



GuideMyGrades

— YOUR GOALS. OUR EXPERTISE. —

EDEXCEL A LEVEL CHEMISTRY: QUESTIONS BY TOPIC

Transition Metals (15)

A Level Chemistry Topic 15

10 questions · 119 marks · Mark schemes included

Pearson Edexcel A Level Chemistry (9CH0), June 2017 - June 2025

 [guidemygrades.com](https://www.guidemygrades.com)

 @Guidemygrades

 @Guidemygrades

 @Guidemygrades

 info@guidemygrades.com

 Piccadilly Business Centre, Unit C, Aldow Enterprise Park
Blackett Street, Manchester, M12 6AE

HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic; within each sub-topic they run from the lowest mark tariff to the highest.

Click any sub-topic heading or question row below to jump straight to it.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

QUESTION	SOURCE	MARKS	PAGE
15(a) PRINCIPLES OF TRANSITION METAL CHEMISTRY		8 questions · 102 marks	3
1. Q7	A Level Paper 3 October 2020	6	4
2. Q4	A Level Paper 1 June 2017	9	6
3. Q4	A Level Paper 1 June 2018	9	8
4. Q8	A Level Paper 1 November 2021	12	10
5. Q6	A Level Paper 3 June 2019	14	13
6. Q7	A Level Paper 3 June 2017	15	16
7. Q3	A Level Paper 1 October 2020	18	19
8. Q6	A Level Paper 1 June 2025	19	22
15(b) TRANSITION METAL REACTIONS		1 question · 11 marks	26
9. Q1	A Level Paper 3 June 2017	11	27
15(c) TRANSITION METALS AS CATALYSTS		1 question · 6 marks	29
10. Q8	A Level Paper 1 June 2023	6	30



QUESTIONS

10 questions · 119 marks · grouped by sub-topic



SUB-TOPIC 15(a)

PRINCIPLES OF TRANSITION METAL CHEMISTRY

8 questions in this sub-topic · 102 marks · lowest tariff first



(Total for Question 7 = 6 marks)



4 Iron and zinc are in the d-block of the Periodic Table.(a) Which of these is the electronic configuration of an iron(II) ion, Fe^{2+} ?

(1)

	3d	4s
☐ A [Ar]	$\uparrow\downarrow$ $\uparrow\downarrow$ $\uparrow\downarrow$ $\square$ $\square$	$\square$
☐ B [Ar]	$\uparrow\downarrow$ $\uparrow$ $\uparrow$ $\uparrow$ $\uparrow$	$\square$
☐ C [Ar]	$\uparrow\downarrow$ $\uparrow\downarrow$ $\square$ $\square$ $\square$	$\uparrow\downarrow$
☐ D [Ar]	$\uparrow$ $\uparrow$ $\uparrow$ $\uparrow$ $\square$	$\uparrow\downarrow$

(b) Iron(II) ions, $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$, form a pale green solution but zinc ions, $[\text{Zn}(\text{H}_2\text{O})_6]^{2+}$, form a colourless solution.

Explain why zinc ions are colourless.

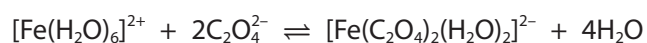
(2)

.....

.....

.....

.....

(c) Hydrated iron(II) ions react with ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, to form a complex ion.(i) Draw a structure of the $[\text{Fe}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]^{2-}$ ion, showing **all** of the bonds.

(2)



(ii) Explain, in terms of entropy, why this reaction is feasible.

(2)

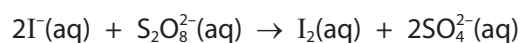
.....

.....

.....

.....

(d) Iodide ions, I^- , react with peroxodisulfate(VI) ions, $\text{S}_2\text{O}_8^{2-}$



This reaction is catalysed by iron(II) ions, $\text{Fe}^{2+}(\text{aq})$.

Write **two** ionic equations to show how iron(II) ions act as a catalyst in this reaction.
State symbols are not required.

(2)

(Total for Question 4 = 9 marks)



4 This question is about transition metals.

(a) Which of these ions has the electronic configuration $[\text{Ar}]3d^5$?

(1)

- ☐ A Cr^{3+}
- ☐ B Fe^{2+}
- ☐ C Mn^{2+}
- ☐ D Mn^{3+}

(b) In which of these complex ions does the transition metal have the oxidation number +3?

(1)

- ☐ A $[\text{Ag}(\text{CN})_2]^-$
- ☐ B $[\text{CuCl}_4]^{2-}$
- ☐ C $[\text{Fe}(\text{CN})_6]^{3-}$
- ☐ D $[\text{Ni}(\text{EDTA})]^{2-}$

(c) Which type or types of bonding exist **within** the complex ion $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$?

(1)

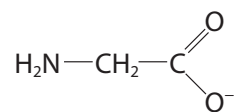
- ☐ A dative covalent only
- ☐ B dative covalent and covalent only
- ☐ C dative covalent and ionic only
- ☐ D dative covalent, covalent and ionic

(d) Which **best** explains why $[\text{Cu}(\text{NH}_3)_2]^+$ ions are colourless?

(1)

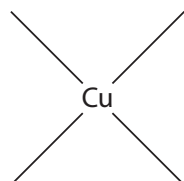
- ☐ A all complex ions having a metal ion with a +1 charge are colourless
- ☐ B no electronic transitions can take place between *d*-orbitals
- ☐ C the *d*-orbitals cannot split in energy
- ☐ D there are no electrons in the *d*-subshell

(e) Glycinate ions are bidentate ligands and can be represented by the structure

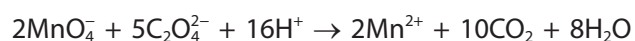


Complete the diagram below to show the structure of the $[\text{Cu}(\text{NH}_2\text{CH}_2\text{COO})_2]$ complex, which is square planar.

(2)



(f) Manganate(VII) ions, MnO_4^- , react with ethanedioate ions in acid solution.



The reaction starts slowly, the rate of reaction then increases, before it decreases again. Explain this sequence.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question 4 = 9 marks)



8 Transition metals form complex ions.

(a) Complex ions have a central metal ion surrounded by ligands.

(i) Give a reason why the ammonium ion cannot act as a ligand.

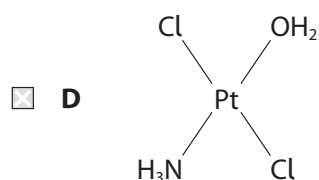
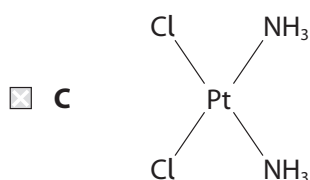
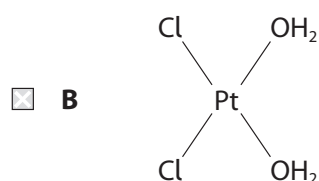
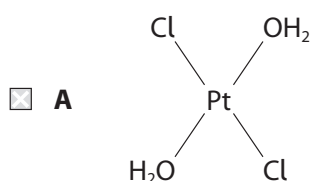
(1)

(ii) Explain why the complex ions $[\text{Co}(\text{NH}_3)_6]^{2+}$ and $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ are coloured and have different colours.

