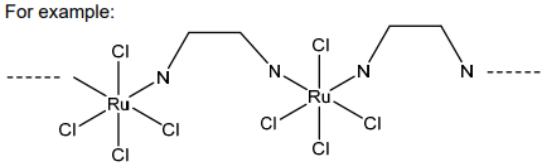
28. Chemistry of transition elements

28.2 General physical and chemical properties of the first set of transition elements, titanium to copper

Paper 4

Marking Scheme

Q1.

(c)	**M1** $2AgNO_3 + 2NaOH \rightarrow Ag_2O + 2NaNO_3 + H_2O$ **OR** $2Ag^+ + 2OH^- \rightarrow Ag_2O + H_2O$ **M2** $Ag_2O + 4NH_3 + H_2O \rightarrow 2[Ag(NH_3)_2]OH$ **OR** $Ag^+ + 2NH_3 + OH^- \rightarrow [Ag(NH_3)_2]OH$	**2**
(d)	**M1** bond angle H–N–Ag is 109.5° **M2** shape is linear **AND** bond angle for N–Ag–N is 180°	**2**
(e)	**M1** $Ag_2O + H_2O + 2e^- \rightarrow 2Ag + 2OH^-$ **M2** $Zn + 2OH^- \rightarrow Zn(OH)_2 + 2e^-$	**2**
(f)	For example:  **M1** presence of *dps* ligand bonded to two Ru **M2** the rest of the structure correct	**2**

Q2.

(d)	$2K_3Fe(C_2O_4)_3 \rightarrow 2K_2Fe(C_2O_4)_2 + K_2C_2O_4 + 2CO_2$	**1**

Q3.

(b)	**M1 M2** any two for one mark or all four for two marks: • mol total MnO_4^- = $0.125 \times 0.0500 = 6.25 \times 10^{-3}$ • mol Fe^{2+} = $0.0400 \times 0.0225 = 9.00 \times 10^{-4}$ • mol unreacted MnO_4^- = $9.00 \times 10^{-4} \div 5 = 1.80 \times 10^{-4}$ ecf • mol reacted MnO_4^- = $6.25 \times 10^{-3} - 1.80 \times 10^{-4} = 6.07 \times 10^{-3}$ ecf **M3** mol NO_2^- = $2.5 \times 6.07 \times 10^{-3} = 1.5175 \times 10^{-2}$ conc $NaNO_2$ = $4 \times 1.5175 \times 10^{-2} = 6.07\text{-}6.08 \times 10^{-2}$ mol dm^{-3} ecf min 2sf	**3**

Q4.

(b)	• precipitation solution **A**: e.g. NaOH / OH^- • observations: (pale) blue ppt. / solid • product: $Cu(OH)_2$ **OR** $[Cu(OH)_2(H_2O)_4]$ ecf from **A** • ligand substitution solution **B**: e.g. HCl / Cl^-, NH_3 • observations: dark/deep blue solution (with NH_3) **OR yellow** solution (with Cl^-) • product: $[Cu(NH_3)_4(H_2O)_2]^{2+}$ **OR** $[CuCl_4]^{2-}$ any two [1] any four [2] all six [3]	**3**

(d)	**M1** species with two lone pairs (of electrons) **M2** that form dative (covalent) / co-ordinate bond(s) to a (central) metal atom / ion	**2**

Q5.

(a)(i)	red/pink blue	[1]	**1**
(a)(ii)	$[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(H_2O)_4(OH)_2 + 2H_2O$	[1]	**1**
(a)(iii)	acid-base	[1]	**1**
(b)(i)	$[CoL_2]^{2+}$	[1]	**1**

(b)(ii)	+2	[1]	**1**
(b)(iii)	2 3	[1]	**1**
(b)(iv)	Not of the same **energy** / have different **energy**	[1]	**1**
(c)(i)	$5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$	[1]	**1**
(c)(ii)	$0.02 \times 18.7/1000 = 3.74 \times 10^{-4}$ $3.74 \times 10^{-4} \times 5 = 1.87 \times 10^{-3}$	[1] [1]	**2**
(c)(iii)	$1.87 \times 10^{-3} \times 10 = 1.87 \times 10^{-2}$ $4.18/1.87 \times 10^{-2} = 224$ / 223.5(294) $n = 2$	[1] [1]	**2**

Q6.

