Questions

Q1.

Transition metals form complex ions.

Hydrated chromium(III) chloride, $CrCl_3 \cdot 6H_2O$, 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 $[Cr(H_2O)_x(Cl)_y]^{(3-y)+}$

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)

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(Total for question = 2 marks)

Q2.

Iron and zinc are in the d-block of the Periodic Table.

Hydrated iron(II) ions react with ethanedioate ions, $C_2O_4^{2-}$, to form a complex ion.

$$[Fe(H_2O)_6]^{2+} + 2C_2O_4^{2-} \rightleftharpoons [Fe(C_2O_4)_2(H_2O)_2]^{2-} + 4H_2O$$

(i) Draw a structure of the $[Fe(C_2O_4)_2(H_2O)_2]^{2-}$ ion, showing **all** of the bonds.

(2)

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

(2)

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(Total for question = 4 marks)

Q3.

Transition metals form complex ions.

Complex ions have a central metal ion surrounded by ligands.

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

(1)

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(ii) Explain why the complex ions $[Co(NH_3)_6]^{2+}$ and $[Co(H_2O)_6]^{2+}$ are coloured and have different colours.

(4)

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(Total for question = 5 marks)

Q4.

This is a question about chromium(III) and chromium(VI) compounds.

The chromium(III) complex, $[Cr(OH)_6]^{3-}$, can be oxidised to chromate(VI) ions, CrO_4^{2-}, by hydrogen peroxide solution.

(i) Deduce the oxidation half-equation for this reaction, which takes place in alkaline conditions.
State symbols are not required.

(2)

(ii) If the solution of chromate(VI) ions is then acidified, the colour of the solution changes to orange as dichromate(VI) ions form.

Write the equation for this change. State symbols are not required.

(1)

(iii) In acidic conditions, dichromate(VI) ions can also be reduced to chromium(III) ions using hydrogen peroxide.

The value of $E^{\ominus}_{cell}$ cell = + 0.65 V for which the cell diagram is

$$Pt(s)\,|\,H_2O_2(aq),\,[2H^+(aq)+O_2(g)]\,\vdots\vdots\,[Cr_2O_7{}^{2-}(aq)+14H^+(aq)],\,[2Cr^{3+}(aq)+7H_2O(l)]\,|\,Pt(s)$$

Deduce from the cell diagram the oxidation and the reduction half-equations, and thus the overall equation for this reaction.
State symbols are not required.

(3)

(Total for question = 6 marks)

Q5.

This question is about transition metal chemistry.

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)

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(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 = 4 marks)

Q6.

This question is about catalytic converters.

A catalytic converter decreases the emissions of gases, such as carbon monoxide and nitrogen monoxide, from an internal combustion engine.

Describe the stages in a catalytic converter that result in this decrease.
No equations are required.

(3)

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(Total for question = 3 marks)

Q7.

This question is about chromium and some of its compounds.

The common oxidation numbers of chromium are +2, +3 and +6.

Give a reason, in terms of ionisation energies, why chromium can show variable oxidation numbers.

(1)

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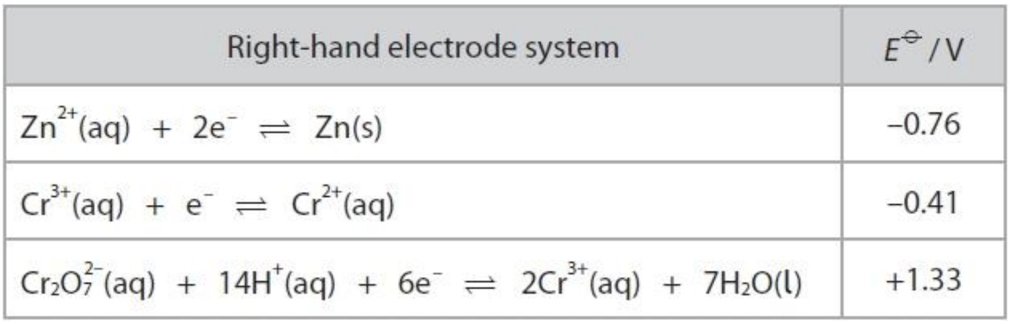
(Total for question = 1 mark)

Q8.

This question is about chromium and some of its compounds.

A student added some pieces of zinc to an acidified solution of potassium dichromate(VI).

Some standard electrode potentials are given in the table.



Right-hand electrode system	$E^{\ominus}$ / V
$Zn^{2+}(aq) + 2e^{-} \rightleftharpoons Zn(s)$	–0.76
$Cr^{3+}(aq) + e^{-} \rightleftharpoons Cr^{2+}(aq)$	–0.41
$Cr_2O_7^{2-}(aq) + 14H^{+}(aq) + 6e^{-} \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33

(i) Write the overall equation for the reduction of dichromate(VI) ions to chromium(III) ions by zinc in acid conditions.

State symbols are not required.

(2)

(ii) Calculate $E^{\ominus}_{\text{cell}}$ for the reaction in (i).

(1)

(iii) Predict whether or not a further reduction of chromium(III) ions to chromium(II) ions will occur. Justify your answer.

(1)

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(iv) Aqueous solutions containing chromium(III) ions and chromium(II) ions have different colours.

Explain why these solutions **differ** in colour.
An explanation of the origin of the colours is not required.

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(Total for question = 6 marks)

Q9.

This question is about transition metals and their ions.

Tungsten wire catalyses the decomposition of ammonia.

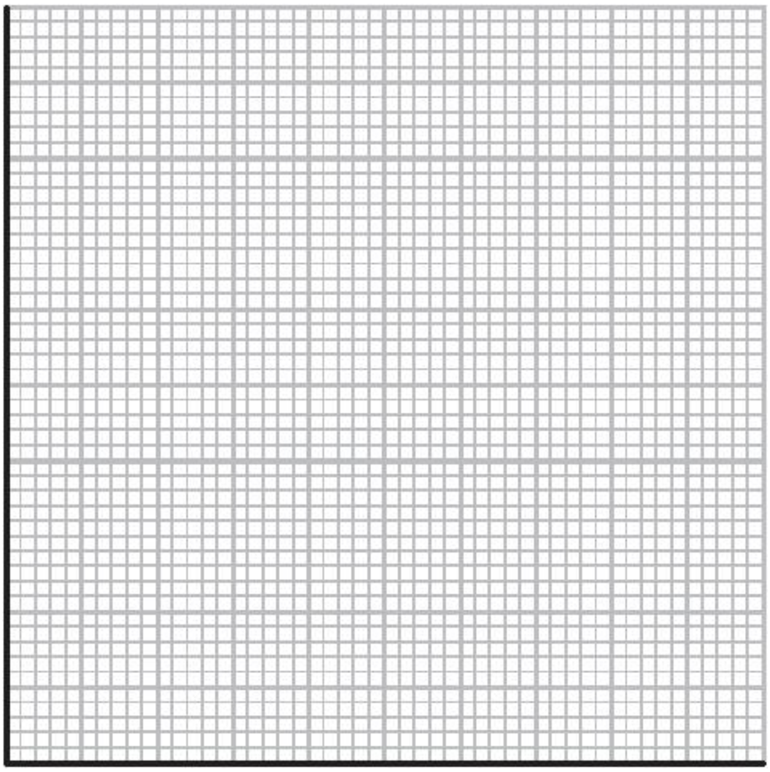
$$2NH_3(g) \rightarrow N_2(g) + 3H_2(g)$$

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 (i).
Justify your answer.

