6: Acids and bases – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
2	2017	June	41
2	2017	June	43
2	2017	November	41

The mark scheme for each question is provided at the end of the document.

2 **(a)** One atom of each of the four elements H, C, N and O can bond together in different ways. Two examples are molecules of cyanic acid, HOCN, and isocyanic acid, HNCO. The atoms are bonded in the order they are written.

(i) Draw 'dot-and-cross' diagrams of these two acids, showing outer shell electrons only.

HOCN, cyanic acid

HNCO, isocyanic acid

[3]

(ii) Suggest the values of the bond angles HNC and NCO in **isocyanic acid**.

HNC .... NCO .... [1]

(iii) Suggest which acid, cyanic or isocyanic, will have the **shorter** C–N bond length. Explain your answer.

....

.... [1]

(b) **(i)** Isocyanic acid is a weak acid.

$$HNCO \rightleftharpoons H^+ + NCO^- \qquad K_a = 1.2 \times 10^{-4}\,mol\,dm^{-3}$$

Calculate the pH of a 0.10 $mol\,dm^{-3}$ solution of isocyanic acid.

pH = ... [2]

(ii) Sodium cyanate, NaNCO, is used in the production of isocyanic acid. Sodium cyanate is prepared commercially by reacting urea, $(NH_2)_2CO$, with sodium carbonate. Other products in this reaction are carbon dioxide, ammonia and steam.

Write an equation for the production of NaNCO by this method.

.... [1]

(c) Barium hydroxide, $Ba(OH)_2$, is completely ionised in aqueous solutions.
During the addition of $30.0\,cm^3$ of $0.100\,mol\,dm^{-3}$ $Ba(OH)_2$ to $20.0\,cm^3$ of $0.100\,mol\,dm^{-3}$ isocyanic acid, the pH was measured.

(i) Calculate the $[OH^-]$ at the end of the addition.

$[OH^-]$ = ... $mol\,dm^{-3}$ [2]

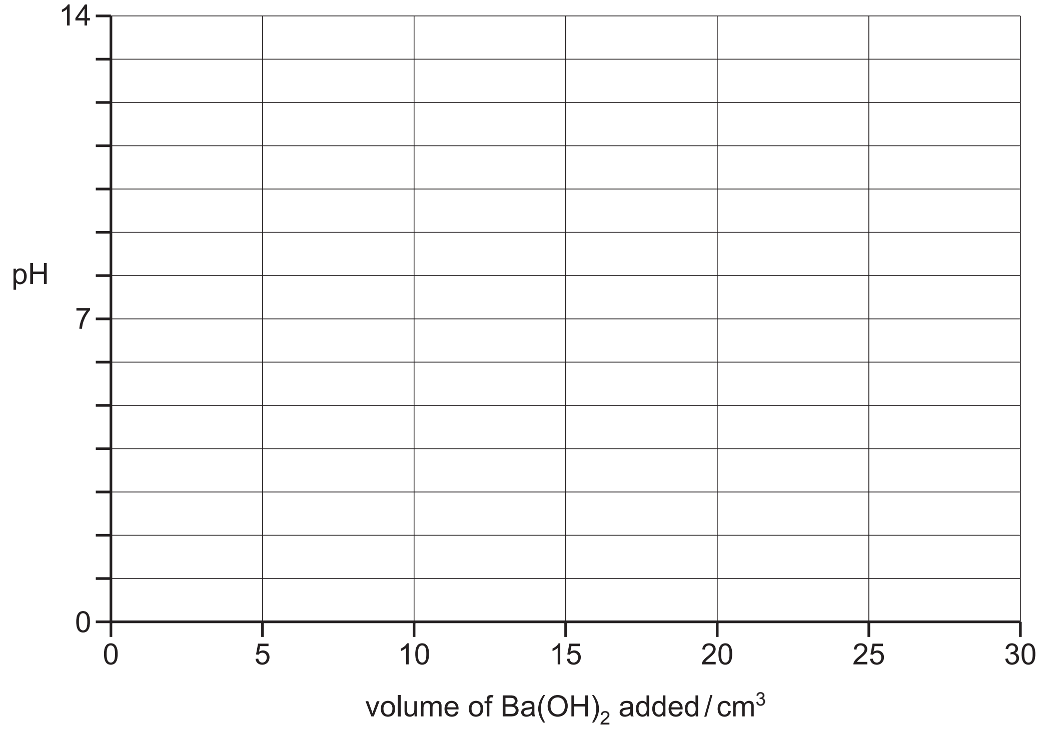
(ii) Use your value in **(i)** to calculate $[H^+]$ and the pH of the solution at the end of the addition.

final [$^{+}$] = ... $mol\,dm^{-3}$

final pH = ...

[2]

(iii) On the following axes, sketch how the pH changes during the addition of a total of $30.0\,cm^3$ of $0.100\,mol\,dm^{-3}$ $Ba(OH)_2$ to $20.0\,cm^3$ of $0.100\,mol\,dm^{-3}$ isocyanic acid.