(c)	<table><tr><th>copper-containing species</th><th>formula of copper-containing species formed</th><th>colour copper-containing formed</th></tr><tr><td>**A**</td><td>$[Cu(H_2O)_6]^{2+}$</td><td>(pale) blue</td></tr><tr><td>**B**</td><td>$Cu(H_2O)_4(OH)_2$ ***or*** $Cu(OH)_2$</td><td>(pale) blue</td></tr><tr><td>**C**</td><td>$[Cu(NH_3)_4(H_2O)_2]^{2+}$</td><td>**dark** blue</td></tr><tr><td>**D**</td><td>$CuCl_4^{2-}$</td><td>yellow</td></tr></table> Two correct for one mark, four correct for two marks, six correct for three marks, eight correct for four marks.	**4**
(d)(i)	**M1** (a species) that donates more than two lone pairs **M2** to form dative / coordinate bonds to a metal atom or ion	**2**
(d)(ii)	six atoms circled, 2N and 4O from different CO_2^-	**1**
(d)(iii)	the number of co-ordinate bonds being formed by the metal ion	**1**

(e)	**M1** moles of $Cr^{3+} = 2.096 \times 10^{-4}$ in 25.0 cm^3) **M2** moles of $Cr^{3+} = 8.384 \times 10^{-4}$ (in 100.0 cm^3) moles of $Cr_2(SO_4)_3 \cdot nH_2O = 8.384 \times 10^{-4} / 2 = 4.192 \times 10^{-4}$ **M3** M_r of $Cr_2(SO_4)_3 \cdot nH_2O = 0.2550 / 4.192 \times 10^{-4} = 608.3$ n = (608.3 – 392.3) / 18 = 12	**3**

Q7.

(b)	square planar	**1**

Q8.

(c)(i)	$2MnO_4^- + 6H^+ + 5SO_3^{2-} \rightarrow 2Mn^{2+} + 3H_2O + 5SO_4^{2-}$	**1**

(c)(ii)	**M1 M2** any two bullets [1] or all four [2] • moles $MnO_4^- = 0.025 \times 22.40 / 1000 = 5.6 \times 10^{-4}$ • moles $SO_3^{2-} = 5.6 \times 10^{-4} \times 5 / 2 = 1.4 \times 10^{-3}$ (in 25 cm^3) ecf from **(c)(i)** and bullet 1 • moles $SO_3^{2-} = 1.4 \times 10^{-2}$ (in 250 cm^3) ecf bullet 2 • mass $K_2SO_3 = 1.4 \times 10^{-2} \times 158.3 = 2.2162$ g ecf bullet 3 **OR** moles K_2SO_3 (if 100% pure) = 3.40 ÷ 158.3 = 0.02148 **M3** % purity = 100 × 2.2162 / 3.40 = 65.2 / 65.3 % ecf min 2sf **OR** % purity = 100 × 0.014 / 0.02148 = 65.2 / 65.3 %	**3**

Q9.

(b)(i)	(is a molecule or ion formed by a central) metal atom / metal ion bonded / surrounded by (one or more) ligands	1

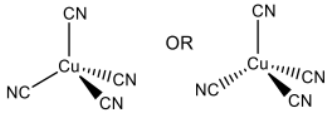
(b)(ii)	<table><tr><th>reagent added</th><th>formula of species formed</th><th>colour / state of species formed</th><th>type of reaction</th></tr><tr><td>an excess of $NH_3(aq)$</td><td>$[Co(NH_3)_6]^{2+}$</td><td>brown solution **ALLOW** *yellow-brown* solution</td><td>**ligand** exchange</td></tr><tr><td>an excess of concentrated HC*l*</td><td>$[CoCl_4]^{2-}$</td><td>blue solution</td><td>**ligand** exchange</td></tr><tr><td>NaOH(aq)</td><td>$Co(OH)_2$ **OR** $Co(OH)_2(H_2O)_4$</td><td>blue ppt. **ALLOW** pink ppt</td><td>precipitation</td></tr></table> formula and colour / state: any two [1], any four [2], all six [3] type of reaction: all three correct [1]	4
(c)(i)	**M1** (a species) that donates / uses two lone pairs **M2** to form a two dative / coordinate bond to a metal atom / metal ion	2

Q10.

