7: Electricity and metals – 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
6	2017	March	42
3	2017	June	41
5	2017	June	42

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

6 **(a)** **(i)** Draw the shape of one of the d orbitals.

[1]

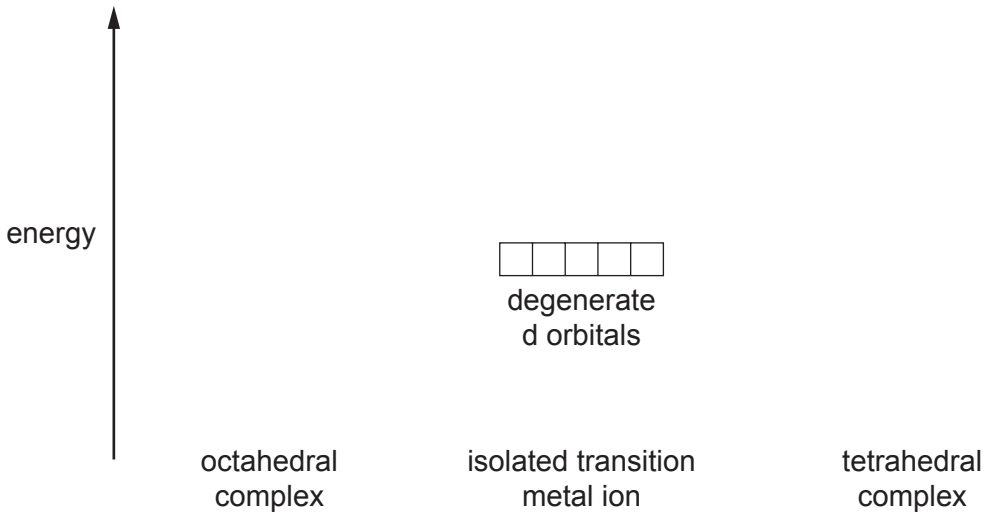
(ii) Complete the following electronic configurations.

Ni $1s^2 2s^2 2p^6 3s^2 3p^6$ .....

Ni^{3+} $1s^2 2s^2 2p^6 3s^2 3p^6$ .....

[1]

(b) **(i)** Complete the diagram to show how the presence of ligands around an isolated transition metal ion affects the **energy** of the d orbitals.



[1]

(ii) Explain why transition metal complexes are coloured.

.....

.....

.....

..... [2]

(iii) $[Cu(H_2O)_6]^{2+}$ is pale blue but $[Cu(NH_3)_4(H_2O)_2]^{2+}$ is deep purple-blue.

Suggest a reason for this.

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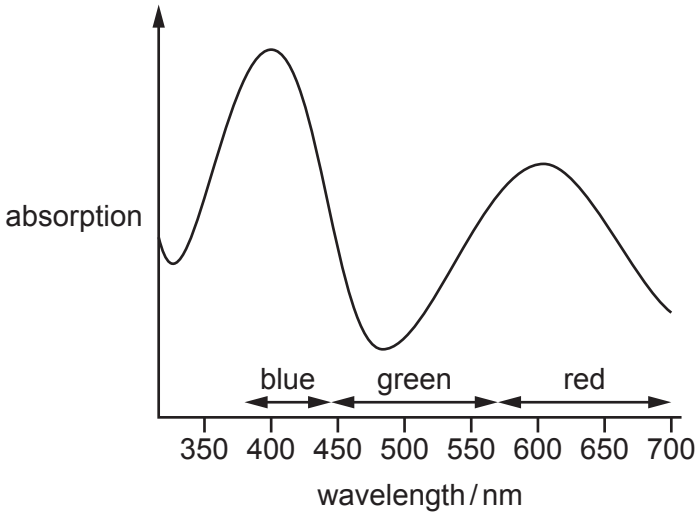
.....

..... [1]

(c) The diagram shows the visible spectrum of a solution of $[V(H_2O)_6]^{3+}$.



State and explain what colour the solution is.

colour of solution .....

