Cambridge Assessment International Education

Interactive

Interactive Example Candidate Responses Paper 42 (May/June 2016), Question 5

Cambridge International AS & A Level Chemistry 9701

Version 1.0

Cambridge Pathway

In order to help us develop the highest quality resources, we are undertaking a continuous programme of review; not only to measure the success of our resources but also to highlight areas for improvement and to identify new development needs.

We invite you to complete our survey by visiting the website below. Your comments on the quality and relevance of our resources are very important to us.

www.surveymonkey.co.uk/r/GL6ZNJB

Would you like to become a Cambridge International consultant and help us develop support materials?

Please follow the link below to register your interest.

www.cambridgeinternational.org/cambridge-for/teachers/teacherconsultants/

Select page

HIGH | MIDDLE | LOW

5 Cadmium ions form complexes with primary amines and with 1,2-diaminoethane.

$Cd^{2+}(aq) + 4CH_3NH_2(aq) \rightleftharpoons [Cd(CH_3NH_2)_4]^{2+}(aq)$ $K_{stab} = 3.6 \times 10^6$ equilibrium I

$Cd^{2+}(aq) + 2H_2NCH_2CH_2NH_2(aq) \rightleftharpoons [Cd(H_2NCH_2CH_2NH_2)_2]^{2+}(aq)$ $K_{stab} = 4.2 \times 10^{10}$ equilibrium II

(a) (i) Write an expression for the stability constant, K_{stab}, for equilibrium I, and state its units.

$K_{stab} = \dfrac{[[Cd(CH_3NH_2)_4]^{2+}_{(aq)}]}{[CH_3NH_{2(aq)}]^4[Cd^{2+}_{(aq)}]}$ $mol^{-4}\ dm^{12}$

units .... [2]

Cadmium ions are poisonous and need to be removed from some water supplies. This is often done by adding a complexing agent.

(ii) In a sample of ground water the concentration of $Cd^{2+}(aq)$ is 1.00×10^{-4} mol dm^{-3}.

Calculate the concentration of $CH_3NH_2(aq)$ needed to reduce the concentration of $Cd^{2+}(aq)$ in this dilute solution by a factor of one thousand. $\times 1000 \longrightarrow 1 \times 10^{-7}$

$Cd^{2+} + 4CH_3NH_2 \rightleftharpoons [Cd(CH_3NH_2)_4]^{2+}$

1 : 4

1.00×10^{-4}

$(1 \times 10^{-4}) - 4x = (1 \times 10^{-7}) =$

$4x = 9.99 \times 10^{-5}$

$x = 2.4975 \times 10^{-5}$

$= 2.50 \times 10^{-5}$ mol dm^{-3}

concentration of $CH_3NH_2(aq)$ = ...2.50........ mol dm^{-3} [2]

Your Mark

5(a)(i)

5(a)(ii)

5(b)(i)

5(b)(ii)

5(b)(iii)

5(b)(iv)

Q5	Mark scheme
(a)(i)	$K_{stab} = \dfrac{[Cd(CH_3NH_2)_4^{2+}]}{[Cd^{2+}][CH_3NH_2]^4}$ units: $mol^{-4}\ dm^{12}$ **[2]**
(a)(ii)	$Cd^{2+} + 4CH_3NH_2 \rightleftharpoons [Cd(CH_3NH_2)4]^{2+}$ at start: 1×1^{-4} **0** at eqm: 1×10^{-7} **y** **$1 \times 10^{-4} - 1 \times 10^{-7}$** **or 9.99×10^{-5} or 1.0×10^{-4}** $9.99 \times 10^{-5} / (y^4 \times 10^{-7}) = 3.6 \times 10^6$ and y = $4\sqrt{(9.99 \times 10^{-5})} / (1 \times 10^{-7} \times 3.6 \times 10^6)$ = **0.129 / 0.13** **[2]**
(b)(i)	(each complex is formed by) making (4 ×)N-Cd bonds and breaking (6 ×) O-Cd bonds **or** same types of / similar bonds forming / breaking **or** same number of bonds forming / breaking **[1]**
(b)(ii)	$\Delta S = (\Delta H - \Delta G) / T = (60.7 - 56.5) \times 1000 / 298$ = (+)**14** / (+)**14.1** **[1]**
(b)(iii)	fewer moles (of solutes) are forming (one mole of) the complex (so less loss of disorder) **or** one en displaces two H_2O whereas one CH_3NH_2 only displaces one H_2O **[1]**
(b)(iv)	The $[Cd(H_2NCH_2CH_2NH_2)_2]^{2+}$ / equilibrium 2 complex (is more stable) because: *either* K_{stab} is greater or ΔG° is more negative. **[1]** **[Total: 8]**

EXAMINER COMMENTS

MARK SCHEME

(b) Values for ΔH° and ΔG° for equilibria I and II, and the value of ΔS° for equilibrium I, are given in the table below. All values are at a temperature of 298 K.

equilibrium	ΔH° / kJ mol^{-1}	ΔG° / kJ mol^{-1}	ΔS° / J K^{-1} mol^{-1}
I	–57.3	–37.4	–66.8
II	–56.5	–60.7	to be calculated

(i) Suggest a reason why the ΔH° values for the two equilibria are very similar.