(a)(i)	• $Co(OH)_2$ OR $Co(OH)_2(H_2O)_4$ • $[Co(NH_3)_6]^{2+}$ OR $[Co(NH_3)_6]^{3+}$ • $[CoCl_4]^{2-}$ any two [1] all three [2]	2
(a)(ii)	pink to blue [1]	1

Q11.

(b)(i)	oxid. no. = + 4 AND coord. no. = 8 [1]	1

(b)(ii)	bond angle must go from bond to bond OR CN group to CN group diagram • for Ag: NC—Ag—CN • angle = labelled 180°  • for Cu: • angle = labelled 109–110° any two [1] all four [2]	2

(d)(i)	mol of I_2 = 0.5 × 0.02 × 20.1 / 1000 = 2.01 × 10^{-4} [1] min 2sf	1
(d)(ii)	mol of Cu = 2.01 × 10^{-4} × 2 × 4 = 1.608 / 1.61 × 10^{-3} [1] ecf min 2sf	1
(d)(iii)	% of Cu = 100 × (1.608×10^{-3} × 63.5) / 0.567 = 18.0 [1] ecf	1

Q12.

(a)(i)	NH_3 = monodentate $EDTA^{4-}$ = polydentate / hexadentate CN^- = monodentate $C_2O_4^{2-}$ = bidentate any two [1] all four [2]	2
(a)(ii)	(ligand that) donates 3 lone pairs to central metal atom / ion OR (ligand that) forms 3 dative bonds to central metal atom / ion [1]	1
(a)(iii)	ref to using the electrons / lone pair on (each) N / amine group [1]	1

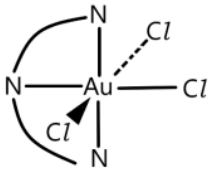
Q13.

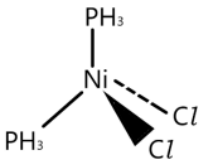
(b)	+2 **AND** + 3 [1]	1
(c)	Six [1]	1

Q14.

(c)	(27.05 ÷ 1000) × 0.02 = 5.41 × 10^{-5} moles MnO_4^- [1] 5.41 × 10^{-5} × 5/2 = 1.3525 × 10^{-4} moles $C_2O_4^{2-}$ [1] 0.00338 mol dm^{-3} [1]	3

Q15.

(a)(i)	donates one lp to metal atom or ion [1]	1
(a)(ii)	metal atom or ion bonded to one or more ligands [1]	1
(a)(iii)	has vacant d-orbitals which are energetically accessible [1]	1
(b)(i)	octahedral square planar octahedral [1]	1
(b)(ii)	$[Au(dien)(H_2O)_2Cl]^{2+} + 2Cl^- \rightarrow [Au(dien)Cl_3] + 2H_2O$ [1] **OR** $[Au(dien)Cl_3] + 2H_2O \rightarrow [Au(dien)(H_2O)_2Cl]^{2+} + 2Cl^-$	1
(b)(iii)	 [1]	

(b)(iv)	 [1]	1

Q16.

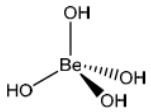
(d)	**M1** reaction 1: $2KMnO_4 + H_2SO_4 \rightarrow Mn_2O_7 + H_2O + K_2SO_4$ **OR** $2KMnO_4 + 2H_2SO_4 \rightarrow Mn_2O_7 + H_2O + 2KHSO_4$ **M2** reaction 2: $Mn_2O_7 \rightarrow 2MnO_2 + 1.5O_2$	2
(e)(i)	**M1** $[Mn(H_2O)_6]^{2+} + 2OH^- \rightarrow Mn(OH)_2 + 6H_2O$ **M2** precipitation / acid-base / deprotonation	2
(e)(ii)	**M1** $[Mn(H_2O)_6]^{2+} + 4Cl^- \rightarrow [MnCl_4]^{2-} + 6H_2O$ **M2** ligand exchange / substitution / replacement / displacement	2
(e)(iii)	MnO_2 **AND** redox	1

Q17.

