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Level: CIE AS and A Level (9701)
Subject: Chemistry
Topic: CIE Chemistry
Type: Mark Scheme

Chemistry CIE AS & A Level
To be used for all exam preparation for 2025+

CHEMISTRY AS and A

This to be used by all students studying CIE AS and A level Chemistry (9701) But students of other boards may find it useful

Mark Scheme

Answer 1.

a)

i) A Group 2 element that burns in air to give a white flame is:

- Beryllium / Be
  OR
  Magnesium / Mg; [1 mark]

ii) The balanced chemical equation for the reaction of the Group 2 element in air is:

$2Be + O_2 \rightarrow 2BeO$
OR
$2Mg + O_2 \rightarrow 2MgO$

- Correct chemical formulae; [1 mark]
- Correct balancing; [1 mark]

[Total: 3 marks]

- Beryllium and magnesium both burn in air with a white flame
  - Magnesium is well known
  - Beryllium is less well known
    - It can be ignited but it is difficult to actually burn
- The reaction in air is combustion
  - The equation given must match the element stated as an answer in part (i)
  - Magnesium + oxygen → magnesium oxide
    - $Mg + O_2 \rightarrow MgO$
  - There are two oxygen atoms on the left-hand side so you need 2MgO
    - $Mg + O_2 \rightarrow \mathbf{2}MgO$
  - There are now two magnesium atoms on the right-hand side so you need 2Mg
    - $\mathbf{2}Mg + O_2 \rightarrow \mathbf{2}MgO$
  - The same process can be applied to balancing the equation for the combustion of beryllium
    - $Be + O_2 \rightarrow BeO$
    - $Be + O_2 \rightarrow \mathbf{2}BeO$
    - $\mathbf{2}Be + O_2 \rightarrow \mathbf{2}BeO$

b)

i) The reagent and condition required for magnesium to react with water are:

- Reagent = water; [1 mark]
- Condition = the water must be cold; [1 mark]

ii) The equation for the reaction is:

- $Mg\ (s) + 2H_2O\ (l) \rightarrow Mg(OH)_2\ (s) + H_2\ (g)$; [1 mark]

[Total: 3 marks]

- The reaction of very clean magnesium with cold water is very slow
- After some time, some bubbles of hydrogen form on its surface
  - This typically results in the magnesium floating to the surface
- However, the reaction soon stops because the magnesium hydroxide product is almost insoluble in water
  - It forms a barrier on the magnesium preventing further reaction, similar to the formation of aluminium oxide

c)

i) **One** expected observation for the reaction of calcium with hydrochloric acid is:

- Fizzing / bubbling / effervescence
  OR
  Smoke forms; [1 mark]

ii) The balanced chemical equation for the reaction of calcium with hydrochloric acid is:

$Ca\ (s) + 2HCl\ (aq) \rightarrow CaCl_2\ (aq) + H_2\ (g)$

- Correct chemical formulae; [1 mark]
- Correct balancing
  AND
  All state symbols correct; [1 mark]

[Total: 3 marks]

- The reaction of calcium with hydrochloric acid is similar to the reaction of magnesium with hydrochloric acid
  - Apart from the obvious change in reactant and product, the only noticeable difference is how vigorous the reaction is
- **Remember:** Metal + acid → salt + hydrogen
  - Calcium + hydrochloric acid → calcium chloride + hydrogen
- The unbalanced symbol equation is:
  - $Ca + HCl \rightarrow CaCl_2 + H_2$
- There are two chlorine atoms and two hydrogen atoms on the right-hand side, which means that you need 2HCl
  - $Ca + \mathbf{2}HCl \rightarrow CaCl_2 + H_2$
- You should know that calcium is solid / (s), hydrochloric acid is aqueous / (aq) and hydrogen is gaseous / (g)
- Calcium chloride is soluble, which means that it is aqueous / (aq)
  - $Ca\ (s) + \mathbf{2}HCl\ (aq) \rightarrow CaCl_2\ (aq) + H_2\ (g)$

d) To compare the reactions of barium with hydrochloric acid and sulfuric acid:

Barium and hydrochloric acid equation:

- $Ba\,(s) + 2HCl\,(aq) \rightarrow BaCl_2\,(aq) + H_2\,(g)$; [1 mark]

Barium and sulfuric acid equation:

- $Ba\,(s) + H_2SO_4\,(aq) \rightarrow BaSO_4\,(s) + H_2\,(g)$; [1 mark]

Comparison:

- Both reactions form hydrogen gas / $H_2\,(g)$; [1 mark]
- The reaction with hydrochloric acid / HCl requires 2 moles of hydrochloric acid / HCl (compared to one mole of sulfuric acid / H_2SO_4); [1 mark]
- The reaction with hydrochloric acid forms an aqueous solution
  AND
  The reaction with sulfuric acid forms a solid / precipitate; [1 mark]

[Total: 5 marks]

- **Remember:** Hydrochloric acid forms chloride salts and sulfuric acid forms sulfate salts
- Both reactions follow the same general equation:
  - Metal + acid → salt + hydrogen
  - The key similarity is the production of hydrogen gas
- **Tip:** When you are asked to compare and you are talking about the differences of both things that you are comparing
  - Don't just talk about one and assume the examiner knows the other half, the examiner wants to see that you know it too
  - The differences are with the amount of acid used and the physical state of the product

Answer 2.

a) The general trends in solubility and pH of the Group 2 hydroxides as you move down Group 2 are:

- The solubility increases
  OR
  The (Group 2) hydroxides become more soluble; [1 mark]
- The pH increases
  OR
  The solutions become more alkaline; [1 mark]

[Total: 2 marks]

