.

(i) State the trend in thermal stability of the Group 2 nitrates down the group.

..... [1]

(ii) Identify the other products of the thermal decomposition of Group 2 nitrates.

..... [1]

27. X is a Group 2 element in either Period 3 or Period 5.  $\text{X}(\text{OH})_2$  is less soluble in water than  $\text{Ca}(\text{OH})_2$ .

When  $\text{X}(\text{NO}_3)_2$  is heated, it decomposes.

Which row is correct?

|          | identity of X | equation describing decomposition of $\text{X}(\text{NO}_3)_2$                |
|----------|---------------|-------------------------------------------------------------------------------|
| <b>A</b> | Mg            | $\text{X}(\text{NO}_3)_2 \rightarrow \text{X} + 2\text{NO}_2 + \text{O}_2$    |
| <b>B</b> | Mg            | $2\text{X}(\text{NO}_3)_2 \rightarrow 2\text{XO} + 4\text{NO}_2 + \text{O}_2$ |
| <b>C</b> | Sr            | $\text{X}(\text{NO}_3)_2 \rightarrow \text{X} + 2\text{NO}_2 + \text{O}_2$    |
| <b>D</b> | Sr            | $2\text{X}(\text{NO}_3)_2 \rightarrow 2\text{XO} + 4\text{NO}_2 + \text{O}_2$ |

28. Anhydrous magnesium nitrate,  $\text{Mg}(\text{NO}_3)_2$ , decomposes when heated, giving a white solid and a mixture of two gases, X and Y.

Y is oxygen.

What is the ratio mass of Y released to the mass of X released?

A 1/0.174                      B 1/0.267                      C 1/0.348                      D 1/3.43

29. A sample containing 0.010 mol of anhydrous calcium nitrate is heated strongly until it fully decomposes.

All the gas produced is collected and its volume is measured at room conditions.

What is the volume of gas produced?

A  $120\text{cm}^3$                       B  $600\text{cm}^3$                       C  $720\text{cm}^3$                       D  $840\text{cm}^3$

30. A 4.00 g sample of an anhydrous Group 2 metal nitrate, Z, is heated strongly until there is no further change of mass. A solid residue of mass 1.37 g is formed.

Which metal is present in Z?

A barium                      B calcium                      C magnesium                      D strontium

31. A 5.00 g sample of an anhydrous Group 2 metal nitrate loses 3.29 g in mass when heated strongly.

Which metal is present?

**A** magnesium                      **B** calcium                      **C** strontium                      **D** barium

32. A sample consisting of 1.0 mol of anhydrous calcium nitrate is completely decomposed by strong heating. What is the total amount of gas produced in this reaction?
- A** 1.0 mol                      **B** 2.0 mol                      **C** 2.5 mol                      **D** 3.0 mol
33. Z is an anhydrous compound of a Group 2 element. When it is heated, Z undergoes thermal decomposition to produce two different gases. Z has relatively low thermal stability compared to other Group 2 compounds containing the same anion as Z. What is compound Z?
- A barium carbonate  
B barium nitrate  
C magnesium carbonate  
D magnesium nitrate
34. Equal masses of  $\text{CaCO}_3$ ,  $\text{Ca}(\text{NO}_3)_2$ ,  $\text{BaCO}_3$  and  $\text{Ba}(\text{NO}_3)_2$  are thermally decomposed. The volume of gas produced in each experiment is measured under the same conditions. Which compound will produce the greatest volume of gas?
- A**  $\text{CaCO}_3$                       **B**  $\text{Ca}(\text{NO}_3)_2$                       **C**  $\text{BaCO}_3$                       **D**  $\text{Ba}(\text{NO}_3)_2$
35. For which compound is there the greatest percentage loss of mass on strong heating?
- A anhydrous calcium carbonate  
B anhydrous calcium nitrate  
C anhydrous magnesium carbonate  
D anhydrous magnesium nitrate
36. A mixture of calcium carbonate, calcium nitrate, strontium carbonate and strontium nitrate is thermally decomposed. The decomposition reaction of each substance goes to completion. Each substance is anhydrous. How many different products are formed?
- A** 4                      **B** 5                      **C** 7                      **D** 8
37. In Group 2 of the Periodic Table, the properties of the elements and their compounds show regular change down the group. Which property shows a decrease from magnesium to barium?
- A the decomposition temperature of the carbonates  
B the decomposition temperature of the nitrates  
C the solubility of the hydroxides  
D the solubility of the sulfates

38. Which row is correct?

|          | the temperature needed to decompose Group 2 metal nitrates | the solubility of Group 2 sulfates |
|----------|------------------------------------------------------------|------------------------------------|
| <b>A</b> | decreases down the group                                   | decreases down the group           |
| <b>B</b> | decreases down the group                                   | increases down the group           |
| <b>C</b> | increases down the group                                   | increases down the group           |
| <b>D</b> | increases down the group                                   | decreases down the group           |