(b)(i)	**M1** (a species) that donates / uses two lone pairs **M2** to form dative / coordinate bonds to a metal atom / metal ion / TM / TE / metal	**2**

(c)	$[Fe(CN)_6]^{3-}$ **AND** equilibrium lies most to the left / lowest $E^{\ominus}$ value	**1**

Q18.

(c)(i)	as a molecule or ion formed by a central metal atom / metal ion dative bonded to / surrounded by one or more ligands	**1**
(c)(ii)	 tetrahedral and correct 3D structure	**1**
(d)(i)	d orbitals that are energetically accessible **OR** empty / vacant d orbitals **AND** form dative bonds / accept a lone pair from a ligand	**1**

(d)(ii)		**2**

complex ion	shape	coordination number	polarity
cis-$[Pt(en)Cl_2]$	square planar	4	polar
$[Ag(NH_3)_2]^+$	linear	2	non-polar
$[Fe(C_2O_4)_3]^{3-}$	octahedral	6	non-polar

three for one mark, six for two marks

Q19.

(d)(i)	colourless / (pale) green **to** pink / purple	**1**

(d)(ii)	moles MnO_4^- = 0.0100×0.0350 **OR** 3.50×10^{-4} moles Fe^{2+} = $5 \times 3.50 \times 10^{-4}$ **OR** 1.75×10^{-3} [1] moles Fe^{2+} = $1.75 \times 10^{-3} \times 4 = 7.00 \times 10^{-3}$ % of Fe = $(7.00 \times 10^{-3} \times 55.8) = 0.3906$ g = 0.3906 / 2.62 × 100 = **14.9** % by mass [1] ecf M1 min 2sf	**2**

Q20.

(a)(i)	$[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow [Cu(OH)_2(H_2O)_4] + 2H_2O$ **OR** **OR** $[Cu(H_2O)_6]^{2+} + 2NaOH \rightarrow [Cu(OH)_2(H_2O)_4] + 2H_2O + 2Na^+$	**1**
(a)(ii)	$[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$ **OR** $[Cu(H_2O)_6]^{2+} + 4HCl \rightarrow [CuCl_4]^{2-} + 6H_2O + 4H^+$	**1**

(d)	$[Ru(C_{12}H_8N_2)_2Cl_2]^+$ [1] $[Fe(C_2O_4)_3]^{3-}$ [1]	**2**

Q21.

(a)	a d-block element that forms one or more stable ions with incomplete d-orbitals	**1**

(c)(i)	forms 2 dative / coordinate bonds	**1**

Q22.

(d)	0.0230 moles ethanedioate in whole 100 cm^3 0.00575 moles ethanedioate in 25 cm^3 sample [1] 0.00230 moles of MnO_4^- needed [1] 230 cm^3 [1]	**3**

Q23.

(a)(i)	<table><tr><td>blue or pink</td><td>s / solid</td></tr><tr><td>blue</td><td>aq / aqueous</td></tr></table> two cells correct [1] two more cells correct [1]	**2**
(a)(ii)	$[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2 + 6H_2O$ **or** $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(H_2O)_4(OH)_2 + 2H_2O$	**1**
(a)(iii)	$[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$	**1**

Q24.

(a)(i)	$[1s^2]\ 2s^2 2p^6 3s^2 3p^6 3d^3$	1
(a)(ii)	(a molecule or ion formed by a central) metal atom/ion surrounded by / bonded to one or more ligands	1
(b)	<table><tr><th>$[Cr(H_2O)_6]^{3+}(aq)$</th><th>formula of chromium species formed</th><th>type of reaction</th></tr><tr><td>+ NaOH(aq)</td><td>$Cr(OH)_3$ or $Cr(OH)_3(H_2O)_3$</td><td>precipitation</td></tr><tr><td>+ $H_2O_2(aq)$</td><td>$Cr_2O_7^{2-}$ / CrO_4^{2-}</td><td>redox / oxidation</td></tr><tr><td>+ excess $NH_3(aq)$</td><td>$Cr(NH_3)_6^{3+}$</td><td>ligand substitution</td></tr></table> chromium species: one mark for each correct species type of reaction: two correct for one mark and three correct for two marks	5

(d)(i)	ethanoate ions are bidentate whereas as H_2O are monodentate **OR** ethanoate ions form two dative bonds whereas H_2O forms one (dative) bond **OR** ethanoate ions donate two lone pairs whereas H_2O donates one (lone) pair	1
(d)(ii)	(coordination number) six **AND** (geometry around Cr) octahedral	1
(d)(iii)	coordinate / (dative) covalent	1

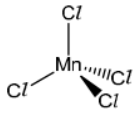
Q25.

