Chem Factsheet

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How To Answer Questions On Alkaline Earth Metals (Group 2) And Their Compounds

This Chem Factsheet gives guidance on answering questions on Group 2 chemistry. The answers that are provided are "best" answers. However, in some cases other answers will gain equal / partial credit. Common mistakes are also sometimes indicated so they can be avoided. However this Factsheet is no substitute for sufficient effort being put in to remember and understand Group 2 chemistry but it should be a big help.

Symbol / outer electrons / ions	Mg / $3s^2$ / Mg^{2+}	Ca / $4s^2$ / Ca^{2+}	Sr / $5s^2$ / Sr^{2+}	Ba / $6s^2$ / Ca^{2+}
Structure and bonding of metal	Giant metallic crystal structures with metallic bonding. 2+ cations and 2 delocalised electrons per atom			

Trends in Physical Properties that Occur on Moving Down Group 2

Atomic radius / Ionic radius	**Increases**. Since atoms of successive elements have an extra electron shell / energy level that is further from the nucleus.
First ionisation energy.	**Decrease**. The outer s electrons of atoms of successive elements are further from the nucleus, each with an extra shell of shielding electrons. These two factors outweigh the increase in nuclear charge. Hence, the nuclear attraction for the outer s electrons decreases meaning less energy is needed to remove one.
$M(g) \rightarrow M^+(g) + e^-$ Reactivity	Since ionisation energy decreases, cations become easier to form on moving down the group and hence reactivity increases.
Melting point	**Decrease**. The ionic radii increase and the charge on the cation is always 2+. Hence, the charge densities of the metal ions decrease causing the electrostatic attraction between outer delocalised s electrons and the metal ions to decrease. (Mg has a unusually low because it has a different crystalline structure.)

Trends in Chemical Properties that Occur on Moving down Group 2

Note. When Group 2 elements (Mg- Ba) react with non-metallic elements redox reactions occur and the products are all white crystaline, ionic solids. If the products are soluble in water colourless solutions are formed containing hydrated ions.

e.g. $Ba(s) + \frac{1}{2}O_2(g) \rightarrow BaO(s)$ – white.

$Sr(s) + Cl_2(g) \rightarrow SrCl_2(s)$ – white.

$SrCl_2(s) + (aq) \rightarrow Sr^{2+}(aq) + 2Cl^-(aq)$

Reactions with Cold Water

Reactivity increases. Alkaline solutions are produced of increasing pH.

Calcium reacts rapidly producing bubbles of a colourless gas (hydrogen) and a white suspension (the metal hydroxide).

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

Sr and Ba react in a similar manner but progressively faster and producing progressively less white suspension as the hydroxide solubility increases; in fact Ba produces a colourless solution.

$$Ba(s) + 2H_2O(l) \rightarrow Ba^{2+}(aq) + 2OH^-(aq) + H_2(g)$$

Mg has only the very slightest reaction with cold water. A rapid reaction is achieved by passing steam over strongly heated magnesium. The magnesium burns with a bright white light producing a white solid (the oxide).

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

These are redox reactions. The atoms lose their two outer s electrons in becoming dipositive ions.

$$M - 2e^- \rightarrow M^{2+} \text{ where } M = Mg, Ca, Sr \text{ or } Ba$$

(Loss of electrons / Increase in oxidation number, 0 to +2, is oxidation.)
The electrons are gained by the water / steam.

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \quad / \quad H_2O + 2e^- \rightarrow O^{2-} + H_2$$

(Gain of electrons / decrease in oxidation number is reduction – the value for hydrogen goes from +1 (in H_2O) to 0 (in H_2).

Relative Solubilities of Group 2 Hydroxides [$M(OH)_2$]

Increase. $Mg(OH)_2$ is sparingly soluble. $Mg(OH)_2(s) + (aq) \rightarrow Mg^{2+}(aq) + 2OH^-(aq)$. pH ≈ 9.

