2.6 The Periodic Table and Inorganic Chemistry

AQA 7405 · Calculator allowed · about 220 minutes · Write-in edition

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 The table below gives approximate melting points for four Period 3 elements.
Na: 371 K Mg: 923 K Al: 933 K Si: 1687 K

(a) Explain, in terms of structure and bonding, why the melting point increases from sodium to magnesium to aluminium. **(3)**

(b) Silicon has a much higher melting point than aluminium. Explain why. **(2)**

(c) The melting point drops sharply between silicon and phosphorus (P_4 melts at 317 K). Explain why. **(2)**

(d) Predict, with a reason, how the melting points of P_4, S_8 and Cl_2 compare with one another. **(3)**

(Total for Question 1 is 10 marks)

2 This question is about the oxides of Period 3 elements and their reactions with water.

(a) Write an equation for the reaction of sodium oxide, Na_2O, with water, and state the approximate pH of the resulting solution. **(2)**

(b) Write an equation for the reaction of phosphorus(V) oxide, P_4O_{10}, with water, and state the approximate pH of the resulting solution. **(2)**

(c) Aluminium oxide, Al_2O_3, does not react with water, but it reacts with both dilute hydrochloric acid and dilute sodium hydroxide solution. Write an equation for each of these two reactions and state the term used to describe an oxide that behaves in this way. **(4)**

(d) Using your answers to parts (a) to (c), deduce and explain the overall pattern in the acid-base character of Period 3 oxides as you move from sodium oxide to phosphorus(V) oxide. **(3)**

(Total for Question 2 is 11 marks)

3 A student reacts small samples of magnesium ribbon and calcium metal, in turn, with cold water.

(a) Write a balanced equation, including state symbols, for the reaction of calcium with cold water. **(2)**

(b) Describe the observations you would expect when comparing magnesium and calcium each added to cold water. **(2)**

(c) Explain why reactivity with water increases down Group 2 from magnesium to calcium. **(3)**

(d) Magnesium does not react with cold water but does react with steam. Write a balanced equation for the reaction of magnesium with steam, and explain why the product formed is different from the product formed when calcium reacts with cold water. **(3)**

(Total for Question 3 is 10 marks)

4 This question is about physical property trends of the Group 7 halogens: fluorine, chlorine, bromine and iodine.

(a) State the trend in boiling point down Group 7, and state the physical state at room temperature of chlorine, bromine and iodine. **(2)**

(b) Explain the trend in boiling point down Group 7. **(3)**

(c) Explain the trend in electronegativity down Group 7. **(2)**

(d) Fluorine is considerably more reactive and electronegative than would be predicted simply by extrapolating the Group 7 trend from chlorine. Suggest, with a reason, why fluorine's properties deviate from this trend. **(2)**

(Total for Question 4 is 9 marks)

5 This question uses practical techniques from the required practical qualitative test for halide ions. A student is given a colourless solution and asked to identify which halide ion it contains. The student adds a few drops of dilute nitric acid, followed by silver nitrate solution, $AgNO_3(aq)$, and then tests the solubility of any precipitate formed in dilute and concentrated ammonia solution.

(a) State the purpose of adding dilute nitric acid to the solution before the silver nitrate solution. **(1)**

(b) Complete the following, stating the colour of the precipitate formed with silver nitrate solution, and its solubility in ammonia, for chloride ions, bromide ions and iodide ions. **(3)**

(c) Write an ionic equation for the reaction between silver ions and bromide ions. **(1)**

(d) A student carries out this test on an unknown solution, X, and observes a cream precipitate that dissolves only when concentrated ammonia solution is added (it does not dissolve in dilute ammonia). Identify the halide ion present in X and justify your answer. **(2)**

(e) Explain why this silver nitrate/ammonia test alone would not distinguish between a solution containing only chloride ions and a solution containing a mixture of chloride and bromide ions. **(2)**

(Total for Question 5 is 9 marks)

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6 This question tests key definitions used throughout the periodic table and inorganic chemistry topic.

(a) Define periodicity. **(1)**

(b) Define disproportionation. **(1)**

(c) Define an amphoteric oxide. **(1)**

(d) State, in terms of oxidation number, what happens to a reducing agent during a redox reaction. **(1)**

(Total for Question 6 is 4 marks)

7 A solid compound X is known to be a Group 2 metal halide, MX2, where M is one of Mg, Ca or Ba, and X is one of Cl, Br or I. Describe a series of chemical tests, with reagents, conditions and expected observations, that a student could use to identify both the metal cation and the halide anion present in solid compound X. Your answer should include the results expected for at least two possible cations and at least two possible anions.

