PEARSON EDEXCEL A-LEVEL CHEMISTRY · 9CH0

CHEMISTRY



MARK SCHEME

TOPIC 15: TRANSITION METALS

SCORE	PERCENTAGE
/394	%

STEMUP

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(Total for question = 7 marks)

Mark Scheme

Q1.

Question Number	Correct Answer	Reject	Mark
	A		1

Q2.

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

Q3.

Question Number	Correct Answer	Reject	Mark
	A		**1**

Q4.

Question Number	Answer	Mark
	The only correct answer is C ***A*** *is not correct because only* Mn^{2+} *is an autocatalyst for this reaction* ***B*** *is not correct because only* Mn^{2+} *is an autocatalyst for this reaction* ***D*** *is not correct because only* Mn^{2+} *is an autocatalyst for this reaction*	**(1)**

Q5.

Question Number	Answer	Additional Guidance	Mark
	• equation with oxidation of cobalt(II) ions • equation with reduction of cobalt(III) ions	<u>Example of equations</u> $2Co^{2+} + ½O_2 + 2H^+ \rightarrow 2Co^{3+} + H_2O$ $2Co_{3+} + SO_{32-} + H_2O \rightarrow 2Co_{2+} + SO_{42-} + 2H_+$ Allow multiples Ignore state symbols even if incorrect	**(2)**

Q6.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following point: • the two negative ions repel each other	 Reference to both charge and repulsion needed	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: • equation with oxidation of iron(II) ions **(1)** • equation with reduction of iron(III) ions **(1)** • (catalysis is possible because) variable oxidation state/iron has more than one oxidation state/number **or** both steps now involve oppositely charged ions **(1)**	<u>Example of equations</u> $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$ $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ Allow multiples Ignore state symbols even if incorrect Allow one mark if the two correct equation are given in the wrong order Allow reference to iron being oxidised and reduced Allow reference to the iron ions being positive and so not repelled	(3)

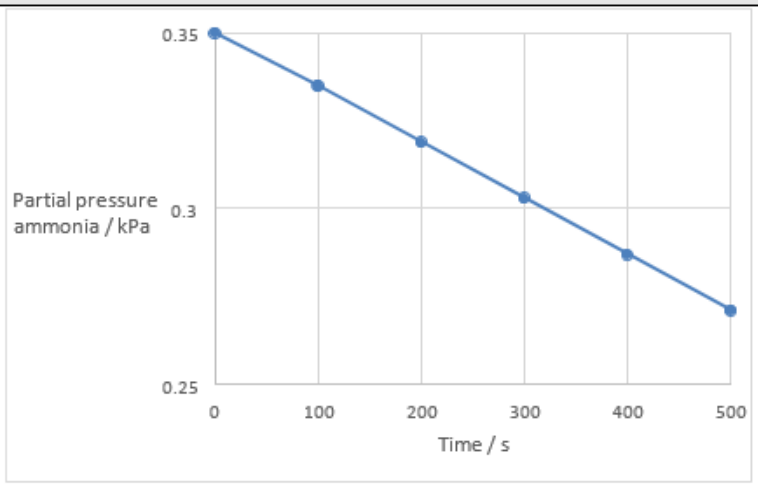
Q7.

Question Number	Correct Answer	Reject	Mark
	D		**1**

Q8.

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)

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 $\frac{(0.271 - 0.350}{500} = (-)\frac{0.079)}{500}$ $k = 1.58 \times 10^{-4}$ / 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: • 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)**

Q10.

Question Number	Answer	Additional guidance	Mark
	A discussion that makes reference to the following points: • both elements / atoms have the last added electron in the d-subshell / d orbital (so are d-block elements) **(1)** • but neither forms a (stable) ion with an incomplete d-subshell / d orbital (so are not transition metals) **(1)** • Zn^{2+} is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ (so d subshell is full) **(1)** • Sc^{3+} is $1s^2 2s^2 2p^6 3s^2 3p^6$ (so d subshell is empty) **(1)**	Do not award just 'contains d electrons' Allow 'transition elements form a (stable) ion with an incomplete d-subshell / d orbital' Allow $[Ar]3d^{10}$ Allow [Ar]	**(4)**

Q11.

Question Number	Answer	Additional guidance	Mark
(a)	• Fe^{2+} / $Fe(H_2O)_6^{2+}$ (1) • Cr^{3+} / $Cr(H_2O)_6^{3+}$ (1)	Allow Ni^{2+} / $Ni(H_2O)_6^{2+}$ V^{3+} / $V(H_2O)_6^{3+}$ Ignore names	2
(b)(i)	Cr^{3+} / $Cr(H_2O)_6^{3+}$	Ignore names	1
(b)(ii)	$Cr(OH)_3$/ $Cr(H_2O)_3(OH)_3$	Ignore names	1
(b)(iii)	$Cr(OH)_6^{3-}$	Accept other correct species Ignore names (no ecf from (b)(i))	1
(c)	Any **one** from: • purple to colourless • purple (solution) decolourised	Allow final colour of solution to be orange Allow pink for purple	1
(d)(i)	Cl^-	Reject Cl Ignore names	1
(d)(ii)	An explanation that makes reference to the following points: ammonia solution cannot be used because: • ammonia reacts with the iron ions to form a precipitate (1) **or** • a precipitate of (Iron(II) hydroxide/ $Fe(OH)_2$/ $Fe(H_2O)_4(OH)_2$ forms (1) **Plus** • and so obscures the dissolving of the white precipitate (1)		2

Q12.

Question Number	Answer	Additional Guidance	Mark
	An explanation that makes reference to the following points: • equilibrium position shifts to the left **(1)** • (because) the hydroxide ions combine with/neutralise the H^+ ions to remove them from the equilibrium **(1)**	'Equilibrium moves to the right' scores (0) Allow Hydroxide ions react with H^+ ions to make water/ hydroxide ions react with H^+ ions to reduce their number/concentration Ignore reference to 'more products formed'	**(2)**

Q13.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• +5		**1**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b) (i)	• choice of suitable reducing agent	From Data Booklet of the standard electrode potentials, the right hand substance in numbers 16-24	**1**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b) (ii)	An answer that makes reference to the following point: • may be kinetically hindered **or** activation energy may be too high	Allow reaction may be too slow	**1**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b) (iii)	An explanation that makes reference to the following points: • (yellow to) green then blue (1) • when the blue colour initially forms, it mixes with the yellow unreacted VO_2^+ (to turn green) (1)	Ignore colours caused by contamination with reducing agent chosen	**2**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(iv)	An explanation that makes reference to the following point: • justification of choice (1) • correct equation for reaction (1)	$E^{\ominus}$ value is between +0.34 V and −0.26 V Allow by comparison of electrode potentials / calculation of E_{cell} / use of anti-clockwise rule $S_2O_3^{2-} + VO^{2+} + 2H^+ \rightarrow V^{3+} + H_2O + \frac{1}{2}S_4O_6^{2-}$ or multiples	**2**

Q14.

Question Number	Acceptable Answers	Reject	Mark
(a)(i)	$TiCl_4 + 4Na \rightarrow 4NaCl + Ti$ IGNORE State symbols, even if incorrect ALLOW Multiples Reversible arrows		**1**

Question Number	Acceptable Answers	Reject	Mark
(a)(ii)	Ti **reduced** as oxidation number decreases from **+4 to 0**/ changes from **+4 to 0** **(1)** Na **oxidized** as oxidation number increases from **0 to +1** /changes from **0 to +1** **(1)** ALLOW Correct oxidation numbers only for one mark **NOTE** Max (1) if no + sign included ALLOW **'4+'** and/or **'1+'** given instead of **+4** and **+1** **NOTE** If any of the oxidation numbers are wrong, award max (1) for the idea that during oxidation the oxidation number increases **AND** during reduction the oxidation number decreases IGNORE References to loss and /or gain of electrons		**2**

Question Number	Acceptable Answers	Reject	Mark
(b)	(Ti [Ar]) $3d^2\ 4s^2$ / $4s^2\ 3d^2$ **(1)** (Ti^{3+} [Ar]) $3d^1$ / $3d^1\ 4s^0$ (Ti^{4+} [Ar]) 'nil' / $3d^0\ 4s^0$ /$3d^0$ space left blank by candidate BOTH Ti^{3+} and Ti^{4+} correct for second mark **(1)** Mark CQ on Ti electron configuration for the second mark ALLOW Upper case (e.g. 'D' for 'd' in electronic configurations) Subscripts for numbers of electrons Full correct electronic configurations $1s^2$, $2s^2$.....		**2**