On shaking solid $Mg(OH)_2$ with water a white suspension forms but a little dissolves giving a low concentration of $OH^-(aq)$. (Note. All that does dissolves exists as separate ions in water.) Solution pH's increase with increasing hydroxide solubility:

$Ca(OH)_2(aq)$ pH ≈ 12, $Sr(OH)_2(aq)$ pH ≈ 13 and $Ba(OH)_2(aq)$ pH ≈ 14.

Note The oxides become more soluble on moving down the group as more of the oxide reacts with water forming a greater concentration of dissolved hydroxide.

$$\text{e.g. } SrO(s) + H_2O(l) \rightarrow Sr^{2+}(aq) + 2OH^-(aq)$$

Relative Solubilities of Group 2 Sulfates [MSO_4]. Decrease. $BaSO_4$ is insoluble.

Solubilities of Group 2 Carbonates [MCO_3]. Group 2 carbonates are **all insoluble** in water.

Test for Soluble Sulfates

Add dilute hydrochloric acid and look for fizzing. If fizzing occurs the substance is a soluble carbonate, e.g. Na_2CO_3. Add enough acid to remove all the carbonate ions. Now add barium chloride solution. A dense white precipitate shows sulfate ions are present in the solution. If sulfate ions are absent the solution remains colourless.

$$\text{Ionic equation: } Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s).$$

(If no precipitate forms there is no equation as no reaction has occurred.)

Thermal Stabilities of Group 2 Carbonates and Nitrates

Increase. The ease of decomposition of group 2 carbonates [MCO_3] and nitrates [$M(NO_3)_2$] decreases down group 2 because, since the metal ion radius is increasing with a fixed 2+ charge, the charge density of the M^{2+} ion is decreasing. This means that its tendency to polarise and weaken the bonds in the anion (Co_3^{2-} or NO_3^-) decreases resulting in greater thermal stability of the anion.

The general decompositions are given by $MCO_3 \rightarrow MO + CO_2$ and $2M(NO_3)_2 \rightarrow 2MO + 4NO_2 + O_2$

although the most stable nitrate, [$Ba(NO_3)_2$], tends to decompose only as far as the nitrite [nitrate(IV)].

$$Ba(NO_3)_2 \rightarrow Ba(NO_2)_2 + O_2$$

Uses of Some Group 2 Compounds

(i) $Mg(OH)_2$ is used in medicines e.g. in some indigestion tablets to neutralise stomach acid.

(ii) $Ca(OH)_2$ is used in agriculture to neutralise acid soils.

(In both case the ionic equation is $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$)

(iii) $BaSO_4$ is used in medicine when it is taken as a "barium meal" before taking an X-ray of the gut.
(Barium sulphate is opaque to X-rays. Soluble barium compounds are poisonous but barium sulphate is very insoluble so the patient is safe.)

Some General Points

(a) There is no need to write out the question as part of any answer.

(b) Since chemical formulas and equations are often required, know the formulas of the ions and how to work out the formula of an ionic compound.
e.g. Mg^{2+} and OH^- $\therefore Mg(OH)_2$; Na^+ and SO_4^{2-} $\therefore Na_2SO_4$; Ca^{2+} and NO_3^- $\therefore Ca(NO_3)_2$.

(c) Don't give explanations if they are not asked for.

(d) When a white precipitate is the required observation, white suspension / white solid are both acceptable alternatives but not "white solution", "cloudy precipitate", "milky precipitate", "white" or "precipitate".

(e) When fizzing / effervescence / bubbles is the required observation, identifying the gas (e.g. "carbon dioxide / CO_2 evolved" is not acceptable

(f) If an observation is required and no reaction occurs don't answer "nothing", "none", "no observation", "soluble", "dissolves", "precipitate dissolves" - a precipitate never formed so it cannot dissolve! "No visible change" is the best response.