(Total for Question 7 is 6 marks)

8 This question is about halogen displacement and disproportionation reactions.

(a) Chlorine water is added to a colourless solution of potassium bromide. Write an ionic equation for the reaction that occurs and state the observation. **(3)**

(b) Explain, in terms of oxidising power, why chlorine displaces bromide ions from solution but iodine does not displace chloride ions from solution. **(2)**

(c) Chlorine gas is bubbled into cold, dilute sodium hydroxide solution. Write a balanced equation for this reaction, state one commercial use of the products formed and name the type of redox reaction that has taken place. **(4)**

(d) Explain what is meant by the term 'disproportionation', using oxidation numbers to show the changes in oxidation state of chlorine in the reaction in part (c). **(3)**

(Total for Question 8 is 12 marks)

9 This question is about the reactions of solid sodium halides with concentrated sulfuric acid.

(a) Write an equation for the reaction of solid sodium chloride with concentrated sulfuric acid, and state the observation made. **(2)**

(b) With solid sodium bromide, the HBr initially formed is partly further oxidised by concentrated sulfuric acid, forming bromine and sulfur dioxide. Write an equation for this further reaction, and state the oxidation state of sulfur in H_2SO_4 and in SO_2. **(3)**

(c) With solid sodium iodide, concentrated sulfuric acid is reduced much further, all the way to hydrogen sulfide, H_2S. Write the overall equation for this reaction, and calculate the oxidation state of sulfur in H_2SO_4 and in H_2S. State what the change in oxidation state shows about iodide compared with bromide. **(4)**

(d) Explain why the reducing power of the halide ions increases down Group 7, from chloride to iodide. **(3)**

(Total for Question 9 is 12 marks)

10 Group 2 carbonates decompose on heating to form the metal oxide and carbon dioxide gas. (Molar volume of a gas at RTP = 24 dm3 mol-1; Mr of $MgCO_3$ = 84.3)

(a) Write a balanced equation for the thermal decomposition of magnesium carbonate, $MgCO_3$. **(1)**

(b) A 5.05 g sample of magnesium carbonate is heated until it decomposes completely. Calculate the volume, in dm3, of carbon dioxide gas produced, measured at room temperature and pressure (RTP). **(3)**

(c) Barium carbonate, $BaCO_3$, requires a much higher temperature than magnesium carbonate to decompose completely. Explain this difference in terms of the polarising effect of the metal cation on the carbonate ion. **(3)**

(d) Predict, with a reason, whether strontium carbonate, $SrCO_3$, would need a higher or lower temperature than magnesium carbonate to decompose completely. **(2)**

(Total for Question 10 is 9 marks)

11 This synoptic question links the bonding trend across Period 3 chlorides to their hydrolysis behaviour and to a resulting pH calculation.

(a) Describe, with an equation, the difference in behaviour when NaCl(s) and $SiCl_4$(l) are separately added to water. **(3)**

(b) Explain, in terms of bonding, why $SiCl_4$ hydrolyses in this way but NaCl does not. **(2)**

(c) 2.00 g of PCl_5 (Mr = 208.5) is added to excess water and hydrolyses completely: $PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$. The resulting solution is made up to 250 cm^3 with distilled water. Calculate the pH of this solution, assuming HCl is fully dissociated and ignoring any contribution to acidity from H_3PO_4. **(5)**

(Total for Question 11 is 10 marks)

12 This question uses first ionisation energy data to examine the Period 3 trend and its two characteristic anomalies.

(a) First ionisation energies across Period 3 (kJ/mol): Na = 496, Mg = 738, Al = 577, Si = 786, P = 1012, S = 1000, Cl = 1251, Ar = 1521. State and explain the general trend in first ionisation energy across Period 3 from Na to Ar. **(2)**

(b) Using the data given, identify the two points where the trend decreases rather than increases, and explain why there is a decrease from Mg to Al. **(3)**

(c) Calculate the percentage decrease in first ionisation energy from Mg to Al, and the percentage decrease from P to S, and state which anomaly is larger in percentage terms. **(4)**

(Total for Question 12 is 9 marks)

13 This question is about the thermal decomposition of Group 2 nitrates.

(a) 3.56 g of magnesium nitrate, $Mg(NO_3)_2$ (Mr = 148.3), is heated until it fully decomposes: $2Mg(NO_3)_2(s) \rightarrow 2MgO(s) + 4NO_2(g) + O_2(g)$. Calculate the number of moles of $Mg(NO_3)_2$ in the sample. **(2)**

(b) Using the equation, calculate the total number of moles of gas (NO_2 and O_2 combined) produced. **(3)**

(c) Calculate the total volume of gas produced at RTP, given the molar volume of a gas at RTP is 24000 cm^3/mol. **(3)**

(d) Barium nitrate, $Ba(NO_3)_2$, requires a much higher temperature than $Mg(NO_3)_2$ to decompose at a comparable rate. Explain this difference in terms of the polarising power of the cation. **(2)**

(Total for Question 13 is 10 marks)

14 This question uses an iodine-thiosulfate titration to determine the concentration of chlorate(I) (hypochlorite) ions in household bleach.

(a) 10.0 cm^3 of household bleach is diluted to 250 cm^3 in a volumetric flask. A 25.0 cm^3 sample of this diluted solution is reacted with excess potassium iodide and acid ($ClO^-(aq) + 2I^-(aq) + 2H^+(aq) \rightarrow Cl^-(aq) + I_2(aq) + H_2O(l)$), and the liberated iodine requires 21.50 cm^3 of 0.100 mol/dm3 sodium thiosulfate solution to reach the starch end point ($I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$). Calculate the number of moles of thiosulfate used. **(2)**

(b) Calculate the number of moles of I_2 that reacted with the thiosulfate. **(2)**

(c) Calculate the number of moles of ClO^- in the 25.0 cm^3 sample. **(2)**

(d) Calculate the concentration of ClO^- (in mol/dm3) in the original, undiluted bleach. **(3)**

(Total for Question 14 is 9 marks)

15 Explain, in terms of bonding and structure, why the oxides of Period 3 elements show a trend from strongly basic (Na_2O, MgO) through amphoteric (Al_2O_3) to strongly acidic (SiO_2, P_4O_{10}, SO_3) across the period, and explain why this trend in acid-base character correlates with the trend in bonding type across the period.

