AC6D The Periodic Table and Inorganic Chemistry: Depth and Exam Drill

Total Marks

AQA 7405 · Calculator allowed · about 155 minutes

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 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 1 is 4 marks)

---

2 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 2 is 9 marks)

3 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 3 is 10 marks)

---

4 This question uses lattice enthalpies and hydration enthalpies to explain the decreasing solubility of Group 2 sulfates down the group.

(a) State the two enthalpy changes, other than the enthalpy of solution itself, that together make up a Hess's law cycle for finding the enthalpy of solution of an ionic solid, MX(s). **(2)**

(b) Lattice enthalpy of formation of $MgSO_4$ = -2870 kJ/mol; hydration enthalpy of Mg^{2+} = -1920 kJ/mol; hydration enthalpy of SO_4^{2-} = -1090 kJ/mol. Calculate the enthalpy of solution of $MgSO_4$. **(4)**

(c) Lattice enthalpy of formation of $BaSO_4$ = -2423 kJ/mol; hydration enthalpy of Ba^{2+} = -1360 kJ/mol; hydration enthalpy of SO_4^{2-} = -1090 kJ/mol. Calculate the enthalpy of solution of $BaSO_4$, and compare it with your answer to (b). **(4)**

(d) Suggest why hydration enthalpy becomes less exothermic (smaller in magnitude) down Group 2. **(2)**

(Total for Question 4 is 12 marks)

5 This question is about the acid-base character of Period 3 oxides.

(a) Write balanced equations for the reaction of aluminium oxide, Al2O3, with (i) hot concentrated hydrochloric acid and (ii) hot concentrated sodium hydroxide solution, to illustrate its amphoteric character. **(2)**

(b) State what the ability of Al2O3 to react with both an acid and a base shows about its character. **(2)**

(c) Predict, with a reason, the approximate pH of the solutions formed when separate samples of sodium oxide, Na2O, and sulfur trioxide, SO3, are each added to water. **(3)**

(d) Write the equation for the reaction of silicon dioxide, SiO2, with hot concentrated sodium hydroxide, and explain why SiO2 does not react with dilute hydrochloric acid. **(2)**

(Total for Question 5 is 9 marks)

---

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

(a) 10.0 cm3 of household bleach is diluted to 250 cm3 in a volumetric flask. A 25.0 cm3 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 cm3 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 I2 that reacted with the thiosulfate. **(2)**

(c) Calculate the number of moles of ClO- in the 25.0 cm3 sample. **(2)**

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

(Total for Question 6 is 9 marks)

---

7 Explain, in terms of bonding and structure, why the oxides of Period 3 elements show a trend from strongly basic (Na2O, MgO) through amphoteric (Al2O3) to strongly acidic (SiO2, P4O10, SO3) 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 7 is 6 marks)

8 This question analyses the measurement uncertainty in the bleach titration described in Question 6.

(a) The 21.50 cm3 titre in Question 6 was obtained using a burette readable to ± 0.05 cm3 per reading. Calculate the percentage uncertainty in this titre (combined from two readings). **(2)**

(b) The 25.0 cm3 sample was measured using a pipette with an uncertainty of ± 0.06 cm3. Calculate its percentage uncertainty. **(2)**

(c) The 10.0 cm3 sample of undiluted bleach was measured using a pipette with an uncertainty of ± 0.04 cm3. Calculate its percentage uncertainty. **(2)**

(d) Estimate the overall percentage uncertainty in the final concentration of bleach calculated in Question 6, and comment on whether this method is likely to give a precise result. **(2)**

(Total for Question 8 is 8 marks)

---

9 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 F2 to I2. **(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 I2 or Br2 from aqueous halide solutions, even though F2 is by far the strongest oxidising agent in the group. **(2)**

(Total for Question 9 is 8 marks)

---

10 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 SiCl4(l) are separately added to water. **(3)**

(b) Explain, in terms of bonding, why SiCl4 hydrolyses in this way but NaCl does not. **(2)**

(c) 2.00 g of PCl5 (Mr = 208.5) is added to excess water and hydrolyses completely: PCl5 + 4H2O -> H3PO4 + 5HCl. The resulting solution is made up to 250 cm3 with distilled water. Calculate the pH of this solution, assuming HCl is fully dissociated and ignoring any contribution to acidity from H3PO4. **(5)**

(Total for Question 10 is 10 marks)

Mark scheme · AC6D The Periodic Table and Inorganic Chemistry: Depth and Exam Drill

Question 1

- (a) **B1** a repeating (periodic) trend in the physical or chemical properties of elements when arranged in order of increasing atomic (proton) number, oe
- **(a) Answer: A repeating trend in element properties with increasing atomic number.**
- (b) **B1** a redox reaction in which the same element is simultaneously oxidised and reduced, oe
- **(b) Answer: A redox reaction in which the same element is both oxidised and reduced.**
- (c) **B1** an oxide that can react with both acids and bases (alkalis), oe
- **(c) Answer: An oxide that reacts with both acids and bases.**
- (d) **B1** its oxidation number increases (it is oxidised), oe
- **(d) Answer: Its oxidation number increases.**

