2.6 The Periodic Table and Inorganic Chemistry: Test Pack

Total Marks

AQA 7405 · Calculator allowed · about 70 minutes

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 This question is about trends across Period 3, from sodium (Na) to argon (Ar).

(a) State how atomic radius changes from sodium to chlorine across Period 3. **(1)**

(b) Explain why atomic radius decreases across Period 3 from sodium to chlorine. **(2)**

(c) The first ionisation energy generally increases across Period 3, but there is a decrease between magnesium and aluminium. Explain this decrease. **(3)**

(d) There is also a decrease in first ionisation energy between phosphorus and sulfur. Explain this decrease. **(2)**

(Total for Question 1 is 8 marks)

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2 This question is about solubility trends of Group 2 compounds and a required practical test for sulfate ions.

(a) State how the solubility of Group 2 hydroxides changes down the group, and use this to explain why magnesium hydroxide, rather than barium hydroxide, is used as the active ingredient in indigestion remedies. **(2)**

(b) State how the solubility of Group 2 sulfates changes down the group, and explain why barium sulfate, despite being an insoluble compound of a toxic metal, can be used safely as a 'barium meal' in medical X-ray imaging. **(2)**

(c) Describe how you would carry out a chemical test on a solution to confirm the presence of sulfate ions, SO_4^{2-}, including the reagents used, the order of addition, and the expected positive result. **(3)**

(d) A student adds excess barium chloride solution to 25.0 cm^3 of 0.150 mol dm-3 magnesium sulfate solution. Calculate the mass, in g, of barium sulfate precipitate formed. (Mr of $BaSO_4$ = 233.4) **(3)**

(Total for Question 2 is 10 marks)

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3 This question uses practical techniques from the required practical on acid-base titrations. A student wants to determine the mass of magnesium hydroxide, $Mg(OH)_2$, in an indigestion tablet. The tablet is crushed and reacted with 50.0 cm^3 of 0.500 mol dm-3 hydrochloric acid, an amount known to be in excess.

Equation: $Mg(OH)_2 + 2HCl \rightarrow MgCl_2 + 2H_2O$

The excess (unreacted) acid is then titrated against 0.200 mol dm-3 sodium hydroxide solution, requiring a mean titre of 24.60 cm^3.

(Mr of $Mg(OH)_2$ = 58.3)

(a) Calculate the initial amount, in mol, of HCl added to the crushed tablet. **(1)**

(b) Calculate the amount, in mol, of NaOH used in the titration, and hence the amount, in mol, of HCl that was left unreacted (in excess) after reacting with the tablet. **(2)**

(c) Calculate the amount, in mol, of HCl that reacted with the $Mg(OH)_2$ in the tablet, and hence the amount, in mol, of $Mg(OH)_2$ present. **(2)**

(d) Calculate the mass, in g, of $Mg(OH)_2$ in the tablet. **(2)**

(e) The tablet packaging states that each tablet contains 600 mg of $Mg(OH)_2$. Evaluate whether the student's experimental result in part (d) supports this claim. **(2)**

(Total for Question 3 is 9 marks)

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

(a) Write balanced equations for the reaction of aluminium oxide, Al_2O_3, 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 Al_2O_3 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, Na_2O, and sulfur trioxide, SO_3, are each added to water. **(3)**

(d) Write the equation for the reaction of silicon dioxide, SiO_2, with hot concentrated sodium hydroxide, and explain why SiO_2 does not react with dilute hydrochloric acid. **(2)**

(Total for Question 4 is 9 marks)

5 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 5 is 12 marks)

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Mark scheme · 2.6 The Periodic Table and Inorganic Chemistry: Test Pack

Question 1

(a) atomic radius decreases (across the period) oe **B1**

(a) Answer: Atomic radius decreases from Na to Cl

(b) nuclear charge (number of protons) increases across the period **B1**

(b) number of shells (and shielding from inner electrons) stays the same, so the increased nuclear charge pulls the outer electrons in more strongly, reducing the radius oe **B1**

(b) Answer: Nuclear charge increases across the period while the number of shells (shielding) stays constant, so outer electrons are pulled closer to the nucleus, decreasing atomic radius