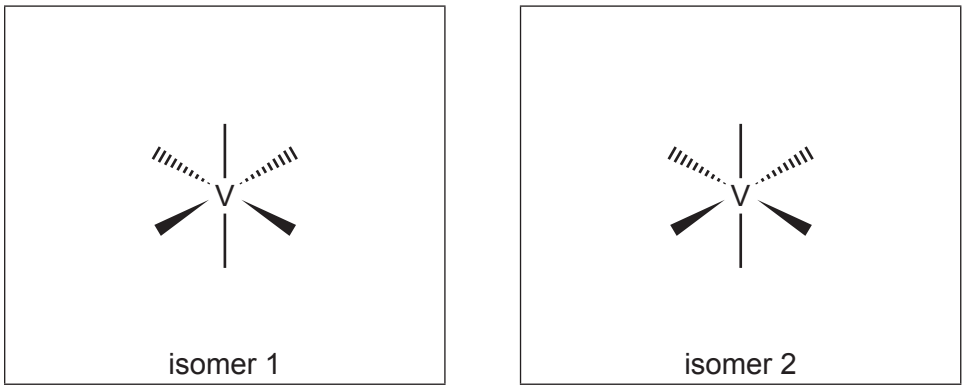
explanation .....

..... [2]

(d) **(i)** In the presence of chloride ions, $[V(H_2O)_6]^{3+}$ reacts to form a mixture of isomeric octahedral complexes.

$$[V(H_2O)_6]^{3+} + 2Cl^- \rightleftharpoons [V(H_2O)_4Cl_2]^+ + 2H_2O$$

Complete the three-dimensional diagrams to show the **two** isomers of $[V(H_2O)_4Cl_2]^+$.



[2]

(ii) State the type of isomerism shown by isomer 1 and isomer 2 in **(i)**.

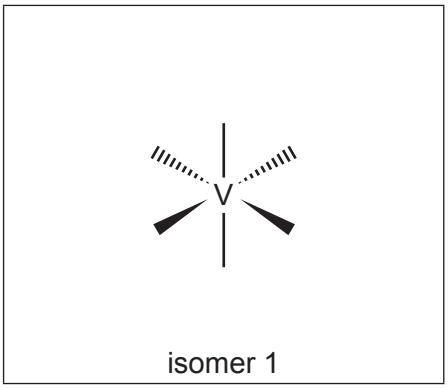
..... [1]

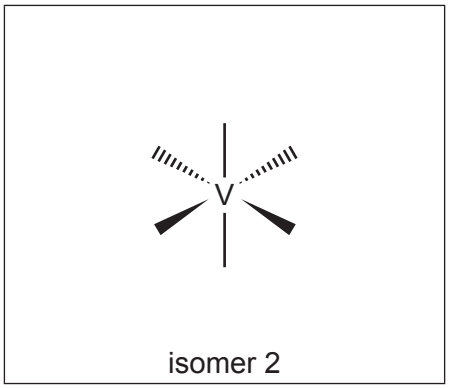
(e) **(i)** The complex $[V(H_2O)_6]^{3+}$ also reacts with ethane-1,2-diamine (*en*), $H_2NCH_2CH_2NH_2$, to form a mixture of isomeric octahedral complexes.

$$[V(H_2O)_6]^{3+} + 3en \rightleftharpoons [V(en)_3]^{3+} + 6H_2O$$

Complete the three-dimensional diagrams to show the **two** isomers of $[V(en)_3]^{3+}$.

You may use  to represent *en*.





[2]

(ii) State the type of isomerism shown by isomer 1 and isomer 2 in **(i)**.

..... [1]

(f) The reaction of $[Ni(H_2O)_6]^{2+}$ with aqueous ammonia produces the complex $[Ni(NH_3)_6]^{2+}$.

$$[Ni(H_2O)_6]^{2+}(aq) + 6NH_3(aq) \rightleftharpoons [Ni(NH_3)_6]^{2+}(aq) + 6H_2O(l)$$

(i) Write the expression for K_{stab} for $[Ni(NH_3)_6]^{2+}$.

K_{stab} =

[1]

(ii) $[Ni(H_2O)_6]^{2+}$ also reacts with *en* to form $[Ni(en)_3]^{2+}$.
The values of the stability constants for the two complexes are shown.