Question Number	Acceptable Answers	Reject	Mark
(c)(i)	**(d-block element)** **EITHER** Ti has (two) electrons in the 3d subshell / Ti has a partially filled d-subshell / Ti has a partially filled d-orbital / Ti has electrons in d-orbital(s) / Ti has electrons in d-subshell (During the build up of its atoms) last added / valence electron is in a d-subshell / d-orbital **OR** (During the build up of its atoms) last added / valence electron is in a d-subshell / d-orbital	**Outer / highest energy** electrons are in a d-orbital / **Outer / highest energy** electrons are in a d-subshell Electrons in the 'd-block'/ 'electrons in the d-shell'	**1**

Question Number	Acceptable Answers	Reject	Mark
(c)(ii)	(transition element) Forms one (or more stable) **ions** / forms **Ti^{3+}** (ions) which have incomplete d-orbital(s) / an incomplete d-subshell / a partially filled d-subshell / an unpaired d electron IGNORE References to variable oxidation states		**1**

Question Number	Acceptable Answers	Reject	Mark
(d)(i)	**First mark:** d-subshell splits /d-orbital**s** split (in energy by ligands) /d energy level(s) split(s) **(1)** **Second mark:** **absorbs light** (in visible region) **(1)** **Third mark:** Electron transitions from lower to higher energy / electron(s) jump from lower to higher energy OR Electron(s) promoted (within d) **(1)** Mark independently **NOTE** Maximum of (1) mark (i.e. the first mark only) if refers to electrons falling back down again	d-**orbital /** d-**shell** splits absorbs **purple** light	**3**

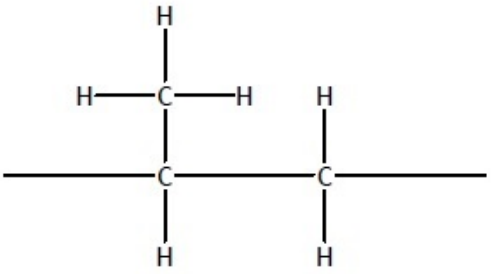
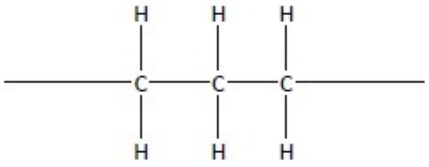
Question Number	Acceptable Answers	Reject	Mark
(d)(ii)	No d-electrons / empty d-subshell		**1**

Question Number	Acceptable Answers	Reject	Mark
(e)(i)	**TiO_2** **'Structure' mark** **EITHER** Giant (structure) **OR** Lattice (structure) IGNORE Whether stated as ionic or covalent for this mark **(1)** **TiO_2** **'Bonding' mark** EITHER **Strong** (electrostatic) attraction between ions ALLOW **Strong** ionic bonds / ionic bonds require a lot of energy to break **OR** **Strong** covalent bonds/covalent bonds require a lot of energy to break **(1)** **$TiCl_4$** **'Structure' mark** (Simple) molecules / (small) molecules **/**molecular **(1)** **$TiCl_4$** **'Bonding' mark** **Weak** London / dispersion / van der Waals' forces (between molecules) / London /dispersion / van der Waals' forces (between molecules) require little energy to break	TiO_2 (small) molecule**s** / simple molecular For TiO_2 mention of any type of intermolecular forces between molecules of TiO_2 $TiCl_4$ giant structure Covalent bonds broken (on melting) in $TiCl_4$ Ionic bonding in $TiCl_4$ Hydrogen bonding **(0)** for this mark	**4**

	NOTE If candidates assumes TiO_2 and $TiCl_4$ are both simple molecular, can score last mark for saying that the **named** intermolecular forces in TiO_2 are stronger that those in $TiCl_4$ IGNORE (Permanent) dipole-dipole forces **(1)** Mark the four scoring points independently		

Question Number	Acceptable Answers	Reject	Mark
(e)(ii)	Amphoteric ALLOW Recognisable spellings		**1**

Question Number	Acceptable Answers	Reject	Mark
(e)(iii)	$TiO_2 + 2H_2O + 2KOH \rightarrow K_2Ti(OH)_6$ OR $TiO_2 + 2H_2O + 2OH^- \rightarrow Ti(OH)_6^{2-}$ IGNORE state symbols even if incorrect		**1**

Question Number	Acceptable Answers	Reject	Mark
(e)(iv)	 **MUST** have continuation bonds at each end ALLOW CH_3 IGNORE n and any brackets	 **Two** (or more) repeat units shown	**1**

Question Number	Acceptable Answers	Reject	Mark
(f)(i)	$(H_2O_2 + 2H^+ +)$ **$2e^{(-)} \rightarrow 2H_2O$** **BOTH** $2e^{(-)}$ **and** **2**H_2O needed for the mark		**1**

Question Number	Acceptable Answers	Reject	Mark
(f)(ii)	(Moles H_2O_2 = $\frac{0.0200 \times 22.50}{1000}$ =) 4.5×10^{-4} mol H_2O_2 **(1)** (Moles Ti^{3+} reacting in 25.0 cm^3) = 9.0×10^{-4} mol Ti^{3+} (Moles Ti^{3+} in 250 cm^3) = 9.0×10^{-3} mol Ti^{3+} **(1)** (Original concentration of Ti^{3+} = $\frac{9.0 \times 10^{-3}}{0.00500}$ =) 1.8 (mol dm^{-3}) **(1)** 1.8 (mol dm^{-3}) with or without working scores **(3)** **NOTES:** If mole ratio H_2O_2 : Ti^{3+} is 1:1 final answer for concentration of Ti^{3+} is 0.9 (mol dm^{-3}) scores **(2)** overall If mole ratio H_2O_2 : Ti^{3+} is 2:1 final answer for concentration of Ti^{3+} is 0.45 (mol dm^{-3}) scores **(2)** overall If candidate forgets to multiply no. of moles of Ti^{3+} by 10 then answer is 0.18 (moldm-3) this scores **(2)** If volume of H_2O_2 used is 25.0 no first mark, but can score **(2)** if final answer CQ is 2(.0) (mol dm^{-3})		**3**

Question Number	Acceptable Answers	Reject	Mark
(f)(iii)	(It/titanium(III)/Ti^{3+}) **oxidized** (by oxygen in the air) ALLOW 'It is a **strong** reducing agent'	Hydrolysis	**1**

Q15.

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

Question Number	Answer	Additional Guidance	Mark
(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)

Q16.

Question Number	Correct Answer	Reject	Mark
(a)	D		**1**
(b)	C		**1**
(c)	A		**1**

Q17.

Question Number	Correct Answer	Reject	Mark
	D		1

Q18.

Question Number	Correct Answer	Reject	Mark
	B		**1**

Q19.

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

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

Question Number	Answer	Additional Guidance	Mark
(iii)	• oxidation half equation **(1)** • reduction half equation **(1)** • overall equation **(1)**	$H_2O_2 \rightarrow 2H^+ + O_2 + 2e^-$ $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$ $Cr_2O_7^{2-} + 8H^+ + 3H_2O_2 \rightarrow 2Cr^{3+} + 7H_2O + 3O_2$ 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	**(3)**

Q20.

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)**

Q21.

Question Number	Correct Answer	Reject	Mark
	B		**1**

Q22.

Question Number	Correct Answer	Reject	Mark
	D		**1**

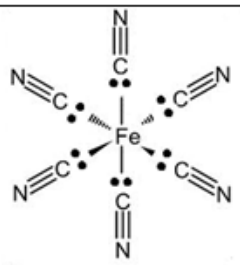
Q23.

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

Q24.

Question Number	Answer	Additional Guidance	Mark
	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)

Q25.

Question number	Answer	Additional guidance	Marks
(a)(i)	A		1
(a)(ii)	 • 3D shape correctly shown (1) • electron pairs shown OR all six bonds shown clearly to the carbons (1)	Charge and square brackets not required Allow dotted lines for the wedges going backwards Allow arrows to represent dative covalent bonds instead of electron pairs	2
(b)	• step 1 – ligand substitution/ligand exchange (1) • step 2 – redox (1)	Allow reduction **and** oxidation Allow oxidation	2
(c)	• identification: green precipitate is iron(II) hydroxide (1) Explanation: • precipitate turns brown because iron(II) hydroxide is oxidised by oxygen (and water) in the air (1) • to form iron(III) hydroxide (1)	$Fe(OH)_2$ / $Fe(H_2O)_4(OH)_2$ $Fe(OH)_3$ / $Fe(H_2O)_3(OH)_3$	3

Q26.