(Total for Question 15 is 6 marks)

16 This question analyses the measurement uncertainty in the bleach titration described in Question 14.

(a) The 21.50 cm^3 titre in Question 14 was obtained using a burette readable to ± 0.05 cm^3 per reading. Calculate the percentage uncertainty in this titre (combined from two readings). **(2)**

(b) The 25.0 cm^3 sample was measured using a pipette with an uncertainty of ± 0.06 cm^3. Calculate its percentage uncertainty. **(2)**

(c) The 10.0 cm^3 sample of undiluted bleach was measured using a pipette with an uncertainty of ± 0.04 cm^3. Calculate its percentage uncertainty. **(2)**

(d) Estimate the overall percentage uncertainty in the final concentration of bleach calculated in Question 14, and comment on whether this method is likely to give a precise result. **(2)**

(Total for Question 16 is 8 marks)

17 This question is about the trend in oxidising power of the Group 7 halogens and its practical consequences.

(a) Atomic radii (pm): F = 64, Cl = 99, Br = 114, I = 133. Using this data, explain the trend in oxidising power of the halogens from F_2 to I_2. **(3)**

(b) Iodine can be prepared industrially by oxidising iodide ions in brine using chlorine gas. Write the ionic equation for this reaction, and use oxidising power to explain why chlorine, but not iodine, can perform this oxidation. **(3)**

(c) Explain why fluorine is not used in this type of displacement reaction to prepare I_2 or Br_2 from aqueous halide solutions, even though F_2 is by far the strongest oxidising agent in the group. **(2)**

(Total for Question 17 is 8 marks)

Mark scheme · 2.6 The Periodic Table and Inorganic Chemistry

Question 1

(a) Na, Mg and Al are all giant metallic structures held together by metallic bonding oe **B1**

(a) going from Na to Mg to Al, each atom contributes one more delocalised electron (1, then 2, then 3) to the 'sea' of electrons, and the ionic charge on the metal ion also increases (+1, +2, +3) **B1**

(a) stronger electrostatic attraction between the metal cations and the increased number/density of delocalised electrons requires more energy to overcome, raising the melting point oe **B1**

(a) Answer: Na, Mg and Al are giant metallic lattices; going across the series the ionic charge and the number of delocalised electrons per atom both increase, strengthening the metallic bonding and so raising the melting point

(b) silicon has a giant covalent (macromolecular) structure, in which each Si atom is joined to four others by strong covalent bonds oe **B1**

(b) melting requires breaking many strong covalent bonds throughout the lattice, which needs much more energy than overcoming the (weaker, delocalised) metallic bonding in aluminium oe **B1**

(b) Answer: Silicon has a giant covalent lattice held together by strong covalent bonds in all directions; melting means breaking these strong bonds, which needs far more energy than overcoming the metallic bonding in aluminium

(c) phosphorus (as P_4) exists as small, simple covalent molecules, unlike the giant covalent lattice of silicon oe **B1**

(c) only weak London (van der Waals) forces act between P_4 molecules, and these require little energy to overcome, so the melting point is much lower oe **B1**

(c) Answer: P_4 is a simple molecular substance; only weak London forces exist between the P_4 molecules, which need much less energy to overcome than the strong covalent bonds in giant covalent silicon

(d) predicted order: S_8 has the highest melting point, then P_4, then Cl_2 the lowest (accept correct order stated either way round with reasoning) **B1**

(d) melting point depends on the strength of London (van der Waals) forces between molecules, which increases with the number of electrons in the molecule / with relative molecular mass oe **B1**

(d) S_8 has the most electrons (largest Mr), then P_4, then Cl_2 has the fewest, so this order matches the strength of the London forces between molecules oe **B1**

(d) Answer: S_8 (highest) > P_4 > Cl_2 (lowest); melting point rises with the number of electrons per molecule (London forces), and S_8 has the most electrons per molecule, followed by P_4, then Cl_2

Question 2

(a) $Na_2O + H_2O \rightarrow 2NaOH$ cao (state symbols not required) **B1**

(a) pH approximately 13-14 (accept 'strongly alkaline') **B1**

(a) Answer: $Na_2O + H_2O \rightarrow 2NaOH$; pH approximately 13-14

(b) $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$ cao **B1**

(b) pH approximately 0-1 (accept 'strongly acidic') **B1**

(b) Answer: $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$; pH approximately 0-1

(c) $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ cao **B1**

(c) $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$ (sodium aluminate) oe (accept $2NaOH + Al_2O_3 \rightarrow 2NaAlO_2 + H_2O$) **B1**

(c) term: amphoteric **B1**

(c) amphoteric means the oxide can react as both a base (with acid) and an acid (with alkali) oe **B1**