K_{stab} $[Ni(NH_3)_6]^{2+} = 4.8 \times 10^{7}\,mol^{-6}\,dm^{18}$

K_{stab} $[Ni(en)_3]^{2+} = 2.0 \times 10^{18}\,mol^{-3}\,dm^{9}$

A solution containing equal numbers of moles of ammonia and *en* is added to $[Ni(H_2O)_6]^{2+}$.

State which complex is produced in the larger amount. Explain your answer.

.....

.....

..... [1]

(iii) Adding a limited amount of *en* to $[Ni(H_2O)_6]^{2+}$ forms the complex $[Ni(H_2O)_2(en)_2]^{2+}$.

Suggest the number of possible stereoisomers of $[Ni(H_2O)_2(en)_2]^{2+}$. Explain your answer.
You are advised to include three-dimensional diagrams in your answer.

.....

.....

.....

..... [2]

[Total: 18]

3 Bubbling air through different aqueous mixtures of $CoCl_2$, NH_4Cl and NH_3 produces various complex ions with the general formula $[Co(NH_3)_{6-n}Cl_n]^{3-n}$.

(a) (i) Determine the oxidation state of the cobalt in these complex ions.

..... [1]

(ii) Name the **two** types of reaction undergone by the cobalt ions during the formation of these complex ions.

.....

..... [2]

(iii) The complex $[Co(NH_3)_4Cl_2]^+$ shows isomerism.

Draw three-dimensional structures of the two isomers, and suggest the type of isomerism shown here.

isomer 1

isomer 2

type of isomerism .....
[3]

(b) (i) What is meant by the term *co-ordination number*?

.....

..... [1]

(ii) Complete the table by predicting appropriate co-ordination numbers, formulae and charges for the complexes **C**, **D**, **E** and **F**.

complex	metal ion	ligand	co-ordination number	formula of complex	charge on complex
C	Cr^{3+}	CN^-			3–
D	Ni^{2+}	$H_2NCH_2CH_2NH_2$	6		
E	Pt^{2+}	Cl^-			2–
F	Fe^{3+}	$^-O_2C–CO_2^-$		$[Fe(O_2CCO_2)_3]$	

[6]

(c) Iron(III) forms complexes in separate reactions with both SCN^- ions and Cl^- ions.

$$Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons [FeSCN]^{2+}(aq) \qquad \text{equilibrium 1}$$

$$Fe^{3+}(aq) + 4Cl^-(aq) \rightleftharpoons [FeCl_4]^-(aq) \qquad \text{equilibrium 2}$$

(i) Write the expressions for the stability constants, K_{stab}, for these two equilibria. Include units in your answers.

K_{stab1} =

units = ...

K_{stab2} =

units = ...

[3]

(ii) An equilibrium can be set up between these two complexes as shown in equilibrium 3.

$$[FeCl_4]^-(aq) + SCN^-(aq) \rightleftharpoons [FeSCN]^{2+}(aq) + 4Cl^-(aq) \qquad \text{equilibrium 3}$$

Write an expression for K_{eq3} in terms of K_{stab1} and K_{stab2}.

K_{eq3} = ... [1]

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

$$K_{stab1} = 1.4 \times 10^2 \qquad K_{stab2} = 8.0 \times 10^{-2}$$

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

K_{eq3} = ... units = ...

[2]

[Total: 19]

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 .....

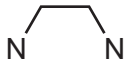
ligand .....

