8: Controlling reactions 2 – 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	March	42
1	2017	June	41
1	2017	June	42

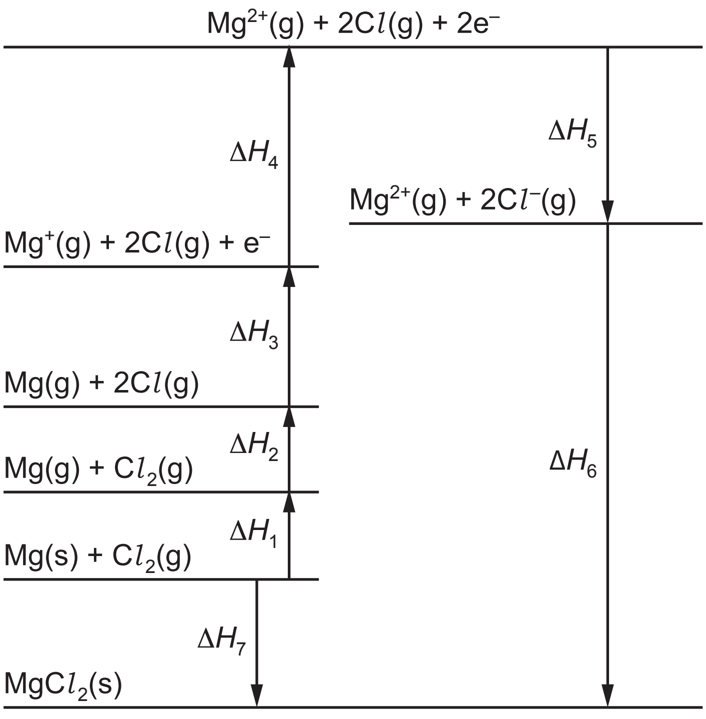
The mark scheme for each question is provided at the end of the document.

2 **(a)** Complete the table using ticks (✓) to indicate whether the sign of each type of energy change, under standard conditions, is always positive, always negative or could be either positive or negative.

energy change	always positive	always negative	either positive or negative
electron affinity			
enthalpy change of atomisation			
ionisation energy			
lattice energy			

[2]

(b) The Born-Haber cycle for magnesium chloride is shown.



(i) Explain why ΔH_4 is greater than ΔH_3.

....

.... [1]

(ii) What names are given to the enthalpy changes ΔH_6 and ΔH_7?

ΔH_6 ....

ΔH_7 ....

[1]

(c) Chlorine is in Group 17.

Suggest the trend in the first electron affinity of the elements in Group 17. Explain your answer.

....

....

.... [2]

(d) The equation for the formation of magnesium oxide from its elements is shown.

$$Mg(s) + \tfrac{1}{2}O_2(g) \rightarrow MgO(s) \qquad \Delta H^\ominus = -602\,kJ\,mol^{-1}$$

substance	$S^\ominus / J\,K^{-1}\,mol^{-1}$
$Mg(s)$	32.7
$O_2(g)$	205
$MgO(s)$	26.9

Use the equation and the data given in the table to calculate $\Delta G^\ominus$ for the reaction at 25 °C.

$\Delta G^\ominus$ = ... units ....
[4]

[Total: 10]

1 (a) Describe and explain the variation in the solubilities of the hydroxides of the Group 2 elements.

....

....

....

....

....

.... [4]

The table lists the standard enthalpy changes of formation, $\Delta H^{\ominus}_{f}$, for some compounds and aqueous ions.

species	$\Delta H^{\ominus}_{f}$ / kJ mol^{-1}
$Ba^{2+}(aq)$	–538
$OH^{-}(aq)$	–230
$CO_2(g)$	–394
$BaCO_3(s)$	–1216
$H_2O(l)$	–286

(b) (i) Reaction 1 occurs when $CO_2(g)$ is bubbled through an aqueous solution of $Ba(OH)_2$.