(2)

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(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.

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(Total for question = 9 marks)

Q10.

This is a question about chromium(III) and chromium(VI) compounds.

Describe the observations when aqueous sodium hydroxide is added drop by drop until in excess to a solution of chromium(III) ions.

(2)

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(Total for question = 2 marks)

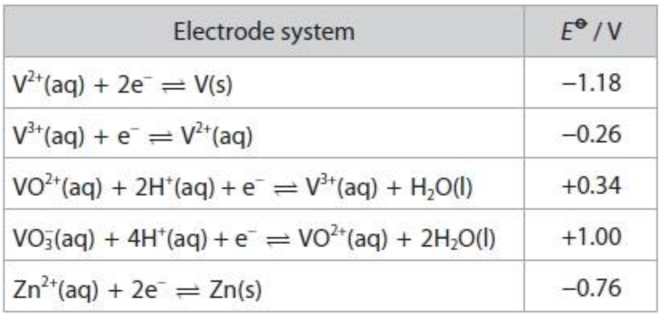
Q11.

This question is about the properties of transition elements, their ions and their complexes.

Excess zinc powder is added to an acidified solution of the compound NH_4VO_3. Using the data in the table, explain the sequence of reactions that takes place.

In your answer, include a description of what you would **see**, and the relevant ionic equations with their calculated $E^{\ominus}_{cell}$ values. State symbols are not required.

(7)



Electrode system	$E^{\ominus}$ / V
$V^{2+}(aq) + 2e^- \rightleftharpoons V(s)$	−1.18
$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	−0.26
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l)$	+0.34
$VO_3^-(aq) + 4H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + 2H_2O(l)$	+1.00
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76

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(Total for question = 7 marks)

Q12.

This is a question about catalysis.

The trend in the strength of gaseous adsorption by three transition elements is

tungsten > platinum > silver

Silver is not suitable as a replacement for platinum in a catalytic converter because the adsorption of gases is too weak to allow significant chemical reaction.

Give a possible reason why tungsten would also **not** be a suitable replacement for platinum in a catalytic converter. Refer to the mechanism of heterogenous catalysis in your answer.

(1)

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(Total for question = 1 mark)

Q13.

Iron and zinc are in the d-block of the Periodic Table.

Iodide ions, I^-, react with peroxodisulfate(VI) ions, $S_2O_8^{2-}$

$$2I^-(aq) + S_2O_8^{2-}(aq) \rightarrow I_2(aq) + 2SO_4^{2-}(aq)$$

This reaction is catalysed by iron(II) ions, Fe^{2+}(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 = 2 marks)

Q14.

Nitrogen monoxide and chlorine react together to form nitrosyl chloride.

$$2NO(g) + Cl_2(g) \rightarrow 2NOCl(g)$$

The rate equation for the formation of nitrosyl chloride is

Rate = $k[NO]^2[Cl_2]$

(i) Complete the table by adding the missing values.

Experiment	[NO] / mol dm^{-3}	[Cl$_2$] / mol dm^{-3}	Rate / mol dm^{-3} s^{-1}
1	0.122	0.241	1.09×10^{-2}
2		0.482	8.72×10^{-2}
3	0.366		4.91×10^{-2}

(2)

(ii) Calculate the rate constant, *k*, using data from Experiment 1.

Include units with your answer.

(3)

(iii) Explain how using a catalyst increases the rate constant, *k*.

(2)

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(iv) The heterogeneous catalyst palladium was suggested for use in this reaction.

Explain how impurities in the gaseous reactants could make the catalyst less effective.

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(Total for question = 10 marks)

Q15.

This is a question about catalytic converters in car exhaust systems.

When petrol is burnt in a car engine, pollutant gases including carbon monoxide and nitrogen monoxide are formed.

(i) Write the equation for the reaction between these two polluting gases that takes place on the surface of a catalytic converter. State symbols are not required.

(1)

(ii) Describe the stages by which the reaction in (i) occurs in a catalytic converter.

(3)

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(Total for question = 4 marks)

Q16.

This question is about the properties of transition elements, their ions and their complexes.

* Describe the reactions of separate portions of aqueous copper(II) ions with aqueous sodium hydroxide solution, with excess aqueous ammonia solution and with concentrated hydrochloric acid.

In your answer you should link observations with equations which include the formulae of any copper-containing complex ions. Include state symbols.

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(Total for question = 6 marks)

Q17.

Tablets containing potassium manganate(VII), $KMnO_4$, are dissolved in water forming an antiseptic solution to treat skin conditions. The manufacturers claim that each tablet contains 400 mg of $KMnO_4$.

To check the claim, the titration procedure outlined was carried out.

- Five tablets were dissolved in distilled water to make 100.0 cm^3 of solution.
- Some of the $KMnO_4$ solution was used to fill a burette.
- 25.0 cm^3 of sodium ethanedioate solution, $Na_2C_2O_4(aq)$, of concentration 0.200 mol dm^{-3}, was added to a conical flask and warmed.
- Sulfuric acid, of concentration 2 mol dm^{-3}, was also added to the conical flask.
- The $KMnO_4$ solution was added to the flask from the burette, until the end-point.

The equation for the reaction between MnO_4^- ions from the $KMnO_4$ and $C_2O_4^{2-}$ ions from the sodium ethanedioate solution is shown.

$$16H^+(aq) + 2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) \rightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$$

The results of the titration are shown.

Run	Trial	1	2	3
Final volume / cm^3	17.50	34.10	17.20	34.10
Initial volume / cm^3	0.00	17.30	0.00	17.20
Titre / cm^3	17.50		17.20	
Concordant titres (✓)				
Mean titre / cm^3				

(i) Complete the table.

(2)

(ii) The equation for the reaction between MnO_4^- ions from the $KMnO_4$ and $C_2O_4^{2-}$ ions from the sodium ethanedioate solution is shown.

$$16H^+(aq) + 2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) \rightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$$

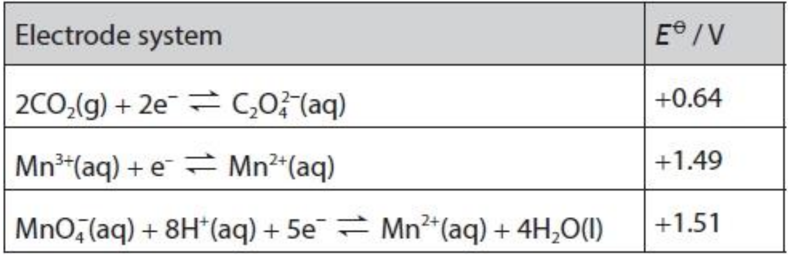
Use this equation and your mean titre from (i) to calculate the mass, in mg, of $KMnO_4$ in **one** tablet.

Give your answer to an appropriate number of significant figures.

(5)

(iii) A textbook suggested the conical flask should be heated during the titration, as the reaction between the MnO_4^- ions and the $C_2O_4^{2-}$ ions is slow.

Use these electrode potentials and your knowledge of homogeneous catalysis to deduce why the heating is very important at the start of the titration, but less important as the titration proceeds. Justify your answer.
You may include equations in your justification.