In both complexes, ~~N~~ 4 nitrogen atoms donate four lone pairs to make dative bonds with cadmium. So the energy released is very similar. [1]

(ii) Calculate ΔS° for equilibrium II.

$\Delta G = \Delta H - T\Delta S$

$(-60.7 \times 1000) = (-56.5 \times 1000) - (298)(\Delta S)$

$\Delta S = 14.09395$

$= 14.1$ JK^{-}mol

$\Delta S^\circ =$ + 14.1 J K^{-1} mol^{-1} [1]

(iii) Suggest a reason for the difference between the ΔS° you have calculated for equilibrium II and that for equilibrium I given in the table.

Increase in entropy for equilibrium 2 because fewer mols of reactant (2) converting to product (1). In equilibrium 1, a decrease in entropy because more mols of reactant (5) converting to product (1). [1]

(iv) Which of the two complexes is the more stable? Give a reason for your answer.

The complex from equilibrium 2 because its formation is favored energetically (ΔG is much more negative so reaction is more spontaneous in forward direction) and also because its equilb. has a higher Kstab value. [1]

[Total: 8]

Select page

HIGH MIDDLE LOW

Your Mark

5(a)(i)

5(a)(ii)

5(b)(i)

5(b)(ii)

5(b)(iii)

5(b)(iv)

Q5	Mark scheme
(a)(i)	$K_{stab} = \dfrac{[Cd(CH_3NH_2)_4{}^{2+}]}{[Cd^{2+}][CH_3NH_2]^4}$ units: mol^{-4} dm^{12} **[2]**
(a)(ii)	$Cd^{2+} + 4CH_3NH_2 \rightleftharpoons [Cd(CH_3NH_2)4]^{2+}$ at start: 1×1^{-4} **0** at eqm: 1×10^{-7} **y** **$1 \times 10^{-4} - 1 \times 10^{-7}$ or 9.99×10^{-5} or 1.0×10^{-4}** $9.99 \times 10^{-5} / (\boldsymbol{y}^4 \times 10^{-7}) = 3.6 \times 10^6$ and $y = 4\sqrt{}(9.99 \times 10^{-5}) / (1 \times 10^{-7} \times 3.6 \times 10^6)$ = **0.129 / 0.13** **[2]**
(b)(i)	(each complex is formed by) making (4 ×)N-Cd bonds and breaking (6 ×) O-Cd bonds **or** same types of / similar bonds forming / breaking **or** same number of bonds forming / breaking **[1]**
(b)(ii)	ΔS = (ΔH – ΔG) / T = (60.7 – 56.5) × 1000 / 298 = (+)**14** / (+)**14.1** **[1]**
(b)(iii)	fewer moles (of solutes) are forming (one mole of) the complex (so less loss of disorder) **or** one en displaces two H_2O whereas one CH_3NH_2 only displaces one H_2O **[1]**
(b)(iv)	The $[Cd(H_2NCH_2CH_2NH_2)_2]^{2+}$ / equilibrium 2 complex (is more stable) because: *either* K_{stab} is greater or ΔG° is more negative. **[1]** **[Total: 8]**

EXAMINER COMMENTS

MARK SCHEME

5 Cadmium ions form complexes with primary amines and with 1,2-diaminoethane.

$Cd^{2+}(aq) + 4CH_3NH_2(aq) \rightleftharpoons [Cd(CH_3NH_2)_4]^{2+}(aq)$ $K_{stab} = 3.6 \times 10^6$ equilibrium I

$Cd^{2+}(aq) + 2H_2NCH_2CH_2NH_2(aq) \rightleftharpoons [Cd(H_2NCH_2CH_2NH_2)_2]^{2+}(aq)$ $K_{stab} = 4.2 \times 10^{10}$ equilibrium II

(a) (i) Write an expression for the stability constant, K_{stab}, for equilibrium I, and state its units.