Answer	Additional Guidance
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. 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, 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 and 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

The following table shows how the marks should be awarded for structure and lines of reasoning

	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	Accept any six indicative content points More than one indicative marking point may be made within the same comment or explanation
• **IP1** formulae and colour of first complex ion	$[Co(H_2O)_6]^{2+}$ allow $[Co(NH_3)_6]^{2+}$ or $[Co(EDTA)]^{2-}$ or $[Co(en)_3]^{2+}$ **and** pink or yellow/brown for the hexaamine complex
• **IP2** formulae and colour of second complex ion	$[CoCl_4]^{2-}$ allow $[Co(OH)_4]^{2-}$ **and** blue
• **IP3** definition of ligand	Atom/ion/molecule/species dative covalently bonded/ coordinately bonded to a central metal ion which can be shown on a diagram
• **IP4** definition of and example(s) of coordination number	The number of dative covalent bonds (to a central metal ion) **and** Six and/or four respectively which may be in a diagram
• **IP5** shape of complex ion(s)	Octahedral and/or tetrahedral respectively and can be a diagram. If two given then both must be correct
• **IP6** the chloride ion is larger (than the oxygen in water ligand or nitrogen in the ammonia ligand)	Allow chloride ions are large and only fit four around the metal ion Do not award 'molecule' when referring to chlorine Accept reverse argument

Q27.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• ligand exchange	Allow ligand substitution / ligand replacement Ignore change in co-ordination number Do not award ligand change Do not award any other type of reaction in addition to correct answer e.g. reduction / acid-base / deprotonation	**(1)**

Q28.

Question Number	Acceptable Answers	Reject	Mark
	C		**1**

Q29.

Question Number	Acceptable Answers	Reject	Mark
	B		**1**

Q30.

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)**

Q31.

Question number	Answer	Additional Guidance	Marks
(a)	• axes: correct way round, labelled, suitable scale (1) • all points plotted correctly to nearest gridline AND straight line through first 3 points, straight line through last 3 points, and the two lines intersect (1)	The scale is suitable if the distance between the first point plotted and the last point plotted covers more than half of the graph paper on each axis.	**2**
(b)(i)	$(0.005 \times 0.5) = 2.5(0) \times 10^{-3}$ / 0.0025 (mol)		**1**
(b)(ii)	10 (cm^3)	Award mark for a value read correctly from the candidate's graph	**1**
(b)(iii)	$(0.010 \times 1.00) = 1 \times 10^{-2}$ / 0.01 (mol)	Answer to (iii) csq on (ii)	**1**
(b)(iv)	x = 4 and y = 2	Answer to (iv) csq on (i) and (ii), but x + y must total 6	**1**

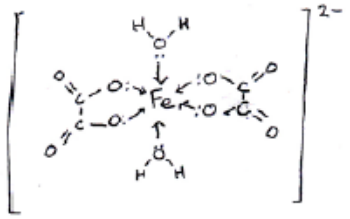
Question number	Answer	Additional Guidance	Marks
(c)	$Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$ • correctly balanced equation (1) • state symbols (1)	Allow $[Cu(H_2O)_6]^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(H_2O)_4(OH)_2(s) + 2H_2O(l)$	**2**

Q32.

Question Number	Acceptable Answers	Reject	Mark
(i)	$2Cu^{+}(aq) \rightarrow Cu(s) + Cu^{2+}(aq)$ IGNORE Eqm sign for →	Reverse equation Any equation involving electrons	1

Question Number	Acceptable Answers	Reject	Mark
(ii)	Both white ALLOW (both) Colourless (1) COMMENT Ignore states eg solution/precipitate As have $3d^{10}$ / have a full 3d sub-shell /**ALL** 3d orbitals are full (1) IGNORE Does not have partially filled d orbitals They do not absorb light No d-d transitions occur		2

Q33.

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)**

Q34.

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

Q35.

Question Number	Correct Answer	Reject	Mark
	D		**1**

Q36.

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

Q37.

Question Number	Correct Answer	Reject	Mark
	B		1

Q38.

Question number	Answer	Additional guidance	Marks
	• (V) $(1s^2 2s^2 2p^6 3s^2) 3p^6 3d^3 4s^2$ (1) • (V^{3+}) $(1s^2 2s^2 2p^6 3s^2) 3p^6 3d^2$ (1)	Allow $4s^2 3d^3$	**2**

Q39.

Question Number	Correct Answer	Reject	Mark
	C		**1**

Q40.

Question Number	Answer	Additional Guidance	Mark
	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 / $[Cr(EDTA)]^-$ 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)**

Q41.

Question Number	Answer	Mark
	The only correct answer is B ***A*** *is not correct because covalent is missing* ***C*** *is not correct because it has ionic is incorrect* ***D*** *is not correct because it has ionic is incorrect*	**(1)**

Q42.

<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.

Reasoning marks may be subtracted for extra incorrect chemistry.</td>
<td>(6)</td>
</tr>
</table>

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

Q43.

Question Number	Answer	Additional Guidance	Mark
	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)**

Q44.

Question Number	Acceptable Answers	Reject	Mark
	(Zinc) does not form a (stable) **ion** with incompletely/partially filled d orbitals ALLOW d sub-shell for d orbitals The only (stable) **ion** formed by zinc has full d sub-shell It does not form a (stable) oxidation state with incompletely/partially filled d orbitals	Element has full d shells.	1

Q45.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• $SO_2 + ½O_2 \rightarrow SO_3$	Allow multiples Ignore state symbols	**1**

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>*(ii)</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>
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The following table shows how the marks should be awarded for structure and lines of reasoning.
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<tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr>
<tr><td>Answer shows a coherent and 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>
Indicative Content:

V_2O_5 acts as a heterogeneous catalyst
SO_2 is adsorbed onto surface and reacts with the V_2O_5
SO_3 forms and is only weakly bonded to surface
the SO_3 desorbs from the surface
oxygen reacts with the VO_2, regenerating the V_2O_5 catalyst
reaction follows different mechanism with lower activation energy

</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 which 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).

Ignore comments related to collision theory</td><td>6</td></tr>
</table>

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Q46.

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)**		

Q47.

Question Number	Acceptable Answers	Additional Guidance	Mark
	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> $[Fe(H_2O)_6]^{2+}$ is green **and** $[Fe(H_2O)_6]^{3+}$ is yellow / orange / red/ brown $[CuCl_4]^{2-}$ is yellow **and** $[CuCl_2]^-$ is colourless $[Cu(H_2O)_6]^{2+}$ is (pale) blue **and** $[CuCl_4]^{2-}$ is yellow $[Cu(H_2O)_6]^{2+}$ is (pale) blue **and** $[Cu(NH_3)_4]^{2+}$ / $[Cu(NH_3)_4(H_2O)_2]^{2+}$ / $[Cu(H_2O)_2(NH_3)_4]^{2+}$ is a **darker** blue than in the aqua ion $[CuCl_4]^{2-}$ is yellow and $[Cu(NH_3)_4]^{2+}$ / $[Cu(NH_3)_4(H_2O)_2]^{2+}$ / $[Cu(H_2O)_2(NH_3)_4]^{2+}$ is (deep / dark) blue	**(3)**

		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 $[CuCl_4]^{2-}$ Do not award $[Cu(NH_3)_6]^{2+}$ Ignore qualifications of colour e.g. pale / dirty	

Q48.

Question Number	Acceptable Answer	Mark
	The only correct answer is **C** ***A*** *is incorrect because gaseous reactants attach only to the surface* ***B*** *is incorrect because this happens after adsorption* ***D*** *is incorrect because this is detachment of the products from the surface*	**(1)**

Q49.

Question number	Answer	Additional guidance	Marks
(i)	An explanation that makes reference to the following points: • $E^{\ominus}$ of redox system 5 is more negative / less positive than that of both redox systems 4 and 3 (but not than that of redox systems 2 and 1) (1) • therefore SO_2 releases electrons to / reduces VO_2^+ to VO^{2+} and then VO^{2+} to V^{3+} (1) • (yellow to) blue <u>then</u> green (1)	 Accept explanations based on calculating $E^{\ominus}_{cell}$ for the reactions Accept correct use of anticlockwise rule Ignore green colour before blue	**3**
(ii)	The reaction is **<u>not</u>** feasible because: • $E^{\ominus}$ of redox system 2 is less negative than that of redox system 1 (1) • therefore V^{2+} ions in system 2 will not release electrons to the V^{2+} ions in system 1 (1)	 Accept explanations based on calculating $E^{\ominus}_{cell}$ for the reactions Accept correct use of anticlockwise rule	**2**

Q50.