- You should know that magnesium hydroxide is insoluble / sparingly soluble in water and barium hydroxide is soluble in water
- Therefore, the solubility increases as you move down Group 2
- This means that there are more hydroxide ions / OH^- in the solution as you move down the group
- As a result of this, the pH increases
  - **Careful:** Students often get mixed up when talking about pH
    - When the pH decreases, the acidity increases i.e. it becomes more acidic / less alkaline
    - When the pH increases, the acidity decreases i.e. it becomes more alkaline / less acidic

b)

i) The balanced chemical equation for the reaction of calcium hydroxide with hydrochloric acid is:

$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$

- Correct chemical formulae; [1 mark]
- Correct balancing; [1 mark]

ii) To calculate the mass of calcium chloride produced in this reaction:

- Formula mass of $Ca(OH)_2$ = 74.1
  AND
  Moles of $Ca(OH)_2$ = 0.05; [1 mark]
- Formula mass of $CaCl_2$ = 111.1
  AND
  Mass of $CaCl_2$ produced = 5.56 (g); [1 mark]

[Total: 4 marks]

- **Remember:** Metal hydroxide + acid → metal salt + water
  - Hydrochloric acid makes chloride salts
  - Calcium hydroxide + hydrochloric acid → calcium chloride + water
    - $Ca(OH)_2 + HCl \rightarrow CaCl_2 + H_2O$
  - There are two chlorine atoms on the right-hand side, so you need 2HCl
    - $Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + H_2O$
  - This has also balanced the entire equation
- To calculate the mass of calcium chloride produced, you need to:
  - Calculate the relative formula masses of calcium hydroxide and calcium chloride
    - $Ca(OH)_2 = 40.1 + ((16.0 + 1.0) \times 2) = 74.1$
    - $CaCl_2 = 40.1 + (35.5 \times 2) = 111.1$
  - The moles of $Ca(OH)_2 = \frac{mass}{M_r} = \frac{3.71}{74.1} = 0.05$
  - One mole of $Ca(OH)_2$ forms one mole of $CaCl_2$
  - Therefore, there are also 0.05 moles of $CaCl_2$
  - Mass of $CaCl_2$ = moles x M_r = 0.05 x 111.1 = 5.56 g

c)

i) You could prove that the gas produced is carbon dioxide by:

- Bubbling / passing the gas through limewater; [1 mark]
- Which turns cloudy / milky
  OR
  Which forms a white precipitate; [1 mark]

ii) The reaction stops even though the reactants have not been used up because:

- Insoluble strontium sulfate is formed; [1 mark]
- Which coats the strontium carbonate (stopping the reaction); [1 mark]

[Total: 4 marks]

- You should know the test for carbon dioxide from your previous studies
  - Any A-level course can ask questions from your prior learning in Chemistry
- The reactions of calcium carbonate, strontium carbonate and barium carbonate with sulfuric acid all form precipitates of their respective sulfates
  - These sulfates can then coat the carbonate
  - This means that the sulfate is acting as a physical barrier between the carbonate and the acid, resulting in the reaction appearing to stop even though it is not complete

Answer 3.

a) The type of reaction that occurs when strontium carbonate is heated to form strontium oxide and carbon dioxide is:

- Thermal decomposition; [1 mark]

[Total: 1 mark]

- The question tells you that the reaction is heated
  - Therefore, it is a 'thermal' reaction
- The question and equation show that the calcium carbonate is being broken down
  - Therefore, it is a 'decomposition' reaction
- Both thermal **AND** decomposition are required for the mark

b) The completed chemical equation is:

$2Sr(NO_3)_2$ (s) → $2SrO$ (s) + $4NO_2$ (g) + O_2 (g)

- Correct chemical formulae
  AND
  Correct state symbols; [1 mark]
- Correct balancing; [1 mark]

[Total: 2 marks]

- The strontium ion has a 2+ and the oxide ion has a 2– charge
  - Therefore, the formula for strontium oxide is SrO
  - Strontium oxide is a solid
- You should know that nitrogen dioxide is NO_2 and oxygen is O_2
  - Nitrogen dioxide and oxygen are both gases
- Adding this information to the equation gives the following unbalanced equation
  - $2Sr(NO_3)_2$ (s) → SrO (s) + NO_2 (g) + O_2 (g)
- There are two strontium atoms on the left-hand side, so we need to produce 2SrO
  - $2Sr(NO_3)_2$ (s) → **2**SrO (s) + NO_2 (g) + O_2 (g)
- There are four nitrogen atoms on the left-hand side, so we need to produce $4NO_2$
  - $2Sr(NO_3)_2$ (s) → **2**SrO (s) + **4**NO_2 (g) + O_2 (g)
- The equation is now balanced

c) To calculate the percentage yield of magnesium oxide:

- Formula mass of $MgCO_3$ = 84.3
  AND
  Moles of $MgCO_3$ = 0.059; [1 mark]
- Formula mass of MgO = 40.3
  AND
  Theoretical mass of MgO = 2.39 (g); [1 mark]
- Percentage yield = 73.2%; [1 mark]

[Total: 3 marks]

- **Remember:** Percentage yield = $\frac{\text{actual yield}}{\text{theoretical yield}} \times 100$
- The actual yield of magnesium oxide is 1.75 g
- To calculate the theoretical yield of magnesium, you have to:
  - Calculate the relative formula mass of magnesium carbonate
    - $MgCO_3 = 24.3 + 12.0 + (16.0 \times 3) = 84.3$
  - Calculate the moles of magnesium carbonate
    - Moles $= \frac{\text{mass}}{M_r} = \frac{5.00}{84.3} = 0.059$
  - One mole of magnesium carbonate forms one mole of magnesium oxide
    - This means that 0.059 moles of magnesium oxide are formed
  - Calculate the formula mass of magnesium oxide
    - MgO = 24.3 + 16.0 = 40.3
  - Calculate the theoretical mass of magnesium oxide
    - Mass = moles x M_r = 0.059 x 40.3 = 2.39 g
  - Calculate the percentage yield
    - Percentage yield = $= \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{1.75}{2.39} \times 100 = 73.2\%$

d) The trend in the thermal stability of the Group 2 carbonates and nitrates as you move down Group 2 is:

