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 NH_3
AND
white ppt **AND** insoluble in excess NH_3

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
$KMnO_4$ is not decolourised / remains purple (added after **M4** or directly to **FA 5** (aq))

3(a)(ii)

Zn^{2+}	X
SO_4^{2-}	✓
H_2O	✓

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

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	

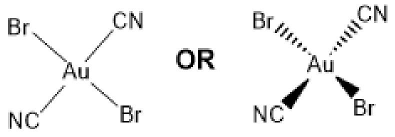
3(c)(ii)

manganese / Mn

3(c)(iii)	<table><tr><th></th><th>FA 6 / FA 7</th><th>FA 8</th></tr><tr><td>oxidation state</td><td>(+)7</td><td>(+)2</td></tr></table>

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 / OH^-(aq) **AND** precipitation / ligand exchange / deprotonation / acid–base
2(c)(ii)	**M1**: $Fe(H_2O)_4(OH)_2$ is oxidised (from + 2 to + 3 on standing) **M2**: $E^\ominus$ of $Fe(H_2O)_3(OH)_3$ is more negative than $E^\ominus$ of O_2 **OR** $E^\ominus_{cell}$ = 0.40 – (–0.56) = (+)0.96 V **M3**: $4Fe(H_2O)_4(OH)_2 + O_2 \rightarrow 4Fe(H_2O)_3(OH)_3 + 2H_2O$
2(d)	$\Delta G^\ominus = -2 \times 1.67 \times 96\,500 = -322\,310$ J mol^{-1} **M1:** $\Delta G^\ominus = -nE^\ominus_{cell}F$ **AND** n = 2 **OR** $-2 \times 1.67 \times 96\,500$ **M2:** $\Delta G^\ominus = -322.3$ kJ mol^{-1}

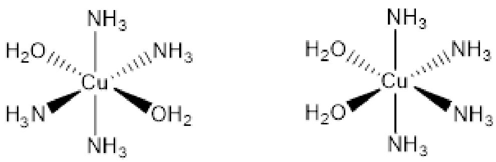
5(a)	<table><tr><th rowspan="2">species</th><th colspan="2">number of **unpaired** electrons</th></tr><tr><th>3d</th><th>4s</th></tr><tr><td>Cu</td><td>0</td><td>1</td></tr><tr><td>Cu^{2+}</td><td>1</td><td>0</td></tr></table>
5(b)	• five 3d orbitals (lines, boxes) in the isolated Cu^{2+} ion of the 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>Fe^{2+}</td><td>**6**</td><td>**$Fe(CN)_6$**</td><td>4–</td></tr></table>each row [1]

5(e)	**M1:**  **M2:** (shape) square planar **AND** (bond angle) 180°
5(f)(i)	**M1**: moles MnO_4^- = 0.075 × 0.0225 = 1.6875 × 10^{-3} **M2:** moles V^{2+} = 5 / 3 × 1.6875 × 10^{-3} = 2.8125 × 10^{-3} **M3:** mass V = 50.9 × 2.8125 × 10^{-3} = 0.143 g % of V = 0.143 / 0.250 × 100 = 57.3 min 2sf
5(f)(ii)	$2VO_3^- + 3Zn + 12H^+ \rightarrow 2V^{2+} + 3Zn^{2+} + 6H_2O$ **M1:** 2 : 3 ratio on both sides **M2:** rest of the equation correct

5(a)(i)	Co^{2+} = [Ar] $3d^7$ **AND** Co^{3+} = [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)	$[Co(H_2O)_6]^{2+} + 4HCl \rightarrow [CoCl_4]^{2-} + 6H_2O + 4H^+$ **OR** $[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$
5(a)(v)	ligand exchange
5(a)(vi)	$[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2(H_2O)_4 + 2H_2O$ **OR** $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2 + 6H_2O$
5(b)(i)	**M1:** Nernst equation $E = E^{\circ} + (0.059 / z) \times \log\left(\frac{[\text{oxidised}]}{[\text{reduced}]}\right)$ **M2:** E = –0.28 + (0.059 / 2) × log(0.02)
5(b)(ii)	1.66 V
5(b)(iii)	$3Co + Cr_2O_7^{2-} + 14H^+ \rightarrow 3Co^{2+} + 2Cr^{3+} + 7H_2O$
5(b)(iv)	Co^{2+} / Co, Co^{2+} / Co, $Cr_2O_7^{2-}$ / Cr^{3+}
5(c)	**M1:** moles of cobalt = 0.547 / 58.9 = 0.00929 **M2:** coulombs required = 0.00929 × 96500 × 2 = 1792 **M3:** time required = 1792 / 0.50 = 3584.8 s = 59.7 minutes 3sf

6(a)(i)	$Ni(CO)_4$
6(a)(ii)	• ethanedioate given as C_2O_4 • formula shows one Ni and three ligands • charge = 4− any two [1], all three [2] $Ni(C_2O_4)_3^{4-}$ scores [2]

6(a)(iii)	**F AND** optical
6(b)(i)	N atom can donate one lone pair of electrons
6(b)(ii)	$[Cd(en)_2]^{2+}$ **AND** has a larger K_{stab} / is more stable
6(b)(iii)	$\frac{[[Cd(CH_3NH_2)_4]^{2+}]}{[Cd^{2+}][CH_3NH_2]^4}$

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)	$[Cu(NH_3)_4(H_2O)_2]^{2+}(aq)$ deep / dark / royal blue **AND** $[CuCl_4]^{2-}(aq)$ 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:** $[CuCl_4]^{2-} + 4NH_3 + 2H_2O \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4Cl^-$
1(d)(ii)	**M1:** one correct 3D structure of $[Cu(H_2O)_2(NH_3)_4]^{2+}$ **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)	$[Co(C_4H_5NO_4)_2]^-$
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)	$[Ag(CN)_2]^-(aq)$ **AND** largest (value of) K_{stab}
1(g)	**M1 M2:** any two [1], all four [2] • moles MnO_4^- = 0.015 ×18.70/1000 = 2.805 × 10^{-4} • moles SO_3^{2-} = 2.805 × 10^{-4} × 5/2 = 7.0125 × 10^{-4} (in 10 cm^3) • moles SO_3^{2-} = 1.753 × 10^{-2} (in 250 cm^3) • mass Na_2SO_3 = 1.753 × 10^{-2} × 126.1 = 2.21 g **M3:** % purity = 100 × 2.21 / 3.75 = **58.9 – 59.0 %** min 2sf