9.2 Group II

Content

9.2.1 Similarities and trends in the properties of the Group II metals magnesium to barium and their compounds

Learning Outcomes

Candidates should be able to:

(a) describe the reactions of the elements with oxygen and water

(b) describe the behaviour of the oxides with water

(c) interpret and explain qualitatively the trend in the thermal stability of the nitrates in terms of the charge density of the cation and the polarisability of the large anion

(d) interpret, and make predictions from, the trends in physical and chemical properties of the elements and their compounds

9.2.1 Similarities and trends in the properties of Group II metals magnesium to barium and their compounds

Define

s-block element

An ***s*-block element** is any element in *Groups I* and *II* of the Periodic Table.

- Group I elements are commonly known as *alkali metals* while Group II elements are commonly known as *alkali earth metals*.
- Group I elements have one valence electron (oxidation state +1) while Group II elements have two valence electrons (oxidation state +2).
- Outershell configuration: ns^2
- Group II metals are reactive with low electronegativity. They form stable ions with an oxidation state of +2 since its two outer s electrons are easily lost.
- They seldom form complexes, and form basic oxides and hydroxides.

Example

1. Barium and magnesium are examples of Group II elements.

Variations in the physical properties of alkali earth metals

Atomic and ionic radii

- Down the group, the atomic and ionic radii increase.
- Each element has progressively one more electron shell, thus the outer electrons are further from the nucleus.

Electronegativity

- Down the group, the electronegativity of the elements decreases.

- The atomic size of the elements increase down the group, thus the nuclear charge effect decreases. Additional electrons are not held as strongly by the nucleus.

Melting and boiling points

- Down the group, the melting and boiling points decrease.

- As the atomic size of the elements increase down the group, the attraction of the ions for the electron cloud decreases, thus weakening the metallic bonds.

Ionisation energy

- Down the group, the ionization energy of the elements decreases.

- The atomic size of the elements increase down the group, thus the screening effect increases. Less energy is required to remove an electron.

Hardness

- Down the group, the hardness of the metals decreases.

- The strength of the metallic bonding decreases down the group.

Variations in the chemical properties of alkali earth metals

- All the alkali earth metals are strong reducing agents with low ionization energy, low electronegativity and negative electrode potentials.

- The reactivity and reducing power of the elements increases down the group as it is easier to remove the outermost electrons.

Reaction with air or oxygen

- All the alkali earth metals burn brilliantly to form a mixture of *metal monoxide* and *nitride*.

- Assuming X is the metal atom, the general equation is:

  $2X\ (s) + O_2\ (g) \rightarrow 2XO\ (s)$

  $3X\ (s) + N_2\ (g) \rightarrow X_3N_2\ (s)$

- Going down the group, the rate of reaction and the proportion of nitride formed increases.

- Group II elements can be identified through the *flame test* whereby the mixture of the metal salt and concentrated hydrochloric acid is heated in a non-luminous Bunsen flame on the tip of a nichrome wire. Each element burns with a different coloured flame. For example, Mg^{2+} gives a bright white flame and Ca^{2+} gives a brick-red flame.

Example

❶ The equation for the reaction of calcium with air is as follows:

$2Ca\ (s) + O_2\ (g) \rightarrow 2CaO\ (s)$

$3Ca\ (s) + N_2\ (g) \rightarrow Ca_3N_2\ (s)$

Reaction with water

- All Group II elements (except beryllium) react with water to form *metal hydroxides* and *hydrogen* gas.

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

- Magnesium reacts readily with steam to form magnesium oxide. It does not react with cold water. Magnesium oxide will dissolve in water to give an alkaline solution of magnesium hydroxide.

- Calcium, strontium and barium react vigorously with cold water to form hydroxides.

- The solubility of Group II hydroxides increases down the group.

- Group II metals must be stored under oil to prevent reaction with oxygen and water vapour in the air.

- Exceptions to this are beryllium and magnesium as they form protective oxide layers and prevent the metals from corrosion.

Example

❶ The equation for the reaction of magnesium with steam is as follows:

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

❷ The equation for the reaction of calcium with cold water is as follows:

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

Reaction with acids

- All Group II elements react with acids to form the corresponding *salts* and *hydrogen* gas.