[3]

(d) The cyanate ion, NCO^-, can act as a *monodentate ligand*.

(i) State what is meant by the terms

monodentate, ...

....

ligand. ....

.... [2]

Silver ions, Ag^+, react with cyanate ions to form a linear complex.

(ii) Suggest the formula of this complex, including its charge.

.... [2]

(e) When heated with $HCl(aq)$, organic isocyanates, RNCO, are hydrolysed to the amine salt, RNH_3Cl, and CO_2.

$$RNCO + H_2O + HCl \rightarrow RNH_3Cl + CO_2$$

A 1.00 g sample of an organic isocyanate, RNCO, was treated in this way, and the CO_2 produced was absorbed in an excess of aqueous $Ba(OH)_2$ according to the equation shown. The solid $BaCO_3$ precipitated weighed 1.66 g.

$$Ba(OH)_2(aq) + CO_2(g) \rightarrow BaCO_3(s) + H_2O(l)$$

(i) Calculate the number of moles of $BaCO_3$ produced.

moles of $BaCO_3$ = ... [1]

(ii) Hence calculate the M_r of the organic isocyanate RNCO.

M_r of RNCO = ... [1]

The R group in RNCO and RNH_3Cl contains carbon and hydrogen only.

(iii) Use your M_r value calculated in **(ii)** to suggest the molecular formula of the organic isocyanate RNCO.

molecular formula of RNCO .... [1]

(iv) Suggest a possible structure of the amine RNH_2, which forms the amine salt, RNH_3Cl.

[1]

[Total: 23]

2 **(a)** The table lists values of solubility products, K_{sp}, of some Group 2 carbonates.

	solubility product in water at 298 K, K_{sp} / $mol^2 dm^{-6}$
$MgCO_3$	1.0×10^{-5}
$CaCO_3$	5.0×10^{-9}
$SrCO_3$	1.1×10^{-10}

Use the data in the table to describe the trend in the solubility of the Group 2 carbonates down the group.

....

.... [1]

(b) **(i)** Write an equation to show the equilibrium for the solubility product for $MgCO_3$.
Include state symbols.

$\rightleftharpoons$

.... [1]

(ii) With reference to your equation in **(i)**, suggest what is observed when a few cm^3 of concentrated $Na_2CO_3(aq)$ are added to a saturated solution of $MgCO_3$. Explain your answer.

....

....

.... [2]

(c) Use the data in the table to calculate the solubility of $MgCO_3$ in water at 298 K, in $g\,dm^{-3}$.

solubility of $MgCO_3$ = ... $g\,dm^{-3}$ [2]

(d) **(i)** Magnesium nitrate decomposes at a **lower** temperature than barium nitrate.

Explain why.

....

....

.... [2]

(ii) A sample of barium nitrate was heated strongly until no further change occurred. A white solid was formed.

Write an equation for the action of heat on barium nitrate.

.... [1]

(iii) When water was added to the white solid produced in **(d)(ii)**, an alkaline solution was produced. Adding sulfuric acid to this solution produced a white precipitate.

Write equations to explain these observations.

....

.... [2]

[Total: 11]

2 **(a)** When water is added to magnesium nitride, Mg_3N_2, the products are a white suspension of $Mg(OH)_2$ and an alkaline gas.

(i) Write an equation for this reaction.

.... [1]

(ii) A 2.52 g sample of Mg_3N_2 is added to an excess of water.

Calculate the mass of $Mg(OH)_2$ formed.

mass of $Mg(OH)_2$ = ... g [2]

(b) State and explain how the solubility of the Group 2 hydroxides varies down the group.

....

....

....

....

.... [4]

(c) Magnesium hydroxide is sparingly soluble in water. The concentration of its saturated solution at 298 K is 1.7×10^{-4} mol dm^{-3}.

(i) Write an expression for the solubility product, K_{sp}, of $Mg(OH)_2$.

K_{sp} =

[1]

(ii) Calculate the value of K_{sp} for $Mg(OH)_2$ at 298 K and state its units.

K_{sp} = ... units .... [2]

(d) The temperature at which the Group 2 hydroxides and carbonates start to decompose increases down the group.

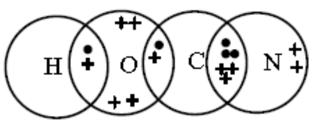
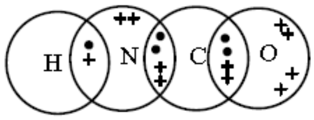
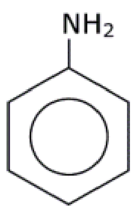
Suggest an explanation for this trend in the decomposition temperature of the Group 2 hydroxides.

....

....