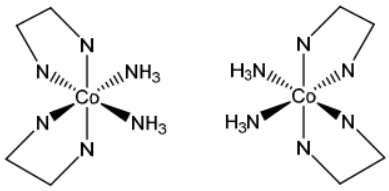
(c)(i)	$BaC_2O_4 \rightarrow BaO + CO_2 + CO$ **OR** $BaC_2O_4 \rightarrow BaO + 2CO + \frac{1}{2}O_2$	1
(c)(ii)	**M1:** [a] initial moles $MnO_4^- = 0.0200 \times 0.050 = 1.00 \times 10^{-3}$ [b] moles $Fe^{2+} = 0.050 \times 0.0304 = 1.52 \times 10^{-3}$ **M2:** [a] moles MnO_4^- unreacted $= 1.52 \times 10^{-3} / 5 = 3.04 \times 10^{-4}$ [b] moles MnO_4^- reacted $= 1.00 \times 10^{-3} - 3.04 \times 10^{-4} = 6.96 \times 10^{-4}$ **M3:** moles $C_2O_4^{2-}$ reacted $= 6.96 \times 10^{-4} \times 5/2 = 1.74 \times 10^{-3}$ **M4:** mass of $BaC_2O_4 = 225.3 \times 1.74 \times 10^{-3} = 0.392$ g % Purity of $BaC_2O_4 = 100 \times 0.392/0.50 = 78.4$	4

Q26.

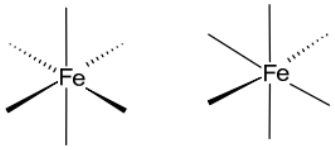
(c)(i)	(a species) that uses / shares a lone pair of electrons to form a coordinate bond to a metal atom / ion	1
(c)(ii)	$K_c = [Ag(S_2O_3)_2^{3-}]\ [Br^-] / [S_2O_3^{2-}]^2$	1

Q27.

(a)(i)	+2 [1]	**1**
(a)(ii)	 [1] bond angle labelled 109.5° [1]	**2**

(b)(i)	$[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(H_2O)_4(OH)_2 + 2H_2O$ **OR** $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2 + 6H_2O$ [1] **blue** precipitate [1]	**2**
(b)(ii)	$[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$ [1] yellow / brown / straw solution [1]	**2**
(b)(iii)	$[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$ [1] blue solution [1]	**2**
(b)(iv)	**ligand** exchange [1]	**1**
(c)(i)	(a species) that **donates <u>two</u> lone pairs** to form **<u>two</u> dative bonds to** a (transition) **metal atom / metal ion** [1] [1]	**2**
(c)(ii)	 M1 one correct 3D structure – trans or cis [1] M2 a correct optical isomer of M1 [must 3D] [1]	**2**

Q28.

(a)(i)	donates **one lone pair** / forms **one** dative bond **AND** to **metal atom** / to **metal ion** [1]	**1**
(a)(ii)	$Mo(CO)_6$ 0 / no charge / neutral / zero $Fe(CN)_6$ 3– both formulae [1] both charges [1]	**2**
(a)(iii)	either of these renditions, with a CN on each bond:  **AND** 180° bond angle between two opposite bonds [1]	**1**
(b)(i)	$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$ **OR** $Cu^{2+} + 2H_2O + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+}$ [1]	**1**
(b)(ii)	M1 **d**-orbitals split (could be in diagram) [1] M2 electrons transition to higher orbital / electrons promoted or excited [1] M3 wavelength / frequency / light / photon / hf / hn absorbed [1] M4 colour seen / reflected / transmitted is complement of colour absorbed [1]	**4**

(c)(i)	$[Cu(NH_3)_4(H_2O)_2]^{2+} + 4HCl \rightarrow CuCl_4^{2-} + 2H_2O + 4NH_4^+$ **OR** $[Cu(NH_3)_4(H_2O)_2]^{2+} + 4Cl^- (+ 4H^+) \rightarrow CuCl_4^{2-} + 2H_2O + 4NH_3 (+ 4H^+)$ M1 formula and charge of $CuCl_4^{2-}$ [1] M2 rest of equation [1]	**2**
(c)(ii)	**ligand** exchange / substitution / replacement / displacement [1]	**1**
(c)(iii)	tetrahedral [1]	**1**
(c)(iv)	yellow [1]	**1**
(c)(v)	**d**-orbital splitting changes / **ΔE** changes [1]	**1**

Q29.