(c) Answer: $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$; $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$; amphoteric (reacts with both acids and bases)

(d) the oxides change from strongly basic (Na_2O, MgO) through amphoteric (Al_2O_3) to acidic then strongly acidic (SiO_2 weakly/not reactive, P_4O_{10} strongly acidic) across the period oe **B1**

(d) this matches a change in bonding from ionic (Na_2O, MgO, metal oxides) to covalent (SiO_2, P_4O_{10}, non-metal oxides), with Al_2O_3 intermediate/having mixed ionic-covalent character oe **B1**

(d) ionic oxides release OH^- ions (or accept H^+ readily) making solutions basic, while covalent oxides of non-metals react with water to form acidic solutions (releasing H^+) oe **B1**

(d) Answer: Across Period 3 the oxides go from strongly basic (Na_2O, MgO) to amphoteric (Al_2O_3) to acidic (SiO_2, weakly) to strongly acidic (P_4O_{10}), reflecting the change in bonding from ionic (metal oxides) to covalent (non-metal oxides)

Question 3

(a) correct formulae: Ca, H_2O, $Ca(OH)_2$, H_2 **M1**

(a) $Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$ fully balanced with correct state symbols cao **A1**

(a) Answer: $Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$

(b) magnesium reacts very slowly (if at all) with cold water, with few/no visible bubbles over a reasonable timescale oe **B1**

(b) calcium reacts noticeably/steadily with cold water, producing a stream of bubbles (hydrogen gas) and forming a cloudy white suspension/precipitate of calcium hydroxide oe **B1**

(b) Answer: Magnesium shows almost no reaction with cold water; calcium reacts steadily, fizzing (releasing hydrogen gas) and forming a cloudy white suspension of calcium hydroxide

(c) atomic radius increases down the group (extra electron shell for each successive element) oe **B1**

(c) shielding by inner shells increases, which more than compensates for the increase in nuclear charge oe **B1**

(c) so the outer two electrons are less strongly attracted to the nucleus / (first and second) ionisation energies decrease down the group, so the atoms lose their outer electrons more easily, making the metal more reactive oe **B1**

(c) Answer: Atomic radius and shielding increase down the group, outweighing the increase in nuclear charge; this lowers ionisation energies down the group, so the outer electrons are lost more easily, increasing reactivity

(d) $Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$ cao **B1**

(d) magnesium hydroxide, $Mg(OH)_2$, is (much less soluble/almost insoluble) and unstable at the high temperature of steam, so it decomposes to the oxide oe **B1**

(d) at the higher temperature of steam magnesium reacts fast enough to form the oxide directly, whereas at room temperature with cold water the reaction is far too slow to be observed oe **B1**

(d) Answer: $Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$; the reaction with steam occurs at a much higher temperature, forming the oxide (as any hydroxide formed is not stable/is far less soluble than $Ca(OH)_2$), whereas cold water reacts too slowly with Mg to be observed

Question 4

(a) boiling point increases down the group oe **B1**

(a) chlorine is a gas, bromine is a liquid, iodine is a solid (all three needed) at room temperature **B1**

(a) Answer: Boiling point increases down the group; Cl_2 is a gas, Br_2 is a liquid, and I_2 is a solid at room temperature

(b) the halogens exist as simple diatomic molecules held together (between molecules) only by London (van der Waals/induced dipole-dipole) forces oe **B1**

(b) the number of electrons per molecule increases down the group (F_2 to I_2), increasing the size of instantaneous/induced dipoles oe **B1**

(b) this increases the strength of the London forces between molecules, so more energy is needed to separate the molecules, raising the boiling point oe **B1**

(b) Answer: Down the group the number of electrons per molecule increases, strengthening the London (van der Waals) forces between molecules, so more energy is needed to boil the substance, raising the boiling point

(c) electronegativity decreases down the group oe **B1**

(c) atomic radius (and shielding) increases down the group, so a bonding pair of electrons is less strongly attracted to the nucleus of the larger atom oe **B1**

(c) Answer: Electronegativity decreases down the group; increasing atomic radius and shielding mean the nucleus attracts a shared (bonding) pair of electrons less strongly

(d) the fluorine atom is exceptionally small, so its outer electrons are extremely close to (and strongly attracted by) the nucleus, giving an unusually high charge density oe **B1**

(d) this makes the F-F bond in F_2 relatively weak (due to strong lone pair-lone pair repulsion between the very close atoms), and makes F^- ions/F atoms attract electrons unusually strongly, so fluorine is more reactive/electronegative than a simple trend would predict oe **B1**

(d) Answer: Fluorine's very small atomic radius gives it an unusually high charge density; strong lone pair repulsion weakens the F-F bond and its outer electrons attract a bonding pair very strongly, making fluorine more reactive and electronegative than the group trend predicts

Question 5

(a) to remove/react away any carbonate or hydroxide ions present, which would otherwise also form a precipitate with Ag^+ and give a false-positive/misleading result oe **B1**

(a) Answer: It removes carbonate or hydroxide ions that would otherwise also form a precipitate with silver ions, giving a false result

(b) chloride: white precipitate, dissolves in dilute ammonia solution **B1**

(b) bromide: cream precipitate, dissolves only in concentrated ammonia solution **B1**