.... [2]

[Total: 12]

Question	Answer	Marks
2 (a) (i)	 	1+1
	16 electrons on each diagram	1
2 (a) (ii)	HNC = 115–125° AND NCO = 180°	1
2 (a) (iii)	cyanic acid, because it's a stronger / higher bond enthalpy / triple / C≡N / more electrons involved bond	1
2 (b) (i)	$[H^+] = \sqrt{([HNCO]K_a)} = \sqrt{(0.1 \times 1.2 \times 10^{-4})}$ or 3.46×10^{-3}	1
	pH = log $[H^+]$ = **2.5** (2.46)	1
2 (b) (ii)	$Na_2CO_3 + 2(NH_2)_2CO \rightarrow 2NaNCO + CO_2 + 2NH_3 + H_2O$	1
2 (c) (i)	($n(OH^-)$ at start = $(2 \times 0.1 \times 30) / 1000 = 6 \times 10^{-3}$ mol) ($n(OH^-)$ reacted = $(0.1 \times 20) / 1000 = 2 \times 10^{-3}$ mol) $n(OH^-)$ remaining = $(6–2) \times 10^{-3} = 4 \times 10^{-3}$ mol, (in 50 cm^3)	1
	so $[OH^-]$end = $(4 \times 10^{-3} \times 1000) / 50$ = **0.08 mol dm^{-3}**	1
2 (c) (ii)	$[H^+] = K_w / [OH^-] = (1 \times 10^{-14}) / 0.08 = 1.25 \times 10^{-13}$ mol dm^{-3}	1
	so pH = $-\log(1.25 \times 10^{-13})$ = **12.9**	1
2 (c) (iii)	curve starts at 2.46 / 2.5	1
	vertical portion (end point) at vol added = 10.0 cm^3	1
	finishes at pH = 12.9	1
2 (d) (i)	*monodentate*: (a species that) forms **one** dative / coordinate bond	1
	ligand: a species that uses a lone pair of electrons to form a dative / coordinate bond to **a metal atom / metal ion**	1
2 (d) (ii)	$[Ag(NCO)_2]^-$ or $[Ag(OCN)_2]^-$ correct formula	1
	correct charge	1
2 (e) (i)	$n(BaCO_3)$ =1.66 / 197.3 = 8.4(1) × 10^{-3} mol	1
2 (e) (ii)	n(RNCO) = 8.41 × 10^{-3} mol, so Mr = 1 / (8.41 × 10^{-3}) = **119**	1
2 (e) (iii)	molecular formula = C7H5NO	1
2 (e) (iv)		1
		Total: 23

Question	Answer	Marks
2 (a)	it / solubility **decreases** down the group **and** K_{sp} decreases	**1**
2 (b) (i)	$MgCO_3$**(s)** $\rightleftharpoons$ Mg^{2+}**(aq)** + CO_3^{2-}**(aq)**	**1**
2 (b) (ii)	(white) solid appears / precipitation (of $MgCO_3$)	**1**
	as $[CO_3^{2-}]$ increases shifting equilibrium to the LHS (precipitating out $MgCO_3$)	**1**
2 (c)	solubility = $\sqrt{1.0 \times 10^{-5}} = 3.16 \times 10^{-3}$ mol dm^{-3}	**1**
	solubility= $3.2 \times 10^{-3} \times 84.3 =$ **0.27** g dm^{-3}	**1**
2 (d) (i)	Mg^{2+} ion is smaller than Ba^{2+} ion **or** ionic radii increase down group ora	**1**
	(Mg^{2+}) distorts / polarises / the anion / nitrate group / nitrate **ion** / $NO_3^{(1)-}$ / NO_3ion more easily (than Ba^{2+}) ora	**1**
2 (d) (ii)	$Ba(NO_3)_2 \rightarrow BaO + 2NO_2 + ½O_2$	**1**
2 (d) (iii)	$BaO + H_2O \rightarrow Ba(OH)_2$	**1**
		Total: 11

Question	Answer	Marks
2 (a) (i)	$Mg_3N_2 + 6H_2O \rightarrow 3Mg(OH)_2 + 2NH_3$	**1**
2 (a) (ii)	moles of Mg_3N_2 = 2.52 / 100.9 = 0.025 (0.0249)	**1**
	(moles of $Mg(OH)_2$ = 0.075 (0.0749)) mass of $Mg(OH)_2$ = (0.075 × 58.3) = 4.37 g or 4.4 g	**1**
2 (b)	solubility increases (down the group)	**1**
	ΔH_{latt} and ΔH_{hyd} both decrease / less exothermic / more endothermic	**1**
	but ΔH_{latt} decreases more (than ΔH_{hyd} decreases)	**1**
	ΔH_{sol} becomes more negative / more exothermic / less endothermic	**1**
2(c) (i)	$K_{sp} = [Mg^{2+}] [OH^-]^2$	**1**
2 (c) (ii)	$K_{sp} = (1.7 \text{ x } 10^{-4}) \times (2 \times 1.7 \times 10^{-4})2 = 2.0 \times 10^{-11}$ (1.97×10^{-11})	**1**
	mol^3 dm^{-9}	**1**
2 (d)	cations become bigger / ionic radius increases	**1**
	polarisation/distortion of anion / hydroxide ion decreases	**1**
		Total: 12

Notes about the mark scheme are available separately.