(a)	red or pink to yellow / straw / brown / orange [1]	**1**

Q30.

(a)(i)	(a molecule or ion) formed by a (central) metal atom / ion surrounded by / bonded to (one or more) ligands	**1**
(a)(ii)	M1: blue ppt/solid M2: $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2 + 6H_2O$ **OR** $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow [Co(H_2O)_4(OH)_2] + 2H_2O$ M3: precipitation/ acid-base M4: blue solution M5: $[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$ M6: **ligand** exchange/displacement/substitution/replacement	**6**
(b)	• solution turns blue → pink • a white ppt. of AgC*l* forms • equilibrium shifts to the left / $[Cl^-]$ decreases Two correct responses = 1 mark Three correct responses = 2 marks	**2**

(d)(i)	**each nitrogen** / the four nitrogen's has a **lone pair of electrons** (to the metal ion) Two correct responses = 1 mark	**1**

(d)(ii)	$[Co(H_2O)_6]^{2+} + C_6H_{18}N_4 \rightarrow [Co(C_6H_{18}N_4)]^{2+} + 6H_2O$ **OR** $[Co(H_2O)_6]^{2+} + C_6H_{18}N_4 \rightarrow [Co(C_6H_{18}N_4)(H_2O)_2]^{2+} + 4H_2O$	**1**

Q31.

(a)(i)	**M1** (a species) that donates/uses a many lone pairs/more than one lone pair **M2** to form a dative/coordinate to a metal atom/metal ion/TM/TE/metal **OR** **M1** (a species) that donates/uses lone pairs to form many/more than one **M2** dative/coordinate bond to a metal atom/metal ion/TM/TE/metal	**2**
(a)(ii)	structure of EDTA any **six** atoms circled of 2 N & 4 O	**1**

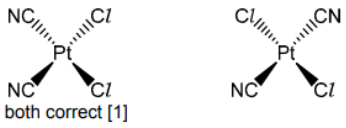
Q32.

(c)(i)	(addition of NH_3) increases $[OH^-]$ (due to ionisation of NH_3 in water) and shifts equilibrium 1 to the right (forming $Ni(OH)_2$)	**1**
(c)(ii)	(a large excess of NH_3) shifts eqm 2 to the right (forming $[Ni(NH_3)_6]^{2+}$) **AND** the $[Ni^{2+}]/[[Ni(H_2O)_6]^{2+}]$ decreases and eqm 1 shifts to the left (causing the ppt to dissolve)	**1**

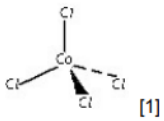
Q33.

(b)	$[Cu(NH_3)_4]^{2+} + 2H_2O \rightarrow Cu(OH)_2 + 2NH_4^+ + 2NH_3$ [1] **OR** $[Cu(NH_3)_4]^{2+} + 2H_2O \rightarrow Cu(OH)_2 + 2H^+ + 4NH_3$	**1**
(c)	$Cu(OH)_2 + 4HCl \rightarrow [CuCl_4]^{2-} + 2H_2O + 2H^+$ **OR** $Cu(OH)_2 + 4Cl^- + 2H^+ \rightarrow [CuCl_4]^{2-} + 2H_2O$ $[CuCl_4]^{2-}$ complex including charge [1] rest of equation fully correct [1]	**2**
(d)	<table><tr><th></th><th>Y</th><th>Z</th></tr><tr><td>colour of complex</td><td>yellow</td><td>blue / pale blue</td></tr><tr><td>geometry of complex</td><td>tetrahedral</td><td>octahedral</td></tr><tr><td>formula of complex</td><td></td><td>$[Cu(H_2O)_6]^{2+}$</td></tr></table> one mark for any **three** cells [1] • • ✓ two marks for all five cells [2] • • ✓ • ✓	**2**

Q34.