(4)

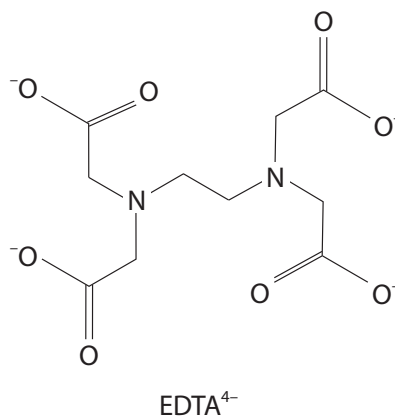
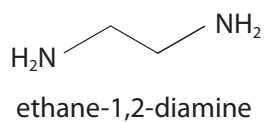
(b) Which of these complexes is used in the treatment of cancer?

(1)



- (c) Compare and contrast the complex ions formed by cobalt(III) ions with the ligand ethane-1,2-diamine and with the ligand EDTA^{4-} .

Ignore any difference in colour.



(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

- (d) Hydrated chromium(III) chloride, $\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$, dissolves in water to form a number of different complex ions containing both chloride and water ligands.

The general formula of these complex ions is $[\text{Cr}(\text{H}_2\text{O})_x(\text{Cl})_y]^{(3-y)+}$

In an experiment, 0.10 mol of a complex reacted with excess silver nitrate solution to produce 0.20 mol of silver chloride.

Chloride ions which are ligands within the complex do not react with silver nitrate.

Deduce the formula of this chromium(III) complex ion. Justify your answer.

(2)

.....

.....

.....

.....

.....

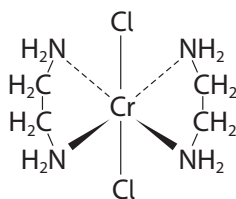
.....

(Total for Question 8 = 12 marks)



6 This question is about transition metals and their ions.

(a) The **shape** of a complex ion formed from Cr^{3+} ions is shown.



(i) State the coordination number of Cr^{3+} in this complex ion.

(1)

(ii) State the overall charge on this complex ion.

(1)

(b) The complex ions of transition metals have different colours in aqueous solution.

Two factors that affect the colour of the solution are the oxidation number of the central metal ion, and the ligands present.

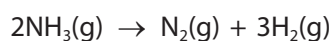
Give examples to illustrate these factors by referring to complex ions of iron and/or copper. Include the formula and colour of each complex.

An explanation of why transition metal ions are coloured is **not** required.

(3)



(c) Tungsten wire catalyses the decomposition of ammonia.

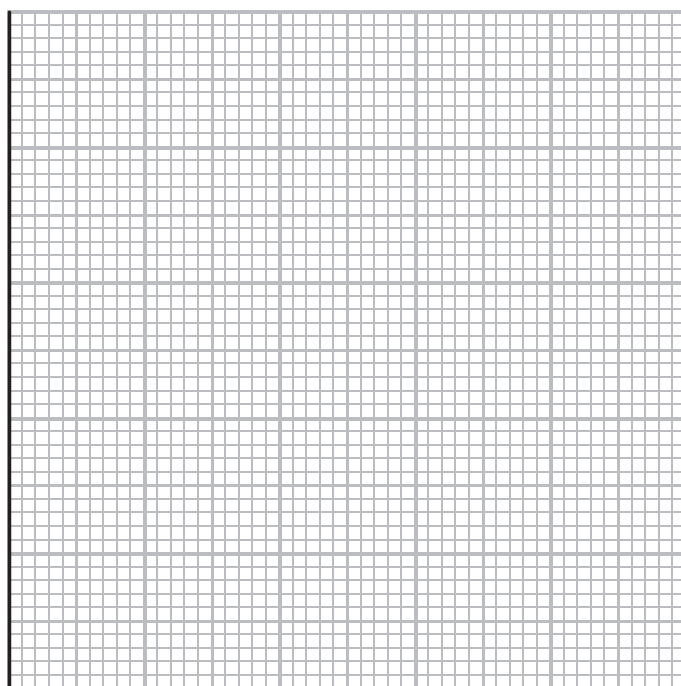


In an experiment, the following results were obtained.

Time /s	Partial pressure of ammonia / kPa
0	0.350
100	0.335
200	0.319
300	0.303
400	0.287
500	0.271

(i) Plot a graph of partial pressure of ammonia against time.

(2)



- (ii) Deduce the rate equation for this reaction by using your graph in (c)(i).
Justify your answer.

(2)

- (iii) Use the graph to calculate the rate constant. Include units in your answer.

(2)

- (iv) Describe the stages in the catalytic decomposition of ammonia by tungsten.

(3)

(Total for Question 6 = 14 marks)



7 This question is about the chemistry of elements in the *d*-block of the Periodic Table.

* (a) Many of the *d*-block elements are also classified as transition metals.

Explain why two of the *d*-block elements within Period 4 (scandium to zinc) are **not** classified as transition metals.

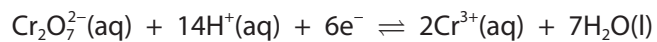
You should include **full** electronic configurations where relevant.

(6)



(b) Under certain conditions, dichromate(VI) ions, $\text{Cr}_2\text{O}_7^{2-}$, can oxidise manganese(II) ions, Mn^{2+} .

In this reaction, dichromate(VI) ions are reduced to chromium(III) ions, in acidic conditions, according to the half-equation



In an experiment it was found that 20.0 cm^3 of $0.100 \text{ mol dm}^{-3}$ potassium dichromate(VI) was required to oxidise 30.0 cm^3 of $0.200 \text{ mol dm}^{-3}$ manganese(II) sulfate solution.

Use these data to calculate the final oxidation state of the manganese.

(5)



(c) A student constructed an electrochemical cell as follows:

- a half-cell was made from a strip of chromium metal and a solution of aqueous chromium(III) sulfate
- a second half-cell was made from a piece of metal, **X**, and a solution of its sulfate, $\text{XSO}_4(\text{aq})$
- the two half-cells were connected and a current allowed to pass for some time.

Results

- the chromium electrode increased in mass by 1.456 g
- the electrode made of metal **X** decreased in mass by 1.021 g.

Use these data to determine the identity of the metal, **X**.

(4)

(Total for Question 7 = 15 marks)



3 This question is about transition metals and transition metal complexes.

- (a) Describe the bonding in the element chromium and use your answer to justify why it has such a high melting temperature.

You may find it helpful to draw a labelled diagram.

(4)

.....

.....

.....

.....

.....

- (b) When chromium(III) sulfate dissolves in water, a green solution containing the $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ ion forms.

- (i) Give the shape of this complex ion.

(1)

.....

- (ii) Explain why the chromium complex ion is coloured.

(3)

.....

.....

.....

.....

.....

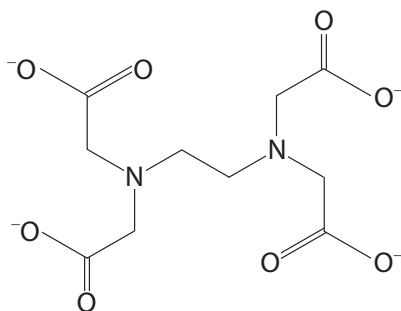
.....

.....

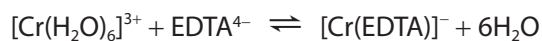
.....



(c) The ligand ethylenediaminetetraacetate, EDTA^{4-} , has the structure shown.



When a solution of EDTA^{4-} is added to a solution of $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ ions, a new complex ion is formed.