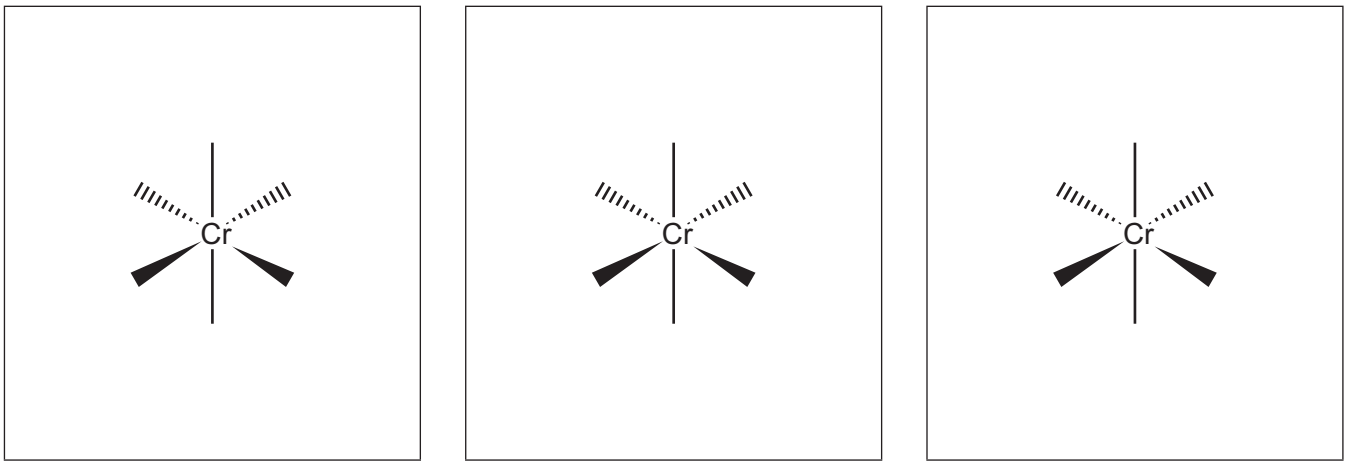
.....

[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.

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

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]

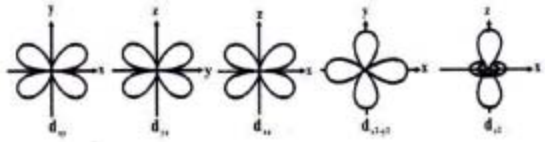
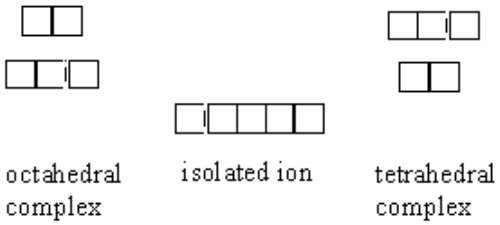
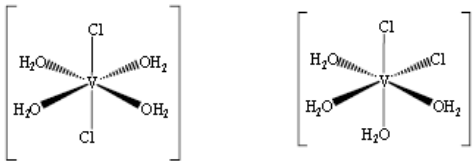
(iv) Using data from the table, suggest a value of $\Delta H^{\ominus}$ for equilibrium 3.

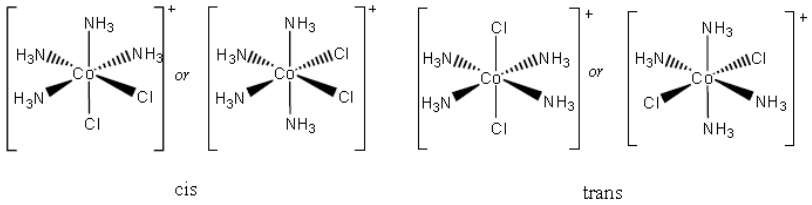
..... [1]

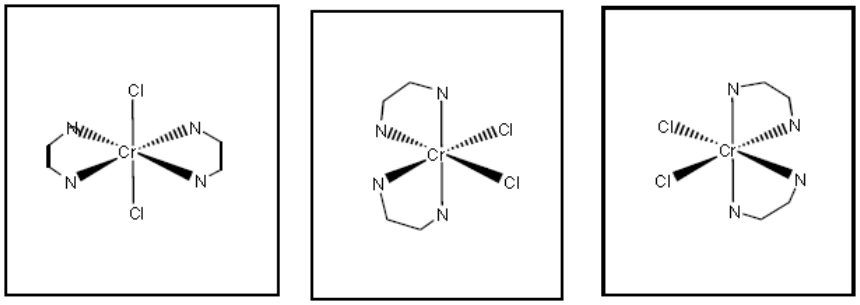
(v) State the *type of reaction* that is occurring in equilibrium 2.