(c) in Mg the outer electron removed is from a full 3s subshell, but in Al the outer electron removed is from the 3p subshell oe **B1**

(c) the 3p electron in Al is at a (slightly) higher energy than the 3s electrons and/or is shielded by the 3s electrons oe **B1**

(c) so less energy is needed to remove the 3p electron from Al than to remove a 3s electron from Mg, giving a lower first ionisation energy despite Al having one more proton **B1**

(c) Answer: Aluminium's outer electron is removed from the higher-energy 3p subshell (shielded slightly by the 3s electrons), so it requires less energy to remove than a 3s electron from magnesium, even though Al has a greater nuclear charge

(d) in P the 3p subshell is half-filled (3p3, one electron in each of three orbitals), which is an extra-stable arrangement oe **B1**

(d) in S the fourth 3p electron must pair up with an existing electron in the same orbital; the repulsion between the two paired electrons makes it easier to remove one, lowering the first ionisation energy oe **B1**

(d) Answer: Phosphorus has a stable, half-filled 3p3 configuration; sulfur's fourth 3p electron must pair in an already-occupied orbital, and the extra electron-electron repulsion makes this electron easier to remove

Question 2

(a) solubility of Group 2 hydroxides increases down the group oe **B1**

(a) $Mg(OH)_2$ is only sparingly soluble, so it forms a mild suspension that safely neutralises small amounts of excess stomach acid without the solution becoming too concentrated/strongly alkaline, unlike the more soluble $Ba(OH)_2$ oe **B1**

(a) Answer: Solubility of Group 2 hydroxides increases down the group; $Mg(OH)_2$ is only sparingly soluble, giving a mild, safely-controlled antacid, whereas the more soluble $Ba(OH)_2$ would give a dangerously concentrated alkaline solution

(b) solubility of Group 2 sulfates decreases down the group oe **B1**

(b) $BaSO_4$ is so insoluble that essentially no Ba^{2+} ions are released into the body/bloodstream, so it is non-toxic even though soluble barium compounds are poisonous oe **B1**

(b) Answer: Solubility of Group 2 sulfates decreases down the group; $BaSO_4$ is so insoluble that virtually no Ba^{2+} ions enter the bloodstream, making it safe despite the toxicity of soluble barium salts

(c) add a few drops of dilute hydrochloric acid to the test solution first oe **B1**

(c) then add barium chloride solution ($BaCl_2(aq)$) oe **B1**

(c) a (white) precipitate forms if sulfate ions are present ($BaSO_4$); the dilute HCl added first removes/prevents a false positive from carbonate or sulfite ions, which would also give a white precipitate with $BaCl_2$ but which dissolves in/reacts away with the acid oe **B1**

(c) Answer: Add dilute HCl to the solution first (to remove any carbonate/sulfite ions), then add $BaCl_2(aq)$; a white precipitate ($BaSO_4$) confirms sulfate ions are present

(d) $n(MgSO_4) = (25.0/1000) \times 0.150 = 3.75 \times 10^{-3}$ mol **M1**

(d) $n(BaSO_4) = n(MgSO_4) = 3.75 \times 10^{-3}$ mol (1:1 ratio, $BaCl_2$ in excess) **M1**

(d) mass = 3.75e-3 x 233.4 = 0.875 g cao (awrt 0.875 g) **A1**

(d) Answer: 0.875 g

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Question 3

(a) 0.0250 mol cao **B1**

(a) Answer: 0.0250 mol

(b) n(NaOH) = 0.200 x (24.60/1000) = 4.92 x 10^{-3} mol **M1**

(b) n(excess HCl) = n(NaOH) = 4.92 x 10^{-3} mol cao (1:1 ratio, NaOH + HCl -> NaCl + H_2O) **A1**

(b) Answer: 4.92 x 10^{-3} mol

(c) n(HCl reacted with tablet) = 0.0250 - 4.92e-3 = 0.02008 mol ft from (a) and (b) **M1**

(c) n($Mg(OH)_2$) = 0.02008/2 = 0.01004 mol cao (awrt 0.0100-0.0101 mol) ft **A1**