  $M (s) + 2H^{+} (aq) \rightarrow M^{2+} (aq) + H_2 (g)$

- Beryllium does not react with acids at room temperature. It reacts slowly at higher temperatures.

- Magnesium, calcium, strontium and barium react vigorously with acids to form the corresponding ion and hydrogen gas.

- Group II metals should not be placed in dilute acids as explosions are likely.

- Reactivity with acids increases down the Group.

Example

❶ The equation for the reaction of barium with acid is as follows:

$Ba (s) + 2H^{+} (aq) \rightarrow Ba^{2+} (aq) + H_2 (g)$

Variations in the chemical properties of oxides of alkali earth metals

- All Group II oxides are colourless ionic solids.

- With the exception of beryllium oxide, which is amphoteric, the other oxides are basic oxides. They react with acids to give salts and water.

- Beryllium oxide is amphoteric as its bonding has some degree of covalency, contributing to its acidic nature. It reacts with both acids and bases.

- Group II oxides tend to be less soluble than Group I oxides due to the higher lattice energies.

- Going down the group, the solubility of the oxides increases as the lattice energy decreases.
  - Beryllium oxide is virtually insoluble.
  - Magnesium oxide is slightly soluble and forms an insoluble hydroxide.
  - The other oxides all dissolve rapidly to produce alkaline solutions.

    $XO (s) + H_2O (l) \rightarrow X^{2+} (g) + 2OH^{-} (aq)$
    where X is the metal atom

- The basic oxides react with acids to form *metallic salts* and *water*.

  $XO (s) + 2HCl (aq) \rightarrow XCl_2 (aq) + H_2O (l)$
  where X is the metal atom.

- Being amphoteric, beryllium oxide reacts with alkalis to form beryllates.

Examples

❶ The equation for the reaction of magnesium oxide with water is as follows:

$$MgO\ (s) + H_2O\ (l) \rightarrow Mg(OH)_2\ (aq)$$

❷ The equation for the reaction of calcium oxide with dilute hydrochloric acid is as follows:

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

❸ The equation for the reaction of beryllium oxide with sodium hydroxide is as follows:

$$BeO\ (s) + 2NaOH\ (aq) + H_2O\ (l) \rightarrow Na_2Be(OH)_4\ (aq)$$

Relative thermal stabilities of the alkali earth salts

- The thermal stability of the salts increases down the group.
    - This is due to the increasing cation size, which decreases the polarizing power of the cation.
    - The cations of the elements lower in the group distort the anion clouds to a smaller extent than the cations of the elements higher in the group.
    - Since anions which have highly distorted electron clouds are more readily decomposed by heat, the thermal stability increases down the group.

- Group II salts are less stable than the Group I salts as the polarizing effect of the Group II ions is greater, thus distorting the anion cloud to a greater extent.

- Group II nitrates decompose on heating to form the *corresponding oxides*, *nitrogen dioxide gas* and *oxygen gas*.

  $M(NO_3)_2\ (s) \rightarrow MO\ (s) + 2NO_2\ (g) + \frac{1}{2}O_2\ (g)$

- Group II carbonates decompose on heating to form the *corresponding oxides* and *carbon dioxide gas*.

  $MCO_3\ (s) \rightarrow MO\ (s) + CO_2\ (g)$

- Group II hydroxides decompose on heating to form the *corresponding oxides* and *water*.

  $M(OH)_2\ (s) \rightarrow MO\ (s) + H_2O\ (g)$

- The oxides are more stable than the nitrates, carbonates and hydroxides as they form stronger lattices, and the smaller oxide anion is less polarisable.

Comparison with Group I salts

- All Group I nitrates decompose on heating to produce the nitrite salt and oxygen gas. Lithium nitrate decomposes in a similar manner as the Group II nitrates due to the high charge density of the lithium ion.

- Only lithium carbonate decomposes on heating to produce lithium oxide and carbon dioxide. All other carbonates are quite stable to heat.

- Only lithium hydroxide decomposes on heating (650^{o}C) to produce lithium oxide and water. All other carbonates are quite stable to heat.

Relative solubility of the sulphates

- Beryllium and magnesium sulphates are soluble in water, and calcium sulphate is sparingly soluble. The other Group II sulphates are insoluble in water.