..... [1]

[Total: 17]

Question	Answer	Marks
6 (a) (i)		**1+1**
6 (a) (ii)	Ni : $[1s^2 2s^2 2p^6 3s^2 3p^6]$ **$3d^8 4s^2$** Ni3+ : $[1s^2 2s^2 2p^6 3s^2 3p^6]$ **$3d^7$**	**1**
6 (b) (i)		**1**
6 (b) (ii)	energy / photon is absorbed in the visible region / light	**1**
	electron jumps from the lower to the upper energy level / is excited	**1**
6 (b) (iii)	different frequency / wavelength of light are absorbed by the two complexes **OR** different size of energy gap	**1**
6 (c)	colour of solution: green	**1**
	explanation: because the solution absorbs most strongly in the blue **AND** red regions	**1**
6 (d) (i)		**1**
6 (d) (ii)	cis-trans / geometrical	**1**
6 (e) (i)		**1**
6 (e) (i)	optical	**1**
6 (f) (i)	$K_{stab} = [Ni(NH_3)_6^{2+}] / ([Ni(H_2O)_6^{2+}][NH_3]^6)$	**1**
6 (f) (ii)	$[Ni(en)_3]^{2+}$ would be formed because it is much more stable / K_{stab} is much greater **OR** in the presence of both ligands the overall equilibrium $[Ni(NH_3)_6]^{2+} \rightleftharpoons [Ni(H_2O)_6]^{2+} \rightleftharpoons [Ni(en)_3]^{2+}$ would shift right	**1**
6 (f) (iii)	cis-trans isomers identified	**1**
	two cis isomers identified	**1**
		Total: 17

Question	Answer	Marks
3 (a) (i)	+3 or Co^{3+}	1
3 (a) (ii)	oxidation	1
	ligand displacement / replacement / exchange / substitution	1
3 (a) (iii)	 cis trans	1
	geometrical or cis-trans	1
3 (b) (i)	The number of bonds / atoms bonded to **an atom / ion / species / metal**	1
3 (b) (ii)	**C** 6 $[Cr(CN)_6]$ – **D** – $[Ni(NH_2CH_2CH_2NH_2)_3]$ 2+/+2 **E** 4 $[PtCl_4]$ – **F** 6 – 3–/–3	6
3 (c) (i)	$K_{stab(1)} = [FeSCN^{2+}]/([Fe^{3+}][SCN^-])$ mol^{-1} dm^3 $K_{stab(2)} = [FeCl^{4-}]/([Fe^{3+}][Cl^-]^4)$ mol^{-4} dm^{12}	3
3 (c) (ii)	$K_{eq(3)} = K_{stab(1)} / K_{stab(2)}$	1
3 (c) (iii)	$K_{eq(3)} = 1750$	1
	mol^3 dm^{-9}	1
		Total: 19

Question	Answer	Marks
5 (a) (i)	*bidentate*: (a species that) forms **two** dative bonds / donates **two** lone pairs	1
	ligand: a species that uses a **lone pair** to form a **dative** bond to **a metal atom / metal ion**	1
5 (a) (ii)	 each structure [1] × 3	3
5 (b) (i)	$K_{stab1} = [Cu(NH_3)_4^{2+}]/[Cu^{2+}][NH_3]^4$	1
	$K_{stab2} = [Cu(en)_2^{2+}]/[Cu^{2+}][en]^2$	1
	mol^{-4} dm^{12} AND mol^{-2} dm^6	1

Question	Answer	Marks
5 (b) (ii)	$K_{eq3} = K_{stab2} / K_{stab1}$	**1**
5 (b) (iii)	$K_{eq3} = K_{stab2} / K_{stab1} = 4.4(2) \times 10^{6}$	**1**
	$mol^{2}\ dm^{-6}$	**1**
5 (c) (i)	(ΔS_{eq1} is negative as) **more / 5** moles of reactants are forming (one mole of) the complex OR (ΔS_{eq2} is positive as) **fewer / 3** moles of reactants are forming (one mole of) the complex	**1**
5 (c) (ii)	ΔG_{eq2} = –100 – 298 × 40 / 1000 OR $\Delta G = \Delta H - T\Delta S$	**1**
	= –112 or –111.9 ($kJ\ mol^{-1}$) correct answer	**1**
		Total: 14

Notes about the mark scheme are available separately.