$K_{stab} = \frac{[[Cd(CH_3NH_2)_4]^{2+}(aq)]}{[Cd^{2+}(aq)]\ [CH_3NH_2(aq)]^4}$ $\frac{(mol\,dm^{-3})}{(mol\,dm^{-3})\ (mol\,dm^{-3})^4}$ ⇒ $mol^{-4}\,dm^{12}$

units $mol^{-4}\,dm^{12}$ [2]

Cadmium ions are poisonous and need to be removed from some water supplies. This is often done by adding a complexing agent.

(ii) In a sample of ground water the concentration of $Cd^{2+}(aq)$ is 1.00×10^{-4} mol dm^{-3}.

Calculate the concentration of $CH_3NH_2(aq)$ needed to reduce the concentration of $Cd^{2+}(aq)$ in this dilute solution by a factor of one thousand.

$\frac{1.00 \times 10^{-4} \times 4}{1000}$ ⇒ 4×10^{-7}

concentration of $CH_3NH_2(aq)$ = 4×10^{-7} mol dm^{-3} [2]

Your Mark

5(a)(i)

5(a)(ii)

5(b)(i)

5(b)(ii)

5(b)(iii)

5(b)(iv)

Q5	Mark scheme
(a)(i)	$K_{stab} = \frac{[Cd(CH_3NH_2)_4{}^{2+}]}{[Cd^{2+}]\,[CH_3NH_2]^4}$ units: $mol^{-4}\,dm^{12}$ **[2]**
(a)(ii)	$Cd^{2+} + 4CH_3NH_2 \rightleftharpoons [Cd(CH_3NH_2)4]^{2+}$ at start: 1×1^{-4} **0** at eqm: 1×10^{-7} **y** **$1 \times 10^{-4} - 1 \times 10^{-7}$** **or 9.99×10^{-5} or 1.0×10^{-4}** $9.99 \times 10^{-5}/ (\boldsymbol{y}^4 \times 10^{-7}) = 3.6 \times 10^6$ and $y = 4\sqrt{}(9.99 \times 10^{-5}) / (1 \times 10^{-7} \times 3.6 \times 10^6)$ = **0.129 / 0.13** **[2]**
(b)(i)	(each complex is formed by) making (4 ×)N-Cd bonds and breaking (6 ×) O-Cd bonds **or** same types of / similar bonds forming / breaking **or** same number of bonds forming / breaking **[1]**
(b)(ii)	$\Delta S = (\Delta H - \Delta G) / T = (60.7 - 56.5) \times 1000 / 298$ = (+)**14** / (+)**14.1** **[1]**
(b)(iii)	fewer moles (of solutes) are forming (one mole of) the complex (so less loss of disorder) **or** one en displaces two H_2O whereas one CH_3NH_2 only displaces one H_2O **[1]**
(b)(iv)	The $[Cd(H_2NCH_2CH_2NH_2)_2]^{2+}$ / equilibrium 2 complex (is more stable) because: *either* K_{stab} is greater or ΔG° is more negative. **[1]** **[Total: 8]**

HIGH MIDDLE LOW

Select page

EXAMINER COMMENTS

MARK SCHEME

Select page

HIGH | MIDDLE | LOW

(b) Values for ΔH° and ΔG° for equilibria **I** and **II**, and the value of ΔS° for equilibrium **I**, are given in the table below. All values are at a temperature of 298 K.

equilibrium	ΔH° / kJ mol^{-1}	ΔG° / kJ mol^{-1}	ΔS° / J K^{-1} mol^{-1}
I	–57.3	–37.4	–66.8
II	–56.5	–60.7	to be calculated

(i) Suggest a reason why the ΔH° values for the two equilibria are very similar.

The values are very similar because the energy required by reactant to form a product for both equilibrium is nearly same. [1]

(ii) Calculate ΔS° for equilibrium **II**.

$\Delta G = \Delta H_{reaction} - T\Delta S$

$\Delta G = \Delta H - T\Delta S$

$\frac{-60.7 \times 1000}{-298}$

$\frac{(-60.7 \times 1000) + (56.5 \times 1000)}{-298} = \Delta S$

ΔS° = 14.1 J K^{-1} mol^{-1} [1]

(iii) Suggest a reason for the difference between the ΔS° you have calculated for equilibrium **II** and that for equilibrium **I** given in the table.

The difference in equilibrium of II and equilibrium I is because equilibrium II is more random and spontaneous than that of equilibrium I. [1]

(iv) Which of the two complexes is the more stable? Give a reason for your answer.