The equilibrium constant for this equilibrium is $2.51 \times 10^{23} \text{ dm}^3 \text{ mol}^{-1}$.

By considering the equilibrium for this reaction and changes in entropy, comment on the value of the equilibrium constant. No calculations are required.

(3)

.....

.....

.....

.....

.....

.....

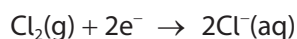
.....

.....

- (d) Aqueous vanadium(II) chloride, $\text{VCl}_2(\text{aq})$, can be oxidised by bubbling gaseous chlorine, $\text{Cl}_2(\text{g})$, through the solution in the absence of air.

40.0 cm^3 of $0.100 \text{ mol dm}^{-3}$ VCl_2 solution was oxidised by 144 cm^3 of chlorine gas, at room temperature and pressure (r.t.p.).

The chlorine was reduced to chloride ions, according to the half-equation



[Molar volume of a gas at r.t.p. = $24.0 \text{ dm}^3 \text{ mol}^{-1}$]

- (i) Use these data to calculate the final oxidation state of vanadium.
You **must** show your working.

(5)

- (ii) State the initial and final colours you would see as the chlorine bubbles through the aqueous vanadium(II) chloride, $\text{VCl}_2(\text{aq})$.

(2)

.....

.....

(Total for Question 3 = 18 marks)



6 This question is about transition metals.

(a) (i) Which pair of electronic configurations is correct?

(1)

	Cr	Cr ³⁺
☐ A	[Ar] 3d ⁴ 4s ²	[Ar] 3d ¹ 4s ²
☐ B	[Ar] 3d ⁵ 4s ¹	[Ar] 3d ¹ 4s ²
☐ C	[Ar] 3d ⁴ 4s ²	[Ar] 3d ³
☐ D	[Ar] 3d ⁵ 4s ¹	[Ar] 3d ³

(ii) State why chromium is classified as a transition metal.

(1)

.....

.....

(b) (i) Draw the structure of the complex ion, [Cr(H₂O)₆]³⁺(aq), showing clearly its 3-dimensional shape, and the bonds between the chromium ion and the water ligands.

(2)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) Name the **shape** of the [Cr(H₂O)₆]³⁺(aq) complex ion.

(1)

.....

.....

.....

.....

.....

.....

.....

.....



- (c) Write **two ionic** equations which demonstrate the amphoteric nature of chromium(III) hydroxide $[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3]$. Include state symbols.

(3)

- (d) Name the type of reaction that occurs when chromium(III) hydroxide reacts with excess aqueous ammonia.

(1)

- (e) (i) Explain why aqueous solutions of $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ are coloured.

(4)



- (ii) Give the reason why the solutions of $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ and $[\text{CrCl}_4]^-$ are **different** colours.

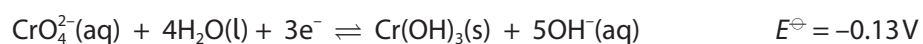
(1)

.....

.....

.....

- (f) The standard electrode potentials for two half-cell reactions are shown.



- (i) Write the overall equation for the reaction of chromium(III) hydroxide with hydrogen peroxide in alkaline conditions to form chromate(VI) ions. State symbols are not required.

(2)

- (ii) Calculate the $E_{\text{cell}}^\ominus$ for this reaction. Include a reason whether or not the reaction is thermodynamically feasible.

(2)

.....

.....



(iii) Which is a correct statement about $E_{\text{cell}}^{\ominus}$?

(1)

- ☐ A $E_{\text{cell}}^{\ominus}$ is directly proportional to $\ln K$
- ☐ B $E_{\text{cell}}^{\ominus}$ is directly proportional to ΔS_{system}
- ☐ C $E_{\text{cell}}^{\ominus}$ is directly proportional to $\ln \Delta S_{\text{total}}$
- ☐ D $E_{\text{cell}}^{\ominus}$ is directly proportional to K

(Total for Question 6 = 19 marks)



SUB-TOPIC 15(b)

TRANSITION METAL REACTIONS

1 question in this sub-topic · 11 marks · lowest tariff first



1 This question is about transition metal chemistry.

(a) The **amphoteric** character of solid chromium(III) hydroxide is shown by the fact that it reacts separately with both dilute hydrochloric acid and dilute sodium hydroxide solution.

(i) Write an **ionic** equation for the reaction of solid chromium(III) hydroxide with dilute hydrochloric acid, showing the formula of the complex ion formed. Include state symbols in your answer.

(2)

(ii) Describe the changes you would **see** when the reaction in (a)(i) is carried out.

(2)

.....

.....

.....

.....

(iii) Write an **ionic** equation for the reaction of solid chromium(III) hydroxide with dilute sodium hydroxide solution, showing the formula of the complex ion formed. Include state symbols in your answer.

(2)

(iv) State the final appearance of the reaction mixture in (a)(iii).

(1)

.....

.....



(b) Dilute aqueous ammonia is added, drop by drop, to an aqueous solution of copper(II) sulfate until the aqueous ammonia is in excess.

(i) Describe what you would **see** during this experiment.

(2)

.....

.....

.....

.....

(ii) The reaction between aqueous copper(II) sulfate and **excess** aqueous ammonia is an example of a **ligand substitution** reaction.

Write an equation for the ligand substitution reaction that occurs, showing the formulae of the complex ions involved. State symbols are not required.

(2)

(Total for Question 1 = 11 marks)



SUB-TOPIC 15(c)

TRANSITION METALS AS CATALYSTS

1 question in this sub-topic · 6 marks · lowest tariff first



(Total for Question 8 = 6 marks)



MARK SCHEMES

official Pearson Edexcel mark schemes



Question Number	Answer	Additional Guidance	Mark																				
*7	This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5-4</td><td>3</td></tr><tr><td>3-2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> The following table shows how the marks should be awarded for structure and lines of reasoning <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained lines of reasoning</th></tr><tr><td>Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5-4	3	3-2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained lines of reasoning	Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, a response with four indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and zero marks for linkages). Penalise incorrect chemistry such as bond angles of 90° for tetrahedral complexes or incorrect oxidation number by deducting a reasoning mark	(6)
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																						
6	4																						
5-4	3																						
3-2	2																						
1	1																						
0	0																						
	Number of marks awarded for structure of answer and sustained lines of reasoning																						
Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																						
Answer is partially structured with some linkages and lines of reasoning	1																						
Answer has no linkages between points and is unstructured	0																						



	Indicative content • IP1 formulae and colour of first complex ion • IP2 formulae and colour of second complex ion • IP3 definition of ligand • IP4 definition of and example(s) of coordination number • IP5 shape of complex ion(s) • IP6 the chloride ion is larger (than the oxygen in water ligand or nitrogen in the ammonia ligand)	Accept any six indicative content points More than one indicative marking point may be made within the same comment or explanation $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ allow $[\text{Co}(\text{NH}_3)_6]^{2+}$ or $[\text{Co}(\text{EDTA})]^{2-}$ or $[\text{Co}(\text{en})_3]^{2+}$ and pink or yellow/brown for the hexaamine complex $[\text{CoCl}_4]^{2-}$ allow $[\text{Co}(\text{OH})_4]^{2-}$ and blue Atom/ion/molecule/species dative covalently bonded/ coordinately bonded to a central metal ion which can be shown on a diagram The number of dative covalent bonds (to a central metal ion) and Six and/or four respectively which may be in a diagram Octahedral and/or tetrahedral respectively and can be a diagram. If two given then both must be correct Allow chloride ions are large and only fit four around the metal ion Do not award 'molecule' when referring to chlorine Accept reverse argument	
--	--	--	--