Use the data in the table to calculate the standard enthalpy change for reaction 1, $\Delta H^{\ominus}_{r1}$.

$$Ba(OH)_2(aq) + CO_2(g) \rightarrow BaCO_3(s) + H_2O(l) \qquad \text{reaction 1}$$

$\Delta H^{\ominus}_{r1}$ = ... kJ mol^{-1} [2]

If $CO_2(g)$ is bubbled through an aqueous solution of $Ba(OH)_2$ for a long time, the precipitated $BaCO_3(s)$ dissolves, as shown in reaction 2.

$$BaCO_3(s) + CO_2(g) + H_2O(l) \rightarrow Ba(HCO_3)_2(aq) \qquad \text{reaction 2}$$

The standard enthalpy change for reaction 2, $\Delta H^{\ominus}_{r2}$, = –26 kJ mol^{-1}.

(ii) Use this information and the data in the table to calculate the standard enthalpy change of formation of the $HCO_3^-(aq)$ ion.

$\Delta H^{\ominus}_{f}$ $HCO_3^-(aq)$ = ... kJ mol^{-1} [2]

(iii) The overall process is shown by reaction 3.

Use your answer to **(ii)**, and the data given in the table, to calculate the standard enthalpy change for reaction 3, $\Delta H^{\ominus}_{r3}$.

$$Ba(OH)_2(aq) + 2CO_2(g) \rightarrow Ba(HCO_3)_2(aq) \qquad \text{reaction 3}$$

$\Delta H^{\ominus}_{r3}$ = ... kJ mol^{-1} [1]

(iv) How would the value of $\Delta H^{\ominus}_{r3}$ compare with the value of $\Delta H^{\ominus}_{r4}$ for the similar reaction with $Ca(OH)_2(aq)$ as shown in reaction 4?
Explain your answer.

$$Ca(OH)_2(aq) + 2CO_2(g) \rightarrow Ca(HCO_3)_2(aq) \qquad \text{reaction 4}$$

....

....

.... [2]

(c) The standard entropy change for reaction 1 is $\Delta S^{\ominus}_{r1}$.

Suggest, with a reason, how the standard entropy change for reaction 3 might compare with $\Delta S^{\ominus}_{r1}$.

....

....

.... [2]

[Total: 13]

1 **(a)** **(i)** Describe and explain the variation in the thermal stabilities of the carbonates of the Group 2 elements.

....

....

....

....

.... [3]

(ii) Suggest and explain a reason why sodium carbonate is more stable to heat than magnesium carbonate.

....

....

.... [1]

(b) Sodium hydrogencarbonate, $NaHCO_3$, and potassium hydrogencarbonate, $KHCO_3$, decompose on heating to produce gases and the solid metal carbonate.

(i) Write an equation for the decomposition of $KHCO_3$.

.... [1]

(ii) Predict which of $NaHCO_3$ or $KHCO_3$ will decompose at the **lower** temperature. Explain your answer.

....

.... [1]

(c) **(i)** Use the data in the table below, and relevant data from the *Data Booklet*, to calculate the lattice energy, $\Delta H^{\ominus}_{latt}$, of potassium oxide, $K_2O(s)$.

energy change	value / kJ mol^{-1}
enthalpy change of atomisation of potassium, $\Delta H^{\ominus}_{at}$ K(s)	+89
electron affinity of O(g)	–141
electron affinity of O^-(g)	+798
enthalpy change of formation of potassium oxide, $\Delta H^{\ominus}_{f}$ $K_2O(s)$	–361

$\Delta H^{\ominus}_{latt}$ = ... kJ mol^{-1} [3]

(ii) State whether the lattice energy of Na_2O would be more negative, less negative or the same as that of K_2O. Give reasons for your answer.

....

.... [1]

[Total: 10]

5 **(a)** 1,2-diaminoethane, *en*, $H_2NCH_2CH_2NH_2$, is a bidentate ligand.

(i) What is meant by the terms *bidentate* and *ligand*?

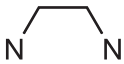
bidentate ....

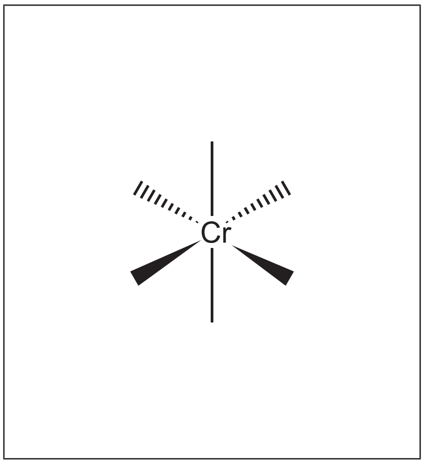
ligand ....