Electrode system	$E^\ominus$ / V
$2CO_2(g) + 2e^- \rightleftharpoons C_2O_4^{2-}(aq)$	+0.64
$Mn^{3+}(aq) + e^- \rightleftharpoons Mn^{2+}(aq)$	+1.49
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51

(4)

(Total for question = 11 marks)

Q18.

This question is about transition metals and transition metal complexes.

Aqueous vanadium(II) chloride, VCl_2(aq), can be oxidised by bubbling gaseous chlorine, Cl_2(g), through the solution in the absence of air.

40.0 cm^3 of 0.100 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

$$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$$

[Molar volume of a gas at r.t.p. = 24.0 dm^3 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, VCl_2(aq).

(2)

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(Total for question = 7 marks)

Q19.

This question is about the properties of transition elements, their ions and their complexes.

Explain how vanadium(V) oxide acts as a catalyst in one step of the contact process. The equation for this step is

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

(2)

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(Total for question = 2 marks)

Q20.

This question is about transition metal chemistry.

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 (i) is carried out.

(2)

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(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 (iii).

(1)

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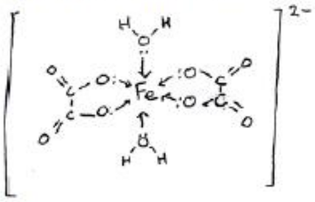
(Total for question = 7 marks)

Mark Scheme

Q1.

Question Number	Answer	Additional Guidance	Mark
	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)	$[Cr(H_2O)_5(Cl)]^{2+}$	(2)

Q2.

Question Number	Answer	Additional Guidance	Mark
(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 *cis* or *trans* Allow delocalised bonds in ethanedioate ions Allow bonds not shown in H_2O, provided the ligands are attached to Fe^{2+} 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
(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 $\Delta S_{surroundings}$ 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 $\Delta S_{surroundings}$ changes Ignore just 'entropy is positive' Ignore references to free energy	**(2)**

Q3.

Question Number	Answer	Additional Guidance	Mark
(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
(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)

Q4.

Question Number	Answer	Additional Guidance	Mark
(i)	• four correct species (1) • balancing and the correct number of electrons (1)	<u>An example of equation</u> $[Cr(OH)_6]^{3-} + 2OH^- \rightarrow CrO_4^{2-} + 4H_2O + 3e^-$ Accept multiples	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	• equation	<u>An example of equation</u> $2CrO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + H_2O$ Accept $\rightleftharpoons$ / multiples	(1)

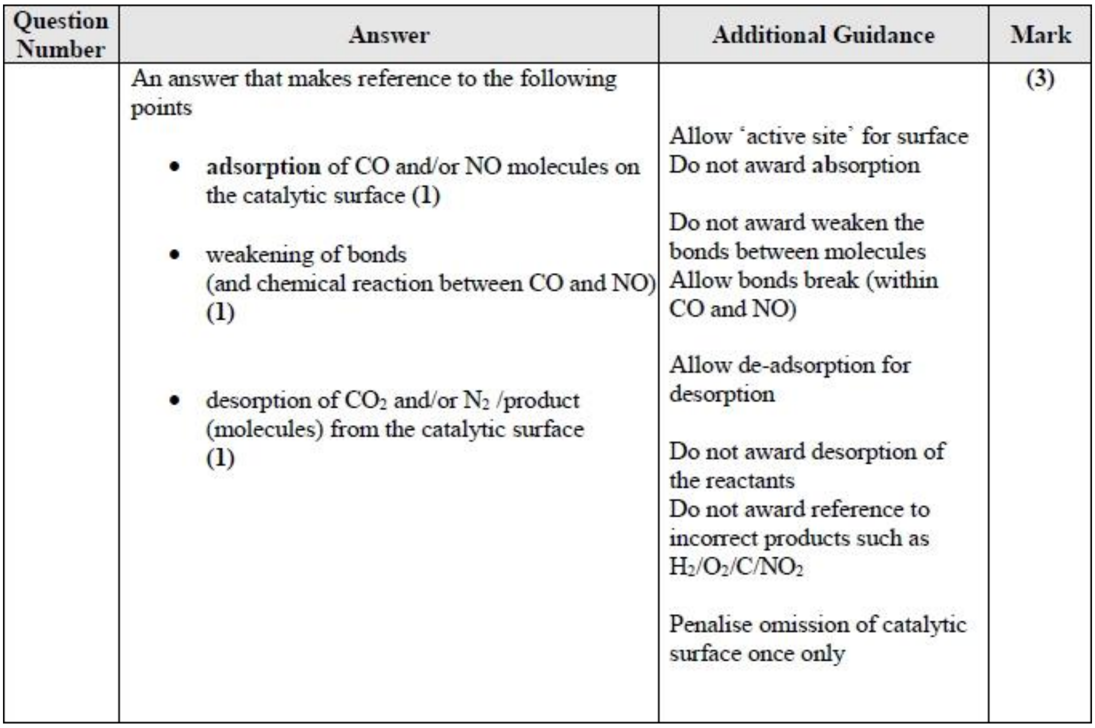
Question Number	Answer	Additional Guidance	Mark
(iii)	- oxidation half equation **(1)**	$H_2O_2 \rightarrow 2H^+ + O_2 + 2e^-$	**(3)**
	- reduction half equation **(1)**	$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$	
	- overall equation **(1)**	$Cr_2O_7^{2-} + 8H^+ + 3H_2O_2 \rightarrow 2Cr^{3+} + 7H_2O + 3O_2$ for M3 do not award if H^+/ e^- left on both sides Accept multiples Allow $\rightleftharpoons$ Ignore state symbols even if incorrect Oxidation and reduction half equations scores (2) if not identified but in correct order Award (1) only for M1 and M2 if half equations are not in correct order No TE on incorrect half equations	

Q5.