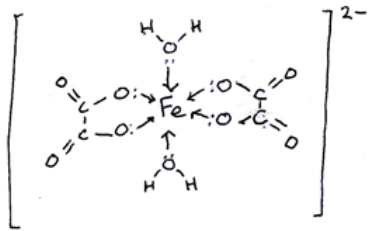
Total Question 7 = 6 marks)



Question Number	Answer	Mark
4(a)	The only correct answer is B <i>A is not correct because 4 of the 3d electrons should be unpaired</i> <i>C is not correct because there should not be any electrons in the 4s orbital</i> <i>D is not correct because there should not be any electrons in the 4s orbital</i>	(1)

Question Number	Answer	Additional Guidance	Mark
4(b)	An explanation that makes reference to the following points: (zinc (ions) / Zn^{2+}) has / have a full (3)d sub-shell / $3d^{10}$ / all (3)d orbitals are full (1) - so d-d transitions cannot take place or electrons cannot move between (3)d orbitals or electrons cannot be promoted / excited to higher (3)d orbitals (1)	Allow zinc (ions) / Zn^{2+} do not have a partially filled / incomplete (3)d (sub-) shell / no empty (3)d orbitals Do not allow zinc atoms Ignore omission of 'd' in the 'or's, if it is included in M1 Do not allow the (3)d orbitals do not split / the (3)d subshell does not split Ignore just 'movement to different energy level'	(2)



Question Number	Answer	Additional Guidance	Mark
4(c)(i)	2 water ligands joined between O and Fe (1) 2 ethanedioate ligands drawn correctly showing all the bonds and joined between single-bonded O atoms and Fe as shown (1)	Example of structure  Allow water ligands arranged as <i>cis</i> or <i>trans</i> Allow delocalised bonds in ethanedioate ions Allow bonds not shown in H₂O, provided the ligands are attached to Fe²⁺ through oxygen atoms Ignore bond lengths and angles Ignore wedges and dotted lines to show shape Ignore missing lone pairs and arrowheads Ignore missing square brackets and charge / incorrect charge Ignore -ve charges on ethanedioate ions / +ve charge on Fe	(2)

Question Number	Answer	Additional Guidance	Mark
4(c)(ii)	An explanation that makes reference to the following points: (there are) more particles / moles / species on the right of the equation (than on the left) or (there is an increase from) 3 particles on the left of the equation to 5 on the right (1) - so ΔS_{system} increases / is positive (and $\Delta S_{\text{surroundings}}$ is unchanged so ΔS_{total} increases) (1)	Do not allow incorrect numbers of particles Do not allow 3 molecules on the left and 5 molecules on the right Allow ΔS_{total} is positive / increasing Allow entropy / ΔS increases Allow there is a positive entropy change Ignore just there is an increase in disorder (from left to right) Ignore $\Delta S_{\text{surroundings}}$ changes Ignore just 'entropy is positive' Ignore references to free energy	(2)

Question Number	Answer	Additional Guidance	Mark
4(d)	- Fe²⁺ oxidised to Fe³⁺ in reaction with S₂O₈²⁻ (1) - Fe³⁺ reduced to Fe²⁺ in reaction with I⁻ (1)	<u>Examples of equations</u> $2\text{Fe}^{2+} + \text{S}_2\text{O}_8^{2-} \rightarrow 2\text{Fe}^{3+} + 2\text{SO}_4^{2-}$ $2\text{Fe}^{3+} + 2\text{I}^- \rightarrow 2\text{Fe}^{2+} + \text{I}_2$ Ignore state symbols Allow equations in either order Allow multiples Penalise uncanceled electrons once only Note If no other mark is awarded, allow (1) for all correct species in 2 unbalanced equations	(2)

(Total for Question 4 = 9 marks)

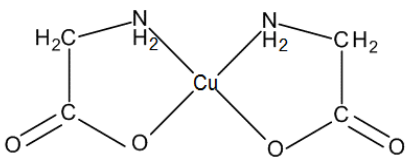
Question Number	Answer	Mark
4(a)	The only correct answer is C <i>A is not correct because it is $3d^3$ not $3d^5$</i> <i>B is not correct because it is $3d^6$ not $3d^5$</i> <i>D is not correct because it is $3d^4$ not $3d^5$</i>	(1)

Question Number	Answer	Mark
4(b)	The only correct answer is C <i>A is not correct because it is +1 not +3</i> <i>B is not correct because it is +2 not +3</i> <i>D is not correct because it is +2 not +3</i>	(1)

Question Number	Answer	Mark
4(c)	The only correct answer is B <i>A is not correct because covalent is missing</i> <i>C is not correct because it has ionic is incorrect</i> <i>D is not correct because it has ionic is incorrect</i>	(1)

Question Number	Answer	Mark
4(d)	The only correct answer is B <i>A is not correct because it is not an explanation</i> <i>C is not correct because the d-orbitals can be split in energy</i> <i>D is not correct because there are ten electrons in the d-subshell</i>	(1)



Question Number	Acceptable Answer	Additional Guidance	Mark
4(e)	• 2 glycinate ligands attached to Cu through nitrogen atoms (1) • 2 glycinate ligands attached to Cu through single bonded oxygen atoms and rest of structure correct (1)	<u>Example of structure</u>  Allow the two ligands attached to any 2 pairs of adjacent bonds Allow <i>cis</i> or <i>trans</i> isomer / delocalised carboxylate groups / skeletal formulae Ignore bond lengths and bond angles Ignore lone pairs of electrons, charge on the copper or oxygen ions and direction of dative covalent bonds Do not award M1 if bond between Cu and H of NH₂	(2)

Question Number	Acceptable Answer	Additional Guidance	Mark
4(f)	An explanation that makes reference to the following points: (the initial rate of reaction is slow) because both reacting species are negatively charged / repel each other or the reaction has a high activation energy / few particles have energy greater than (or equal to) the activation energy (1) (the rate of reaction increases) because Mn²⁺ ions (are formed) and they act as a catalyst / are autocatalytic / provide an alternative route with a lower activation energy (1) (the rate decreases) because the concentrations / amounts of the reactants decrease / the reactants are used up (1)	Allow because there is no catalyst / no Mn²⁺ ions present at the start Allow a description of how the Mn²⁺ ions are acting as a catalyst e.g. the idea of Mn²⁺ ions reacting and being regenerated Do not award 'enzyme' Allow example of one of the reagents used up / becoming a limiting factor Do not award 'the Mn²⁺ ions are used up'	(3)

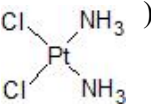
(Total for Question 4 = 9 marks)



Question Number	Answer	Additional Guidance	Mark
8(a)(i)	ammonium ions do not have a lone pair (of electrons for bonding)	Allow ammonium ions are positive and so are repelled (by the positive metal cation) Ignore reference to it already having a dative/coordinate bond	(1)