Question Number	Correct Answer	Mark
	D	**1**

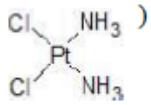
Q51.

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 'absorption'	**(1)**

Q52.

Question Number	Correct Answer	Mark
	C	**1**

Q53.

Question Number	Answer	Mark
	The only correct answer is C ( **)** **A** *is not correct because water is not one of the ligands and the configuration of chloride ions should be cis not trans* **B** *is not correct because water is not one of the ligands* **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*	**(1)**

Q54.

Question Number	Correct Answer	Reject	Mark
	C		1

Q55.

Question Number	Correct Answer	Reject	Mark
	D		1

Q56.

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)**

Q57.

Question Number	Answer	Additional Guidance	Mark
(i)	• (The cation in **X** is) Fe^{2+} / iron(II) / Fe(II) **(1)** • (The anion in **X** is) SO_4^{2-} / sulfate(VI) **(1)**	Allow Fe^{+2} Allow sulfate / SO_4^{-2} Do not award sulfite / sulfate(IV)	**(2)**

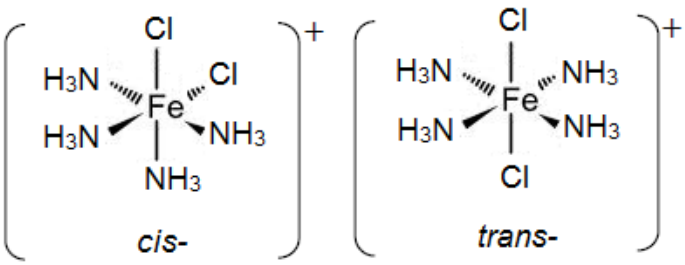
Question Number	Answer	Additional Guidance	Mark
(ii)	• species and balancing (1) • state symbols (1)	Examples of equation $Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$ **or** $[Fe(H_2O)_6]^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s) + 6H_2O(l)$ **or** $[Fe(H_2O)_6]^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(H_2O)_4(s) + 2H_2O(l)$ Ignore missing square brackets TE on cation that forms an insoluble hydroxide in **Test 1** State symbols conditional on correct species or 'near miss' / non-ionic equation	(2)

Question Number	Answer	Additional Guidance	Mark
(iii)	An answer that makes reference to the following point: • Fe^{2+} is oxidised (to Fe^{3+}) by oxygen / air	Allow iron(III) hydroxide / iron(III) (ions) are formed by reaction with oxygen / air TE on cation in **Test 1** Allow just 'the precipitate / it is oxidised by oxygen / air'	(1)

Question Number	Answer	Additional Guidance	Mark
(iv)	An answer that makes reference to the following point: • to react with / remove any carbonate / sulfite / sulfate(IV) ions **or** to eliminate the possibility of carbonate / sulfite / sulfate(IV) ions	Allow to prevent any other ions forming a precipitate with barium ions / Ba^{2+}	(1)

Q58.

Question number	Acceptable Answer	Additional Guidance	Marks
(i)	$[Fe(NH_3)_4Cl_2]^+$ / $[FeCl_2(NH_3)_4]^+$	Square brackets not essential	**1**

Question number	Acceptable Answer	Additional Guidance	Marks
(ii)	 • both isomers (1) • *cis* and *trans* correctly labelled (1)	Ignore absence of square brackets and charge Allow one isomer with correct label for 1 mark	**2**

Q59.

Question Number	Correct Answer	Mark
	D	**1**

Q60.

Question Number	Correct Answer	Reject	Mark
	D		1

Q61.

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)

Q62.

Question Number	Acceptable Answer	Additional Guidance	Mark
	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 **Mn^{2+} 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 Mn^{2+} ions present at the start Allow a description of how the Mn^{2+} ions are acting as a catalyst e.g. the idea of Mn^{2+} 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 Mn^{2+} ions are used up'	**(3)**

Q63.

Question Number	Acceptable Answers	Reject	Mark
(a)	Oxygen atoms in water molecules have δ− charge. **(1)** Which form electrostatic / ion-dipole attractions with sodium (ion). **(1)** ALLOW for one mark copper(II) ions form dative covalent bonds but sodium ions do not (**both** needed)	 Ionic bonds / attractions Intermolecular forces Hydrogen bonds	**2**

Question Number	Acceptable Answers	Reject	Mark
(b)	Additional (dative covalent bond) lone pairs are accommodated in vacant (3)d orbitals / (3)d sub-shell ALLOW Vacant **higher** energy orbitals / sub-shells IGNORE 3s/3p	'Partially filled' for 'vacant'	**1**

Question Number	Acceptable Answers	Reject	Mark
*** (c)(i)**	(3)d orbitals / (3)d subshell split (by the attached ligands) **(1)** Electrons are promoted (from lower to higher energy d orbital(s) / levels) OR Electrons move from lower to higher energy (d orbital(s) / levels) ALLOW d—d transitions occur /electrons are excited **(1)** Absorbing energy /photons of a certain frequency (in the visible region) ALLOW Absorbing light **(1)** Reflected / transmitted / remaining light is coloured / in the visible region ALLOW Complementary colour seen Reflected / transmitted / remaining light / frequency is seen **(1)** Penalise omission of (3)d once only. Ignore reference to electrons relaxing / dropping to the ground state	Orbital / shell is split Emitted	**4**

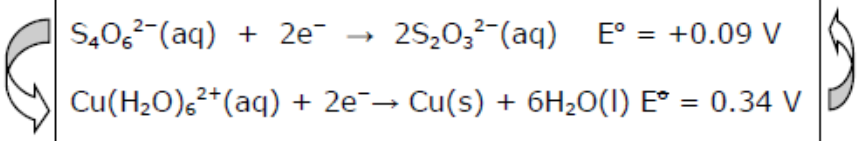
Question Number	Acceptable Answers	Reject	Mark
(c)(ii)	Zn (3)d orbitals are / (3)d subshell is **full / complete** (so d–d transitions are not possible) / Zinc is $3d^{10}$	Zn does not have partially filled d subshell	**1**

Question Number	Acceptable Answers	Reject	Mark
(c)(iii)	(d–d) energy gap is large **(1)** the energy absorbed is outside the visible region / in the UV region **(1)** Stand alone marks		**2**

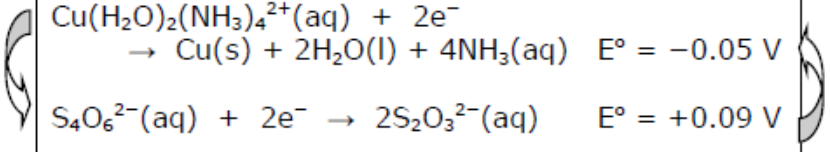
Question Number	Acceptable Answers	Reject	Mark
(d)	**<u>Method 1: cell emfs</u>** For the reaction $Cu(H_2O)_6^{2+}(aq) + 2S_2O_3^{2-}(aq)$ $\rightarrow Cu(s) + 6H_2O(l) + S_4O_6^{2-}(aq)$ * $E^{\circ}_{cell} = +0.34 - 0.09 = (+)0.25$ (V) **and** (Positive so) reaction is feasible **(1)** For the reaction $Cu(H_2O)_2(NH_3)_4^{2+}(aq) + 2S_2O_3^{2-}(aq)$ $\rightarrow Cu(s) + 2H_2O(l) + 4NH_3(aq) + S_4O_6^{2-}(aq)$ ** $E^{\circ}_{cell} = -0.05 - 0.09 = -0.14$ (V) **and** (Negative so) reaction is not feasible **(1)** If both values correct but feasibility omitted or incorrect award 1 mark **Both** equations (* & **) correct IGNORE Omission of H_2O and states from the equations **(1)**	electrons in equations	**3**

Method 2: anticlockwise rule

Place the reactions in order of increasing (more positive) $E^{\ominus}$ values and check which reaction occurs in the anticlockwise direction. **(1)**



Reaction is feasible (desired reaction proceeds in anticlockwise direction) **(1)**



Reaction is not feasible (proceeds in the opposite direction). **(1)**

Question Number	Acceptable Answers	Reject	Mark
(e)(i)	(coordination number =) 4 / four		**1**