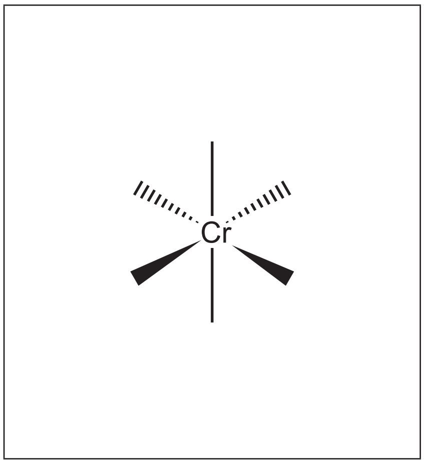
.... [2]

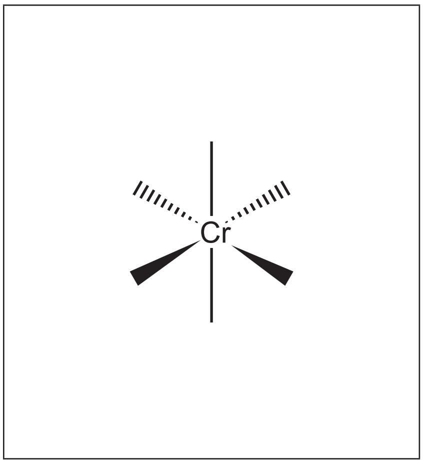
(ii) There are three isomeric complex ions with the formula $[Cr(en)_2Cl_2]^+$.

Complete the three-dimensional diagrams of the isomers in the boxes.

You may use  to represent *en*.







[3]

(b) Copper forms complexes with NH_3 and *en* according to equlibria 1 and 2.

equilibrium 1 $Cu^{2+}(aq) + 4NH_3(aq) \rightleftharpoons [Cu(NH_3)_4]^{2+}(aq)$

equilibrium 2 $Cu^{2+}(aq) + 2en(aq) \rightleftharpoons [Cu(en)_2]^{2+}(aq)$

(i) Write the expressions for the stability constants, K_{stab1} and K_{stab2}, for equilibria 1 and 2. Include units in your answers.

K_{stab1} =

units = ...

K_{stab2} =

units = ...

[3]

(ii) An equilibrium is set up when both *en* and NH_3 ligands are added to a solution containing Cu^{2+}(aq) as shown in equilibrium 3.

equilibrium 3 $[Cu(NH_3)_4]^{2+}(aq) + 2en(aq) \rightleftharpoons [Cu(en)_2]^{2+}(aq) + 4NH_3(aq)$

Write an expression for the equilibrium constant, K_{eq3}, in terms of K_{stab1} and K_{stab2}.

K_{eq3} = ... [1]

(iii) The numerical values for these stability constants are shown.

$K_{stab1} = 1.2 \times 10^{13}$ $K_{stab2} = 5.3 \times 10^{19}$

Calculate the value of K_{eq3} stating its units.

K_{eq3} = ... unit = ... [2]

(c) $\Delta S^{\ominus}$ values for equilibria 1 and 2 differ greatly, as can be seen in the table. All values are at a temperature of 298 K.

equilibrium	$\Delta H^{\ominus}$ / kJ mol^{-1}	$\Delta S^{\ominus}$ / J K^{-1} mol^{-1}	$\Delta G^{\ominus}$ / kJ mol^{-1}
1	–92	–60	–74
2	–100	+40	

(i) Explain why $\Delta S^{\ominus}_{eq2}$ is so different from $\Delta S^{\ominus}_{eq1}$.

....

.... [1]

(ii) Calculate $\Delta G^{\ominus}_{eq2}$ at 298 K.

$\Delta G^{\ominus}_{eq2}$ = ... kJ mol^{-1} [2]

(iii) What conclusion can be made about the relative feasibility of equilibria 1 and 2?

Explain your answer.

.... [1]

(iv) Using data from the table, suggest a value of $\Delta H^{\ominus}$ for equilibrium 3.

.... [1]

(v) State the *type of reaction* that is occurring in equilibrium 2.