(g) If no reaction occurs there is no equation.
e.g. $2NaNO_3(aq) + BaCl_2(aq) \rightarrow 2NaCl(aq) + Ba(NO_3)_2(aq)$.
This is not a chemical reaction because no new substances have been made. The LHS and RHS is a solution containing four hydrated ions.

(h) Always use words not formulae when you have a choice as there is less chance of error.
e.g. Identify a sparingly soluble Group 2 hydroxide: Ans. Magnesium hydroxide / $Mg(OH)_2$ would be acceptable but not MgOH, MgOH2, $Mg(OH)_2^-$, Mg^{2+} or Mg.

(i) Do not give two answers to a question requiring one answer. If either answer is wrong then no mark is gained.

Practice Questions

1. Aqueous solutions of potassium sulfate and potassium nitrate are both colourless. Describe a chemical test you could perform to distinguish them. State the observation you would make with each solution. Write an equation for any reaction which occurs.(4 marks)

2. (a) Give the formula of the most soluble hydroxide of the Group II elements Mg to Ba. (1 mark.)

   (b) Aqueous solutions of sodium chloride and sodium sulfate may be distinguished from each other using a chemical test.

   (i) Identify a reagent for this test.

   (ii) State the observations you would expect to make if the reagent identified in part (b)(i) is added to a separate sample of each solution. Write an ionic equation with state symbols for any reaction which occurs.(4 marks)

3. (a) The first three ionisation energies of magnesium are in $kJmol^{-1}$ are 738, 1451, 7733 respectively.

   (i) Write an equation to show the process occurring when the first ionisation energy of magnesium is measured.

   (ii) Explain why the second ionisation energy of Mg is very much smaller than the third ionisation energy of Mg.

   (iii) State and explain the trend in the first ionisation energy of the elements Mg to Ba in Group II.(7 marks)

   (b) What is the trend in the reactivity of the Group II metals with H_2O. State the conditions needed for Mg and Ca to react rapidly with H_2O. Write an equation for each of these reactions. (4 marks)

4. A solution contains both sodium carbonate and sodium sulfate. To this solution an excess of dilute hydrochloric acid was first of all added and next an aqueous solution of barium chloride. State all observations, identify the product for each observation and write equations for both reactions that occur. (6 marks)

5. Give the formula of the least soluble sulfate and the most soluble hydroxide of the elements Mg to Ba. (2 marks)

6. Dilute sodium hydroxide solution was added to separate dilute aqueous solutions of magnesium chloride and barium chloride. Describe what you would observe in each case and account for your observations. (4 marks)

7. (a) State the trend in atomic radius down Group II from Be to Ba and give a reason for this trend.(2 marks)

   (b) State and explain the trend in melting points of the elements down Group II from Mg to Ba. (3 marks)

   (c) State the trend in reactivity with water of the elements down Group II from Mg to Ba. Write an equation for the reaction of magnesium with steam and an equation for the reaction of strontium with water. (3 marks)

   (d) Sulphates of the Group II elements from Mg to Ba have different solubilities. Give the formula of the least soluble of these sulphates and state **one** use that depends upon the insolubility of this sulphate. (2 marks)

8. 0.486 g of pure magnesium is reacted with steam. What volume of 0.100 mol dm^{-3} sulfuric acid would just dissolve the solid product?
   What is the maximum mass of barium sulfate that could be produced on addition of excess barium chloride solution to the solution produced after adding the sulfuric acid. (All calculation should be answered to the appropriate numbers of significant figures.) (5 marks)

9. (a) What is the concentration of 50 cm^3 of stomach acid (HCl(aq)) neutralised by a tea spoon (5 cm^3) of saturated solution of magnesium hydroxide with a solubility of 120 mg dm^{-3}?

   (b) Suggest a why a saturated solution of calcium hydroxide is not used to neutralise stomach acid.