(b) iodide: yellow precipitate, insoluble in ammonia (even concentrated) **B1**

(b) Answer: Cl^-: white precipitate, dissolves in dilute NH_3; Br^-: cream precipitate, dissolves only in concentrated NH_3; I^-: yellow precipitate, insoluble even in concentrated NH_3

(c) $Ag^+ + Br^-$ -> AgBr cao **B1**

(c) Answer: $Ag^+(aq) + Br^-(aq)$ -> AgBr(s)

(d) bromide ions, Br^- **B1**

(d) justification: a cream precipitate that is insoluble in dilute ammonia but dissolves in concentrated ammonia is characteristic of AgBr (unlike AgCl, which dissolves in dilute ammonia, or AgI, which does not dissolve even in concentrated ammonia) oe **B1**

(d) Answer: Bromide ions (Br^-); the observations (cream precipitate, insoluble in dilute ammonia but soluble in concentrated ammonia) uniquely match AgBr

(e) both AgCl and AgBr would be present as a mixed precipitate, and the overall colour/behaviour may be dominated by or hard to distinguish from a pure chloride result oe **B1**

(e) in particular, both AgCl and AgBr dissolve in (a suitable concentration of) ammonia, and small amounts of a second halide can be masked by the excess of the first, so the test cannot reliably confirm the absence of a second halide ion oe **B1**

(e) Answer: A mixture of AgCl and AgBr precipitates would form together, and since both dissolve in ammonia (AgCl in dilute, AgBr only in concentrated), a small amount of a second halide can be masked by an excess of the other, so the simple test cannot reliably distinguish a pure chloride solution from a chloride/bromide mixture

Question 6

(a) a repeating (periodic) trend in the physical or chemical properties of elements when arranged in order of increasing atomic (proton) number, oe **B1**

(a) Answer: A repeating trend in element properties with increasing atomic number.

(b) a redox reaction in which the same element is simultaneously oxidised and reduced, oe **B1**

(b) Answer: A redox reaction in which the same element is both oxidised and reduced.

(c) an oxide that can react with both acids and bases (alkalis), oe **B1**

(c) Answer: An oxide that reacts with both acids and bases.

(d) its oxidation number increases (it is oxidised), oe **B1**

(d) Answer: Its oxidation number increases.

Question 7

Level 3 A clear, logically ordered method is given for both the cation and the anion test, with correct reagents and conditions throughout, and correct, distinguishing observations given for at least two possible metal cations and at least two possible halide anions. **5-6**

Level 2 A mostly correct method for identifying the cation and/or the anion is given, with some correct observations, but with minor omissions (such as a missing acidification step, or observations given for only one ion of a pair) or a small inaccuracy. **3-4**

Level 1 Some relevant but isolated or incomplete points made, such as naming a test without stating reagents/conditions, or stating an observation without a valid method; limited coverage of cations or anions. **1-2**

Level 0 No relevant chemistry given, or the response is entirely incorrect or irrelevant. **0**

Indicative content:

- Dissolve a small sample of solid X in distilled water to make a solution for testing.
- Flame test for the cation: dip a clean nichrome (or platinum) wire into concentrated hydrochloric acid, then into a sample of the solid or solution, and hold it in a blue Bunsen flame.
- Observe the flame colour: magnesium gives no distinctive flame colour (or is not usually flame tested); calcium gives a brick-red/orange-red flame; barium gives a green (apple-green) flame.
- Anion (halide) test: add a few drops of dilute nitric acid to a fresh sample of the solution (to remove any carbonate/hydroxide interference), then add silver nitrate solution, $AgNO_3(aq)$.
- Observe the precipitate: a white precipitate that dissolves in dilute ammonia solution indicates chloride ions (AgCl); a cream precipitate that dissolves only in concentrated ammonia solution indicates bromide ions (AgBr); a yellow precipitate that is insoluble even in concentrated ammonia solution indicates iodide ions (AgI).
- Test the solubility of any precipitate in dilute ammonia solution, then in concentrated ammonia solution, to distinguish between the three halides.
- An alternative or confirmatory anion test is to add a small sample of the solid to concentrated sulfuric acid: chloride gives only steamy white fumes (HCl); bromide gives steamy fumes plus orange bromine vapour/fumes (from further redox with H_2SO_4); iodide gives purple/black solid or vapour (iodine) together with the toxic, rotten-egg-smelling gas hydrogen sulfide, from more extensive reduction of the sulfuric acid.
- Combining the flame test result (identifying the metal cation) with the silver nitrate/ammonia (or concentrated sulfuric acid) result (identifying the halide anion) allows the full identity of compound X to be deduced.