Question Number	Answer	Additional Guidance	Mark
8(a)(ii)	An answer that makes reference to - d orbitals/d sub-shell split (into two different energies) (1) - difference in energy depends on the ligands (1) - difference in energy leads in different frequencies/wavelengths/photons of light absorbed (1) (so) the unabsorbed frequencies/wavelengths/photons are reflected/transmitted (1)	Ignore 'distort' Do not award splitting of singular d orbital Allow 'colour seen' for reflected/transmitted Do not award 'emission' Do not award M3 nor M4 if reference to electron 'falling' releases energy is stated	(4)



Question Number	Answer	Mark
8(b)	The only correct answer is C () <i>A is not correct because water is not one of the ligands and the configuration of chloride ions should be cis not trans</i> <i>B is not correct because water is not one of the ligands</i> <i>D is not correct because the configuration should be cis not trans for the chloride ligands and one of the other ligands is a water molecule rather than ammonia</i>	(1)



Question Number	Answer	Additional Guidance	Mark
8(c)	An answer that makes reference to (Similarities) At least one from - both ligands form dative covalent bonds with the cobalt(III) ions (1) - both have coordination number 6 (1) - both complex ions will be octahedral (1) (Differences) At least one from - EDTA is hexadentate, ethane-1,2-diamine is bidentate OR ratio of cobalt(III) to EDTA is 1:1, with ethane-1,2-diamine it is 1:3 (1) - complex with EDTA will be anionic / negatively charged, with ethane-1,2-diamine will be cationic / positively charged (1) - complex of EDTA is more stable than the complex with ethane-1,2-diamine because there is an increase in entropy (1)	There must be some comparison. Hence two separate paragraphs on each complex without this scores max (3) Allow both donate lone pairs of electrons to cobalt(III) ions Allow both have 6 coordinate bonds Accept EDTA forms 6 bonds and ethane-1,2diamine forms 2 Ignore multidentate/polydentate ALLOW EDTA is an anion, ethane-1,2-diamine is neutral Allow molar ratios to illustrate, even if incorrect	(4)



Question Number	Answer	Additional Guidance	Mark
8(d)	An answer that makes reference to the following points (Justification) - two moles of chloride ions in aqueous solution so one mole of chloride ion is in the complex (1) - complex ion formula (1)	$[\text{Cr}(\text{H}_2\text{O})_5(\text{Cl})]^{2+}$	(2)

(Total Question 8 = 12 marks)



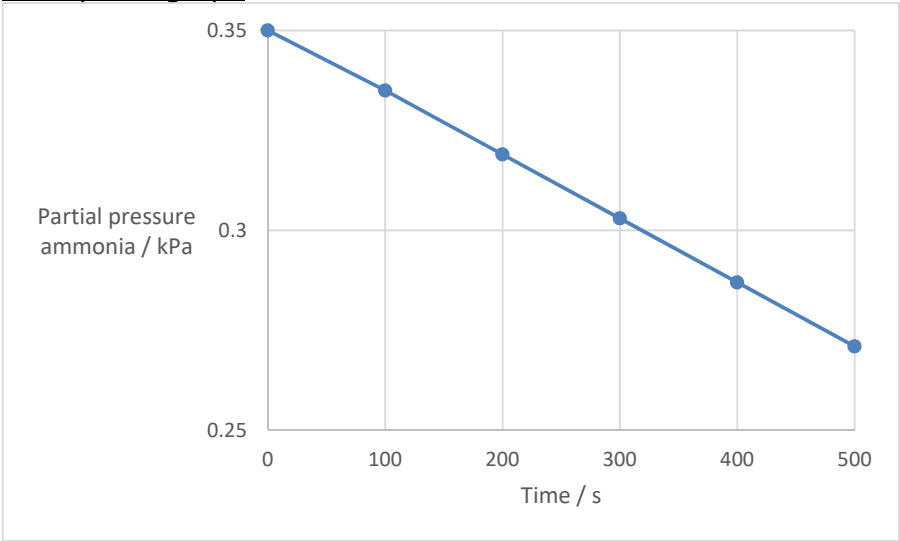
Question Number	Acceptable Answers	Additional Guidance	Mark
6(a)(i)	• six / 6		(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
6(a)(ii)	• 1+ / +1	Allow + / one positive charge Ignore positive / plus	(1)



Question Number	Acceptable Answers	Additional Guidance	Mark
6(b)	Oxidation state: - Two ions of the same metal (iron or copper) with different oxidation states and the same ligands with appropriate colours (1) Ligands: - formula and colour of complex with first ligand (1) - formula and colour of complex with second ligand (1)	Ignore ions of metals other than iron or copper Ignore use of precipitates instead of complex ions Ignore names of complex ions, even if incorrect Penalise additional incorrect species / colours once only <u>Examples of ions</u> $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ is green and $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ is yellow / orange / red/ brown $[\text{CuCl}_4]^{2-}$ is yellow and $[\text{CuCl}_2]^-$ is colourless $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ is (pale) blue and $[\text{CuCl}_4]^{2-}$ is yellow $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ is (pale) blue and $[\text{Cu}(\text{NH}_3)_4]^{2+}$ / $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ / $[\text{Cu}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$ is a darker blue than in the aqua ion $[\text{CuCl}_4]^{2-}$ is yellow and $[\text{Cu}(\text{NH}_3)_4]^{2+}$ / $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ / $[\text{Cu}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$ is (deep / dark) blue Allow any correct example of the same metal in the same oxidation state with different ligands and their corresponding colours, including colourless – the metal can be different to that in M1 Note Formulae and colours must be correct but ignore missing square brackets e.g. Do not award mention of green for $[\text{CuCl}_4]^{2-}$ Do not award $[\text{Cu}(\text{NH}_3)_6]^{2+}$ Ignore qualifications of colour e.g. pale / dirty	(3)



Question Number	Acceptable Answers	Additional Guidance	Mark
6(c)(i)	- axes with time on x axis and labelled, including units and suitable scale all points plotted correctly and best fit line	Example of graph  Partial pressure ammonia / kPa Time / s Allow y axis labelled with partial pressure / pressure and unit Do not allow partial pressure axis starting at 0 Both axes must cover at least half the graph paper Allow $\pm \frac{1}{2}$ square M2 can be awarded if axes the wrong way around in M1	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
6(c)(ii)	- rate = k / rate = $k \times p(\text{NH}_3)^0$ (1) (zero / 0 order) because the rate is independent of the partial pressure of ammonia / rate is constant or because the graph is a straight line / linear (1)	Allow r for rate Allow $-\text{rate} = k$ / rate = $k[\text{NH}_3]^0$ Ignore $[\text{H}_2]^0$ or $[\text{N}_2]^0$ Conditional on M1 Allow because the gradient is constant	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
6(c)(iii)	- calculation of gradient of graph / rate / rate constant (1) - corresponding units for rate constant (1)	Example of calculation $\frac{0.271 - 0.350}{500} = (-) \frac{0.079}{500}$ $k = 1.58 \times 10^{-4} / 0.000158$ Allow any value in the range 1.50 to 1.65×10^{-4} $1.58 \times 10^{-4} / 0.000158 \text{ kPa s}^{-1}$ Allow $158 \times 10^{-6} \text{ kPa s}^{-1}$ / 0.158 Pa s^{-1} / $1.58 \times 10^{-1} \text{ Pa s}^{-1}$ Do not award units of $\text{mol dm}^{-3} \text{ s}^{-1}$ Ignore SF except 1 SF Ignore negative value for k Correct answer with corresponding units and no working scores (2)	(2)