- The solubility of the Group II sulphates decreases down the Group.
  - Down the group, the cationic size increases, leading to less exothermic lattice and hydration energies.
  - Enthalpy change of solution = hydration energy + lattice energy
  - The hydration energy decreases more than the lattice energy, causing the enthalpy change of solution to become less exothermic.

- Barium sulphate can be swallowed as it is insoluble and only small traces can be found in the bloodstream.

- Barium carbonate is capable of reacting with stomach acid to form a soluble barium salt, and thus is more poisonous than barium sulphate.

Relative solubility of the hydroxides

- Solubility of the Group II hydroxides increases down the group.
  - Down the group, the cationic size increases, leading to less exothermic lattice and hydration energies. The hydroxide ion is much smaller than the sulphate ion.
  - The lattice energy decreases more than the hydration energy, causing the enthalpy change of solution to become more exothermic.

- Due to the presence of the hydroxide ions, solutions of hydroxides are alkaline.

- Barium hydroxide is more soluble in water as compared to magnesium and calcium hydroxide which are sparingly soluble in water.
- All Group I hydroxides are soluble in water producing strongly alkaline solutions.
- Group II hydroxides are less soluble than those of Group I.

Uses of some Group II compounds

- Calcium carbonate, calcium hydroxide and calcium oxide – fertilizer for correcting acidity (liming)
- Calcium sulphate – making plaster; constituent of concrete, cement and in road surfacing; blackboard chalk
- Calcium carbonate – building material; used in blast furnace in iron extraction
- Magnesium oxide – refractory lining material
- Anhydrous magnesium sulphate – anti-inflammatory agent; drying agent
- Magnesium sulphate – fertilizer; astringent; laxative
- Barium sulphate – swallowed as “barium metal” in X-ray diagnostic work
- Barium carbonate – rat poison

Worked Examples

Example 1

State and explain whether magnesium nitrate or barium nitrate is more susceptible to thermal decomposition.

Solution:

The thermal stability of the nitrates increases down the group. This is due to the increasing cation size, which decreases the polarizing power of the cation. The cations of the elements lower in the group distort the anion clouds to a smaller extent than the cations of the elements higher in the group. Since anions which have highly distorted electron clouds are more readily decomposed by heat, the thermal stability increases down the group.

Thus magnesium nitrate is more susceptible to thermal decomposition. (ans)

☺ *Group II nitrates decompose on heating to form the corresponding oxides, nitrogen dioxide gas and oxygen gas.*

Example 2

Calcium is in Group II of the Periodic Table.

(a) Write a balanced equation to show the action of heat on calcium nitrate.

(b) Compare the thermal stability of calcium nitrate with barium nitrate.

Solution:

(a) $2Ca(NO_3)_2\ (s) \rightarrow 2CaO\ (s) + 4NO_2\ (g) + O_2\ (g)$ (ans)

(b) Calcium nitrate is expected to have a lower thermal stability than barium nitrate. It has a smaller cation than barium, which increases the polarizing action of the cation and the anion is distorted to a greater extent than in barium nitrate. Since anions which have highly distorted electron clouds are more readily decomposed by heat, calcium nitrate is more susceptible to heat. (ans)

Example 3

(a) Explain why magnesium nitride is formed in addition to magnesium oxide when magnesium is burned in air.

(b) Magnesium nitride contains about 73% of magnesium by mass. Calculate the empirical formula of magnesium nitride.

(c) Write a balanced equation to show what happens when water is added to magnesium nitride.

Solution:

(a) Magnesium is very reactive. Thus nitrogen is also reduced by magnesium to form magnesium nitride at high temperatures, especially when the oxygen has been used up. This only occurs at high temperatures as the triple bond between the nitrogen atoms requires a large amount of energy for the reaction to occur. (ans)

(b) Assuming there is 100 g of magnesium nitride,

	Mg	**N**
Mass/g	73	27
Molar mass/ $g\ mol^{-1}$	24.3	14
Amount/mol	3.00	1.93
Simplest ratio	3	2

Thus the empirical formula is Mg_3N_2. (ans)

