

3(a)(i)	M1 Heat (solid FA 5) AND observe condensation, droplets, steam, water vapour M2 Make an aqueous solution of FA 5 / dissolve in water to use for tests M3 (To portion of the solution) add aqueous NH₃ AND white ppt AND insoluble in excess NH₃ M4 (To portion of the solution) add aqueous barium chloride or barium nitrate AND white precipitate M5 to distinguish sulfate / sulfite (white precipitate from M4) insoluble in hydrochloric OR nitric acid OR KMnO₄ is not decolourised / remains purple (added after M4 or directly to FA 5 (aq))																									
3(a)(ii)	<table><tr><td>Zn²⁺</td><td>X</td></tr><tr><td>SO₄²⁻</td><td>✓</td></tr><tr><td>H₂O</td><td>✓</td></tr></table>			Zn ²⁺	X	SO ₄ ²⁻	✓	H ₂ O	✓																	
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3(b)(i)	• (FA 6) starting colour purple • solid jumps / moves around • black residue • test with glowing splint • splint relights / glows more brightly																									
3(b)(ii)	(dark) Green																									
3(c)(i)	'No change' 2 correct = *, 3 correct = ** 2* = 1 mark Max mark = 4 <table><tr><th rowspan="2">test</th><th colspan="3">observations</th></tr><tr><th>FA 7</th><th>FA 8</th><th>FA 9</th></tr><tr><td>Test 1 Add hydrogen peroxide</td><td>Bubbles/ effervescence * Purple / FA 7 (solution) to colourless (solution) * (Gas / oxygen) relights glowing splint *</td><td>No change</td><td>Bubbles / effervescence * (Gas/ oxygen) relights glowing splint *</td></tr><tr><td>Test 2 Add sodium hydroxide, then</td><td></td><td>Off-white ppt*</td><td>No change</td></tr><tr><td>leave to stand</td><td></td><td>brown ppt on standing*</td><td></td></tr><tr><td>Test 3 Add aqueous iron(II) sulfate</td><td>Turns colourless / yellow OR colourless / yellow solution formed*</td><td>No change</td><td></td></tr></table>			test	observations			FA 7	FA 8	FA 9	Test 1 Add hydrogen peroxide	Bubbles/ effervescence * Purple / FA 7 (solution) to colourless (solution) * (Gas / oxygen) relights glowing splint *	No change	Bubbles / effervescence * (Gas/ oxygen) relights glowing splint *	Test 2 Add sodium hydroxide, then		Off-white ppt*	No change	leave to stand		brown ppt on standing*		Test 3 Add aqueous iron(II) sulfate	Turns colourless / yellow OR colourless / yellow solution formed*	No change	
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3(c)(ii)	manganese / Mn																									

3(c)(iii)		FA 6 / FA 7	FA 8
	oxidation state	(+7)	(+2)

2(a)	the (3)d and (4)s sub-shells / orbitals / electrons are close / similar in energy
2(b)	species or ion formed by a central metal atom/ion AND surrounded by/bonded to (one or more) ligands
2(c)(i)	NaOH / $\text{OH}^-(\text{aq})$ AND precipitation / ligand exchange / deprotonation / acid–base
2(c)(ii)	M1: $\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2$ is oxidised (from + 2 to + 3 on standing) M2: E° of $\text{Fe}(\text{H}_2\text{O})_3(\text{OH})_3$ is more negative than E° of O_2 OR $E^\circ_{\text{cell}} = 0.40 - (-0.56) = (+)0.96 \text{ V}$ M3: $4\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2 + \text{O}_2 \rightarrow 4\text{Fe}(\text{H}_2\text{O})_3(\text{OH})_3 + 2\text{H}_2\text{O}$
2(d)	$\Delta G^\circ = -2 \times 1.67 \times 96\,500 = -322\,310 \text{ J mol}^{-1}$ M1: $\Delta G^\circ = -nE^\circ_{\text{cell}}F$ AND $n = 2$ OR $-2 \times 1.67 \times 96\,500$ M2: $\Delta G^\circ = -322.3 \text{ kJ mol}^{-1}$

5(a)	<table><tr><th rowspan="2">species</th><th colspan="2">number of unpaired electrons</th></tr><tr><th>3d</th><th>4s</th></tr><tr><td>Cu</td><td>0</td><td>1</td></tr><tr><td>Cu²⁺</td><td>1</td><td>0</td></tr></table>	species	number of unpaired electrons		3d	4s	Cu	0	1	Cu ²⁺	1	0	
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5(b)	• five 3d orbitals (lines, boxes) in the isolated Cu²⁺ ion of the same energy • splitting: three higher and two lower d orbitals • energy of all five d orbitals in complex higher than all d orbitals in isolated ion any two [1], all three [2]												
5(c)	M1: more than one (stable) oxidation state / exist in variable oxidation states M2: vacant / empty (d) orbitals are energetically accessible OR vacant / empty (d) orbitals can form dative bonds with ligands												
5(d)	<table><tr><th>metal ion</th><th>coordination number</th><th>formula of complex ion</th><th>charge of complex ion</th></tr><tr><td>Ag⁺</td><td>2</td><td>Ag(CN)₂</td><td>1-</td></tr><tr><td>Fe²⁺</td><td>6</td><td>Fe(CN)₆</td><td>4-</td></tr></table> each row [1]	metal ion	coordination number	formula of complex ion	charge of complex ion	Ag ⁺	2	Ag(CN)₂	1-	Fe ²⁺	6	Fe(CN)₆	4-
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5(e)	M1: M2: (shape) square planar AND (bond angle) 180°
5(f)(i)	M1: moles $\text{MnO}_4^- = 0.075 \times 0.0225 = 1.6875 \times 10^{-3}$ M2: moles $\text{V}^{2+} = 5 / 3 \times 1.6875 \times 10^{-3} = 2.8125 \times 10^{-3}$ M3: mass V = $50.9 \times 2.8125 \times 10^{-3} = 0.143 \text{ g}$ % of V = $0.143 / 0.250 \times 100 = 57.3 \text{ min 2sf}$
5(f)(ii)	$2\text{VO}_3^- + 3\text{Zn} + 12\text{H}^+ \rightarrow 2\text{V}^{2+} + 3\text{Zn}^{2+} + 6\text{H}_2\text{O}$ M1: 2 : 3 ratio on both sides M2: rest of the equation correct