Question Number	Acceptable Answers	Additional Guidance	Mark
6(c)(iv)	A description that makes reference to the following points: - adsorption of ammonia / reactant onto surface of tungsten / catalyst (1) - breaking bonds in ammonia / reactant or breaking N-H bonds (1) - desorption of nitrogen and hydrogen / products / gases from surface of tungsten / catalyst (1)	Ignore reference to heterogeneous / homogeneous / active sites Allow gas for ammonia Allow adsorb / adsorp for adsorption Ignore "stick" Do not award absorption Allow bonds weaken instead of break Ignore mention of atoms / radicals Allow products released / detached from catalyst surface Allow de-adsorbed / desorped for desorption Do not award desorption of ammonia	(3)

(Total for Question 6 = 14 marks)

Question Number	Acceptable Answers	Additional Guidance	Mark												
*7(a)	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><td>Number of indicative marking points seen in answer</td><td>Number of marks awarded for indicative marking points</td></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> The following table shows how the marks should be awarded for structure and lines of reasoning.	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages). In general it would be expected that 5 or 6 indicative points would score 2 reasoning marks, and 3 or 4 indicative points would score 1 reasoning mark. A total of 2, 1 or 0 indicative points would score 0 marks for reasoning. Reasoning marks may be subtracted for extra incorrect chemistry.	(6)
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points														
6	4														
5–4	3														
3–2	2														
1	1														
0	0														



		Number of marks awarded for structure of answer and sustained line of reasoning			
	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.	2			
	Answer is partially structured with some linkages and lines of reasoning.	1			
	Answer has no linkages between points and is unstructured.	0			



	Indicative content (IPs) IP1: (transition metal) forms an ion with an incomplete <i>d</i> sub-shell IP2: - scandium and zinc are not transition metals IP3: Sc^{3+} and $1s^2 2s^2 2p^6 3s^2 3p^6$ IP4: Zn^{2+} and $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ IP5: Sc^{3+} and <i>d</i> sub-shell empty / <i>d</i>-orbitals empty IP6: Zn^{2+} and <i>d</i> sub-shell full / ALL <i>d</i>-orbitals are full	Allow 'partially-filled' for incomplete Allow <i>d</i>-orbital(s) Do not award "<i>d</i>-shell" Allow "<i>D</i>" for "<i>d</i>" throughout Allow if only Sc and Zn are used to illustrate <i>d</i>-block elements that are not transition metals Allow $4s^0$ and/or $3d^0$ Penalise use of [Ar] once only Allow "Sc^{3+} has no <i>d</i> sub-shell" Allow 'd orbital is full' if clarified by $3d^{10}$	
--	---	--	--



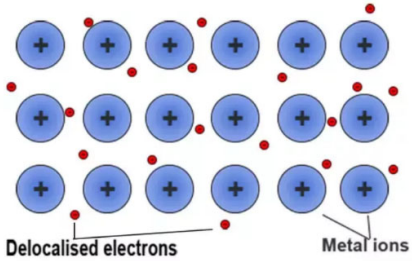
Question Number	Acceptable Answers	Additional Guidance	Mark
7(b)	- calculation of moles of $\text{Cr}_2\text{O}_7^{2-}$ (1) - calculation of moles of Mn^{2+} (1) - deduction of whole number mole ratio of $\text{Cr}_2\text{O}_7^{2-} : \text{Mn}^{2+}$ (1) - deduction of total number of electrons lost by 3 mol of Mn^{2+} (1) - deduction of final oxidation state of manganese (1)	<u>Example of calculation</u> - moles of $\text{Cr}_2\text{O}_7^{2-} = \frac{0.100 \times 20.0}{1000}$ $= 2(.00) \times 10^{-3} \text{ (mol)}$ - moles of $\text{Mn}^{2+} = \frac{0.200 \times 30.0}{1000}$ $= 6(.00) \times 10^{-3} \text{ (mol)}$ - mole ratio $\text{Cr}_2\text{O}_7^{2-} : \text{Mn}^{2+}$ $= \quad \quad \quad 1 \quad : \quad 3$ 3 mol Mn^{2+} lose a total of 6e^- - each Mn^{2+} loses 2e^-, so final oxidation state of Mn is (+)4 / IV / Mn^{4+} MP3 and MP4 may be awarded via alternative methods e.g. use of oxidation numbers / moles of electrons correct final oxidation state with no working scores M5 only	(5)

Question Number	Acceptable Answers	Additional Guidance	Mark
7(c)	- calculation of moles of Cr (1) MP2, 3 & 4 are only available for answers using a 3:2 mole ratio - deduction of mole ratio of X to Cr^{3+} (1) - calculation of moles of X (1) - calculation of molar mass / A_r of X and identification of X accordingly (1)	<u>Example of calculation</u> Moles Cr = $\frac{1.456}{52(.0)} = 0.028(0)$ 3 mol X : 2 mol Cr^{3+} / Cr Allow $2\text{Cr}^{3+} + 3\text{X} \rightarrow 3\text{X}^{2+} + 2\text{Cr}$ Moles X = $0.028(0) \times 1.5 = 0.042(0)$ Correctly multiplying by 1.5 for MP3 implies MP2 $M_r = \frac{1.021}{0.042(0)} = 24.3 \text{ (g mol}^{-1}\text{)}$ and (so) X is magnesium/Mg COMMENT: If transpose 3:2 ratio, X has $M_r = 54.7 \text{ (g mol}^{-1}\text{)}$ and X = Mn so scores M1, then M3 and M4 by TE (i.e. (3) marks overall)	(4)

(Total for Question 7 = 15 marks)

Question Number	Acceptable Answers	Additional Guidance	Mark
-----------------	--------------------	---------------------	------



Question Number	Answer	Additional Guidance	Mark
3(a)	An explanation that makes reference to the following points (Structure consisting of) - lattice of positive ions / regular arrangement of positive ions (1) (in sea of) delocalised electrons (1) - strong forces of attraction between ions and delocalised electrons (so high melting temperature) (1) - so lots of (heat) energy needed to break attraction between ions and delocalised electrons / metallic bonds (1)	M1 and M2 can be scored by use of a labelled diagram, but if both given both must be correct For example  Allow charge on ion of 2+ or 3+ Diagram should show at least 4 ions (for M1) a number of electrons roughly consistent with charge on ions and random (for M2) The attraction between ions and delocalised electrons only needs to be mentioned once in M3 and M4 Allow 'lots of energy needed to separate the ions'	(4)

Question Number	Answer	Additional Guidance	Mark
3(b)(i)	octahedral	Allow octahedron / octahedral Ignore diagrams Do not award octagonal	(1)

Question Number	Answer	Additional Guidance	Mark
3(b)(ii)	An explanation that makes reference to the following points (ligand / water molecule causes) d orbitals to split (into 2 energy levels) (1) - light/energy (in the visible region) absorbed to promote electrons (to higher d orbitals) (1) - the remaining light / unabsorbed light / complementary colour / green light is transmitted (1)	Allow d subshell for d orbitals Do not award d orbital splits Allow (some light) energy is absorbed when d-d electron transitions occur Do not award 'emitted' or transmission linked to electrons returning to ground state Allow reflected / emerged	(3)