Question 2

- (a) **B1** first ionisation energy generally increases across the period
- (a) **B1** 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
- **(a) Answer: First ionisation energy generally increases across Period 3.**
- (b) **B1** identifies both anomalies: Mg to Al, and P to S
- (b) **B1** 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
- (b) **B1** so despite Al's higher nuclear charge, this 3p electron is easier to remove than a 3s electron from Mg, oe
- **(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) **M1** correct substitution: (738-577)/738 x 100
- (c) **A1** 21.8% (accept 21.7-21.9%)
- (c) **M1** correct substitution: (1012-1000)/1012 x 100
- (c) **A1** 1.2% (accept 1.1-1.2%); the Mg to Al decrease is much larger in percentage terms
- **(c) Answer: Mg to Al: 21.8% decrease; P to S: 1.2% decrease.**

Question 3

- (a) **M1** correct substitution: 3.56/148.3
- (a) **A1** 0.0240 mol, cao
- **(a) Answer: 0.0240 mol**
- (b) **M1** correct mole ratio: 2 mol Mg(NO3)2 produces (4+1) = 5 mol gas, i.e. 2.5 mol gas per mol Mg(NO3)2, ft from (a)
- (b) **M1** correct substitution: 0.0240 x 2.5
- (b) **A1** 0.0600 mol, ft, cao
- **(b) Answer: 0.0600 mol**
- (c) **M1** correct substitution: 0.0600 x 24000, ft from (b)
- (c) **A1** 1440 cm3, ft, cao
- (c) **B1** equivalent to 1.44 dm3 (correct conversion)
- **(c) Answer: 1440 cm3 (1.44 dm3)**
- (d) **B1** Mg2+ is much smaller than Ba2+ for the same ionic charge (+2), giving Mg2+ a much higher charge density and greater polarising power, oe
- (d) **B1** Mg2+ 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(NO3)2 than Ba(NO3)2, oe
- **(d) Answer: Mg2+ has a higher charge density than Ba2+, polarising the nitrate ion more and lowering the decomposition temperature.**

Question 4

- (a) **B1** breaking the ionic lattice into gaseous ions (equal in magnitude but opposite in sign to the lattice enthalpy of formation), oe
- (a) **B1** hydrating each of the resulting gaseous ions (the cation and the anion), oe
- **(a) Answer: Lattice dissociation into gaseous ions, then hydration of each gaseous ion.**
- (b) **M1** lattice dissociation enthalpy = +2870 kJ/mol (reverse sign of the lattice enthalpy of formation)
- (b) **M1** correct Hess's law sum: delta Hsoln = 2870 + (-1920) + (-1090)
- (b) **A1** -140 kJ/mol, cao
- (b) **B1** the exothermic value is consistent with MgSO4 being freely soluble in water, oe
- **(b) Answer: -140 kJ/mol**
- (c) **M1** lattice dissociation enthalpy = +2423 kJ/mol
- (c) **M1** correct Hess's law sum: delta Hsoln = 2423 + (-1360) + (-1090)
- (c) **A1** -27 kJ/mol, cao
- (c) **B1** delta Hsoln for BaSO4 is much less exothermic than for MgSO4, consistent with BaSO4 being far less soluble in water, oe
- **(c) Answer: -27 kJ/mol**
- (d) **B1** ionic radius increases down the group, so the cation's charge density decreases, oe
- (d) **B1** giving a weaker electrostatic attraction to (and so weaker hydration by) surrounding water molecules, oe
- **(d) Answer: Larger ionic radius down the group gives a lower charge density and weaker hydration.**

Question 5

- (a) **B1** Al2O3 + 6HCl -> 2AlCl3 + 3H2O
- (a) **B1** Al2O3 + 2NaOH + 3H2O -> 2NaAl(OH)4, oe (accept Al2O3 + 2NaOH -> 2NaAlO2 + H2O)
- **(a) Answer: Al2O3 + 6HCl -> 2AlCl3 + 3H2O; Al2O3 + 2NaOH + 3H2O -> 2NaAl(OH)4.**
- (b) **B1** Al2O3 is amphoteric, oe
- (b) **B1** this reflects Al2O3's intermediate bonding character, between the ionic oxides of Na and Mg and the covalent oxides of Si, P, S and Cl, oe
- **(b) Answer: Al2O3 is amphoteric, reflecting intermediate ionic/covalent bonding character.**
- (c) **B1** Na2O gives a strongly alkaline solution (pH about 13-14), because Na2O is a basic ionic oxide that reacts with water to form NaOH, oe
- (c) **B1** SO3 gives a strongly acidic solution (pH about 0-1), because SO3 is an acidic covalent oxide that reacts with water to form H2SO4, oe
- (c) **B1** basic oxides are typically ionic (metal) oxides, while acidic oxides are typically covalent (non-metal) oxides, oe
- **(c) Answer: Na2O gives pH about 13-14 (forms NaOH); SO3 gives pH about 0-1 (forms H2SO4).**
- (d) **B1** SiO2 + 2NaOH -> Na2SiO3 + H2O
- (d) **B1** SiO2 is acidic, not basic, so it cannot react with another acid such as HCl, oe
- **(d) Answer: SiO2 + 2NaOH -> Na2SiO3 + H2O; SiO2 is acidic so does not react with HCl.**