Equilibrium II is more stable (1,2-diaminoethane) as Kstab is more and Gibbs energy also shows more energy or work is to be done in experiment II [1]

[Total: 8]

Your Mark

5(a)(i)

5(a)(ii)

5(b)(i)

5(b)(ii)

5(b)(iii)

5(b)(iv)

Q5	Mark scheme
(a)(i)	$K_{stab} = \frac{[Cd(CH_3NH_2)_4^{2+}]}{[Cd^{2+}][CH_3NH_2]^4}$ units: mol^{-4} dm^{12} **[2]**
(a)(ii)	$Cd^{2+} + 4CH_3NH_2 \rightleftharpoons [Cd(CH_3NH_2)4]^{2+}$ at start: 1×1^{-4} **0** at eqm: 1×10^{-7} **y** **$1 \times 10^{-4} - 1 \times 10^{-7}$** **or 9.99×10^{-5} or 1.0×10^{-4}** $9.99 \times 10^{-5} / (\boldsymbol{y}^4 \times 10^{-7}) = 3.6 \times 10^6$ and y = $4\sqrt{}(9.99 \times 10^{-5}) / (1 \times 10^{-7} \times 3.6 \times 10^6)$ = **0.129 / 0.13** **[2]**
(b)(i)	(each complex is formed by) making (4 ×)N-Cd bonds and breaking (6 ×) O-Cd bonds **or** same types of / similar bonds forming / breaking **or** same number of bonds forming / breaking **[1]**
(b)(ii)	$\Delta S = (\Delta H - \Delta G) / T = (60.7 - 56.5) \times 1000 / 298$ = (+)**14** / (+)**14.1** **[1]**
(b)(iii)	fewer moles (of solutes) are forming (one mole of) the complex (so less loss of disorder) **or** one en displaces two H_2O whereas one CH_3NH_2 only displaces one H_2O **[1]**
(b)(iv)	The $[Cd(H_2NCH_2CH_2NH_2)_2]^{2+}$ / equilibrium 2 complex (is more stable) because: *either* K_{stab} is greater or ΔG° is more negative. **[1]** **[Total: 8]**

EXAMINER COMMENTS

MARK SCHEME

5 Cadmium ions form complexes with primary amines and with 1,2-diaminoethane.

$Cd^{2+}(aq) + 4CH_3NH_2(aq) \rightleftharpoons [Cd(CH_3NH_2)_4]^{2+}(aq)$ $K_{stab} = 3.6 \times 10^6$ equilibrium I

$Cd^{2+}(aq) + 2H_2NCH_2CH_2NH_2(aq) \rightleftharpoons [Cd(H_2NCH_2CH_2NH_2)_2]^{2+}(aq)$ $K_{stab} = 4.2 \times 10^{10}$ equilibrium II

(a) (i) Write an expression for the stability constant, K_{stab}, for equilibrium I, and state its units.

$K_{stab} = \frac{[Cd(CH_3NH_2)_4]}{[Cd][CH_3NH_2]^4}$

units mol^{-4} dm^{12} [2]

Cadmium ions are poisonous and need to be removed from some water supplies. This is often done by adding a complexing agent.

(ii) In a sample of ground water the concentration of $Cd^{2+}(aq)$ is 1.00×10^{-4} mol dm^{-3}.

Calculate the concentration of $CH_3NH_2(aq)$ needed to reduce the concentration of $Cd^{2+}(aq)$ in this dilute solution by a factor of one thousand.

$\frac{(4.2 \times 10^{10})}{1000} = \frac{1}{(1 \times 10^{-4})x}$

$\frac{(3.6 \times 10^6)}{1000} = \frac{1}{(1 \times 10^{-4})x}$

concentration of $CH_3NH_2(aq)$ = 0.36 mol dm^{-3} [2]

Select page

HIGH MIDDLE LOW

Your Mark

5(a)(i)

5(a)(ii)

5(b)(i)

5(b)(ii)

5(b)(iii)

5(b)(iv)