Question Number	Answer	Additional Guidance	Mark
3(c)	An answer that makes reference to the following points: (the equilibrium constant is large) so the equilibrium lies well / far to the right hand side / $[\text{Cr}(\text{EDTA})]^-$ is more stable (1) - as ΔS_{system} is positive / increases entropy (of the system) (1) - as 2 mol of reactants form 7 mol of products (1)	Allow forward reaction is very feasible / spontaneous / goes (virtually) to completion Allow an increase in the number of moles / particles / molecules if number of moles is given, they must be correct i.e. do not award 2 moles to 6 moles Do not award just '2 molecules form 7 molecules' Do not award M3 if M2 states 'entropy decreases'	(3)

Question Number	Answer	Additional guidance	Mark
3(d)(i)	- calculation of moles of $\text{VCl}_2(\text{aq})$ (1) - calculation of moles of $\text{Cl}_2(\text{g})$ (1) - deduction of whole number ratio of $\text{V}^{2+} : \text{Cl}_2$ (1) - deduction of electrons lost per vanadium ion (1) - deduction of final oxidation number of V (1)	<u>Example of calculation</u> $(40/1000) \times 0.100 = 4 \times 10^{-3} / 0.004 \text{ (mol)}$ $(144/24000) = 6 \times 10^{-3} / 0.006 \text{ (mol)}$ $2\text{V}^{2+} : 3\text{Cl}_2$ allow $\text{V}^{2+} : 1.5\text{Cl}_2$ 6 electrons lost by 2V^{2+}, so 3 lost per V^{2+}, (+)5 Allow TE throughout Correct answer with no working scores M5 only	(5)



Question Number	Answer	Additional Guidance	Mark
3(d)(ii)	- purple / lilac / violet - to yellow (solution)	Ignore references to blue / green / turquoise or similar, as intermediate colours, regardless of order If no final oxidation state given in (d)(i) do not award M2 Allow lavender / mauve for M1 Mark consequentially from (d)(i) Do not award colourless Use list principle for additional inappropriate intermediate colours e.g. red / pink For consequential marking from (d)(i) V(IV) – blue ; V(III) – green If both colours are given but the wrong way round, allow 1 mark out of 2	(2)

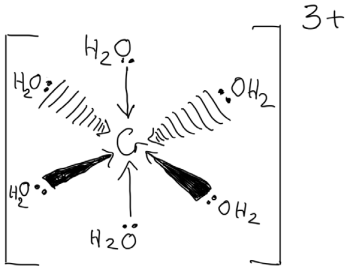
(Total Question 3 = 18 marks)



Question Number	Answer	Mark
6(a)(i)	The only correct answer is D ($[\text{Ar}] 3d^5 4s^1$, $[\text{Ar}] 3d^3$) <i>A is not correct because neither of the electronic configurations is correct</i> <i>B is not correct because the Cr atom is correct, but the Cr^{3+} ion is not correct</i> <i>C is not correct because the Cr atom is not correct, but the Cr^{3+} ion is correct</i>	(1)

Question Number	Answer	Additional Guidance	Mark
6(a)(ii)	An answer that makes reference to the following point: (Cr) is a transition metal because it forms (one or more stable) ion(s) with incompletely filled <i>d</i>-orbital(s) / <i>d</i>-subshell	Ignore <i>d</i> -shell	(1)



Question Number	Answer	Additional Guidance	Mark
6(b)(i)	An answer that makes reference to the following points: - six water ligands around chromium ion with 3D structure indicated (ignore connectivity for M1) - dative bonds between water ligands and chromium indicated by arrows from the oxygen of the water ligands to the chromium ion or bonds to Cr from lone pairs shown on the oxygen atoms	(1) (1) <u>Example of structure</u>  Ignore missing square brackets and charge Ignore incorrect charge Ignore comments linked to shape names / bond angles Allow bonds labelled as dative / co-ordinate	(2)
6(b)(ii)	An answer that makes reference to the following point: octahedral	Allow octahedron Do not award octagonal / octagon	(1)

Question Number	Answer	Additional Guidance	Mark
6(c)	An answer that makes reference to the following points: - equation for $[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3]$ with H^+ (1) - equation for $[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3]$ with OH^- (1) - all state symbols correct (1)	$[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3](\text{s}) + 3\text{H}^+(\text{aq}) \rightarrow [\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ $[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3](\text{s}) + \text{H}^+(\text{aq}) \rightarrow [\text{Cr}(\text{H}_2\text{O})_4(\text{OH})_2]^+(\text{aq})$ $[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3](\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow [\text{Cr}(\text{H}_2\text{O})_5(\text{OH})]^{2+}(\text{aq})$ $[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3](\text{s}) + 3\text{OH}^-(\text{aq}) \rightarrow [\text{Cr}(\text{OH})_6]^{3-}(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$ $[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3](\text{s}) + \text{OH}^-(\text{aq}) \rightarrow [\text{Cr}(\text{H}_2\text{O})_2(\text{OH})_4]^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$ $[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3](\text{s}) + 2\text{OH}^-(\text{aq}) \rightarrow [\text{Cr}(\text{H}_2\text{O})(\text{OH})_5]^{2-}(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$ M3 dependent on M1 and M2 No TE for state symbol mark Allow reversible arrows Penalise full equations once only Ignore missing square brackets	(3)

Question Number	Answer	Additional Guidance	Mark
6(d)	An answer that makes reference to the following point: ligand exchange / ligand substitution	Allow ligand replacement	(1)



Question Number	Answer	Additional Guidance	Mark
6(e)(i)	An explanation that makes reference to the following points: (when a ligand approaches) d-orbitals split or d-subshell splits (into higher and lower energy levels) (1) - electron is promoted / d–d transition / excited (1) - absorbing (visible) light (energy) / photons (of specific wavelength / frequency) (1) - complementary colour / seen / transmitted / reflected (1)	Do not award the splitting of a single d –orbital Ignore d-shell Ignore electrons returning to ground state Allow remaining light seen / transmitted / reflected Do not award any reference to emission (of light)	(4)

Question Number	Answer	Additional Guidance	Mark
6(e)(ii)	An answer that makes reference to the following point: (colours are different because) with different ligands the energy gap / splitting / ΔE between the d-orbitals is different or (colours are different because) with different coordination numbers as the energy gap / splitting / ΔE between the d-orbitals is different	Allow different ligands / coordination number so energy needed to promote electron(s) is different Allow different ligand / coordination number changes the wavelength / frequency of light absorbed Ignore different oxidation states (of metal ion)	(1)



Question Number	Answer	Additional Guidance	Mark
6(f)(i)	An answer that makes reference to the following points: - multiplication of equation (a) by 2 and - multiplication of equation (b) by 3 and - overall equation	(1) $2\text{CrO}_4^{2-}(\text{aq}) + 8\text{H}_2\text{O}(\text{l}) + 6\text{e}^- \rightleftharpoons 2\text{Cr}(\text{OH})_3(\text{s}) + 10\text{OH}^-(\text{aq})$ Accept half equation for the chromium written as an oxidation (1) $3\text{H}_2\text{O}_2(\text{aq}) + 6\text{e}^- \rightleftharpoons 6\text{OH}^-(\text{aq})$ M1 can be shown by use of $2\text{Cr}(\text{OH})_3 : 3 \text{H}_2\text{O}_2$ in attempted equation or via equations in stem of question (1) $2\text{Cr}(\text{OH})_3(\text{s}) + 3\text{H}_2\text{O}_2(\text{aq}) + 4\text{OH}^-(\text{aq}) \rightarrow 2\text{CrO}_4^{2-}(\text{aq}) + 8\text{H}_2\text{O}(\text{l})$ Allow multiples Ignore state symbols even if incorrect Allow reversible arrow for full equation as long as reaction is written in the forward direction Award 2 marks for correct overall equation with no working	(2)