- The thermal stability increases (as you move down Group 2); [1 mark]

[Total: 1 mark]

- You should be able to describe and, also, explain this trend

Answer 4.

a) The general trends as you move down Group 2 are:

- Melting point = decreases; [1 mark]
- First ionisation energy = decreases; [1 mark]
- Atomic radius = increases; [1 mark]

[Total: 3 marks]

- You need to be able to describe and, also, explain the trends as you move down Group 2

b) The Group 2 element that does not follow the general trend in melting point is

- Magnesium / Mg; [1 mark]

[Total: 1 mark]

- You are not expected to know the reason for the deviation of magnesium

c) The chemical equations for the first ionisation energy of barium and the second ionisation energy of calcium are:

- $Ba\ (g) \rightarrow Ba^{+}\ (g) + e^{-}$; [1 mark]
- $Ca^{+}\ (g) \rightarrow Ca^{2+}\ (g) + e^{-}$; [1 mark]

[Total: 2 marks]

- **Remember:** First ionisation energy is the energy required to remove one mole of electrons from one mole of gaseous atoms
  - $X\ (g) \rightarrow X^{+}\ (g) + e^{-}$;
- **Remember:** Second ionisation energy is the energy required to remove one mole of electrons from one mole of gaseous 1+ ions
  - $X^{+}\ (g) \rightarrow X^{2+}\ (g) + e^{-}$

d) The points to explain the trend in first ionisation energies down Group 2 are:

- Distance between the nucleus and outer electron = increase; [1 mark]
- Shielding = increase; [1 mark]
- Nuclear attraction = decrease; [1 mark]

[Total: 3 marks]

- The distance between the nucleus and outer electron and the amount of shielding are two points that you should comment on for this type of question
- You can then link these two points to the overall force of nuclear attraction to give your final answer
- When asked to explain the trend in ionisation energy, you should always refer to these three factors
  - State the trend and then talk about the distance between the nucleus and the outer e^- and the amount of shielding first, before linking these to nuclear attraction
  - For example:
    - The first ionisation energy decreases down Group 2
    - This is because the distance between the nucleus and outer electrons increases as well as the amount of shielding increasing which means that the overall force of nuclear attraction decreases, i.e. less energy is required to remove the outer electron

Answer 5.

a)

i) The balanced chemical equation for the reaction of barium carbonate and sulfuric acid is:

- $BaCO_3 + H_2SO_4 \rightarrow BaSO_4 + H_2O + CO_2$; [1 mark]

ii) This preparation of barium sulfate will not have a 100% yield because:

- Not all the barium carbonate reacts; [1 mark]
- (Because,) a layer of barium sulfate coats the barium carbonate / stops the barium carbonate reacting; [1 mark]

[Total: 3 marks]

- **Remember:** Metal carbonate + acid → Metal salt + water + carbon dioxide
  - Sulfuric acid forms sulfates
- Barium sulfate is the desired product
  - However, barium sulfate is insoluble and coats any remaining barium carbonate
  - This stops the barium carbonate from being able to fully react with the sulfuric acid

b)

i) The type of reaction that occurs in step 1 is

- Thermal decomposition; [1 mark]

ii) The chemical equation for the reaction in step 2 is:

- $BaO + H_2SO_4 \rightarrow BaSO_4 + H_2O$; [1 mark]

[Total: 2 marks]

- In step 1, barium carbonate is heated and breaks down to form barium oxide and carbon dioxide
  - $BaCO_3 \rightarrow BaO + CO_2$
  - Using heat to break a compound down is thermal decomposition
- **Remember:** Metal oxide + sulfuric acid → metal sulfate + water

c) The correct solubilities in water are:

- Barium hydroxide = soluble; [1 mark]
- Barium sulfate = insoluble; [1 mark]

[Total: 2 marks]

- You should know the trend in solubility of the Group 2 hydroxides and sulfates
  - The hydroxides become more soluble as you move down the group
  - The sulfates become less soluble as you move down the group
- Since barium is near the bottom of Group 2
  - Barium hydroxide will be soluble
  - Barium sulfate will be insoluble

d) The ionic equation for the reaction in step 3 between barium hydroxide and sulfuric acid to form barium sulfate is:

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

- Correct chemical formulae; [1 mark]
- Correct state symbols; [1 mark]

[Total: 2 marks]

- The reaction taking place in step 3 is:
  - $Ba(OH)_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(s) + H_2O(l)$
- **Remember:** Spectator ions are not included in ionic equations
  - This means that the following ions and chemicals should be removed
    - The hydroxide ions from barium hydroxide
    - The hydrogen ions from sulfuric acid
    - The water
- This leaves the correct ionic equation
  - $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

Answer 6.

a) The trend in the atomic radius of Group 2 elements from beryllium to strontium is:

- The atomic radius increases / atoms get bigger (as you descend Group 2); [1 mark]
- (Because) there are more shells / energy levels
  OR
  The number of shells / energy levels increases; [1 mark]

[Total: 2 marks]

- This is a Group 2 trend that you need to learn and be able to explain
- As you descend the group:
  - Each atom has the same effective nuclear charge of +2
  - Each atom gains an additional shell of electrons
  - This means that the force of attraction between the nucleus and the outermost electrons becomes weaker resulting in the atomic radius increasing

b) When magnesium burns in oxygen:

- $2Mg + O_2 \rightarrow 2MgO$; [1 mark]
- Magnesium burns with a bright white light; [1 mark]

[Total: 2 marks]

- Burning magnesium in oxygen is a common demonstration; you need to be able to state the observation which would be made
  - The bright white light is dangerous if looked at directly - it can cause temporary loss of sight
  - A blue screen / blue glass must be used
- The burning of magnesium also generates intense heat which can cause burns or could initiate combustion of any flammable materials which are too close

c)

i) Equations for the formation of calcium hydroxide and magnesium hydroxide from magnesium and calcium as elemental metals are:

- $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$; [1 mark]
- $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$; [1 mark]

ii) The pH values and uses of calcium hydroxide and magnesium hydroxide are:

- pH value of both hydroxides must be between 8 and 14
  AND
  The pH value of calcium hydroxide must be higher than the pH value stated for magnesium hydroxide; [1 mark]
- Magnesium hydroxide is used as a cure / remedy for indigestion
  OR
  Magnesium hydroxide is milk of magnesia; [1 mark]
- Calcium hydroxide is used in agriculture
  OR
  Calcium hydroxide is used to neutralise / raise the pH of acidic soil; [1 mark]

[Total: 5 marks]

- As well as the trends of Group 2, you need to know the reactions which the Group 2 elements undergo and the uses of the Group 2 compounds
- You should be able to provide approximate pH values for the hydroxides of Group 2

d) Comparing the reaction of calcium with water and barium with water:

Observations:

- The student would see effervescence / bubbles / fizzing in both boiling tubes
  OR
  The student would see effervescence / bubbles / fizzing with calcium **AND** barium; [1 mark]
- The solid would dissolve / disappear in both boiling tubes; [1 mark]

Difference:

- The reaction would be more vigorous / violent with barium
  OR
  The solid would dissolve / disappear faster with barium
  OR
  A colourless solution would form with barium; [1 mark]

[Total: 3 marks]

- The reactions of Group 2 elements with water are asked about very often in exam questions
  - You must be able to describe the reactions of different Group 2 metals with water, comparing them to each other and must be able to provide reaction equations
- The reactivity of Group 2 elements increases down the group, so the reaction of barium with water is more vigorous than of calcium with water
  - The atoms get bigger and the outermost electrons become further from the nucleus
  - The attraction between the nucleus and the outermost electrons is weaker as you descend the group, meaning the outermost electrons are lost more easily
  - This makes the elements lower down the group more reactive

Answer 7.

a) The equation for the reaction of barium with cold water is:

- $Ba + 2H_2O \rightarrow Ba(OH)_2 + H_2$; [1 mark]

[Total: 1 mark]

- Barium reacts with cold water to form an alkaline solution of barium hydroxide and hydrogen
  - $Ba + H_2O \rightarrow Ba(OH)_2 + H_2$
- The oxygen and hydrogen atoms are unbalanced
  - 1 oxygen atom on the left-hand side and 2 on the right
  - 2 hydrogen atoms on the left-hand side and 4 on the right
  - This can be balanced by having $2H_2O$ on the left-hand side
  - $Ba + 2H_2O \rightarrow Ba(OH)_2 + H_2$

b) A saturated solution of barium hydroxide is more alkaline than a saturated solution of magnesium hydroxide because:

- Barium hydroxide is more soluble than magnesium hydroxide

  OR

  The solubility of the hydroxides increases going down Group 2; [1 mark]
- The concentration of hydroxide / OH^- ions is greater (in barium hydroxide)

  OR

  There are more hydroxide / OH^- ions in (barium hydroxide) solution; [1 mark]

[Total: 2 marks]

- The Group 2 metal hydroxides can dissolve into solution forming the M^{2+} ion and $2OH^-$ ions
- The solubility of the Group 2 metal hydroxides increases as you move down the group
- This means that as you move down the group, the concentration of OH^- ions increases
- Therefore, the pH increases / the solution becomes more alkaline

c)

i) The **ionic** equation for the formation of the gas is:

- $CO_3^{2-} + 2H^+ \rightarrow CO_2 + H_2O$; [1 mark]

ii) The equation for the formation of the precipitate is:

$$CO_2(g) + Ca(OH)_2(aq) \rightarrow CaCO_3(s) + H_2O(l)$$

- Correct balanced equation; [1 mark]
- Correct state symbols; [1 mark]

[Total: 3 marks]

- For part (i)
  - The carbon dioxide gas is formed by the reaction of the metal carbonate with hydrochloric acid
    - $MCO_3 + 2HCl \rightarrow MCl_2 + CO_2 + H_2O$
  - You then need to convert this into the ionic equation
    - $M^{2+} + CO_3^{2-} + 2H^+ + 2Cl^- \rightarrow M^{2+} + 2Cl^- + CO_2 + H_2O$
  - You then remove the spectator ions
    - $CO_3^{2-} + 2H^+ \rightarrow CO_2 + H_2O$
- For part (ii)
  - The precipitate formed by bubbling carbon dioxide through limewater is solid calcium carbonate / $CaCO_3(s)$
    - You are expected to know that limewater is calcium hydroxide solution / $Ca(OH)_2(aq)$
  - Carbon dioxide is an acidic gas, so this is a neutralisation reaction
    - Acid + base → salt + water
    - $CO_2(g) + Ca(OH)_2(aq) \rightarrow CaCO_3(s) + H_2O(l)$
  - There is no balancing required for this equation

d) To calculate the minimum mass of magnesium hydroxide needed to neutralise 0.210 mol of hydrochloric acid:

- Moles of $Mg(OH)_2$ = 0.105; [1 mark]
- M_r of $Mg(OH)_2$ = 58.3; [1 mark]
- Mass of $Mg(OH)_2$ = 6.1215 (g)
  AND
  Answer given to 2 significant figures = 6.1 (g) **OR** to 3 significant figures = 6.12 (g); [1 mark]

[Total: 3 marks]

- There is a 1 : 2 stoichiometric relationship between the $Mg(OH)_2$ and HCl
  - So, the number of moles of $Mg(OH)_2 = \frac{0.210}{2} = 0.105$ moles
- The M_r of $Mg(OH)_2$ is needed to calculate the minimum mass
  - M_r of $Mg(OH)_2 = 24.3 + (2 \times (16.0 + 1.0)) = 58.3$
- Mass = moles x M_r
  - So, the mass of $Mg(OH)_2 = 0.105 \times 58.3 = 6.1215$ g
  - **Remember:** The question asks for your answer to the appropriate number of significant figures, which for this question is 2 or 3 significant figures