Question Number	Acceptable Answers	Reject	Mark
(e)(ii)	Amount of complex = 4.82 / 288.7 (= 0.0166955 mol) Mass of nickel = 58.7 x 4.82 / 288.7 = 0.98003 g **(1)** % Nickel in alloy = 100 x 0.98 / 1.02 = 96.08 % **(1)** Correct answer with no working scores 2 Ignore SF except 1 ALLOW TE unless %>100 Use of A_r(Ni) = 59 (gives 96.57%)		**2**

Q64.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	**Test 1** • (gas is) ammonia / NH_3 **(1)** • (cation is) ammonium / NH_4^+ **(1)** **Test 2** • (cation is) cobalt(II) / Co^{2+} / $[Co(H_2O)_6]^{2+}$ **(1)** • (complex ion is) $[CoCl_4]^{2-}$ **(1)** **Test 3** • (precipitate is) barium sulfate / $BaSO_4$ **(1)** • (anion is) sulfate((VI)) / SO_4^{2-} **(1)**	If name and formula are given, both must be correct Mark independently Do not award gas is ammonium / NH_4 Do not award cation is ammonia / NH_3^+ Oxidation number of cobalt is needed in the name but allow cobalt **with** Co^{2+} Charge is needed on the ion Allow +2 and −2 for the charges on the ions Allow brackets around Cl Ignore missing square brackets in complex ions Do not award $[CoCl_6]^{4-}$ **Note** If cation in Test 2 is identified as copper(II) / Cu^{2+}, do not award M3 but M4 can be awarded as TE for $[CuCl_4]^{2-}$ Oxidation number of sulfate is not needed but if given must be correct e.g. do not award sulfate(IV)	**(6)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	• correct formula	Examples of correct formula $(NH_4)_2Co(SO_4)_2$ $(NH_4)_2SO_4.CoSO_4$ Allow NH_4, Co and SO_4 in any order Allow multiples Allow any combination of Co^{2+} / NH_4^+ / SO_4^{2-} that gives a neutral complex TE on the **three** ions identified in (a)(i) Ignore missing dot in second formula Ignore any amount of water of crystallisation	**(1)**

Q65.

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)

Q66.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	An explanation that makes reference to the following points: • glycinate ions / they do not contain a carbon atom with four different atoms / groups attached **or** the glycinate ion is superimposable on its mirror image **(1)** • so there will be no effect (on plane-polarised monochromatic light) **(1)**	An answer that states there will be an effect scores (0) Allow not chiral / achiral / has no enantiomers / has no asymmetric carbon atom Allow the carbon atom attached to NH_2 is only attached to 3 different atoms / groups / is not attached to 4 different atoms / groups Ignore glycinate ions are not optically active / do not exhibit optical isomerism Do not award it is a racemic mixture / there are equal amounts of the two isomers / four different molecules attached M2 is conditional on M1 Do not award the (monochromatic) light will not be polarised	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	• correct formula of one of the copper species **(1)** • rest of equation correct **(1)**	Example of equation $(CH_3COO)_2Cu + 2\ NH_2CH_2COOH \rightarrow (NH_2CH_2COO)_2Cu + 2CH_3COOH$ Allow $Cu(CH_3COO)_2$ / $Cu(NH_2CH_2COO)_2$ Allow both charges shown e.g. $(CH_3COO^-)_2Cu^{2+}$ Allow displayed / skeletal formulae for organic substances but not molecular formulae Ignore state symbols, even if incorrect Do not award M1 if covalent bond between Cu and O in any species but M2 can still score	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(iii)	An answer that makes reference to any **four** of the following points: Student **1** / higher yield • the crystals were not dry / still damp when they were weighed **(1)** • there are impurities in the crystals **(1)** Student **2** / lower yield • reaction was incomplete **(1)** • not all of the copper(II) glycinate had crystallised / some is left in solution **(1)** • description of a specific handling loss **(1)**	Ignore reference to weighing errors for both students Allow the student did not subtract the mass of filter paper / product container Do not award the crystals contain water of crystallisation / are (partially) hydrated Allow a specific impurity e.g. glycine Allow the reaction reached equilibrium / side reactions occur / by-products form Ignore just 'the solution has not cooled enough' Allow any specific example e.g. some crystals left on the walls of the container / beaker / flask / lost during filtration / lost during transfer Ignore just 'transfer error' / lost when handling	**(4)**

Q67.

Question number	Answer	Additional Guidance	Marks
(a)	**C** ([Ar] $3d^6 4s^0$)		**1**

Question number	Answer	Additional Guidance	Marks
(b)(i)	**D** (+6)		**1**

Question number	Acceptable Answer	Additional Guidance	Marks
(b)(ii)	• $E^\ominus$ for the reaction is +0.97 V (1) • because $E^\ominus$ is positive FeO_4^{2-} will react and so is unstable (in acidic conditions) (1) • $4FeO_4^{2-} + 20\ H^+ \rightarrow 4Fe^{3+} + 10\ H_2O + 3O_2$ – correct species (1) – balancing (1)	Accept correct use of 'anti-clockwise rule' Award 1 mark for: $4FeO_4^{2-} + 32H^+ + 6H_2O \rightarrow 4Fe^{3+} + 16H_2O + 3O_2 + 12H^+$ Ignore state symbols	**4**

Question number	Answer	Additional Guidance	Marks
(c)	**B** ($Cl_2(g)$)		**1**

Q68.

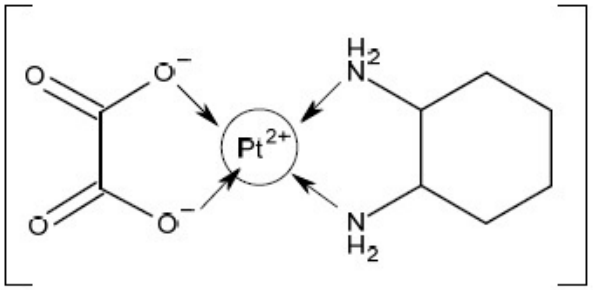
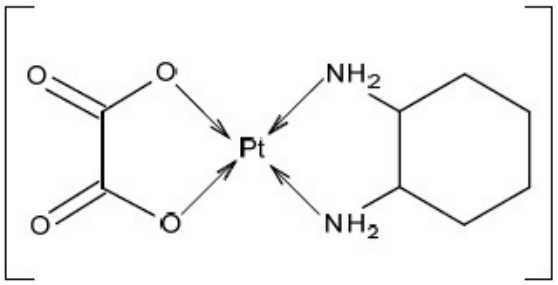
Question Number	Acceptable Answers	Reject	Mark
(a)(i)	The electron withdrawing effect of the (extra) COOH group / oxygen atoms **(1)** Increases the stability of the (hydrogenethanedioate) ion ALLOW Weakens the OH bond **(1)** IGNORE Reference to OH bond becoming more polar		**2**

Question Number	Acceptable Answers	Reject	Mark
(a)(ii)	H^+ ions formed (in first dissociation) shifts (second equilibrium) to the left ALLOW H^+ formed suppresses (second) ionization		**1**

Question Number	Acceptable Answers	Reject	Mark
(b)(i)	Colourless to (pale) pink ALLOW purple for pink	Clear for colourless	**1**

Question Number	Acceptable Answers	Reject	Mark
(b)(ii)	Amount of MnO_4^- = $28.55 \times 10^{-3} \times 0.0200$ (= 5.71×10^{-4} mol) **(1)** Amount of $C_2O_4^{2-}$ = $5.71 \times 10^{-4} \times \frac{5}{2}$ **(1)** = 1.4275×10^{-3} (mol) Amount of $C_2O_4^{2-}$ in 250 cm^3 / rhubarb leaves = $1.4275 \times 10^{-3} \times 10 = 1.4275 \times 10^{-2}$ (mol) **(1)** Mass $H_2C_2O_4$ in 250 cm^3 = $1.4275 \times 10^{-2} \times 90$ **(1)** = 1.28475 g % $H_2C_2O_4$ in rhubarb = $\frac{1.28475}{250} \times 100$ = 0.5139 % **(1)** IGNORE SF except 1 SF Correct answer with no working scores 5 TE on all parts of calculation If M_r = 88 used then final answer is 0.50248%		**5**

Question Number	Acceptable Answers	Reject	Mark
(c)(i)	(Ligand that) Has two lone pairs that can bond (separately) (to the central ion / atom) OR Occupies two coordination positions (around a central ion / atom) OR Two points of attachment (to the central ion / atom) OR Forms two **dative** bonds (to the central ion / atom) OR Two atoms of the same ion / molecule that bond with central metal ion / atom	Two ligands **Just** two lone pairs	**1**