39. Four properties of beryllium, Be, or a beryllium compound are listed. Which property is different from the property of magnesium or the equivalent magnesium compound?
- Be reacts with  $O_2$  when heated in air; Mg does not.
  - Be reacts with aqueous  $H_2SO_4$  to form a metal sulfate and  $H_2$ ; Mg does not.
  - $Be(NO_3)_2$  decomposes on heating to form a metal oxide,  $NO_2$  and  $O_2$ ;  $Mg(NO_3)_2$  does not.
  - $BeCl_2$  reacts with water to form fumes of  $HCl$ ;  $MgCl_2$  does not.
40. An anhydrous white salt, Z, is heated strongly for 30 minutes. A mixture of gases is given off. The solid remaining in the test-tube is then dissolved in a small volume of dilute hydrochloric acid. The addition of a few drops of dilute sulfuric acid to the test-tube causes a white precipitate to form. Which substance could be Z?
- barium carbonate
  - barium nitrate
  - magnesium carbonate
  - magnesium nitrate
41. Which statement about the compounds of the Group 2 metals is correct?
- Barium carbonate is less thermally stable than strontium carbonate.
  - Barium sulfate is less soluble than magnesium sulfate.
  - Calcium hydroxide is less soluble than magnesium hydroxide.
  - Calcium nitrate is more thermally stable than strontium nitrate.

### Trends in physical and chemical properties of the elements and their compounds

27. The table shows the melting points of some Group 2 metal oxides.

| compound | melting point/ $^{\circ}C$ |
|----------|----------------------------|
| MgO      | 2825                       |
| CaO      | 2613                       |
| SrO      | 2531                       |
| BaO      | 1923                       |

Explain the trend in the melting points of the oxides down Group 2.

28. Separate samples of **R**, **S**, **T** and **U** are added to cold water. The identity of each sample is unknown. However, each sample is known to be pure and can only be one of  $Ba(OH)_2$ ,  $NaCl$ ,  $P_4O_{10}$  or  $SiCl_4$ .  
**(a) (i)** Use the observations in the table to identify each sample as one of  $Ba(OH)_2$ ,  $NaCl$ ,  $P_4O_{10}$  and  $SiCl_4$ .  
 Write your answers in the table.

[4]

|          | state at room temperature | observations on addition of sample to water                         | identity of sample |
|----------|---------------------------|---------------------------------------------------------------------|--------------------|
| <b>R</b> | solid                     | alkaline, colourless solution is produced, some white solid remains |                    |
| <b>S</b> | solid                     | white solid disappears, solution is neutral                         |                    |
| <b>T</b> | liquid                    | misty fumes produced, white solid is made in vigorous reaction      |                    |
| <b>U</b> | solid                     | acidic, colourless solution produced in vigorous reaction           |                    |

(ii) Identify the formula of the white solid made when sample **T** reacts with water. [1]

(iii) Name the solution formed when sample **U** reacts with water. [1]

1. The table gives some data for compounds of two elements from Group 2 of the Periodic Table.

| Element | decomposition temperature of carbonate /°C | solubility of sulfate in mol / 100 g of water | solubility of hydroxide in mol / 100 g of water |
|---------|--------------------------------------------|-----------------------------------------------|-------------------------------------------------|
| calcium | 840                                        | $4.66 \times 10^{-3}$                         | $1.53 \times 10^{-3}$                           |
| Z       | ?                                          | ?                                             | $2.00 \times 10^{-5}$                           |

What is the missing data for element Z?

|          | Decomposition temperature of carbonate /°C | solubility of sulfate in mol / 100 g of water |
|----------|--------------------------------------------|-----------------------------------------------|
| <b>A</b> | 350                                        | $1.83 \times 10^{-1}$                         |
| <b>B</b> | 350                                        | $7.11 \times 10^{-5}$                         |
| <b>C</b> | 1100                                       | $1.83 \times 10^{-1}$                         |
| <b>D</b> | 1100                                       | $7.11 \times 10^{-5}$                         |

2. Q is a mixture of two compounds of Group 2 elements.

Q undergoes thermal decomposition to produce a white solid and only two gaseous products. One of the gaseous products relights a glowing splint.

What could be the components of mixture Q?

- A**  $\text{MgCl}_2$  and  $\text{CaCO}_3$   
**B**  $\text{MgCO}_3$  and  $\text{Ca}(\text{NO}_3)_2$   
**C**  $\text{Mg}(\text{NO}_3)_2$  and  $\text{Ca}(\text{NO}_3)_2$   
**D**  $\text{MgO}$  and  $\text{CaO}$

3. All solubility data in this question is given at the same temperature.

The table gives some data for compounds of calcium and for compounds of X, an unidentified element in Group 2.

| element | decomposition temperature of carbonate /°C | solubility of sulfate / mol per 100 g of water | solubility of hydroxide / mol per 100 g of water |
|---------|--------------------------------------------|------------------------------------------------|--------------------------------------------------|
| Ca      | 840                                        | $4.66 \times 10^{-3}$                          | $1.53 \times 10^{-3}$                            |
| X       | 1150                                       |                                                |                                                  |