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

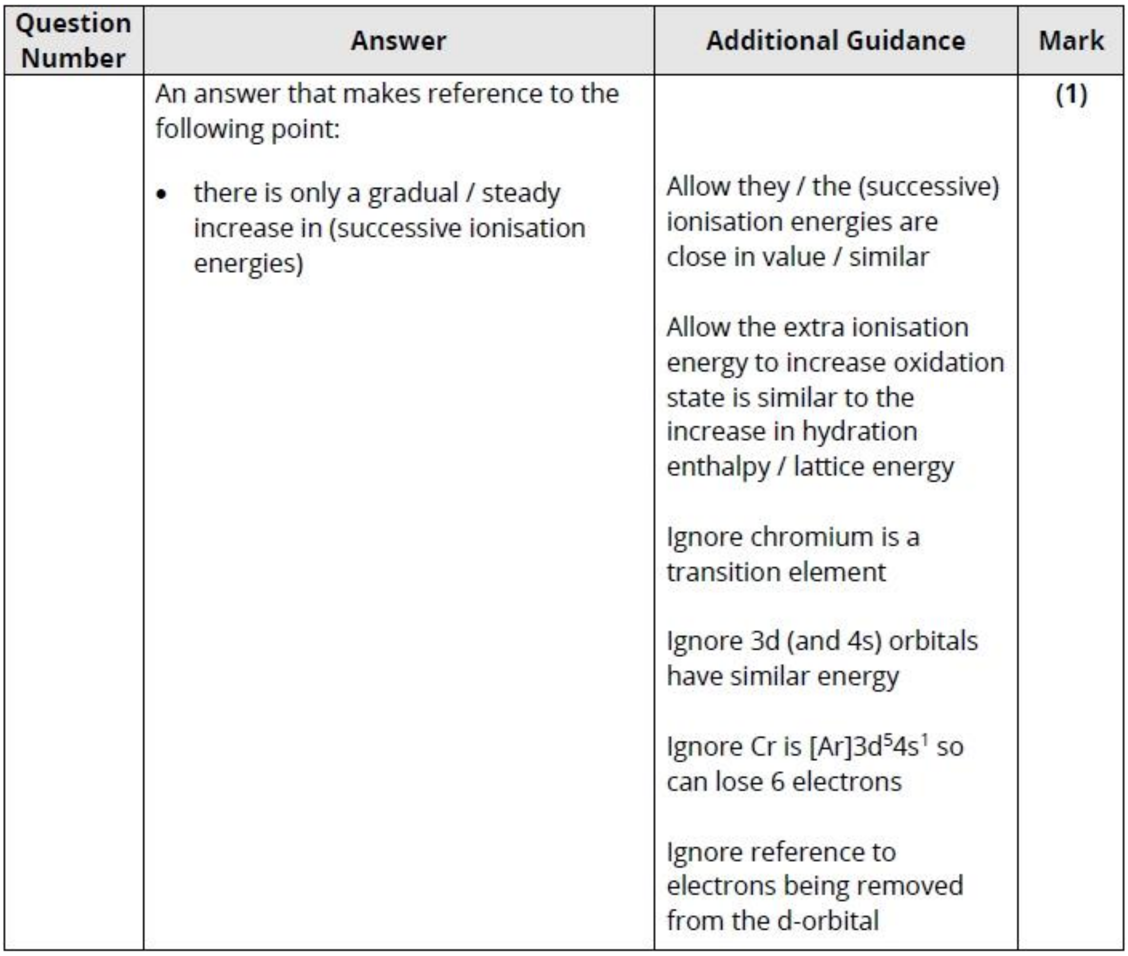
Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$	Ignore state symbols even if incorrect Ignore balanced sulfate ions	**(2)**
	- LHS of equation correct **(1)**	Do not award just Cu^{2+} on LHS	
	- RHS of equation correct **(1)**	Allow $[Cu(OH)_2(H_2O)_4] + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 2H_2O + 2OH^-$ Do not award for $[Cu(NH_3)_4]^{2+}$ / $[Cu(NH_3)_6]^{2+}$ on RHS	

Q6.



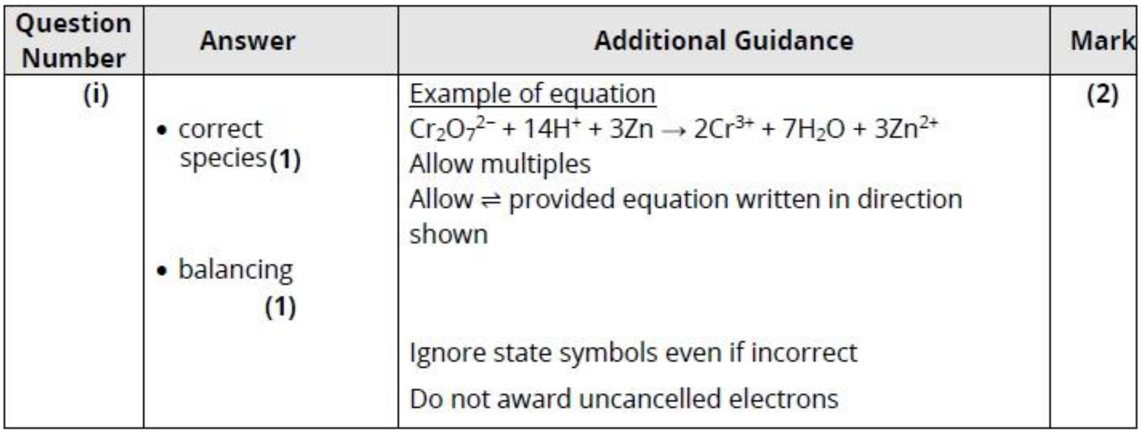
Question Number	Answer	Additional Guidance	Mark
	An answer that makes reference to the following points • **adsorption** of CO and/or NO molecules on the catalytic surface (1) • weakening of bonds (and chemical reaction between CO and NO) (1) • desorption of CO_2 and/or N_2 /product (molecules) from the catalytic surface (1)	Allow 'active site' for surface Do not award absorption Do not award weaken the bonds between molecules Allow bonds break (within CO and NO) Allow de-adsorption for desorption Do not award desorption of the reactants Do not award reference to incorrect products such as H_2/O_2/C/NO_2 Penalise omission of catalytic surface once only	(3)

Q7.



Question Number	Answer	Additional Guidance	Mark
	An answer that makes reference to the following point: • there is only a gradual / steady increase in (successive ionisation energies)	Allow they / the (successive) ionisation energies are close in value / similar Allow the extra ionisation energy to increase oxidation state is similar to the increase in hydration enthalpy / lattice energy Ignore chromium is a transition element Ignore 3d (and 4s) orbitals have similar energy Ignore Cr is [Ar]$3d^5 4s^1$ so can lose 6 electrons Ignore reference to electrons being removed from the d-orbital	**(1)**

Q8.



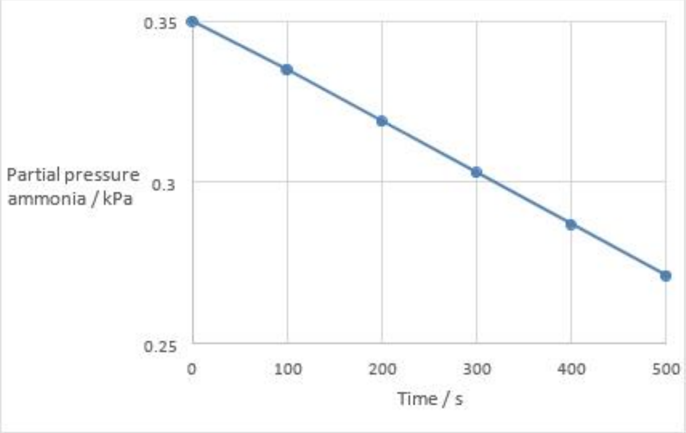
Question Number	Answer	Additional Guidance	Mark
(i)	• correct species **(1)** • balancing **(1)**	Example of equation $Cr_2O_7^{2-} + 14H^+ + 3Zn \rightarrow 2Cr^{3+} + 7H_2O + 3Zn^{2+}$ Allow multiples Allow $\rightleftharpoons$ provided equation written in direction shown Ignore state symbols even if incorrect Do not award uncancelled electrons	**(2)**

Question Number	Answer	Additional Guidance	Mark
(ii)	- calculation of $E^\ominus_{cell}$	<u>Example of calculation</u> ($E^\ominus_{cell}$ = 1.33 – (−0.76)) = (+) 2.09 (V) Allow −2.09 (V) if equation written in reverse in (c) (i) Correct answer with no working scores (1)	(1)

Question Number	Answer	Additional Guidance	Mark
(iii)	yes/zinc and acid will reduce chromium(III) ions to chromium(II) ions **and** because $E^\ominus_{cell}$ for the reaction between Zn and Cr^{3+} is (+) 0.35 (V) **or** Zn^{2+} / Zn electrode potential / SEP / $E^\ominus$ value is more negative / less positive / lower than the Cr^{3+} / Cr^{2+} value **or** Zn/ Zn^{2+} electrode potential / SEP / $E^\ominus$ value is less negative / more positive / higher than the Cr^{3+} / Cr^{2+}	Allow positive or >0 if not calculated Allow explanations in terms of the anti-clockwise rule	(1)