Question 8

(a) correct species: Cl_2, Br^-, Cl^-, Br_2 **M1**

(a) $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$ fully balanced cao **A1**

(a) solution turns (from colourless) to orange oe **B1**

(a) Answer: $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$; the solution turns orange

(b) oxidising power (ability to gain electrons/be reduced) decreases down Group 7, so chlorine is a stronger oxidising agent than bromine (and iodine) oe **B1**

(b) chlorine, as the stronger oxidising agent, can oxidise (remove electrons from) Br^-; but iodine is a weaker oxidising agent than chlorine, so it cannot oxidise Cl^- (remove electrons from the already more strongly held chloride ion) oe **B1**

(b) Answer: Oxidising power decreases down Group 7, so Cl_2 (a stronger oxidising agent) can oxidise Br^- to Br_2, but I_2 (a weaker oxidising agent than Cl_2) cannot oxidise Cl^- to Cl_2

(c) correct species: Cl_2, NaOH, NaCl, NaOCl (or NaClO), H_2O **M1**

(c) $Cl_2 + 2NaOH \rightarrow NaCl + NaOCl + H_2O$ fully balanced cao **A1**

(c) commercial use: household bleach / disinfectant oe **B1**

(c) this is an example of a disproportionation reaction **B1**

(c) Answer: $Cl_2 + 2NaOH \rightarrow NaCl + NaOCl + H_2O$; the mixture (containing sodium chlorate(I), NaOCl) is used as household bleach/disinfectant; this is a disproportionation reaction

(d) disproportionation is a reaction in which the same element is simultaneously oxidised and reduced oe **B1**

(d) chlorine in Cl_2 has oxidation state 0, and is reduced to -1 in Cl^- (NaCl) ft from (c) **B1**

(d) chlorine in Cl_2 (oxidation state 0) is also oxidised to +1 in ClO^- (NaOCl) ft from (c) **B1**

(d) Answer: Disproportionation is when the same element is simultaneously oxidised and reduced; here Cl (0 in Cl_2) is reduced to -1 (in Cl^-) and oxidised to +1 (in ClO^-) in the same reaction

Question 9

(a) $NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$ cao **B1**

(a) steamy/misty white fumes (of HCl gas) observed oe **B1**

(a) Answer: $NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$; steamy white fumes of HCl gas are observed

(b) $2HBr + H_2SO_4 \rightarrow Br_2 + SO_2 + 2H_2O$ cao **B1**

(b) sulfur in H_2SO_4 = +6 **B1**

(b) sulfur in SO_2 = +4 **B1**

(b) Answer: $2HBr + H_2SO_4 \rightarrow Br_2 + SO_2 + 2H_2O$; S in H_2SO_4 = +6, S in SO_2 = +4

(c) $8HI + H_2SO_4 \rightarrow 4I_2 + H_2S + 4H_2O$ (accept $8NaI + 9H_2SO_4 \rightarrow 8NaHSO_4 + 4I_2 + H_2S + 4H_2O$, or $8H^+ + 8I^- + H_2SO_4 \rightarrow 4I_2 + H_2S + 4H_2O$) oe **M1**

(c) sulfur in H_2SO_4 = +6 **A1**

(c) sulfur in H_2S = -2 **A1**

(c) this is a change of 8 in oxidation state (from +6 to -2), showing iodide is a much stronger reducing agent than bromide (which only reduces S to +4 in SO_2) oe **B1**

(c) Answer: $8HI + H_2SO_4 \rightarrow 4I_2 + H_2S + 4H_2O$; S in H_2SO_4 = +6, S in H_2S = -2

(d) reducing power depends on how readily the halide ion loses an electron (is oxidised) oe **B1**

(d) ionic radius increases down the group ($Cl^- < Br^- < I^-$), so the outer electron to be lost is further from the nucleus and more shielded oe **B1**

(d) this electron is less strongly attracted/held, so it is lost more easily down the group, meaning I^- loses an electron more readily than Cl^- and is therefore a stronger reducing agent oe **B1**

(d) Answer: Ionic radius increases down the group, so the outer electron of I^- is further from the nucleus and more shielded than in Cl^-; it is therefore lost more easily, making I^- a stronger reducing agent than Cl^-

Question 10

(a) $MgCO_3$ -> $MgO + CO_2$ cao **B1**

(a) Answer: $MgCO_3$ -> $MgO + CO_2$

(b) $n(MgCO_3) = 5.05/84.3 = 0.0599$ mol **M1**

(b) $n(CO_2) = n(MgCO_3) = 0.0599$ mol (1:1 ratio from equation in (a)) ft **M1**

(b) volume = 0.0599 x 24 = 1.44 dm3 cao (awrt 1.44 dm3) ft **A1**

(b) Answer: 1.44 dm3

(c) Mg^{2+} is a smaller, more highly charge-dense ion than Ba^{2+} (both have the same 2+ charge, but Mg^{2+} has a much smaller ionic radius) oe **B1**

(c) the smaller, more charge-dense Mg^{2+} ion polarises (distorts) the electron cloud of the neighbouring carbonate ion more strongly than the larger Ba^{2+} ion does oe **B1**

(c) this greater distortion weakens a C-O bond within the carbonate ion more in $MgCO_3$, so less energy (a lower temperature) is needed to break it down to the oxide and CO_2, whereas $BaCO_3$ needs a much higher temperature oe **B1**

(c) Answer: Mg^{2+} is smaller and more charge-dense than Ba^{2+}, so it polarises the carbonate ion's electron cloud more strongly, weakening a C-O bond more and allowing $MgCO_3$ to decompose at a lower temperature than $BaCO_3$

(d) $SrCO_3$ would need a higher temperature than $MgCO_3$ to decompose oe **B1**