Question Number	Acceptable Answers	Reject	Mark
(c)(ii)	 Or  Square planar shape around Pt drawn as above and zero net charge NOTE The structure of each ligand must be totally correct **(1)** Both nitrogen atoms attached **and** both C-O oxygen atoms attached from separate COO^- groups **(1)** **Dative** covalent bonds **(1)** **Mark each point separately**	Different oxygen atoms from the same carboxyl group attached to different coordination positions. If O attached from a C=O oxygen	3

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Question Number	Acceptable Answers	Reject	Mark
(d)(i)	(Alkaline or neutral or acidified) potassium manganate(VII) / $KMnO_4$ / MnO_4^- **(1)** Forms ethane-1,2-diol (name or structural / skeletal / displayed formula) **(1)** NOTE It does not matter how the ethane-1,2-diol has been formed (Oxidized by) (refluxing with) acidified potassium dichromate(VI) / $Cr_2O_7^{2-}$ and H^+ OR Acidified/alkaline potassium manganate(VII) / MnO_4^- with either H^+ or OH^- OR (Oxidized by) nitric acid (c.f. passage) **(1)** **Mark each point separately** Max 2 for a three step synthesis e.g. bromine followed by NaOH then oxidation ALLOW correct formulae instead of names	Molecular formula $C_2H_6O_2$ Air catalyzed by V_2O_5	**3**

Question Number	Acceptable Answers	Reject	Mark
(d)(ii)	Carbohydrates and / or glucose are obtained from renewable / sustainable resources (whereas ethene is obtained from crude oil) ALLOW Reverse argument for ethene		**1**

Question Number	Acceptable Answers	Reject	Mark
(d)(iii)	**Ethanedioic acid** Will have one (singlet) peak / hydrogen environment (due to the COOH protons) **(1)** **Propanoic acid** Will have three peaks / three hydrogen environments **(1)** Triplet, quartet / quadruplet & singlet in any order OR Split(ting) pattern 3,4,1 in any order **(1)** NOTE If first mark for **propanoic acid** hasn't been awarded "triplet, quartet / quadruplet & singlet" **scores 2** Intensity in ratio 3:2:1 in any order **(1)** ALLOW labelled and annotated diagrams Max. 3 if not clear that hydrogens/protons give rise to the peaks		**4**

Q69.

Question Number	Answer	Additional guidance	Mark
(i)	An explanation that makes reference to the following points: • copper forms an ion with an incomplete d-sub-shell / with a configuration of $3d^9$ (1) • but the only ion formed by zinc has a completely filled d-sub-shell (1)		**2**
(ii)	An explanation that makes reference to the following points: • (in brass) the layers of positive ions can slide over one another (1) • and there are (always) electrons between the layers preventing repulsion between the ions in one layer and those in another layer (1) • (in sodium chloride) when a layer of ions is displaced, ions with the same charge become close to one another and repel (1)		**3**

Q70.

Question Number	Answer	Additional Guidance	Mark
(i)	• (The cation in **Y** is) Cu^{2+} / copper(II) (1) • (The anion in **Y** is) Cl^- / chloride (1)	Allow Cu^{+2} Ignore water ligands Do not award just copper / Cu Do not award just 'chlorine' / Cl	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	• $[Cu(NH_3)_4(H_2O)_2]^{2+}$	Allow $[Cu(NH_3)_4]^{2+}$ Allow $[Co(NH_3)_6]^{2+}$ if Co^{2+} in (i) Ignore missing square brackets	(1)

Question Number	Answer	Additional Guidance	Mark
(iii)	A description that makes reference to the following points: • add dilute (aqueous) ammonia (and stir the mixture) (1) • the precipitate dissolves (1)	If Cl^- / chloride / chlorine ion: Allow add aqueous ammonia / $NH_3(aq)$ Do not award concentrated ammonia Conditional on use of ammonia Ignore colourless solution If Br^- / bromide / bromine ion identified in Test 4: precipitate is insoluble in dilute ammonia (1) but soluble in concentrated ammonia (1) If I^- / iodide / iodine ion identified in test 4: precipitate is insoluble (1) in dilute and concentrated ammonia (1) Do not award addition of concentrated sulfuric acid	(2)

Q71.

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	

Q72.

Question Number	Acceptable Answers	Reject	Mark
(a)(i)	$Cr_2(SO_4)_3(aq) = Cr(H_2O)_6^{3+}$ ALLOW $Cr^{3+}(aq)$ / Cr^{3+} **(1)** A = $Cr(H_2O)_3(OH)_3$ / $Cr(OH)_3$ **(1)** B = $Cr(H_2O)_2(OH)_4^-$ / $Cr(OH)_4^-$ / $Cr(OH)_6^{3-}$ **(1)** C = CrO_4^{2-} **(1)** IGNORE SO_4^{2-} and/or Na+		**4**

Question Number	Acceptable Answers	Reject	Mark
(a)(ii)	$H_2O_2 + 2e^{(-)} \rightarrow 2OH^-$		**1**

Question Number	Acceptable Answers	Reject	Mark
(a)(iii)	Sulfuric acid / H_2SO_4 ALLOW Name or formula of any strong acid (e.g. HCl) IGNORE H^+ and 'an acid' Dilute or concentrated		**1**

Question Number	Acceptable Answers	Reject	Mark
(a)(iv)	$2CrO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + H_2O$ ALLOW Equation showing Na^+ and anion on both sides IGNORE State symbols even if incorrect	Non-ionic equations	**1**

Question Number	Acceptable Answers	Reject	Mark
(b)	**First mark for both half equations** Mentions / some evidence for the use of BOTH half equations in any way even if reversed or left unbalanced $Cr^{3+}(aq) + e^- \rightarrow Cr^{2+}(aq)$ ($E^\ominus = -0.41$ V) $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^-$ $\rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$ ($E^\ominus = +1.33$ V) **(1)** **Second mark for** $8Cr^{3+}(aq) + 7H_2O(l) \rightarrow 6Cr^{2+}(aq) + Cr_2O_7^{2-}(aq) + 14H^+(aq)$ **(1)** **Third mark for** $E^\ominus_{cell} = -0.41 - 1.33 = -1.74$ (V) For **second** and **third marks,** ALLOW reverse equation and $E^\ominus_{cell}$ = **+**1.74 (V) (for **reverse** reaction) **(1)** ALLOW 1.74 (V) only if 'positive' stated in words elsewhere **Fourth mark for** EITHER Disproportionation / (proposed) reaction / "it is" **not feasible** (because its $E^\ominus_{cell}$ is negative) OR Reverse of disproportionation **is feasible** (because its $E^\ominus_{cell}$ is positive) **(1)** IGNORE state symbols even if incorrect ALLOW $\rightleftharpoons$ instead of $\rightarrow$ Third and fourth marks can be awarded CQ on incorrect half equation(s) and stated $E^\ominus$ values		**4**

Q73.

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Question Number	Acceptable Answers	Reject	Mark
14 (a)	**A** = copper(II) hydroxide / $Cu(OH)_2$ / $Cu(OH)_2(H_2O)_4$ **(1)** **B** = copper(II) oxide / CuO **(1)** **C** = tetraamminecopper(II) / $Cu(NH_3)_4^{2+}$ / $Cu(NH_3)_4(H_2O)_2^{2+}$ ALLOW $Cu(NH_3)_6^{2+}$ / hexaamminecopper(II) **(1)** **D** = copper / Cu / copper(0) / Cu(0) **(1)** **E** = copper(II) sulfate / $CuSO_4$ / Cu^{2+} / $Cu(H_2O)_6^{2+}$ **(1)** **F** = diamminecopper(I) / $Cu(NH_3)_2^+$ **(1)** ALLOW coordination numbers 1-6 in **F** Oxidation number separate from name IGNORE state symbols even if incorrect names without oxidation numbers except for **D**	Formulae with incomplete or unbalanced charges Incorrect oxidation states even with correct formulae	**6**

Question Number	Acceptable Answers	Reject	Mark
14 (b)	(Dilute) sulfuric acid / H_2SO_4 / $H_2SO_4(aq)$ ALLOW concentrated		**1**

Question Number	Acceptable Answers	Reject	Mark
14 (c)(i)	(transition metal / d-block element) complex(es) /complex ion(s) IGNORE ammines	Complex molecules amines, ions, ligands	**1**