Question Number	Answer	Additional Guidance	Mark
(iv)	An explanation that makes reference to the following points:		(2)
	- the energy difference between the two sets of d orbitals is different in the two ions / Cr^{3+} and Cr^{2+} **or** there is different splitting of the d orbital**s** / d subshell **(1)**	Allow the d orbital energies are different Allow different charges / oxidation numbers alter the d orbital energies differently Do not award reference to a single d orbital splitting/ d orbital splitting Ignore references to charges/charge density/oxidation numbers/electron configurations of the ions	
	- electrons undergo different d-d transitions/ are promoted to a higher d-orbital absorbing/requiring a different amount of energy **or** a different amount of energy is absorbed the frequency / wavelength/colour of (visible) light absorbed is different **(1)**	Do not award references to electrons being excited and falling back to the ground state (or words to that effect) Allow the frequency / wavelength of (visible) light transmitted / reflected is different Do not award emitted instead of absorbed Ignore reference to different ligands	

Q9.

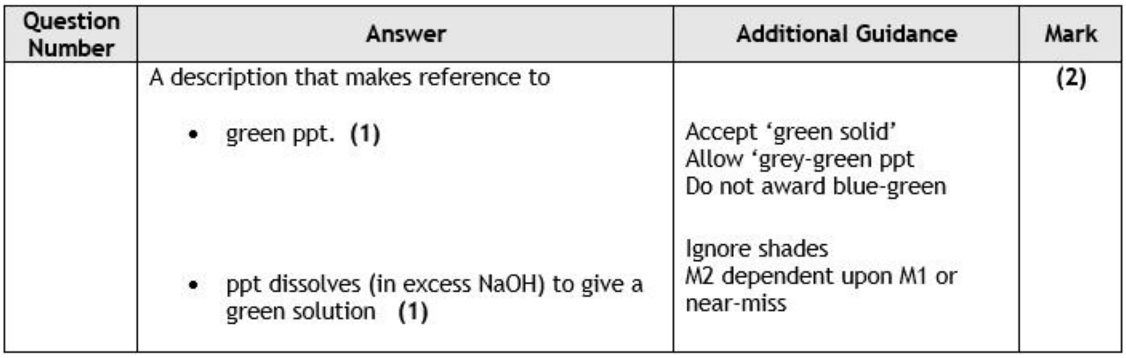
Question Number	Acceptable Answers	Additional Guidance	Mark
(i)		 Example of graph	**(2)**
	• axes with time on x axis **and** labelled, including units **and** suitable scale **(1)**	Allow y axis labelled with partial pressure / pressure and unit Do not allow partial pressure axis starting at 0 Both axes must cover at least half the graph paper	
	• **all** points plotted correctly **and** best fit line **(1)**	Allow ± ½ square M2 can be awarded if axes the wrong way around in M1	

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	• rate = *k* / rate = *k* x $p(NH_3)^0$ **(1)**	Allow r for rate Allow −rate = *k* / rate = $k[NH_3]^0$ Ignore $[H_2]^0$ or $[N_2]^0$	**(2)**
	• (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)**	Conditional on M1 Allow because the gradient is constant	

Question Number	Acceptable Answers	Additional Guidance	Mark
(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 x 10^{-4} / 0.000158 Allow any value in the range 1.50 to 1.65 x 10^{-4} 1.58 x 10^{-4} / 0.000158 kPa s^{-1} Allow 158 x 10^{-6} kPa s^{-1} / 0.158 Pa s^{-1} / 1.58 x 10^{-1} Pa s^{-1} Do not award units of mol dm^{-3} s^{-1} Ignore SF except 1 SF Ignore negative value for k Correct answer with corresponding units and no working scores (2)	**(2)**

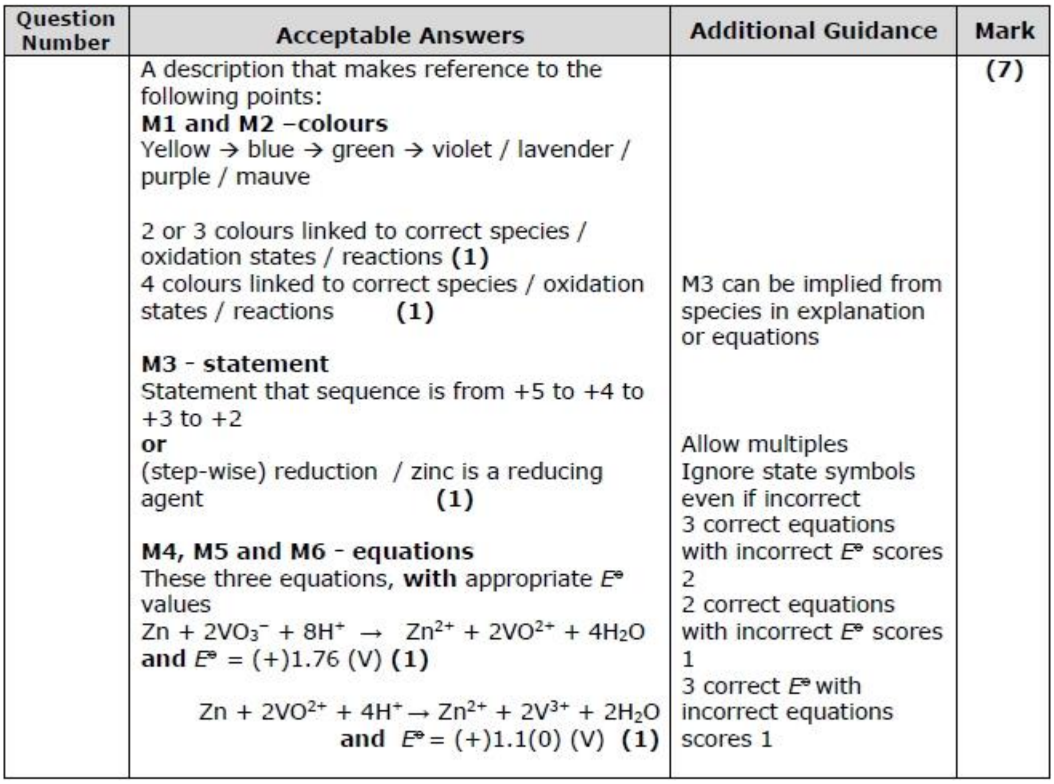
Question Number	Acceptable Answers	Additional Guidance	Mark
(iv)	A description that makes reference to the following points:	Ignore reference to heterogeneous / homogeneous / active sites	**(3)**
	• adsorption of ammonia / reactant onto surface of tungsten / catalyst **(1)**	Allow gas for ammonia Allow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

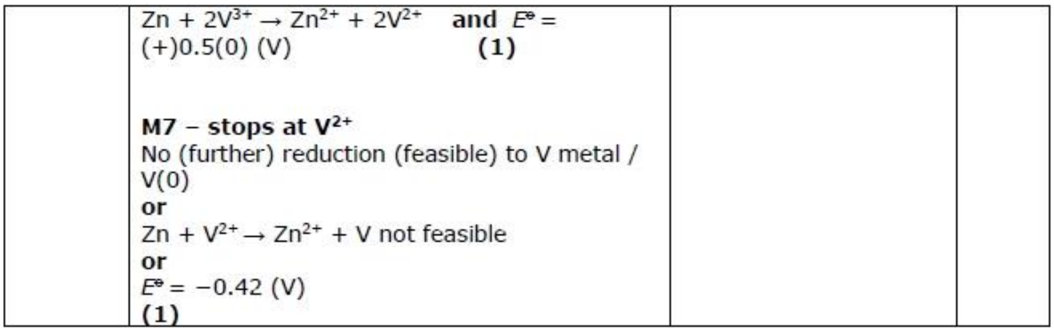
Q10.