(d) Sr^{2+} is larger than Mg^{2+} (lower down Group 2), so it is less polarising/has a lower charge density, causing less distortion of the carbonate ion and so requiring more energy (a higher temperature) to decompose oe **B1**

(d) Answer: $SrCO_3$ needs a higher temperature than $MgCO_3$; Sr^{2+} is larger and less polarising than Mg^{2+}, so it distorts the carbonate ion less, making $SrCO_3$ more thermally stable

Question 11

(a) NaCl simply dissolves in water, dissociating into hydrated Na^+(aq) and Cl^-(aq) ions, giving a neutral solution (pH about 7), oe **B1**

(a) $SiCl_4$ reacts (hydrolyses) vigorously with water, producing steamy, acidic white fumes of HCl gas (and a precipitate of hydrated SiO_2), oe **B1**

(a) $SiCl_4 + 2H_2O$ -> $SiO_2 + 4HCl$ **B1**

(a) Answer: NaCl simply dissolves (neutral); $SiCl_4$ hydrolyses vigorously ($SiCl_4 + 2H_2O$ -> $SiO_2 + 4HCl$), giving an acidic solution.

(b) $SiCl_4$ is a simple covalent molecule (Si and Cl have a small electronegativity difference), so a water molecule's lone pair can attack the electron-deficient/polar silicon atom directly, breaking the Si-Cl covalent bonds, oe **B1**

(b) NaCl is ionic; it simply dissociates into its already-separate ions on dissolving, with no covalent bonds present to attack or break, so no hydrolysis reaction of this kind occurs, oe **B1**

(b) Answer: $SiCl_4$'s covalent Si-Cl bonds are attacked by water; NaCl has no covalent bonds to hydrolyse.

(c) moles $PCl_5 = 2.00/208.5$ **M1**

(c) moles HCl produced = 5 x moles PCl_5 (mole ratio), ft **M1**

(c) $[H^+] = [HCl]$ = moles HCl / 0.250 dm3, ft **M1**

(c) $[H^+] = 0.192$ mol/dm3 (accept 0.19-0.192), ft **A1**

(c) pH = $-\log10[H^+] = 0.72$ (accept 0.7-0.72), ft, cao **A1**

(c) Answer: pH = 0.72

Question 12

(a) first ionisation energy generally increases across the period **B1**

(a) because nuclear charge increases while electrons are added to the same outer shell (shielding stays roughly constant), so the effective nuclear attraction on the outer electrons increases, oe **B1**

(a) Answer: First ionisation energy generally increases across Period 3.

(b) identifies both anomalies: Mg to Al, and P to S **B1**

(b) Al's outermost electron occupies a 3p sub-shell, which is at a slightly higher energy (further from the nucleus, more shielded by the full 3s2 sub-shell) than the 3s electrons removed from Mg, oe **B1**

(b) so despite Al's higher nuclear charge, this 3p electron is easier to remove than a 3s electron from Mg, oe **B1**

(b) Answer: Anomalies at Mg->Al and P->S; the Mg->Al drop occurs because Al's electron is removed from a higher-energy 3p sub-shell.

(c) correct substitution: (738-577)/738 x 100 **M1**

(c) 21.8% (accept 21.7-21.9%) **A1**

(c) correct substitution: (1012-1000)/1012 x 100 **M1**

(c) 1.2% (accept 1.1-1.2%); the Mg to Al decrease is much larger in percentage terms **A1**

(c) Answer: Mg to Al: 21.8% decrease; P to S: 1.2% decrease.

Question 13

(a) correct substitution: 3.56/148.3 **M1**

(a) 0.0240 mol, cao **A1**

(a) Answer: 0.0240 mol

(b) correct mole ratio: 2 mol $Mg(NO_3)_2$ produces (4+1) = 5 mol gas, i.e. 2.5 mol gas per mol $Mg(NO_3)_2$, ft from (a) **M1**

(b) correct substitution: 0.0240 x 2.5 **M1**

(b) 0.0600 mol, ft, cao **A1**

(b) Answer: 0.0600 mol

(c) correct substitution: 0.0600 x 24000, ft from (b) **M1**

(c) 1440 cm^3, ft, cao **A1**

(c) equivalent to 1.44 dm3 (correct conversion) **B1**

(c) Answer: 1440 cm^3 (1.44 dm3)

(d) Mg^{2+} is much smaller than Ba^{2+} for the same ionic charge (+2), giving Mg^{2+} a much higher charge density and greater polarising power, oe **B1**

(d) Mg^{2+} polarises (distorts the electron cloud of) the nitrate ion more strongly, weakening its N-O bonds more, so less thermal energy (a lower temperature) is needed to decompose $Mg(NO_3)_2$ than $Ba(NO_3)_2$, oe **B1**

(d) Answer: Mg^{2+} has a higher charge density than Ba^{2+}, polarising the nitrate ion more and lowering the decomposition temperature.