Question Number	Acceptable Answers	Reject	Mark
14 (c)(ii)	Copper ion in **C** has partially filled **d** orbital(s) / subshell / $3d^9$ ALLOW unpaired d electron d shell **(1)** Copper ion in **F** has (completely) filled **d** orbitals / subshell / $3d^{10}$ **(1)** Reference to complete / incomplete d orbitals **max 1** EITHER Electronic **transitions** between partially filled (d) orbitals (of different energy) are possible OR Electronic **transitions** between (completely) filled (d) orbitals (of different energy) are not possible **(1)** ALLOW Equivalent words for transition e.g. promotion / jump / movement Penalise use of just 'shell' once IGNORE references to electrons returning to lower energy levels and emission of light	d orbitals empty no unpaired electrons (in F) orbital (singular) Splitting impossible because d orbitals full	**3**

Question Number	Acceptable Answers	Reject	Mark
14 (c)(iii)	Copper(I) is **oxidized** (to copper(II)) ALLOW **F** / it is **oxidized** **(1)** By oxygen / air **(1)** Second mark depends on first IGNORE 'shaking'		**2**

Question Number	Acceptable Answers	Reject	Mark
14 (d)(i)	(simultaneous) oxidation and reduction **(1)** OR Simultaneous increase or decrease in oxidation number of an element **(1)** ALLOW 'Species' 'atoms of the same type' for 'element' Explanation in terms of copper(I) IGNORE Atom / ion / compound / substance / reactant	molecule	**2**

Question Number	Acceptable Answers	Reject	Mark
14 (d)(ii)	$2Cu^+ \rightarrow Cu + Cu^{2+}$ OR $2CuI + 2H^+ \rightarrow Cu + Cu^{2+} + 2HI$ OR $2CuI \rightarrow Cu + Cu^{2+} + 2I^-$ IGNORE state symbols even if incorrect	Non-ionic equations	**1**

Question Number	Acceptable Answers	Reject	Mark
14 (d)(iii)	ALLOW The use of cell notation (as in the Data Booklet SEP table) in place of equations e.g. $Cu^+(aq) \mid Cu(s)$ $E^\ominus = +0.52$ (V) (from the data book the equations are) $Cu^+(aq) + e^- \rightarrow Cu(s)$ $E^\ominus = +0.52$ (V) $Cu^{2+}(aq) + e^- \rightarrow Cu^+(aq)$ $E^\ominus = +0.15$ (V) **(1)** So $E^\ominus_{cell} = 0.52 - 0.15 = +0.37$ (V) **(1)** Correct answer including sign with no working scores full marks TE for second mark for use of Cu^{2+}|Cu +0.34 (V) which gives +0.19(V)/+0.18(V) No TE on incorrect equation in (d)(ii)	**Answer** without + sign	**2**

Question Number	Acceptable Answers	Reject	Mark
14 (d)(iv)	ALLOW In both schemes the use of cell notation (as in the Data Booklet SEP table) in place of equations e.g. $Cu^{2+}(aq) \mid Cu(s)$ $E^{\ominus} = +0.34$ (V) Penalise omission of electrons from equations and vertical lines from cell diagrams and reversal of equation without reversing sign. once only IGNORE omission of + sign for all $E^{\ominus}$ values **Scheme 1 (oxidation of copper)** Copper (formed (by disproportionation)) is oxidized (by nitric acid) must be stated in words stand alone mark **(1)** Relevant half equations are $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ $E^{\ominus} = +0.34$ (V) **(1)** $2NO_3^-(aq) + 4H^+(aq) + 2e^- \rightarrow N_2O_4(g) + 2H_2O(l)$ $E^{\ominus} = +0.80$ (V) OR $NO_3^-(aq) + 3H^+(aq) + 2e^- \rightarrow HNO_2(aq) + H_2O(l)$ $E^{\ominus} = +0.94$ (V) **(1)**		**4**
	Correct overall equation scores both marks: $Cu + 2\ NO_3^- + 4H^+ \rightarrow Cu^{2+} + N_2O_4 + 2H_2O$ OR $Cu + NO_3^- + 3H^+ \rightarrow Cu^{2+} + HNO_2 + H_2O$ So $E^{\ominus}_{cell}$ is +0.46 (V) (or +0.60 (V) or just 'positive') **(1)** **Scheme 2 (oxidation of copper(I)** Copper(I) iodide / Cu^+ is oxidized (by nitric acid) must be stated in words **(1)** stand alone mark $Cu^{2+}(aq) + e^- \rightarrow Cu^+(aq)$ $E^{\ominus} = +0.15$ (V) **(1)** $2NO_3^-(aq) + 4H^+(aq) + 2e^- \rightarrow N_2O_4(g) + 2H_2O(l)$ $E^{\ominus} = +0.80$ (V) OR $NO_3^-(aq) + 3H^+(aq) + 2e^- \rightarrow HNO_2(aq) + H_2O(l)$ $E^{\ominus} = +0.94$ (V) **(1)** Correct overall equation scores both marks:		
	$2Cu^+ + 2NO_3^- + 4H^+ \rightarrow 2Cu^{2+} + N_2O_4 + 2H_2O$ $2Cu^+ + NO_3^- + 3H^+ \rightarrow 2Cu^{2+} + HNO_2 + H_2O$ So $E^{\ominus}_{cell}$ is +0.65 (V) (or +0.79 (V) or just 'positive') **(1)** IGNORE (omission of) state symbols even if incorrect		

Q74.

<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

Q75.

Question Number	Correct Answer	Reject	Mark
	A		**1**

Q76.

Question Number	Acceptable Answers	Reject	Mark
(a)	(A transition metal) forms **ions / oxidation states** with partially filled / incomplete d orbital(s) / d sub-shell		1

Question Number	Acceptable Answers	Reject	Mark
(b)(i)	**W** = chromate(VI) (ion) / CrO_4^{2-} **(1)** **X** = chromium(III) hydroxide / $Cr(OH)_3$ / $Cr(OH)_3(H_2O)_3$ **(1)** **Y** = hexahydroxochromate(III) (ions) / $[Cr(OH)_6]^{3-}$ /tetrahydroxochromate(III) (ions) / $[Cr(OH)_4]^-$ / $[Cr(H_2O)_2(OH)_4]^-$ **(1)** **Z** = chromium(II) (ions) / chromium(II) sulfate / Cr^{2+} / $Cr^{2+}(aq)$ / $[Cr(H_2O)_6]^{2+}$ **(1)** ALLOW Name or formula of the compounds IGNORE Omission of square brackets around complexes	Names without oxidation numbers.	4

Question Number	Acceptable Answers	Reject	Mark
(b)(ii)	**A** = ethanol / C_2H_5OH / ethanal / CH_3CHO OR any primary or secondary alcohol or any aldehyde **(1)** **B** = zinc / Zn ALLOW magnesium / Mg **(1)** **C** = any acid (name or formula) **(1)** IGNORE Omission of (aq) with acid formula Concentration of acid	CH_3COH Alkali metals Tin / Sn H^+ or H_3O^+ or acid	3

Question Number	Acceptable Answers	Reject	Mark
(b)(iii)	$Cr_2O_7^{2-} + 2OH^- \rightarrow 2CrO_4^{2-} + H_2O$ OR Multiples Ignore state symbols even if incorrect		1

Question Number	Acceptable Answers	Reject	Mark
(b)(iv)	$(NH_4)_2Cr_2O_7 \rightarrow Cr_2O_3 + N_2 + 4H_2O$ Allow multiples **(1)** Chromium is reduced from (+)6 to (+)3 **(1)** Nitrogen is oxidized from −3 to 0 **(1)** Penalise use of 'changes' / 'increases' / 'decreases' for 'oxidises' or 'reduces' once only		3

Question Number	Acceptable Answers	Reject	Mark
(b)(v)	(chromium(II) ions) oxidized by (oxygen in the) air ALLOW Just 'oxygen'		1

Question Number	Acceptable Answers	Reject	Mark
(c)(i)	(A ligand is a) molecule or (negative) ion with a (lone) pair (of electrons) ALLOW Species / Compound / group **(1)** Which forms a dative covalent bond with a (central) metal ion or atom (to form a complex) **(1)** ALLOW (if no other marked scored) Electron pair donor	Positive ion	2

Question Number	Acceptable Answers	Reject	Mark
(c)(ii)	$Cr(H_2O)_6^{3+} + 6NH_3 \rightarrow Cr(NH_3)_6^{3+} + 6H_2O$ ALLOW $Cr(H_2O)_6^{3+} + 4NH_3 \rightarrow Cr(NH_3)_4(H_2O)_2^{3+} + 4H_2O$ Correct formula for ammine **(1)** Rest of the equation correct **(1)**	Cr^{3+} and $Cr^{3+}(aq)$	2

Q77.