   (c) Give a use of calcium hydroxide. (7 marks)

10. State and explain what would be seen when an aqueous solution of magnesium sulphate is added to an aqueous solution of barium hydroxide. Write ionic equations with state symbols for any reactions that have occurred. (7 marks)

11. A small sample of barium metal was added to water in a beaker. When the reaction had finished dilute sulfuric acid was added to the contents of the beaker. Describe all that you would observe and write equations, with state symbols, for the reactions that occur. (7 marks)

12. This question concerns the chemistry of the Group II metals Mg to Ba. An aqueous solution of a Group II metal chloride, XCl_2, forms a white precipitate when dilute aqueous sodium hydroxide is added. A separate sample of the solution of XCl_2 does not form a precipitate when dilute aqueous sodium sulfate is added. An aqueous solution of a different Group II metal chloride, YCl_2, does not form a precipitate when dilute aqueous sodium hydroxide is added. A separate sample of the solution of YCl_2 forms a dense white precipitate when dilute aqueous sodium sulfate is added.
    Suggest identities for the Group II metals X and Y. Write equations, including state symbols, for the reactions which occur. (6 marks)

13. Which nitrate, magnesium or strontium, is more thermally stable? Explain your answer. (3 marks)

Answers

1. Add barium chloride ✓solution to separate samples of both solutions.
   The potassium sulfate solution produces a white precipitate. ✓
   The potassium nitrate solution produces no change or remains colourless or no precipitate forms or no reaction). (See f) ✓
   Equation: $BaCl_2 + K_2SO_4 \rightarrow BaSO_4 + 2KCl$
   or $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ ✓

2. (a) $Mg(OH)_2$✓
   (b) (i) Barium chloride sol'n. ✓. (Ba^{2+} is not a reagent.)
   (ii) NaCl: No change. ✓ (See f) Na_2SO_4: White ppte. ✓ (See d)
   $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ ✓
   Alternative ans:
   (b) (i) $AgNO_3(aq)$.
   (ii) NaCl: White precipitate. ✓ $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$ ✓.
   Na_2SO_4: No change. ✓

3. (a) (i) $Mg(g) \rightarrow Mg^+(g) + e^-$ ✓, ✓ for both (see g).
   (ii) The 3s electron (removed during 2nd I.E.) is further from the nucleus ✓and shielded by two full shells whereas the 2p electron (3rd I.E.) is only shielded by the two 1s electrons. ✓. Hence there is much less attraction from the protons in the nucleus. [Also, for the 2nd I.E., the electron is removed from an ion of lower charge (+1) and this is easier than removing it from a 2+ ion (as for 3rd I.E.). for one mark]
   (iii) Decreases ✓ as the outer electron gets further from ✓and more shielded ✓from the attracting nucleus (even though the nucleus has more protons).
   (b) Trend: Reactivity increases from Mg to Ba. ✓.
   Conditions for Mg: Steam and a high temperature. ✓.
   $Mg + H_2O \rightarrow MgO + H_2$ ✓.
   Conditions for Ca: Water at room temp. ✓. (Not "standard conditions" or "liquid" – too vague.)
   $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$ ✓

4. + HCl(aq) - Obs: Fizzing . ✓ (See e).
   Product - carbon dioxide / CO_2. ✓
   $Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$/ $CO_3^{2-} + 2H^+ \rightarrow H_2O + CO_2$ ✓
   + $BaCl_2(aq)$ – Obs: Dense white precipitate. ✓ (See d)

   Product: Barium sulfate. ✓
   Equation: $BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaCl$ / $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$ ✓

5. Least soluble sulphate is $BaSO_4$. ✓
   Most soluble hydroxide is $Ba(OH)_2$. ✓

6. $MgCl_2$ - a white precipitate ✓ of magnesium hydroxide forms because it is insoluble (in water.) ✓
   $BaCl_2$. No visible reaction ✓ because barium hydroxide is soluble (in water.) ✓.