Question Number	Answer	Additional Guidance	Mark
	A description that makes reference to • green ppt. **(1)** • ppt dissolves (in excess NaOH) to give a green solution **(1)**	Accept 'green solid' Allow 'grey-green ppt Do not award blue-green Ignore shades M2 dependent upon M1 or near-miss	**(2)**

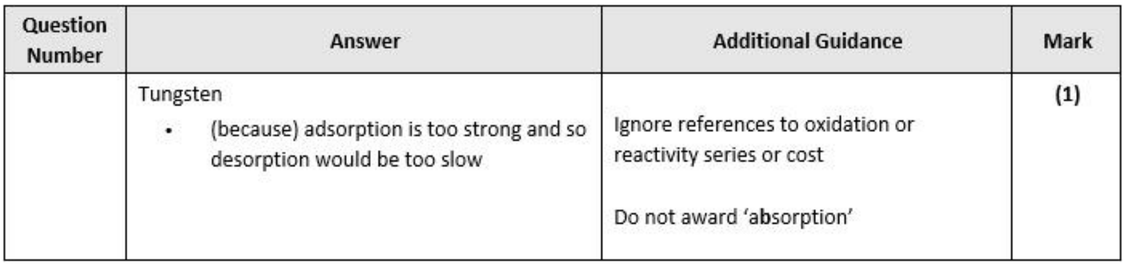
Q11.





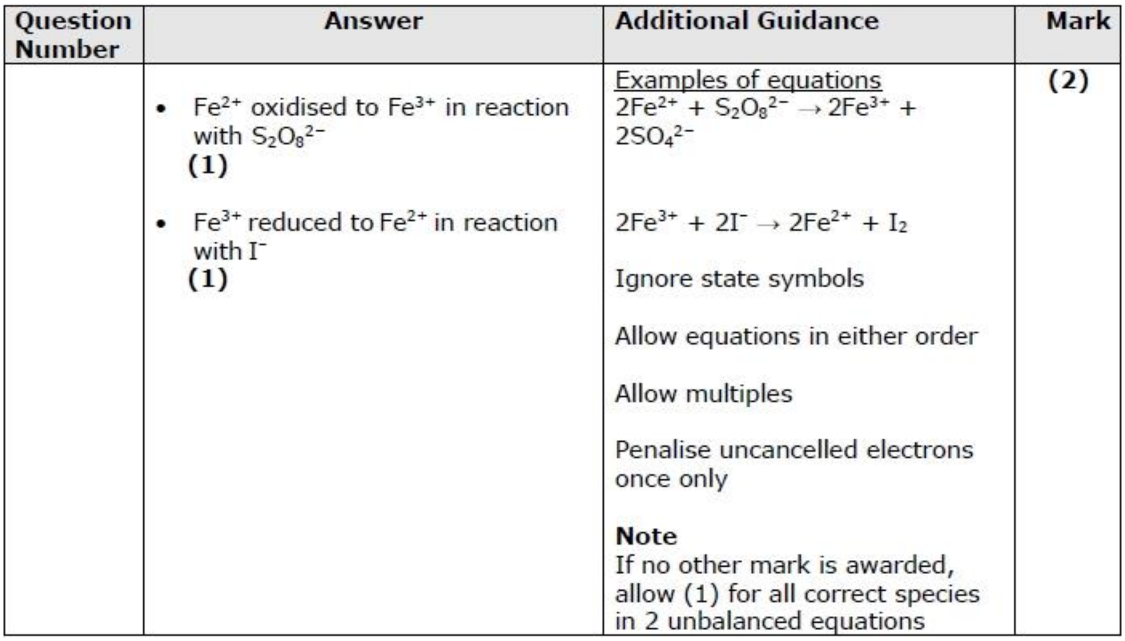
Question Number	Acceptable Answers	Additional Guidance	Mark
	A description that makes reference to the following points: **M1 and M2 –colours** Yellow → blue → green → violet / lavender / purple / mauve 2 or 3 colours linked to correct species / oxidation states / reactions **(1)** 4 colours linked to correct species / oxidation states / reactions **(1)** **M3 - statement** Statement that sequence is from +5 to +4 to +3 to +2 **or** (step-wise) reduction / zinc is a reducing agent **(1)** **M4, M5 and M6 - equations** These three equations, **with** appropriate $E^\ominus$ values $Zn + 2VO_3^- + 8H^+ \rightarrow Zn^{2+} + 2VO^{2+} + 4H_2O$ **and** $E^\ominus$ = (+)1.76 (V) **(1)** $Zn + 2VO^{2+} + 4H^+ \rightarrow Zn^{2+} + 2V^{3+} + 2H_2O$ **and** $E^\ominus$ = (+)1.1(0) (V) **(1)**	M3 can be implied from species in explanation or equations Allow multiples Ignore state symbols even if incorrect 3 correct equations with incorrect $E^\ominus$ scores 2 2 correct equations with incorrect $E^\ominus$ scores 1 3 correct $E^\ominus$ with incorrect equations scores 1	**(7)**
	$Zn + 2V^{3+} \rightarrow Zn^{2+} + 2V^{2+}$ **and** $E^\ominus$ = (+)0.5(0) (V) **(1)** **M7 – stops at V^{2+}** No (further) reduction (feasible) to V metal / V(0) **or** $Zn + V^{2+} \rightarrow Zn^{2+} + V$ not feasible **or** $E^\ominus = -0.42$ (V) **(1)**		

Q12.



Question Number	Answer	Additional Guidance	Mark
	Tungsten - (because) adsorption is too strong and so desorption would be too slow	Ignore references to oxidation or reactivity series or cost Do not award 'a**b**sorption'	**(1)**

Q13.