Question Number	Answer	Additional Guidance	Mark
6(f)(ii)	- calculation of $E^\ominus_{\text{cell}}$ value and $E^\ominus_{\text{cell}}$ / answer is positive / > 0 the reaction is (thermodynamically) feasible	(1) <u>Example of calculation</u> $E^\ominus_{\text{cell}} = 0.13 + 0.88 = (+) 1.01 \text{ (V)}$ Allow correct answer without calculation (1) Allow as TE if negative $E^\ominus_{\text{cell}}$ calculated Answer is negative / < 0 and the reaction is not (thermodynamically) feasible	(2)



Question Number	Answer	Mark
6(f)(iii)	The only correct answer is A ($E^{\ominus}_{\text{cell}}$ is directly proportional to $\ln K$) <i>B is not correct because $E^{\ominus}_{\text{cell}}$ is directly proportional to ΔS_{total}, and not ΔS_{system}</i> <i>C is not correct because $E^{\ominus}_{\text{cell}}$ is directly proportional to ΔS_{total}, and not $\ln \Delta S_{\text{total}}$</i> <i>D is not correct because $E^{\ominus}_{\text{cell}}$ is not directly proportional to K but to $\ln K$</i>	(1)

(Total for Question 6 = 19 marks)



Question Number	Acceptable Answers	Additional Guidance	Mark
1(a)(i)	- All species and balancing correct (1) - All state symbols correct (1)	<u>Examples of equation</u> $\text{Cr(OH)}_3(\text{s}) + 3\text{H}_2\text{O}(\text{l}) + 3\text{H}^+(\text{aq}) \rightarrow [\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ Or $\text{Cr(OH)}_3(\text{s}) + 3\text{H}_3\text{O}^+(\text{aq}) \rightarrow [\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ Or $[\text{Cr(OH)}_3(\text{H}_2\text{O})_3](\text{s}) + 3\text{H}^+(\text{aq})$ on LHS as an alternative Allow correct equations for sequential protonation e.g. $[\text{Cr(OH)}_3(\text{H}_2\text{O})_3](\text{s}) + \text{H}^+(\text{aq}) \rightarrow [\text{Cr}(\text{H}_2\text{O})_4(\text{OH})_2]^+(\text{aq})$ M2 consequential on M1 being awarded, or a 'near-miss' e.g. Cl^- on both sides / one missing charge	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
1(a)(ii)	A description that makes reference to the following points: - green solid / grey-green solid (1) - forms green solution (1)	Allow ppt/precipitate for solid Allow purple /violet /ruby solution Do not award yellow-green / red / blue-green bubbles etc means MP2 should not be awarded Ignore adjectives to describe green e.g. pale	(2)



Question Number	Acceptable Answers	Additional Guidance	Mark
1(a)(iii)	- all species and balancing correct (1) - all state symbols correct (1)	<u>Examples of equation</u> $\text{Cr(OH)}_3(\text{s}) + 3\text{OH}^-(\text{aq}) \rightarrow [\text{Cr(OH)}_6]^{3-}(\text{aq})$ Or $[\text{Cr(OH)}_3(\text{H}_2\text{O})_3](\text{s}) + 3\text{OH}^-(\text{aq}) \rightarrow [\text{Cr(OH)}_6]^{3-}(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$ Allow $\text{Cr(OH)}_3(\text{s}) + \text{OH}^-(\text{aq}) \rightarrow [\text{Cr(OH)}_4]^{-}(\text{aq})$ Or $[\text{Cr(OH)}_5(\text{H}_2\text{O})]^{2-}(\text{aq})$ as complex ion on RHS, with rest of equation correctly balanced M2 consequential on M1 being awarded, or a 'near-miss'	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
1(a)(iv)	An answer that makes reference to the following point: green and solution	Ignore 'Qualifiers' for any colour (e.g. 'dark', 'deep', etc)	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
1(b)(i)	A description that makes reference to the following points: (blue solution initially forms pale) blue precipitate (1) (which dissolves to) form dark/deep/royal blue solution (1)	Allow 'solid' / 'ppt' for 'precipitate' Do not award for 'blue crystals' Do not allow dark blue ppt	(2)



Question Number	Acceptable Answers	Additional Guidance	Mark
1(b)(ii)	$[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{H}_2\text{O}$ - LHS of equation correct - RHS of equation correct	Ignore state symbols even if incorrect Ignore balanced sulfate ions (1) Do not award just Cu^{2+} on LHS Allow $[\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4] + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 2\text{H}_2\text{O} + 2\text{OH}^-$ (1) Do not award for $[\text{Cu}(\text{NH}_3)_4]^{2+}$ / $[\text{Cu}(\text{NH}_3)_6]^{2+}$ on RHS	(2)

(Total for Question 1 = 11 marks)

Question Number	Acceptable Answers	Additional Guidance	Mark
-----------------	--------------------	---------------------	------

Question Number	Acceptable Answers	Additional Guidance	Mark																				
8	This question assesses the student’s ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5-4</td><td>3</td></tr><tr><td>3-2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> The following table shows how the marks should be awarded for structure and lines of reasoning <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained lines of reasoning</th></tr><tr><td>Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5-4	3	3-2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained lines of reasoning	Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, a response with four indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and zero marks for linkages). In general it would be expected that 5 or 6 indicative points would get 2 reasoning marks, and 3 or 4 indicative points would get 1 mark for reasoning, and 0, 1 or 2 indicative points would score zero marks for reasoning	(6)
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																						
6	4																						
5-4	3																						
3-2	2																						
1	1																						
0	0																						
	Number of marks awarded for structure of answer and sustained lines of reasoning																						
Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																						
Answer is partially structured with some linkages and lines of reasoning	1																						
Answer has no linkages between points and is unstructured	0																						



	Indicative Points IP1 Similarity both (increase the rate of a reaction) by providing an alternative mechanism / route with lower activation energy (and are chemically unchanged at the end of the reaction) IP2 Heterogeneous / homogeneous platinum is heterogenous / different physical state to reactants and Mn^{2+} is homogenous / same physical state to reactants Platinum IP3 reactants adsorb onto platinum (surface) IP4 the reactant bonds are weakened and the products are desorbed Mn^{2+} IP5 the negative ions repel so the reaction starts slowly IP6 Mn^{2+} acts as an autocatalyst or the reaction then speeds up as Mn^{2+} catalyst forms or the reaction is faster between positive ions / Mn^{2+} and negative ions	Allow specific states mentioned – Pt is a solid and the reactants are gases and Mn^{2+} and the reactants are all in aqueous solution Allow names / formulae of specific reactants (CO and NO / NO_2 / NO_x) and products (CO_2 and N_2) Allow active sites for platinum surface Allow broken for weakened Allow just MnO_4^- and $\text{C}_2\text{O}_4^{2-}$ ions repel (each other) Allow Mn^{2+} reduces MnO_4^- then the Mn species / Mn^{3+} formed oxidises the $\text{C}_2\text{O}_4^{2-}$ ions Allow Mn^{2+} acts as a catalyst as Mn has a (wide range of) variable oxidation states	
--	---	--	--

(Total for Question 8 = 6 marks)