7. (a) Increases. ✓ Since atoms of successive elements have an extra electron shell / energy level that is further from the nucleus. ✓
   (b) Decrease. ✓ The ionic radii increase and the charge on the cation is always 2+. Hence, the charge densities of the metal ions decrease ✓ causing the electrostatic attraction between outer delocalised s electrons and the metal ions to decrease / causing the metallic bonding to become weaker. ✓
   (c) Reactivity: Increase from Mg to Ba. ✓.
   $Mg + H_2O \rightarrow MgO + H_2$ ✓. $Sr + 2H_2O \rightarrow Sr(OH)_2 + H_2$ ✓
   (d) $BaSO_4$ ✓. $BaSO_4$ is used in medicine when it is taken as a "barium meal" before taking an X-ray of the gut. ✓

8. $Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$.
   $MgO(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O(l)$
   $MgSO_4(aq) + BaCl_2(aq) \rightarrow BaSO_4(s) + MgCl_2(aq)$.

   Moles Mg = 0.486/24.3 ✓ = 2.00×10^{-3} mol.
   = Moles MgO = Moles H_2SO_4
   ∴ Volume H_2SO_4 = 1000 × moles / concentration
   = $1000 \times 2.00 \times 10^{-3} / 0.100$ ✓ = 20.0 cm^3.
   Moles $BaCl_2$ needed = 2.00×10^{-3} mol. = Moles $BaSO_4$ produced. ✓
   ∴ Mass $BaSO_4$ produced = $2.00\times10^{-3} \times 233.4 = 0.467$ g. ✓
   All calc. to 3 s.f. ✓

9. (a) $Mg(OH)_2 + 2HCl \rightarrow MgCl_2(aq) + 2H_2O$ ✓.
   Moles $Mg(OH)_2$ in 120 mg = $120\times10^{-3} / 58.3 = 2.058\times10^{-3}$ mol. ✓
   ∴ Moles $Mg(OH)_2$ in 5 cm^3 = $2.0583\times10^{-3} \times 5 / 1000$ ✓
   = 1.029×10^{-5}
   ∴ Moles HCl needed = $2 \times 1.029\times10^{-5}$ ✓ = 2.058×10^{-5}
   ∴ Conc. HCl = $2.058\times10^{-5} \times 1000 / 50$ ✓ = 4.12×10^{-4} mol dm^{-3}
   (b) $Ca(OH)_2$ is too corrosive / too alkaline. ✓.
   (c) Neutralising acid soils. ✓

10. White precipitate. ✓. This is a mixture of magnesium hydroxide and barium sulphate as they are both insoluble in water. ✓✓.
    $Mg^{2+}(aq) + 2OH^-(aq) \rightarrow Mg(OH)_2(s)$ ✓ ✓.
    $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ ✓✓.

11. The barium and water produce bubbles ✓. The Ba dissolves / forms a (colourless) solution. ✓.
    $Ba(s) + 2H_2O(l) \rightarrow Ba^{2+}(aq) + 2OH^-(aq) + H_2(g)$. ✓✓.
    Addition of $BaCl_2(aq)$ produces a dense white precipitate. ✓.
    $BaCl_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(aq) + 2HCl(aq)$
    / $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(aq)$ ✓✓.

12. X is Mg ✓; Y is Ba. ✓
    $MgCl_2(aq) + 2NaOH(aq) \rightarrow 2NaCl(aq) + Mg(OH)_2(s)$
    / $Mg^{2+}(aq) + 2OH^-(aq) \rightarrow Mg(OH)_{2(s)}$ ✓ ✓.
    $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(aq) + 2NaCl(aq)$
    / $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(aq)$ ✓✓
    (Note. The question asks for two identities and two equations with state symbols – no need to provide explanations.)

13. Strontium nitrate [$Sr(NO_3)_2$] is more stable ✓ because the Sr^{2+} ion is larger ✓ than the Mg^{2+} ion causing it to be less charge dense. Hence, it causes less polarisation ✓ of the covalent bonds in the nitrate ions. This means the bonds in the nitrate ions require more energy to break them.

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