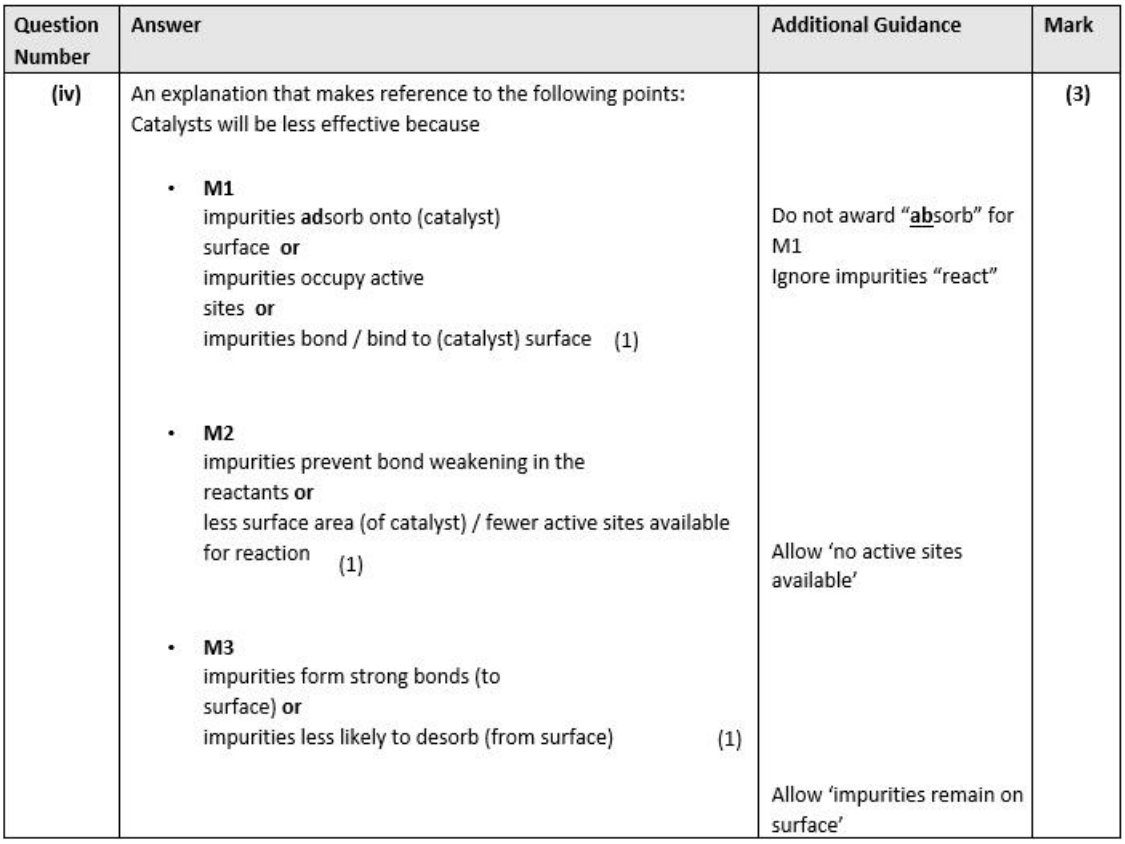
Question Number	Answer	Additional Guidance	Mark
	- Fe^{2+} oxidised to Fe^{3+} in reaction with $S_2O_8^{2-}$ **(1)** - Fe^{3+} reduced to Fe^{2+} in reaction with I^- **(1)**	Examples of equations $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$ $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ Ignore state symbols Allow equations in either order Allow multiples Penalise uncancelled electrons once only **Note** If no other mark is awarded, allow (1) for all correct species in 2 unbalanced equations	**(2)**

Q14.

Question Number	Answer	Additional Guidance	Mark
(i)	• concentration of NO in experiment 2 (1) • concentration of Cl_2 in experiment 3 (1)	Example of calculation 0.244 0.121 Do not award 0.1205 **Both** values must be to **3SF**	(2)

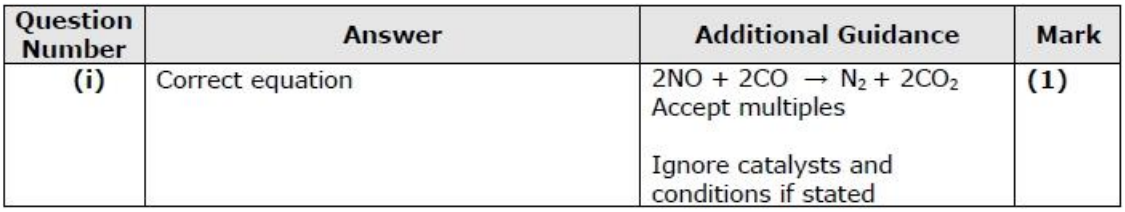
Question Number	Answer	Additional Guidance	Mark
(ii)	**M1** rearrangement of rate equation to find *k* (1) **M2** calculation of *k* (1) **M3** correct units for *k* (1)	Example of calculation $k = \frac{\text{rate}}{[NO]^2[Cl_2]}$ $\frac{1.09 \times 10^{-2}}{(0.122 \times 0.122 \times 0.241)}$ =3.03871 = 3.04 Ignore SF Correct numerical answer for *k* scores both M1 and M2 dm$_6$ mol-$_2$ s-$_1$ Allow units in any order M3 stand alone mark	(3)

Question Number	Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to the following points: *k* increases because • the catalyst provides an alternative pathway of lower activation energy (1) • so a greater proportion of molecules / more molecules have energy greater than the activation energy (so faster reaction) (1)	Award 'particles' instead of 'molecules' Do not award "atoms" instead of 'molecules'	(2)



Question Number	Answer	Additional Guidance	Mark
(iv)	An explanation that makes reference to the following points: Catalysts will be less effective because - **M1** impurities **ad**sorb onto (catalyst) surface **or** impurities occupy active sites **or** impurities bond / bind to (catalyst) surface (1) - **M2** impurities prevent bond weakening in the reactants **or** less surface area (of catalyst) / fewer active sites available for reaction (1) - **M3** impurities form strong bonds (to surface) **or** impurities less likely to desorb (from surface) (1)	Do not award “**ab**sorb” for M1 Ignore impurities “react” Allow ‘no active sites available’ Allow ‘impurities remain on surface’	**(3)**

Q15.



Question Number	Answer	Additional Guidance	Mark
(i)	Correct equation	$2NO + 2CO \rightarrow N_2 + 2CO_2$ Accept multiples Ignore catalysts and conditions if stated	**(1)**

Question Number	Answer	Additional Guidance	Mark
(ii)	A description that makes reference to the following points:	Absence of reference to the catalytic surface results in a deduction of one mark	(3)
	• **adsorption** of gases to catalytic surface **(1)**	Do not award absorption or "stick"	
	• weakening of bonds (and chemical reaction) on catalytic surface **(1)**	Allow bonds break (and reaction occurs) on catalytic surface Ignore the type of interaction referred to between the reactants and the catalytic surface	
	• desorption of products from catalytic surface **(1)**	Allow 'release' of products from catalytic surface Allow de-adsorbed	

Q16.

<table>
<tr><th>Question Number</th><th>Acceptable Answers</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>*</td><td>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><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.</td><td>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.

If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).</td><td>(6)</td></tr>
</table>

Indicative content (IPs) **IP1:** - $[Cu(H_2O)_6]^{2+}(aq) + 2OH^-(aq) \rightarrow [Cu(OH)_2(H_2O)_4](s) + 2H_2O(l)$	Allow omission of square brackets throughout Allow for IP1 $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$
IP2: - blue ppt / blue solid (when $[Cu(OH)_2(H_2O)_4](s)$ is formed)	Only penalise incorrect or missing state symbols in this equation (IP1)
IP3: - $[Cu(H_2O)_6]^{2+}(aq) + 4NH_3(aq) \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+}(aq) + 4H_2O(l)$	Allow for IP3 $Cu^{2+}(aq) + 4NH_3\ (aq) \rightarrow [Cu(NH_3)_4]^{2+}(aq)$
IP4: - Deep blue solution / dark blue solution (when $[Cu(NH_3)_4(H_2O)_2]^{2+}(aq)$ is formed)	$[Cu(OH)_2(H_2O)_4](s) + 4NH_3\ (aq) \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+}(aq) + 2H_2O(l) + 2OH^-(aq)$
IP5: - $[Cu(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \rightarrow [CuCl_4]^{2-}(aq) + 6H_2O(l)$	$[Cu(OH)_2(H_2O)_4](s) + 6NH_3\ (aq) \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+}(aq) + 2NH_4^+\ (aq)\ 2H_2O(l) + 2OH^-(aq)$
IP6: - Yellow / green (solution when $[CuCl_4]^{2-}(aq)$ is formed)	Ignore formation of initial precipitate $Cu(OH)_2(s)$ Do not award $[Cu(NH_3)_6]^{2+}(aq)$
	Do not award 'yellow precipitate' Allow equilibrium sign ⇌ in any reaction Ignore any initial colours, even if incorrect

Q17.