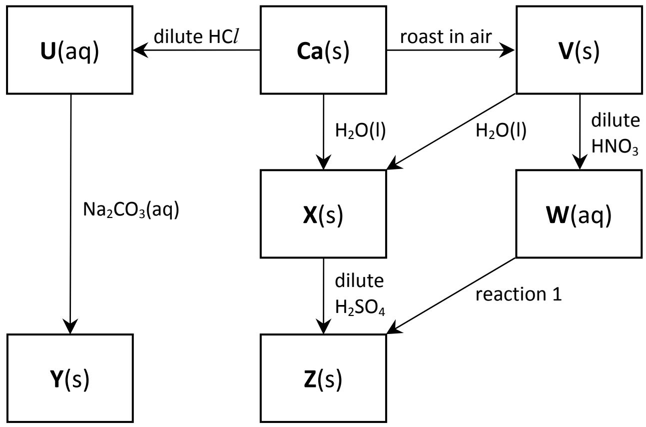
(c) $Mg_3N_2\ (s) + 6H_2O\ (l) \rightarrow 2Mg(OH)_2\ (s) + 2NH_3\ (g)$ (ans)

Worked Problems

Example 1

Calcium is the fifth most common element in the Earth's crust. Calcium compounds occur in bones and teeth and also in many minerals.

Some reactions of calcium and its compounds are shown in the reaction scheme below.



(a) State the formula of each of the calcium compounds U to Y. [5]

(b) Compound Y may be converted into compound V.

Outline how this reaction would be carried out in a school or college laboratory using a small sample of Y. [1]

(c) (i) Construct balanced equations for the following reactions.

calcium to compound U

compound V to compound W

compound U to compound Y

(ii) Construct a balanced equation for the effect of heat on solid compound W.

[4]

(d) Suggest the formula of an aqueous reagent, other than an acid, for reaction 1. [1]

(e) What would be observed when each of the following reactions is carried out in a test tube?

the formation of X from Ca(s)

the formation of X from V

[2]

[Total: 13]

Solution:

(a) U $CaCl_2$

V CaO

W $Ca(NO_3)_2$

X $Ca(OH)_2$

Y $CaCO_3$

(b) heat strongly in a test-tube or a boiling tube do not allow 'heat gently' or 'reflux'.

(c) (i) Ca to U

$Ca + 2HCl \rightarrow CaCl_2 + H_2$

V to W

$CaO + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$

U to Y

$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$

(ii) $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$

(d) $Na_2SO_4(aq)$

(e) (i) Ca to X

colourless gas formed

(ii) vigorous reaction

☺ **Mark Scheme**

(a)

U	$CaCl_2$	(1)	
V	CaO	(1)	
W	$Ca(NO_3)_2$	(1)	
X	$Ca(OH)_2$	(1)	
Y	$CaCO_3$	(1)	[5]

(b) heat strongly in a test-tube or a boiling tube
do not allow 'heat gently' or 'reflux' (1) [1]

(c) (i) Ca to U

$Ca + 2HCl \rightarrow CaCl_2 + H_2$ (1)

V to W

$CaO + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$ (1)

U to Y

$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$ (1)

(ii) $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$ (1) [4]

(d) $Na_2SO_4(aq)/K_2SO_4(aq)$ or formula of any soluble sulfate (1) [1]

(e) (i) Ca to X
colourless gas formed/fizzing/effervescence/bubbles or
Ca dissolves or
white precipitate/suspension formed (1)

(ii) strongly exothermic/vigorous reaction or
steam formed/steamy fumes or
surface crumbles (1)
do not allow white ppt. [2]

[Total: 13]

☺ **Exam Report**

This question tested candidates' knowledge of the reactions of calcium and its compounds. There were many good answers but a significant number of candidates did not check their work carefully and gave answers with incorrect formulae and/or unbalanced equations.

(a) This was well answered with many candidates being awarded full credit for this part. However, other candidates gave answers in which the oxidation number of calcium varied from compound to compound and were penalised.

(b) Candidates were expected to state that Y needed heating which some candidates confused with burning or combustion.

(c) (i) These reactions were usually well known with only occasional slips in balancing the equations.

(ii) The products of the thermal decomposition of calcium nitrate were less well known, oxygen often being omitted, or calcium a product.

(d) The formula of a soluble sulphate was needed. Barium sulphate was a common wrong answer while many answers contained an anion other than sulphate.

(e) Most candidates knew that in forming X, calcium dissolves with effervescence, leaving a white precipitate.

However, answers suggested that candidates had little experience of the second reaction – the formation of X from V – as an observation from the previous answer was often simply repeated.

The vigorous and exothermic nature of the reaction was rarely stated.