(c) Answer: 0.01004 mol

(d) mass = 0.01004 x 58.3 ft from (c) **M1**

(d) 0.585 g cao (awrt 0.585 g) ft **A1**

(d) Answer: 0.585 g

(e) percentage difference = (0.600 - 0.585)/0.600 x 100 = 2.5% ft from (d) **M1**

(e) valid conclusion: the result (0.585 g) is close to the stated 0.600 g, within a small (about 2.5%) experimental difference, so it broadly supports the manufacturer's claim (allowing for rounding of atomic masses and experimental/titration error) oe ft **A1**

(e) Answer: The experimental mass (0.585 g) is about 2.5% below the stated 0.600 g, which is a small difference consistent with normal experimental error, so the result broadly supports the label claim

Question 4

(a) Al_2O_3 + 6HCl -> $2AlCl_3$ + $3H_2O$ **B1**

(a) Al_2O_3 + 2NaOH + $3H_2O$ -> $2NaAl(OH)_4$, oe (accept Al_2O_3 + 2NaOH -> $2NaAlO_2$ + H_2O) **B1**

(a) Answer: Al_2O_3 + 6HCl -> $2AlCl_3$ + $3H_2O$; Al_2O_3 + 2NaOH + $3H_2O$ -> $2NaAl(OH)_4$.

(b) Al_2O_3 is amphoteric, oe **B1**

(b) this reflects Al_2O_3's intermediate bonding character, between the ionic oxides of Na and Mg and the covalent oxides of Si, P, S and Cl, oe **B1**

(b) Answer: Al_2O_3 is amphoteric, reflecting intermediate ionic/covalent bonding character.

(c) Na_2O gives a strongly alkaline solution (pH about 13-14), because Na_2O is a basic ionic oxide that reacts with water to form NaOH, oe **B1**

(c) SO_3 gives a strongly acidic solution (pH about 0-1), because SO_3 is an acidic covalent oxide that reacts with water to form H_2SO_4, oe **B1**

(c) basic oxides are typically ionic (metal) oxides, while acidic oxides are typically covalent (non-metal) oxides, oe **B1**

(c) Answer: Na_2O gives pH about 13-14 (forms NaOH); SO_3 gives pH about 0-1 (forms H_2SO_4).

(d) SiO_2 + 2NaOH -> Na_2SiO_3 + H_2O **B1**

(d) SiO_2 is acidic, not basic, so it cannot react with another acid such as HCl, oe **B1**

(d) Answer: SiO_2 + 2NaOH -> Na_2SiO_3 + H_2O; SiO_2 is acidic so does not react with HCl.

Question 5

(a) breaking the ionic lattice into gaseous ions (equal in magnitude but opposite in sign to the lattice enthalpy of formation), oe **B1**

(a) hydrating each of the resulting gaseous ions (the cation and the anion), oe **B1**

(a) Answer: Lattice dissociation into gaseous ions, then hydration of each gaseous ion.

(b) lattice dissociation enthalpy = +2870 kJ/mol (reverse sign of the lattice enthalpy of formation) **M1**

(b) correct Hess's law sum: delta Hsoln = 2870 + (-1920) + (-1090) **M1**

(b) -140 kJ/mol, cao **A1**

(b) the exothermic value is consistent with $MgSO_4$ being freely soluble in water, oe **B1**

(b) Answer: -140 kJ/mol

(c) lattice dissociation enthalpy = +2423 kJ/mol **M1**

(c) correct Hess's law sum: delta Hsoln = 2423 + (-1360) + (-1090) **M1**

(c) -27 kJ/mol, cao **A1**

(c) delta Hsoln for $BaSO_4$ is much less exothermic than for $MgSO_4$, consistent with $BaSO_4$ being far less soluble in water, oe **B1**

(c) Answer: -27 kJ/mol

(d) ionic radius increases down the group, so the cation's charge density decreases, oe **B1**

(d) giving a weaker electrostatic attraction to (and so weaker hydration by) surrounding water molecules, oe **B1**

(d) Answer: Larger ionic radius down the group gives a lower charge density and weaker hydration.

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