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>(i)</td><td>
- titres calculated and both ticks correct
(1)
- mean calculated
(1)
</td><td>
<table>
<tr><td>Run</td><td>Trial</td><td>One</td><td>Two</td><td>Three</td></tr>
<tr><td>Final volume / cm³</td><td>17.50</td><td>34.10</td><td>17.20</td><td>34.10</td></tr>
<tr><td>Initial volume /cm³</td><td>0.00</td><td>17.30</td><td>0.00</td><td>17.20</td></tr>
<tr><td>Titre / cm³</td><td>17.50</td><td>16.80</td><td>17.20</td><td>16.90</td></tr>
<tr><td>Concordant titres (✓)</td><td></td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>Mean titre /cm³</td><td colspan="4">16.85</td></tr>
</table>
Both titres to 2 dp
mean = (16.90+16.80)÷2 = 16.85 (cm³)
allow TE for M2 for mean of One, Two and Three = 16.97 (cm³)
</td><td>(2)</td></tr>
</table>

Question Number	Answer	Additional Guidance	Mark
(ii)	• calculation of moles of $Na_2C_2O_4(aq)$ **(1)** • calculation of moles of $KMnO_4$ in titre **(1)** • calculation of moles of $KMnO_4$ in 100 cm^3 **(1)** • calculation of *M*r for $KMnO_4$ **(1)** • calculation of mass of 1 tablet in mg to 2 or 3SF **(1)**	Example of calculation $(25.0 \div 1000) \times 0.200 = 0.005$ / 5.00×10^{-3} (mol) $5.00 \times 10^{-3} \times 2 \div 5 = 0.002$ / 2.00×10^{-3} (mol) $2.00 \times 10^{-3} \times (100 \div 16.85) = 0.011869$ (mol) 158 $0.011869 \times 158 = 1.8754$ g $(1.8754 \div 5) \times 1000 = 375.07$ mg = 380 / 375 (mg) Correct answer with or without working scores 5 marks 0.38 g scores 4 marks (M5 not awarded) TE at each stage and on mean titre 379 mg from 0.012 scores (5)	**(5)**

Question Number	Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to the following points • (reaction is slow initially) as MnO_4^- and $C_2O_4^{2-}$ are (both) negative (ions) so will repel (each other) **(1)** • when (sufficient) Mn^{2+} ions form they (auto) catalyse the reaction **(1)** • Mn^{2+} ions will reduce MnO_4^- ions (as E° is more negative) forming Mn^{3+} ions OR $MnO_4^- + 8H^+ + 4Mn^{2+} \rightarrow 5Mn^{3+} + 4H_2O$ ($E^\circ = +0.02V$) **(1)** • Mn^{3+} ions then oxidise $C_2O_4^{2-}$ ions (reforming Mn^{2+}) (as E° is more positive) OR $C_2O_4^{2-} + 2Mn^{3+} \rightarrow 2Mn^{2+} + 2CO_2$ ($E^\circ = +0.85V$) **(1)**	Allow 'heat is required to overcome high activation energy when catalyst is absent' Allow Mn^{2+} ions will react with MnO_4^- ions as E° is more negative Allow Mn^{3+} ions then react with $C_2O_4^{2-}$ ions (reforming Mn^{2+}) as E° is more positive May be shown in equations and / or by calculating E°	**(4)**

Q18.

Question Number	Answer	Additional guidance	Mark
(i)		Example of calculation	**(5)**
	- calculation of moles of VCl_2(aq) **(1)**	$(40/1000) \times 0.100 = 4 \times 10^{-3}$ / 0.004 (mol)	
	- calculation of moles of Cl_2(g) **(1)**	$(144/24000) = 6 \times 10^{-3}$ / 0.006 (mol)	
	- deduction of whole number ratio of $V^{2+} : Cl_2$ **(1)**	$2V^{2+} : 3Cl_2$ allow $V^{2+} : 1.5Cl_2$	
	- deduction of electrons lost per vanadium ion **(1)**	6 electrons lost by $2V^{2+}$, so 3 lost per V^{2+},	
	- deduction of final oxidation number of V **(1)**	(+)5 Allow TE throughout Correct answer with no working scores M5 only	

Question Number	Answer	Additional Guidance	Mark
(ii)		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	**(2)**
	- purple / lilac / violet **(1)**	Allow lavender / mauve for M1 Mark consequentially from (d)(i)	
	- to yellow (solution) **(1)**	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	

Q19.

Question Number	Acceptable Answers	Additional Guidance	Mark
	A explanation that makes reference to the following points: M1 V changes (its oxidation state / oxidation number) from +5 to +4 (as it oxidises the sulfur dioxide) OR The oxidation number of V decreases in the reaction OR Vanadium is reduced in the reaction with SO_2	Ignore any references to heterogeneous catalysis Allow Forms V_2O_4 / VO_2 (as an intermediate) Do not award VO^{2+} or VO_3^- or VO_2^+	**(2)**
	OR V_2O_5 oxidises the SO_2 / S OR $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ **(1)** M2 (Then) returns to +5 (oxidation state / oxidation number) by reacting with oxygen OR $2 V_2O_4 + O_2 \rightarrow 2 V_2O_5$ **(1)**	Allow (re-) forms V_2O_5	

Q20.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	- All species and balancing correct **(1)** - All state symbols correct **(1)**	Examples of equation $Cr(OH)_3(s) + 3H_2O(l) + 3H^+(aq) \rightarrow [Cr(H_2O)_6]^{3+}(aq)$ **Or** $Cr(OH)_3(s) + 3H_3O^+(aq) \rightarrow [Cr(H_2O)_6]^{3+}(aq)$ **Or** $[Cr(OH)_3(H_2O)_3](s) + 3H^+(aq)$ on LHS as an alternative Allow correct equations for sequential protonation e.g. $[Cr(OH)_3(H_2O)_3](s) + H^+(aq) \rightarrow [Cr(H_2O)_4(OH)_2]^+(aq)$ 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
(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
(iii)	• all species and balancing correct **(1)** • all state symbols correct **(1)**	Examples of equation $Cr(OH)_3(s) + 3OH^-(aq) \rightarrow [Cr(OH)_6]^{3-}(aq)$ **Or** [Cr(OH)3(H2O)3](s) + 3OH−(aq) → [Cr(OH)6]3−(aq) + 3H2O(l) Allow $Cr(OH)_3(s) + OH^-(aq) \rightarrow [Cr(OH)_4]^-(aq)$ **Or** $[Cr(OH)_5(H_2O)]^{2-}(aq)$ 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
(iv)	An answer that makes reference to the following point: • green **and** solution	Ignore 'Qualifiers' for any colour (e.g. 'dark', 'deep', etc)	**(1)**