5(a)(i)	$\text{Co}^{2+} = [\text{Ar}] 3d^7$ AND $\text{Co}^{3+} = [\text{Ar}] 3d^6$
5(a)(ii)	has vacant d orbitals that are energetically accessible
5(a)(iii)	- pink - blue - aqueous Any two [1], all three [2]
5(a)(iv)	$[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{HCl} \rightarrow [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O} + 4\text{H}^+$ OR $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O}$
5(a)(v)	ligand exchange
5(a)(vi)	$[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Co}(\text{OH})_2(\text{H}_2\text{O})_4 + 2\text{H}_2\text{O}$ OR $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Co}(\text{OH})_2 + 6\text{H}_2\text{O}$
5(b)(i)	M1: Nemst equation $E = E^\ominus + (0.059 / z) \times \log\left(\frac{[\text{oxidised}]}{[\text{reduced}]}\right)$ M2: $E = -0.28 + (0.059 / 2) \times \log(0.02)$
5(b)(ii)	1.66 V
5(b)(iii)	$3\text{Co} + \text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ \rightarrow 3\text{Co}^{2+} + 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$
5(b)(iv)	$\text{Co}^{2+} / \text{Co}, \text{Co}^{2+} / \text{Co}, \text{Cr}_2\text{O}_7^{2-} / \text{Cr}^{3+}$
5(c)	M1: moles of cobalt = $0.547 / 58.9 = 0.00929$ M2: coulombs required = $0.00929 \times 96500 \times 2 = 1792$ M3: time required = $1792 / 0.50 = 3584.8 \text{ s} = 59.7 \text{ minutes 3sf}$
6(a)(i)	$\text{Ni}(\text{CO})_4$
6(a)(ii)	- ethanedioate given as C_2O_4 - formula shows one Ni and three ligands - charge = 4- any two [1], all three [2] $\text{Ni}(\text{C}_2\text{O}_4)_3^{4-}$ scores [2]

6(a)(iii)	F AND optical
6(b)(i)	N atom can donate one lone pair of electrons
6(b)(ii)	$[\text{Cd}(\text{en})_2]^{2+}$ AND has a larger K_{stab} / is more stable
6(b)(iii)	$\frac{[[\text{Cd}(\text{CH}_3\text{NH}_2)_4]^{2+}]}{[\text{Cd}^{2+}][\text{CH}_3\text{NH}_2]^4}$

1(a)	forms (one or more) stable ions / compounds / oxidation states with incomplete / partially filled (3)d orbital(s) / d shell / d sub-shell
1(b)(i)	(orbitals) are at the same energy
1(b)(ii)	$(1s^2) 2s^2 2p^6 3s^2 3p^6 3d^9$
1(c)(i)	$[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq})$ deep / dark / royal blue AND $[\text{CuCl}_4]^{2-}(\text{aq})$ yellow
1(c)(ii)	M1: d orbital(s) of different energy / d-d splitting occurs / d sub-shell splits M2: electron(s) promoted / excited M3: light / wavelength / frequency / photon absorbed AND complementary colour seen
1(d)(i)	M1: ligand exchange / replacement / substitution / displacement M2: $[\text{CuCl}_4]^{2-} + 4\text{NH}_3 + 2\text{H}_2\text{O} \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{Cl}^-$
1(d)(ii)	M1: one correct 3D structure of $[\text{Cu}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$ M2: correct 3D stereoisomer structure of isomer 1
1(d)(iii)	cis isomer AND dipoles do not cancel
1(e)(i)	(two) oxygen and (one) nitrogen (can donate) three lone pair(s) of electrons (to the metal ion)
1(e)(ii)	$[\text{Co}(\text{C}_4\text{H}_5\text{NO}_4)_2]^-$
1(f)(i)	equilibrium constant for the formation of the complex (ion) in a solvent / water / solution OR from its constituent ions or molecules
1(f)(ii)	$[\text{Ag}(\text{CN})_2]^-$ (aq) AND largest (value of) K_{stab}
1(g)	M1 M2: any two [1], all four [2] - moles $\text{MnO}_4^- = 0.015 \times 18.70 / 1000 = 2.805 \times 10^{-4}$ - moles $\text{SO}_3^{2-} = 2.805 \times 10^{-4} \times 5/2 = 7.0125 \times 10^{-4}$ (in 10 cm^3) - moles $\text{SO}_3^{2-} = 1.753 \times 10^{-2}$ (in 250 cm^3) - mass $\text{Na}_2\text{SO}_3 = 1.753 \times 10^{-2} \times 126.1 = 2.21 \text{ g}$ M3: % purity = $100 \times 2.21 / 3.75 = 58.9 - 59.0 \%$ min 2sf