What is the missing data for element X?

|          | solubility of sulfate / mol per 100 g of water | solubility of hydroxide / mol per 100 g of water |
|----------|------------------------------------------------|--------------------------------------------------|
| <b>A</b> | $7.11 \times 10^{-5}$                          | $2.00 \times 10^{-5}$                            |
| <b>B</b> | $7.11 \times 10^{-5}$                          | $3.37 \times 10^{-3}$                            |
| <b>C</b> | $1.83 \times 10^{-1}$                          | $2.00 \times 10^{-5}$                            |
| <b>D</b> | $1.83 \times 10^{-1}$                          | $3.37 \times 10^{-3}$                            |

4. What is the total volume of gas produced, measured at room conditions, when 0.010 mol of anhydrous magnesium nitrate is completely decomposed by heating?

A 240 cm<sup>3</sup>B 480 cm<sup>3</sup>C 600 cm<sup>3</sup>D 720 cm<sup>3</sup>

5. X is an impure sample of a Group 2 metal carbonate, MCO<sub>3</sub>. X contains 57% by mass of MCO<sub>3</sub>.  
The impurities in X do not react with hydrochloric acid.  
7.4 g of X is reacted with an excess of dilute hydrochloric acid.  
0.050 mol of the Group 2 metal chloride is produced.  
What is the identity of the Group 2 metal?

A Mg

B Ca

C Sr

D Ba

6. This question is about two elements in Group 2, Q and R.  
Three of the statements shown are correct for metal Q.  
The one remaining statement is correct for metal R.  
Which statement applies to R?

A A saturated solution of the hydroxide of this metal has the higher pH value.  
B This metal has a carbonate that is used in agriculture to reduce the acidity of soil.  
C This metal has the greater atomic radius.  
D This metal reacts more quickly with cold water.

7. A student mixes pairs of chemicals together in separate test-tubes.
- excess calcium (s) + water (l)
  - barium chloride (aq) + strontium hydroxide (aq)
  - calcium carbonate (s) + excess hydrochloric acid (aq)
  - magnesium sulfate (aq) + barium nitrate (aq)
- How many of the mixtures produce a white, solid product?

A 0

B 1

C 2

D 3

8. Steam is passed over heated magnesium to give compound J and hydrogen.  
What is not a property of compound J?

A It has an Mr of 40.3.  
B It is basic.  
C It is a white solid.  
D It is very soluble in water.

9. A 0.005 mol sample of anhydrous calcium carbonate is completely thermally decomposed to give 100 cm<sup>3</sup> of gas.  
In a separate experiment carried out under the same conditions, a 0.005 mol sample of anhydrous calcium nitrate is completely thermally decomposed. The volume of gaseous products is measured.  
What total volume of gaseous products is produced from the calcium nitrate?

A 50 cm<sup>3</sup>B 100 cm<sup>3</sup>C 200 cm<sup>3</sup>D 250 cm<sup>3</sup>

29. (i) Complete the equation for the reaction that occurs when a solution of Ba(OH)<sub>2</sub> is added to aqueous sulfuric acid. Include state symbols.

.....  $\text{H}_2\text{SO}_4(\text{aq}) + \dots \text{Ba}(\text{OH})_2(\text{aq})$  .....

[2]

(ii) Suggest why the enthalpy change of neutralisation cannot be determined using the addition of dilute sulfuric acid to aqueous barium hydroxide. [1]

10. X is the ion of a metal which burns with a red flame.

Y is an ion that reacts with concentrated  $\text{H}_2\text{SO}_4$  to produce  $\text{H}_2\text{S}$ .

What could be the formula of a compound containing X and Y?

A  $\text{BaBr}_2$

B  $\text{BaI}_2$

C  $\text{SrBr}_2$

D  $\text{SrI}_2$

11. Compound T is a white crystalline solid.

When a sample of compound T is mixed with aqueous sodium hydroxide and heated, a gas is produced which turns damp red litmus paper blue.

Further testing of a solution of compound T with aqueous barium chloride produces a dense white precipitate which does not dissolve when dilute hydrochloric acid is added to the mixture.

What is the identity of compound T?

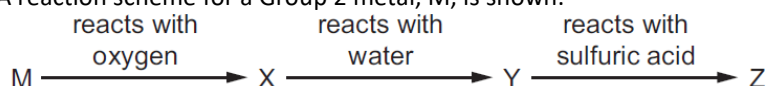
A ammonium carbonate

B ammonium sulfate

C sodium carbonate

D sodium sulfate

12. A reaction scheme for a Group 2 metal, M, is shown.



Which row is correct as M descends Group 2 from Mg to Ba?

|   | solubility of Y in water | solubility of Z in water |
|---|--------------------------|--------------------------|
| A | decreases                | decreases                |
| B | decreases                | increases                |
| C | increases                | decreases                |
| D | increases                | increases                |

\*\*\*This is not a complete note. It is to guide you. It is recommended to study the prescribed textbooks along with this material.\*\*\*