Question Number	Correct Answer	Reject	Mark
	A		1

Q78.

Question Number	Correct Answer	Reject	Mark
	D		**1**

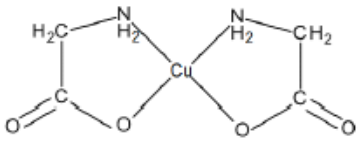
Q79.

Question Number	Correct Answer	Mark
	C	**1**

Q80.

Question Number	Acceptable Answers	Additional Guidance	Mark
	An explanation that makes reference to any **TWO** of the following points:		**(2)**
	• carbon monoxide replaces / takes the place of the oxygen molecule **(1)**	Allow carbon monoxide displaces the oxygen molecule Allow ligand substitution / exchange reaction between oxygen and carbon monoxide	
	• (and may be toxic because) it binds strongly to the Fe^{2+} (ion) **(1)**	Allow carbon monoxide forms a stronger bond / binds more tightly to / has a stronger affinity for Fe^{2+} Allow reduces the amount of oxygen that can bind to Fe^{2+} Allow carbon monoxide binds (almost) irreversibly / permanently to Fe^{2+} Allow CO forms a more stable complex ion with Fe^{2+} / has a larger equilibrium constant / K Ignore CO bonds more easily to Fe^{2+} Ignore just 'CO bonds more strongly to haemoglobin'	
	• effect on the body **(1)**	Allow prevents oxygen being carried to the cells / organs / around the body / blood Allow reduces the amount of oxygen that can be carried to the cells / organs / around the body / blood	

Q81.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• **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)**	Example of structure  Allow the two ligands attached to any 2 pairs of adjacent bonds Allow *cis* or *trans* 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 NH_2	**(2)**

Q82.

Question Number	Correct Answer	Reject	Mark
	D		**1**

Q83.

<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 / cm^3</td><td>17.50</td><td>34.10</td><td>17.20</td><td>34.10</td></tr>
<tr><td>Initial volume /cm^3</td><td>0.00</td><td>17.30</td><td>0.00</td><td>17.20</td></tr>
<tr><td>Titre / cm^3</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 /cm^3</td><td colspan="4">16.85</td></tr>
</table>
Both titres to 2 dp
mean = (16.90+16.80)÷2 = 16.85 (cm^3)
allow TE for M2 for mean of One, Two and Three = 16.97 (cm^3)
</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)**	<u>Example of calculation</u> (25.0÷1000) x 0.200 = 0.005 / 5.00 x 10^{-3} (mol) 5.00 x 10^{-3} x 2÷5 = 0.002 / 2.00 x 10^{-3} (mol) 2.00 x 10^{-3} x (100÷16.85) = 0.011869 (mol) 158 0.011869 x 158 = 1.8754 g (1.8754÷5) x 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 $E^\ominus$ is more negative) forming Mn^{3+} ions OR $MnO_4^- + 8H^+ + 4Mn^{2+} \rightarrow 5Mn^{3+} + 4H_2O$ ($E^\ominus = +0.02V$) **(1)** • Mn^{3+} ions then oxidise $C_2O_4^{2-}$ ions (reforming Mn^{2+}) (as $E^\ominus$ is more positive) OR $C_2O_4^{2-} + 2Mn^{3+} \rightarrow 2Mn^{2+} + 2CO_2$ ($E^\ominus = +0.85V$) **(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 $E^\ominus$ is more negative Allow Mn^{3+} ions then react with $C_2O_4^{2-}$ ions (reforming Mn^{2+}) as $E^\ominus$ is more positive May be shown in equations and / or by calculating $E^\ominus$	**(4)**

Q84.

Question Number	Answer	Additional guidance	Mark
(i)	• brown fumes (1) • a green/blue solution forming (1)		2
(ii)	• $I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$	State symbols must be present	1
(iii)	• amount of thiosulfate (1) • uses amount of thiosulfate = amount of iodine to determine amount of thiosulfate = amount of copper(II) ions in 25 cm^3 portion (1) • evaluation of number of moles of Cu in sample (1) • calculates mass of Cu (1) • percentage copper to **3.s.f** (1)	Example of calculation amount of thiosulfate = $\frac{22.7 \times 0.25}{1000}$ = 5.675×10^{-3} (mol) 5.675×10^{-3} (mol) = amount of copper(II) ions in 25 cm^3 portion amount of Cu in sample = $5.675 \times 10^{-3} \times 10$ = 5.675×10^{-2} (mol) mass of Cu = $5.675 \times 10^{-2} \times 63.5$ = 3.603625 percentage copper = 3.603625 x 100 /5.00 = 72.0725 = 72.1% Allow ecf from 2nd mark Correct answer to 3.s.f with no working scores 5 marks	5
(iv)	• calculation of percentage uncertainty from balance = ±0.005x 2 x100/5.00 = 0.2% and percentage uncertainty in mean titre from burette = 2x±0.05 x 100 /22.7 = 0.44% (1) • so burette reading is most significant (1)		2

Q85.

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

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

Q86.

Question Number	Answer	Additional guidance	Mark
(i)	• calculation of moles of $VCl_2(aq)$ **(1)** • calculation of moles of $Cl_2(g)$ **(1)** • deduction of whole number ratio of V^{2+} : Cl_2 **(1)** • deduction of electrons lost per vanadium ion **(1)** • deduction of final oxidation number of V **(1)**	Example of calculation $(40/1000) \times 0.100 = 4 \times 10^{-3}$ / 0.004 (mol) $(144/24000) = 6 \times 10^{-3}$ / 0.006 (mol) $2V^{2+} : 3Cl_2$ allow $V^{2+} : 1.5Cl_2$ 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
(ii)	• purple / lilac / violet **(1)** • to yellow (solution) **(1)**	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)**

Q87.

Question Number	Correct Answer	Reject	Mark
	C		1

Q88.

Question Number	Correct Answer	Reject	Mark
	D		1

Q89.

Question Number	Acceptable Answers	Reject	Mark
(i)	Ni: $(1s^2\ 2s^2 2p^6)\ 3s^2 3p^6\ 3d^8\ 4s^2$ (1) Cu: $(1s^2\ 2s^2 2p^6)\ 3s^2 3p^6\ 3d^{10} 4s^1$ (1) ALLOW capital letters, subscripts for superscripts ALLOW 4s before 3d Penalise omission of $3s^2 3p^6$ once only if rest is correct		2

Question Number	Acceptable Answers	Reject	Mark
***(ii)**	First electron removed is from **4s** (in both atoms) (1) Second electron in Cu (is harder to remove so it is) EITHER closer to nucleus/in inner shell OR less shielded (1) IGNORE Comments about second electron being in full shell/ in a 3d shell/in a 3d orbital Reference to $3d^{10}$ stability		2

Question Number	Acceptable Answers	Reject	Mark
(iii)	(attraction on (3d) electrons increases due to) number of protons increasing / nuclear charge increasing IGNORE The charge density of the 2^+ ions increases Effective nuclear charge		1

Q90.

Question Number	Correct Answer	Reject	Mark
	C		**1**

Q91.

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>*</td><td>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></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, 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).

If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).

More than one indicative marking point may be made within the same comment or explanation

Deduct a reasoning mark if no comparison made

Penalise the use of 'atom' instead of ion once only against any indicative point</td><td>(6)</td></tr>
</table>

	Indicative content Similarities • **(IP1)** the differences in energy levels determines the colour of the flame test and complex ion Differences Flame test • **(IP2) heat** (energy) results in electron promotion • **(IP3)** return of an (excited) electron to a lower (energy) state Complex ion • **(IP4)** d orbitals are split (in energy by the ligands) • **(IP5) light** (energy) is needed for electron promotion • **(IP6)** the colour not absorbed is the colour seen	Ignore incorrect colours This can be mentioned separately or as a comparison Allow electrons excited by **heat** Allow electron is 'de-excited' to a lower (energy) state Do not award if d-d transitions stated Allow d subshell splitting Do not award singular "d orbital" splitting Accept "The colour seen is complimentary to that absorbed" Allow 'colour reflected is the colour seen' Do not award if colour attributed to 'fall' of electron to lower energy d orbital Do not award 'emission of light'	

Q92.

Question Number	Acceptable Answers	Reject	Mark
	C		**1**

Q93.

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	

Q94.

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)**