Question 14

(a) correct substitution: 0.100 x (21.50/1000) **M1**

(a) 2.15 x 10^{-3} mol, cao **A1**

(a) Answer: 2.15 x 10^{-3} mol

(b) mole ratio $I_2 : S_2O_3^{2-}$ = 1 : 2, ft from (a) **M1**

(b) 1.075 x 10^{-3} mol, ft **A1**

(b) Answer: 1.075 x 10^{-3} mol

(c) mole ratio $ClO^- : I_2$ = 1 : 1, ft from (b) **M1**

(c) 1.075 x 10^{-3} mol, ft **A1**

(c) Answer: 1.075 x 10^{-3} mol

(d) moles ClO^- in the whole 250 cm^3 diluted solution (= moles in the original 10.0 cm^3 of bleach) = 1.075 x 10^{-3} x 10, ft **M1**

(d) concentration = moles / 0.0100 dm3 **M1**

(d) 1.08 mol/dm3 (accept 1.07-1.08), ft, cao **A1**

(d) Answer: 1.08 mol/dm3

Question 15

Level 3 A detailed, correct and coherent explanation linking the ionic bonding of Na_2O and MgO to basicity, the intermediate/borderline bonding of amphoteric Al_2O_3, and the covalent bonding of SiO_2, P_4O_{10} and SO_3 to acidity, with a clear statement that the trend from ionic to covalent bonding across the period parallels the trend from basic to acidic oxide character. **5-6**

Level 2 A mostly correct explanation linking bonding type to acid-base character for some of the oxides, but with a gap (e.g. amphoteric character not explained) or an underdeveloped link between bonding trend and acid-base trend. **3-4**

Level 1 Some relevant, briefly stated facts about individual oxides (e.g. 'SO_3 is acidic') are given, without a coherent explanation linking bonding type to the acid-base trend across the period. **1-2**

Indicative content:

- Na_2O and MgO are ionic oxides, formed between a reactive metal and oxygen, existing as giant ionic lattices; they react with water to release OH^- ions (or react directly with acids), making them basic.
- Al_2O_3 has intermediate/borderline bonding character: aluminium's small size and high charge (Al^{3+}) give some covalent character to its bonding with oxygen, allowing Al_2O_3 to react with both acids (acting as a base) and alkalis (acting as an acid), so it is described as amphoteric.
- SiO_2 is a giant covalent (macromolecular) oxide; P_4O_{10} and SO_3 are simple molecular covalent oxides, formed between non-metals and oxygen where there is a smaller electronegativity difference.
- These covalent, non-metal oxides react with water (or, for SiO_2, only with hot concentrated alkali) to form acidic solutions or acidic oxoacids (e.g. P_4O_{10} with water forms phosphoric acid; SO_3 with water forms sulfuric acid), so they are described as acidic oxides.
- The trend from ionic to covalent bonding across Period 3 (as the electronegativity of the Period 3 element increases and its metallic character decreases) directly parallels the trend from basic to acidic oxide character.
- In general, a large electronegativity difference between a Period 3 element and oxygen favours ionic bonding and basic character, while a small electronegativity difference favours covalent bonding and acidic character.

Question 16

(a) combined absolute uncertainty = 0.05 + 0.05 = 0.10 cm^3, then (0.10/21.50) x 100 **M1**

(a) 0.47% (accept 0.46-0.47%) **A1**

(a) Answer: 0.47%

(b) correct substitution: (0.06/25.0) x 100 **M1**

(b) 0.24%, cao **A1**

(b) Answer: 0.24%

(c) correct substitution: (0.04/10.0) x 100 **M1**

(c) 0.40%, cao **A1**

(c) Answer: 0.40%

(d) total percentage uncertainty = 0.47 + 0.24 + 0.40, ft **M1**

(d) approximately 1.1%, a small combined percentage uncertainty, so the titration method gives a precise result (though this does not by itself confirm accuracy, since systematic errors are not included in this estimate), oe **B1**

(d) Answer: Approximately 1.1%; the method is precise.

Question 17

(a) atomic radius increases down the group **B1**

(a) so the incoming electron (during reduction, X2 + 2e- -> 2X-) is added at a greater distance from the nucleus and is more shielded by inner electron shells, oe **B1**

(a) the electrostatic attraction between the nucleus and the incoming electron is therefore weaker, so oxidising power (the tendency to gain electrons) decreases down the group, oe **B1**

(a) Answer: Oxidising power decreases down the group as atomic radius and shielding increase.

(b) $Cl_2 + 2I^- \rightarrow 2Cl^- + I_2$ **B1**

(b) chlorine, being higher up the group with a smaller atomic radius, has a stronger oxidising power (greater tendency to gain electrons) than iodine, oe **B1**

(b) so Cl_2 is able to remove electrons from (oxidise) I^- ions, forming I_2 and Cl^-, whereas I_2, being a weaker oxidising agent, could not oxidise Cl^- in the reverse direction, oe **B1**

(b) Answer: $Cl_2 + 2I^- \rightarrow 2Cl^- + I_2$; chlorine is a stronger oxidising agent than iodine.

(c) F_2 reacts directly and violently with water itself (e.g. oxidising water to oxygen), rather than remaining available to oxidise the halide ions in solution, oe **B1**

(c) so F_2 cannot be used as a simple aqueous displacement reagent in the way that Cl_2 and Br_2 can, oe **B1**

(c) Answer: F_2 reacts with water itself, so it cannot be used as an aqueous displacement reagent.