Question 6

- (a) **M1** correct substitution: 0.100 x (21.50/1000)
- (a) **A1** 2.15 x 10^{-3} mol, cao
- **(a) Answer: 2.15 x 10^{-3} mol**
- (b) **M1** mole ratio I2 : $S2O3^{2-}$ = 1 : 2, ft from (a)
- (b) **A1** 1.075 x 10^{-3} mol, ft
- **(b) Answer: 1.075 x 10^{-3} mol**
- (c) **M1** mole ratio ClO- : I2 = 1 : 1, ft from (b)
- (c) **A1** 1.075 x 10^{-3} mol, ft
- **(c) Answer: 1.075 x 10^{-3} mol**
- (d) **M1** moles ClO- in the whole 250 cm3 diluted solution (= moles in the original 10.0 cm3 of bleach) = 1.075 x 10^{-3} x 10, ft
- (d) **M1** concentration = moles / 0.0100 dm3

Question 7

- **Level 3** (5-6): 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.
- **Level 2** (3-4): 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.
- **Level 1** (1-2): 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.
- **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 8

- (a) **M1** combined absolute uncertainty = 0.05 + 0.05 = 0.10 cm3, then (0.10/21.50) x 100
- (a) **A1** 0.47% (accept 0.46-0.47%)
- **(a) Answer: 0.47%**
- (b) **M1** correct substitution: (0.06/25.0) x 100
- (b) **A1** 0.24%, cao
- **(b) Answer: 0.24%**
- (c) **M1** correct substitution: (0.04/10.0) x 100
- (c) **A1** 0.40%, cao
- **(c) Answer: 0.40%**
- (d) **M1** total percentage uncertainty = 0.47 + 0.24 + 0.40, ft
- (d) **B1** 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
- **(d) Answer: Approximately 1.1%; the method is precise.**

Question 9

- (a) **B1** atomic radius increases down the group
- (a) **B1** 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
- (a) **B1** 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
- **(a) Answer: Oxidising power decreases down the group as atomic radius and shielding increase.**
- (b) **B1** Cl2 + 2I- -> 2Cl- + I2
- (b) **B1** chlorine, being higher up the group with a smaller atomic radius, has a stronger oxidising power (greater tendency to gain electrons) than iodine, oe
- (b) **B1** so Cl2 is able to remove electrons from (oxidise) I- ions, forming I2 and Cl-, whereas I2, being a weaker oxidising agent, could not oxidise Cl- in the reverse direction, oe
- **(b) Answer: Cl2 + 2I- -> 2Cl- + I2; chlorine is a stronger oxidising agent than iodine.**
- (c) **B1** F2 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
- (c) **B1** so F2 cannot be used as a simple aqueous displacement reagent in the way that Cl2 and Br2 can, oe
- **(c) Answer: F2 reacts with water itself, so it cannot be used as an aqueous displacement reagent.**

Question 10

- (a) **B1** NaCl simply dissolves in water, dissociating into hydrated Na+(aq) and Cl-(aq) ions, giving a neutral solution (pH about 7), oe
- (a) **B1** SiCl4 reacts (hydrolyses) vigorously with water, producing steamy, acidic white fumes of HCl gas (and a precipitate of hydrated SiO2), oe
- (a) **B1** SiCl4 + 2H2O -> SiO2 + 4HCl
- **(a) Answer: NaCl simply dissolves (neutral); SiCl4 hydrolyses vigorously (SiCl4 + 2H2O -> SiO2 + 4HCl), giving an acidic solution.**
- (b) **B1** SiCl4 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
- (b) **B1** 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
- **(b) Answer: SiCl4's covalent Si-Cl bonds are attacked by water; NaCl has no covalent bonds to hydrolyse.**
- (c) **M1** moles PCl5 = 2.00/208.5
- (c) **M1** moles HCl produced = 5 x moles PCl5 (mole ratio), ft
- (c) **M1** [H+] = [HCl] = moles HCl / 0.250 dm3, ft
- (c) **A1** [H+] = 0.192 mol/dm3 (accept 0.19-0.192), ft
- (c) **A1** pH = -log10[H+] = 0.72 (accept 0.7-0.72), ft, cao
- **(c) Answer: pH = 0.72**