Answer 8.

a) The rate of this reaction decreases when the water temperature falls because:

- A decrease in temperature decreases the energy of the particles / ions / H^+ (in the lake); [1 mark]
- Which decreases the number of particles / ions / H^+ (in the lake) with $E \geq E_a$
  OR
  Which decreases the number of particles / ions / H^+ (in the lake) with sufficient energy to react; [1 mark]
- So there are less frequent successful / effective / productive collisions; [1 mark]

[Total: 3 marks]

- Decreasing temperature results in the particles having less kinetic energy
- This means that more particles don't have the required energy to react, i.e. $E \geq E_a$
- Therefore, there are less frequent successful collisions / less successful collisions per unit time, which results in a slower rate of reaction

b) The **two** other products of the reaction of calcium carbonate with lactic acid are:

- Carbon dioxide / CO_2
  AND
  Water / H_2O; [1 mark]

[Total: 1 mark]

- The displayed formula of lactic acid shows that it is a carboxylic acid
- This means that the question is asking for the products of a neutralisation reaction between a metal carbonate and a carboxylic acid
  - Metal carbonate + carboxylic acid → metal salt + carbon dioxide + water

c)

i) The equation to show how magnesium is used as the reducing agent in the reaction of magnesium with titanium(IV) chloride is:

$$2Mg + TiCl_4 \rightarrow 2MgCl_2 + Ti$$

- Correct chemical species; [1 mark]
- Correct balancing; [1 mark]

ii) In terms of oxidation states, magnesium is the reducing agent because:

- Mg changes its oxidation number from 0 to +2, so electrons are lost
  OR
  Ti changes its oxidation number from +4 to 0, so electrons are gained; [1 mark]

iii) The magnesium sulfate formed is easy to separate from the titanium because:

- Magnesium sulfate / it is soluble in water
  AND
  So, the titanium can be filtered from the solution; [1 mark]

[Total: 4 marks]

- For part (i)
  - You are told that the magnesium reacts with titanium(IV) chloride to produce titanium
    - $Mg + TiCl_4 \rightarrow Ti$
  - The other product must be magnesium chloride
    - $Mg + TiCl_4 \rightarrow MgCl_2 + Ti$
  - There are four chlorine atoms on the left-hand side and two on the right, so you need $2MgCl_2$
    - $Mg + TiCl_4 \rightarrow \mathbf{2}MgCl_2 + Ti$
  - There are now two magnesium atoms on the right-hand side and one on the left, so you need 2Mg
    - $\mathbf{2}Mg + TiCl_4 \rightarrow 2MgCl_2 + Ti$
- For part (ii)
  - **Remember:** Reducing agents cause reduction in other chemicals and are themselves oxidised
  - The oxidation number of the magnesium starts at 0 in Mg and becomes +2 in $MgCl_2$
  - This increase in the oxidation number is oxidation, which means that magnesium is the reducing agent
- For part (iii)
  - Magnesium sulfate is soluble in water
  - Titanium metal is solid and does not dissolve in / react with water
  - This means that the titanium can be filtered from the mixture

d) Strontium has a higher melting point than barium because:

- The delocalised electrons (in strontium) are closer to the positive ions / cations / atom / nuclei
  OR
  The positive ions / cations / atoms (in strontium) are smaller
  OR
  The positive ions / cations / atoms have fewer (electron) shells / levels; [1 mark]

- So, strontium has a stronger attraction between the positive ions / cations / atoms / nuclei and the delocalised electrons
  OR
  So, strontium has stronger metallic bonding; [1 mark]

[Total: 2 marks]

- As you move down Group 2:
  - The elements have the same equivalent nuclear charge of +2
  - The elements have increased shielding
  - This results in a weaker force of attraction between the nuclei and the outermost electrons
- For the metallic bonding present in Group 2 metals, this means that the force of attraction / metallic bond gets weaker as you move down the group

Answer 9.

a) The **three** balanced chemical equations for the Lime cycle are:

- $Ca(OH)_2\,(aq) + CO_2\,(g) \rightarrow CaCO_3\,(s) + H_2O\,(l)$; [1 mark]
- $CaCO_3\,(s) \rightarrow CaO\,(s) + CO_2\,(g)$; [1 mark]
- $CaO\,(s) + H_2O\,(l) \rightarrow Ca(OH)_2\,(aq)$; [1 mark]
- All state symbols correct, $Ca(OH)_2\,(aq)$, $CO_2\,(g)$, $CaCO_3\,(s)$, $H_2O\,(l)$, $CaO\,(s)$; [1 mark]

[Total: 4 marks]

- You are expected to know the formulae of calcium hydroxide, calcium carbonate and calcium oxide
- From Fig. 4.1, you have sufficient information to build the unbalanced reaction equations and deduce the balanced chemical equations
  - Calcium hydroxide
    - $Ca(OH)_2 \rightarrow CaCO_3$
    - Calcium hydroxide is also known as limewater, which tests for the presence of CO_2
      $Ca(OH)_2 + CO_2 \rightarrow CaCO_3$
    - The unbalanced equation is missing one oxygen and two hydrogen atoms on the right-hand side, which is a water molecule
      $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$
  - Calcium carbonate
    - $CaCO_3 \rightarrow CaO$
    - This unbalanced equation is missing one carbon and two oxygen atoms on the right-hand side, which a carbon dioxide molecule
      $CaCO_3 \rightarrow CaO + CO_2$
  - Calcium oxide
    - $CaO \rightarrow Ca(OH)_2$
    - This unbalanced equation is, again, missing one oxygen and two hydrogen atoms on the right-hand side, which is a water molecule
      $CaO + H_2O \rightarrow Ca(OH)_2$
- **Remember:** The question asks for state symbols so you need to add state symbols to all of the equations
  - It is more common to be asked to include state symbols for one of the specific equations but you should be adding state symbols as part of your good practice

b)

i) How calcium hydroxide increases the pH of acidic soil:

- The solid calcium hydroxide dissolves (in rainwater / the moisture of the soil); [1 mark]
- This releases hydroxide ions / OH^- into the soil; [1 mark]
- The hydroxide ions / OH^- react with / remove / neutralise the (acidic) hydrogen ions / H^+; [1 mark]

ii) The **ionic** equation to show the reaction that causes the pH of the soil to increase is:

- $H^+ + OH^- \rightarrow H_2O$; [1 mark]

[Total: 4 marks]

- Questions like this often see extra, unnecessary and incorrect answers
  - This is because part (i) of the question asks specifically about calcium hydroxide but the introductory sentence talks about calcium carbonate, calcium hydroxide and calcium oxide
- **Careful:** The calcium hydroxide is being added as a solid to a field
  - This means that you need to explain how the solid calcium hydroxide releases the hydroxide ions
  - The hydroxide ions will then react with the hydrogen ions in the soil
  - As more hydrogen ions are removed:
    - The soil becomes less acidic
    - The soil becomes more alkaline
    - This means that the pH of the soil increases
- The increase in the pH os a result of a neutralisation reaction, so you should write the ionic equation for neutralisation as your answer to part (ii)
  - $H^+ + OH^- \rightarrow H_2O$

c)

i) The chemical reaction of calcination is:

- Thermal decomposition; [1 mark]

ii) Strontium carbonate has greater thermal stability than calcium carbonate because:

- Strontium ion has a larger / greater ionic radius
  OR
  The strontium ion / cation has a lower / decreased charge density; [1 mark]
- So, the polarising / distorting power of the strontium ion / cation decreases; [1 mark]
- Which means that there is less polarisation / distortion of (the electron cloud) of the carbonate ion / anion; [1 mark]

[Total: 4 marks]

- You should be aware that heating calcium carbonate results in its decomposition to calcium oxide and carbon dioxide
- The thermal stability of the Group 2 carbonates increases as you move down the group
  - The smaller positive metal ions at the top of the group polarise the anions more than the larger ions at the bottom of the group
  - These small positive metal ions attract the delocalised electrons in the carbonate ion towards themselves
  - The higher the charge and the smaller the ion; the higher the polarising power
  - The more polarised the carbonate ions are; the more likely they are to thermally decompose as the covalent bonds within them are weaker

d)

i) The coloured gas and its colour are:

- Nitrogen dioxide / nitrogen(IV) oxide / NO_2 **OR** dinitrogen tetroxide / N_2O_4
  AND
  Brown; [1 mark]

ii) The identity and test, including the result, for the colourless gas are:

- Oxygen / O_2
  AND
  Relights a glowing splint; [1 mark]

[Total: 2 marks]

- The hydrated calcium nitrate is gently heated to remove the water of crystallisation
- Further, heating then causes the calcium nitrate to decompose into calcium oxide, nitrogen dioxide and oxygen
  - $2Ca(NO_3)_2(s) \rightarrow 2CaO(s) + 4NO_2(g) + O_2(g)$
  - Nitrogen dioxide is a dark brown gas
    - Some mark schemes may allow the use of red-brown or reddish-brown as the colour
    - Most mark schemes will not allow red as the colour
  - Oxygen is the colourless gas
    - You should know the gas test for oxygen as well as carbon dioxide, hydrogen, ammonia and chlorine

Answer 10.

a) The first ionisation energy of calcium (590 kJ mol^{-1}) is greater than that of strontium (550 kJ mol^{-1}) because:

- Calciums outer / valence electrons are closer to the nucleus
  OR
  Calcium has a smaller atomic radius
  OR
  Calcium has less electrons shells; [1 mark]
- So, calcium has less shielding
  AND
  Which means that more energy is required to overcome the stronger force of attraction (between the outer / valence electron and the nucleus); [1 mark]

[Total: 2 marks]

- Answers to questions about ionisation energies should include:
  - The distance of the outer electrons from the nucleus
  - The amount of shielding that the outer electrons have from the nucleus
  - The electrostatic force of attraction of the outer electrons to the nucleus
  - The amount of energy required to overcome these electrostatic forces of attraction

b)

i) The balanced chemical equation, including state symbols, to show the formation of strontium chloride from strontium and hydrochloric acid is:

$$Sr\,(s) + 2HCl\,(aq) \rightarrow SrCl_2\,(aq) + H_2\,(g)$$

- Correct chemical species
  AND
  Correct balancing; [1 mark]
- Correct state symbols; [1 mark]

ii) This reaction is not used to produce strontium chloride on an industrial scale because:

- It is a vigorous / violent reaction
  OR
  There is a risk of explosion; [1 mark]

[Total: 3 marks]

- **Remember:** M.A.S.H - **M**etal + **A**cid → **S**alt + **H**ydrogen
  - Due to the formulae of strontium chloride and hydrogen, this is one of the nicer equations to balance
- The reaction between magnesium and hydrochloric acid is quite vigorous
  - The reactivity of the metals increases as you move down the group
  - This means that the reaction of strontium with hydrochloric acid is vigorous and violent
  - On an industrial scale this would mean that there is the risk of an explosion

c) Drinking magnesium sulfate solution is an effective treatment for barium poisoning because:

- Insoluble barium sulfate is formed
  OR
  Barium ions are removed (as a precipitate); [1 mark]
- $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$; [1 mark]

[Total: 2 marks]

- This question is a test of your knowledge of the solubility of the group 2 sulfates
- The solubility of the group 2 sulfates decreases as you move down the group
- Magnesium sulfate is soluble in water (hence being able to make the solution)
- Barium sulfate is insoluble, which means that it will pass through the body after it has been formed

d) The remedy that might cause the person taking it to have wind is:

$Mg(OH)_2\,(s) + 2HCl\,(aq) \rightarrow MgCl_2\,(aq) + 2H_2O\,(l)$

$CaCO_3\,(s) + 2HCl\,(aq) \rightarrow CaCl_2\,(aq) + H_2O\,(l) + CO_2\,(g)$

- Calcium carbonate
  AND
  (Because) the reaction of calcium carbonate with hydrochloric acid forms carbon dioxide (gas); [1 mark]
- Both reactions form the metal chloride and water; [1 mark]

[Total: 2 marks]

- Although they are not necessary, it can be helpful to write both chemical equations:
  - $Mg(OH)_2 + 2HCl \rightarrow MgCl_2 + 2H_2O$
  - $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$
- **Careful:** This question asks you to compare the reactions **AND** give a reason for your choice of the remedy that might cause wind
  - The comparison of the equations shows that both reactions for a group 2 metal chloride and water
  - The difference is that calcium carbonate also forms carbon dioxide
    - Carbon dioxide is a gas and could potentially cause wind in the person taking it

Answer 11.

a) The balanced symbol equations are:

- $Ba\,(s) + O_2\,(g) \rightarrow 2BaO\,(s)$; [1 mark]
- $3Ba\,(s) + N_2\,(g) \rightarrow Ba_3N_2\,(s)$; [1 mark]

[Total: 2 marks]

- From being exposed to the air you can deduce that oxidation has occurred so you need to write the equation for the reaction between barium and oxygen
- You might not have come across barium nitride specifically but you can use your Periodic Table to deduce that the charge on the ion is 3–:
  - Group 2 elements have a 2+ charge so for the charges to cancel out the formula must be Ba_3N_2
    - Based on the fact it causes a black coating indicates it is a solid so the state symbol is (s)

b)

i) The volume of gas produced is calculated by:

- $Ba\,(s) + 2H_2O\,(l) \rightarrow Ba(OH)_2\,(aq) + H_2\,(g)$; [1 mark]
- Mol of Ba = $0.20 \div 137.3 = 0.00146$; [1 mark]
- Volume of $H_2 = 0.00146 \times 24\,000 = 35.0\ (cm^3)$; [1 mark]

ii) The concentration of $Ba(OH)_2$ is calculated by:

- $\frac{0.00146}{0.250} = 0.00584\ mol\ dm^{-3}$; [1 mark]

[Total: 4 marks]

- It is common to bring calculations in from other areas of the course to topics such as Group 2 metals where there is a limited amount of content they can ask about
- In this case, you have not been given the symbol equation for the reaction of barium with water but this is one you are expected to know - you do not need to give state symbols to obtain this mark
- The molar ratio of Ba : H_2 is 1:1
- Make sure you check units, the question has asked for the answer in cm^3 not dm^3 so you need to multiply by 24 000 not 24
- For part ii) concentration is calculated using $\frac{\text{number of moles}}{\text{volume}}$
- The number of moles of barium hydroxide and barium (calculated in part i) are the same due to the ratio being 1:1
- You must convert the volume from dm^3 to dm^3 by dividing by 1000

c) Reactivity with water down Group 2:

- Increases; [1 mark]
- The atomic radius increases
  OR
  There are more shells; [1 mark]
- There is more shielding / screening; [1 mark]
- The nuclear attraction decreases
  OR
  Increased shielding and distance outweigh the increased nuclear charge; [1 mark]
- It is easier to remove the outer electrons; [1 mark]

[Total: 5 marks]

- This is a common exam question to ask, it could be worded the other way around and you are asked to explain what happens to reactivity going up Group 2

d) This is a redox reaction because:

- Calcium has been oxidised
  AND
  Its oxidation number increases from 0 (in Ca) to +2 (in $Ca(OH)_2$); [1 mark]
- Hydrogen has been reduced
  AND
  Its oxidation number decreases from +1 (in H_2O) to 0 (in H_2); [1 mark]

[Total: 2 marks]

- **Remember:**
  - The oxidation number of elements is 0
  - In this example, the oxidation number of oxygen is -2 and hydrogen is +1
  - Make sure you learn the rules for assigning oxidation numbers

e) These two trends are connected because:

- The solubility in water increases as you move down the group
  AND
  The strength as a base increases as you move down the group; [1 mark]
- Increasing the solubility (in water) means that there are more hydroxide / OH^- ions in solution
  OR
  Increasing the solubility (in water) increases the concentration of hydroxide / OH^- ions in solution; [1 mark]
- The hydroxide / OH^- ion makes the metal hydroxide act as a base
  OR
  Base strength is measured by the concentration of hydroxide / [OH^-] ions; [1 mark]

[Total: 3 marks]

- There is a clear trend in solubility as you descend Group 2;
  - The solubility of the hydroxides of Group 2 **increases as you go down the group**
    - Magnesium hydroxide, $Mg(OH)_2$, is almost insoluble - it is actually a suspension in water, and not a solution
    - Barium hydroxide, $Ba(OH)_2$, is the most soluble - it dissolves to produce a strongly alkaline solution
- The strength of a base is measured by the concentration of hydroxide ions

Answer 12.

a) The trend in the expected mass for the precipitates is:

- Calcium hydroxide will have the highest / greatest mass (of precipitate) **AND** barium hydroxide will have the lowest / smallest mass (of precipitate)
  OR
  The mass (of precipitate) will decrease as you move down the group / increase as you move up the group; [1 mark]
- (Because) solubility of Group 2 hydroxides increases going down Group 2; [1 mark]

[Total: 2 marks]

- This question is about the solubility of the Group 2 metal hydroxides in water
  - **Careful**: the talk about precipitates in the question is to distract you
- Calcium hydroxide is sparingly soluble in water so there will be a large amount of precipitate
- The solubility of the hydroxides increases as you move down the group
- Barium hydroxide is very soluble in water so there will be a small amount of precipitate, if any

b) To identify the metal hydroxide in the unknown sample:

- (802 / 1000) = 0.802 g (in 50 cm^3)
  AND
  (0.802 x 20) =16.04 g dm^{-3} (in 1000 cm^3); [1 mark]
- (The unknown metal hydroxide is) strontium hydroxide; [1 mark]

[Total: 2 marks]

- An answer of strontium hydroxide cannot be achieved without a supporting calculation
- **Careful:** The information in the table wants you to work in g dm^{-3} but you have information in mg and cm^3
  - 1 g = 1000 mg
  - 1 dm^3 = 1000 cm^3
- To convert the mass from mg to g, divide by 1000
- To scale the mass according to the volume x 20
- Use your answer to identify the correct metal hydroxide from the table by choosing the closest value
- There will always be differences between experimental values and data book tables
  - In this question, the main reasons for the difference could be due to the temperature of the water and impurities in the unknown sample

c)

i) The balanced symbol equation for the reaction between magnesium hydroxide and sulfuric acid is:

$Mg(OH)_2(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + 2H_2O(l)$

- Correct formulae; [1 mark]
- Correct balancing; [1 mark]

ii) The differences in the observations between the reactions of magnesium hydroxide with sulfuric acid and barium hydroxide and sulfuric acid are:

- With magnesium hydroxide a colourless solution is produced; [1 mark]
- With barium hydroxide a (white) precipitate is produced; [1 mark]
- Because barium sulfate is insoluble
  AND
  Magnesium sulfate is soluble; [1 mark]

[Total: 5 marks]

- Group 2 hydroxides are bases so when they react with sulfuric acid they produce a Group 2 sulfate and water
- The solubility of Group 2 sulfates decreases down the group, so magnesium sulfate is soluble - hence it will need the (aq) state symbol in the equation
- Barium is near the bottom of the group so barium sulfate is insoluble and it forms a white precipitate
- The formation of barium sulfate as a white precipitate should be familiar as the addition of barium ions is a test for the presence of sulfate ions

Answer 13.

a) i) An equation showing the thermal decomposition of calcium nitrate, $Ca(NO_3)_2$ is:

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

ii) Explaining how the thermal stabilities of the nitrates vary down Group 2:

- (Down the group the nitrates) become more stable / are more difficult to decompose / need a higher temperature (to decompose); [1 mark]
- Because the (ionic) radius of the cation / Group 2 ion / M^{2+} increases
  OR
  The charge density of the cation decreases; [1 mark]
- Thus causing less polarisation / distortion of the anion / NO_3^- / nitrate ion; [1 mark]

iii) When lithium nitrate is heated you would see:

- Brown / orange fumes / gas would be evolved
  OR
  Glowing splint relights; [1 mark]

[Total: 5 marks]

- When Group 2 nitrates decompose, they produce a Group 2 oxide, nitrogen dioxide and oxygen
- The explanation about the trend in the thermal stability of Group 2 nitrates is worth learning and it can also be used to explain the trend in the thermal stability of Group 2 carbonates
- The observations that would be made when lithium nitrate thermally decomposes arise due to the gases that are evolved in the reaction:
  - Nitrogen dioxide is a brown / orange gas
  - Oxygen would relight a glowing splint

b) The volume of gas given off when a 10.0 g sample of this mixture decomposes is:

Method 1:

- Mass of mixture = 211.6 + (3 x 12) = 247.6; [1 mark]
- Moles of mixture = $\frac{10}{247.6}$ = 0.0404 (mol); [1 mark]
- No of moles of gas produced = 0.0404 x 4 = 0.1616 (mol)
  AND
  Volume = 0.1616 x 24 = 3.88 **OR** 3.9 dm^3; [1 mark]

Method 2:

- Mass of mixture = 211.6 + (3 x 12) = 247.6; [1 mark]
- 1 mole / 247.6 g of mixture will produce 4 x 24 = 96 dm^3 of gas; [1 mark]
- 10.0 g of mixture will produce 96 x $\frac{10}{247.6}$ = 3.88 **OR** 3.9 dm^3; [1 mark]

[Total: 3 marks]

- The mass of one mole of the mixture can be calculated by adding together the molar masses of the reactants:
  - 211.6 + (3 x 12) = 247.6 g
- One mole of the mixture contains 1 mole of strontium nitrate and 3 moles of carbon and will produce the following:
  - 1 mole of SrO
  - 1 mole of N_2
  - 2 moles of CO_2
  - 1 mole of CO
- N_2, CO_2 and CO are gases which means that a total of 4 moles of gas are produced for every 1 mole of the reaction mixture
- You would lose a mark for not including carbon in the mass of the mixture - this would give a final answer of 4.54 dm^3 which would score 2 marks
- Either method is equally valid, choose which makes the most sense to you

c) The percentage loss in mass that would be observed when a sample of dolomite is heated at a high temperature until the reaction had finished is:

- $M_r(CaMg(CO_3)_2) = 40.1 + 24.3 + 24 + 96 = 184.4$; [1 mark]
- $M_r(2CO_2) = 2 \times 44 = 88$; [1 mark]
- % loss in mass = $\frac{88}{184.4} \times 100 = 47.7\%$ **OR** 48%; [1 mark]

[Total: 3 marks]

- When Group 2 carbonates undergo thermal decomposition reactions, a metal oxide and carbon dioxide are formed
- In this reaction, both calcium oxide and magnesium oxide will be produced:
  - $CaMg(CO_3)_2 \rightarrow CaO + MgO + 2CO_2$
- So, 1 mole of dolomite produces 2 moles of carbon dioxide and 88 grams of carbon dioxide are produced for every 184.4 g of dolomite
- This will be the mass that is lost as carbon dioxide which can be calculated as a percentage of the mass of dolomite