.... [1]

[Total: 17]

Question	Answer	Marks
2 (a)	<table><tr><td>Enthalpy change</td><td>positive</td><td>negative</td><td>either positive or negative</td></tr><tr><td>electron affinity</td><td></td><td></td><td>✓</td></tr><tr><td>enthalpy chare of atomisation</td><td>✓</td><td></td><td></td></tr><tr><td>enthalpy charge of ionisation</td><td>✓</td><td></td><td></td></tr><tr><td>lattice enthalpy</td><td></td><td>✓</td><td></td></tr></table>	**2**
2 (b) (i)	the second electron is removed from a (more) positively charged ion	**1**
2 (b) (ii)	ΔH_6 is lattice (energy / enthalpy) **AND** ΔH_7 is (energy / enthalpy of) formation	**1**
2 (c)	the electron affinity becomes less exothermic / negative down the Group 17	**1**
	electron affinity depends (mainly) on the electron-nucleus distance which increases down Group 17	**1**
2 (d)	**M1** correct use of $\Delta G = \Delta H - T\Delta S$	**1**
	M2 $\Delta S = 26.9 - (32.7 + 102.5) = -108.3$ J K^{-1} mol^{-1} **OR** -0.1083 kJ K^{-1} mol^{-1}	**1**
	M3 $\Delta G = -602 - (298 \times (-0.1083)) = -570$	**1**
	M4 units: kJ mol^{-1}	**1**
		Total: 10

Question	Answer	Marks
1 (a)	solubility increases down the group	**1**
	ΔH_{latt} and ΔH_{hyd} both **decrease** **or** ΔH_{latt} and ΔH_{hyd} both become less exothermic / more endothermic	**1**
	ΔH_{latt} decreases / changes more (than ΔH_{hyd} as OH^- being smaller than M^{2+})	**1**
	ΔHsol becomes more exothermic / more negative / less endothermic / less positive	**1**
1 (b) (i)	$\Delta H_{r1} - (538 + 2x230 + 394) = -(1216 + 286)$ $\Delta H_{r1} - 1392 = -1502$	**1**
	$\Delta H_{r1} =$ **-110**	**1**

Question	Answer	Marks
1 (b) (ii)	let $\Delta H_f(HCO_3^-(aq))$ = y 2y – 538 = –1216 – 394 – 286 – 26	**1**
	y = **–692**	**1**
1 (b) (iii)	ΔH_{r3} –538 – 2(230 + 394) = –538 – 2(692) ΔH_{r3} = **–136**	**1**
1 (b) (iv)	ΔH_{r3} will be identical to ΔH_{r4}, / unchanged	**1**
	as the reaction is the same, or: $2OH^-(aq) + 2CO_2(g) \rightarrow 2HCO_3^-(aq)$ or metal ions stay in solution/metal ions are unchanged / are spectators	**1**
1 (c)	more **gaseous moles** are being consumed (in reaction 3) **or** more **CO_2 moles** are being consumed (in reaction 3)	**1**
	ΔS is therefore expected to be **more negative/less positive** for reaction 3.	**1**
		Total: 13

Question	Answer	Marks
1 (a) (i)	increases down the group	**1**
	radius / size of (cat)ion/M^{2+} increases	**1**
	less polarisation / distortion of anion / carbonate **ion** / CO_3^{2-}	**1**
1 (a) (i)	Na^+ has smaller ionic charge **and** larger ionic radii OR the **charge density** of the **Na^+** is **lower**	**1**
1 (b) (ii)	$2KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$	**1**
1 (b) (ii)	$NaHCO_3$ because Na^+ is **smaller** OR charge density Na^+ is **larger**	**1**
1 (c) (i)	LE = ΔH_f – 2(ΔH_{at} + IE) – ½(O=O) – (EA_1 + EA_2)	**1**
	= –361 – 2(89) **–** 2(418) – 496/2 – (–141+798)	**1**
	= **–2280** (kJ mol^{-1})	**1**
1 (c) (ii)	LE of Na_2O will be **more negative** AND as $Na^{(+)}$ is smaller / larger charge density / smaller radii AND so greater attraction (between the ions) OR (ionic) bonds will be stronger	**1**
		Total: 10

Notes about the mark scheme are available separately.