Q5	Mark scheme
(a)(i)	$K_{stab} = \frac{[Cd(CH_3NH_2)_4{}^{2+}]}{[Cd^{2+}][CH_3NH_2]^4}$ units: mol^{-4} dm^{12} **[2]**
(a)(ii)	$Cd^{2+} + 4CH_3NH_2 \rightleftharpoons [Cd(CH_3NH_2)4]^{2+}$ at start: 1×1^{-4} **0** at eqm: 1×10^{-7} **y** **$1 \times 10^{-4} - 1 \times 10^{-7}$** **or 9.99×10^{-5} or 1.0×10^{-4}** $9.99 \times 10^{-5}/(y^4 \times 10^{-7}) = 3.6 \times 10^6$ and y = $4\sqrt{(9.99 \times 10^{-5})/(1 \times 10^{-7} \times 3.6 \times 10^6)}$ = **0.129 / 0.13** **[2]**
(b)(i)	(each complex is formed by) making (4 ×)N-Cd bonds and breaking (6 ×) O-Cd bonds **or** same types of / similar bonds forming / breaking **or** same number of bonds forming / breaking **[1]**
(b)(ii)	ΔS = (ΔH – ΔG) /T = (60.7 – 56.5) × 1000 / 298 = (+)**14** / (+)**14.1** **[1]**
(b)(iii)	fewer moles (of solutes) are forming (one mole of) the complex (so less loss of disorder) **or** one en displaces two H_2O whereas one CH_3NH_2 only displaces one H_2O **[1]**
(b)(iv)	The $[Cd(H_2NCH_2CH_2NH_2)_2]^{2+}$ / equilibrium 2 complex (is more stable) because: *either* K_{stab} is greater or ΔG° is more negative. **[1]** **[Total: 8]**

EXAMINER COMMENTS

MARK SCHEME

(b) Values for ΔH° and ΔG° for equilibria I and II, and the value of ΔS° for equilibrium I, are given in the table below. All values are at a temperature of 298 K.

equilibrium	ΔH° / kJ mol^{-1}	ΔG° / kJ mol^{-1}	ΔS° / J K^{-1} mol^{-1}
I	–57.3	–37.4	–66.8
II	–56.5	–60.7	to be calculated

(i) Suggest a reason why the ΔH° values for the two equilibria are very similar.

Because it has ~~the~~ the same transition metal involved. [1]

(ii) Calculate ΔS° for equilibrium II.

~~–60.07 = –56.5 – (2~~

x = –4200 / –298 = 14.1

–60,700 = –56500 – (298(~~–66–~~x))

–4200 = –298x

ΔS° = 14.1 J K^{-1} mol^{-1} [1]

(iii) Suggest a reason for the difference between the ΔS° you have calculated for equilibrium II and that for equilibrium I given in the table.

~~More~~ Equilibrium 1 has more disorder ~~due~~ arrangement on its reactant ~~side~~ side while 2 has more disorder on its product side. [1]

(iv) Which of the two complexes is the more stable? Give a reason for your answer.

~~Equili~~ $[Cd(H_2NCH_2CH_2NH_2)_2]^{2+}$ because of its higher Kstab. [1]

[Total: 8]

Select page

HIGH | MIDDLE | LOW

Your Mark

5(a)(i)

5(a)(ii)

5(b)(i)

5(b)(ii)

5(b)(iii)

5(b)(iv)

Q5	Mark scheme
(a)(i)	$K_{stab} = \frac{[Cd(CH_3NH_2)_4^{2+}]}{[Cd^{2+}][CH_3NH_2]^4}$ units: mol^{-4} dm^{12} **[2]**
(a)(ii)	$Cd^{2+} + 4CH_3NH_2 \rightleftharpoons [Cd(CH_3NH_2)4]^{2+}$ at start: 1 × 1^{-4} **0** at eqm: 1× 10^{-7} **y** **1 × 10^{-4} – 1 × 10^{-7}** **or 9.99 × 10^{-5} or 1.0 × 10^{-4}** 9.99 × 10^{-5}/ (***y***^{4} × 10^{-7})= 3.6 × 10^6 and y = 4√(9.99 × 10^{-5}) / (1 × 10^{-7} × 3.6 × 10^6) = **0.129 / 0.13** **[2]**
(b)(i)	(each complex is formed by) making (4 ×)N-Cd bonds and breaking (6 ×) O-Cd bonds **or** same types of / similar bonds forming / breaking **or** same number of bonds forming / breaking **[1]**
(b)(ii)	ΔS = (ΔH – ΔG) /T = (60.7 – 56.5) × 1000 / 298 = (+)**14** / (+)**14.1** **[1]**
(b)(iii)	fewer moles (of solutes) are forming (one mole of) the complex (so less loss of disorder) **or** one en displaces two H_2O whereas one CH_3NH_2 only displaces one H_2O **[1]**
(b)(iv)	The $[Cd(H_2NCH_2CH_2NH_2)_2]^{2+}$ / equilibrium 2 complex (is more stable) because: *either* K_{stab} is greater or ΔG° is more negative. **[1]** **[Total: 8]**

EXAMINER COMMENTS

MARK SCHEME

Cambridge Assessment International Education
The Triangle Building, Shaftesbury Road, Cambridge, CB2 8EA, United Kingdom
t: +44 1223 553554 f: +44 1223 553558
e: info@cambridgeinternational.org www.cambridgeinternational.org