(a)(i)	(a species) that donates one lone pair [1] to form a dative / coordinate to a central metal atom / metal ion [1]	**2**
(a)(ii)	$[Ag(S_2O_3)_2]^{3-}$ [1]	**1**
(b)(i)	$[Ag(S_2O_3)_2]^{3-} + 2CN^- \rightarrow [Ag(CN)_2]^- + 2S_2O_3^{2-}$ [1] **OR** $Ag(S_2O_3)_2]^{3-} + 2NaCN \rightarrow [Ag(CN)_2]^- + Na_2S_2O_3 + S_2O_3^{2-}$	**1**
(b)(ii)	**Q** is more stable / has a larger K_{stab} than **P** [1]	**1**
(b)(iii)	**ligand** exchange / displacement / substitution	**1**
(c)(i)	 both correct [1]	**1**
(c)(ii)	**square planar** [1]	**1**
(c)(iii)	cis-trans **OR** geometric(al) [1]	**1**

Q35.

(c)(i)	 [1] 2– (charge) [1]	**2**
(c)(ii)	ligand exchange / substitution / replacement / displacement [1]	**1**

Q36.

(d)(i)	Oxidation [1]	1

(d)(iv)	six [1]	1

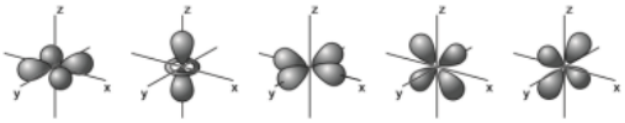
Q37.

(a)	**M1** $[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow Cu(OH)_2 + 6H_2O$ **M2** precipitation **M3** blue precipitate **M4** $[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow CuCl_4^{2-} + 6H_2O$ **M5** **ligand** exchange / displacement / substitution / replacement **M6** yellow solution	6

Q38.

(c)(i)	donates one lone pair to the central metal ion	1

Q39.

(a)	 any diagram [1]	1
(b)(i)	(elements) forming one or more (stable) **ions** with incomplete / partially filled **d** orbital(s) / sub-shell [1]	1
(b)(ii)	dative covalent / coordinate [1]	1

(d)

metal ion	ligand	co-ordination number	formula of complex ion	charge of complex ion
Ni^{2+}	CO	4	**$Ni(CO)_4$**	**2+**
Fe^{3+}	CN^-	**6**	**$Fe(CN)_6$**	3-

mark as • ✓ • ✓ [2] — 2

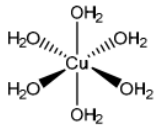
Q40.

(b)(i)	purple to pale pink / colourless **AND** orange to green	**1**
(b)(ii)	$3Sn^{2+} + Cr_2O_7^{2-} + 14H^+ \rightarrow 3Sn^{4+} + 2Cr^{3+} + 7H_2O$	**1**
(c)(i)	• six • coordinate bonds / dative bonds / lone pairs donated • to the (central) metal ion award 1 mark for all three points	**1**
(c)(ii)	$[Ru(NH_3)_4Cl(SO_2)]^+$	**1**

Q41.

(a)	donates one pair of electrons / forms one coordinate bond	**1**
(b)	<table><tr><th>Reagent added to a solution of $CuSO_4$(aq)</th><th>Observations</th><th>Formula of the copper(II) compound or complex ion that is formed</th></tr><tr><td>a few drops of dilute ammonia</td><td>blue ppt</td><td>$Cu(OH)_2$ or $Cu(OH)_2(H_2O)_4$</td></tr><tr><td>an excess of dilute ammonia</td><td>deep blue solution</td><td>$[Cu(NH_3)_4]^{2+}$ or $[Cu(NH_3)_4(H_2O)_2]^{2+}$</td></tr><tr><td>an excess of aqueous sodium hydroxide</td><td>blue ppt</td><td>$Cu(OH)_2$ or $Cu(OH)_2(H_2O)_4$</td></tr><tr><td>an excess of conc HCl</td><td>green-yellow / yellow-green / yellow</td><td>$[CuCl_4]^{2-}$</td></tr></table> Award 1 mark for each correct observation and formula in a row of the table.	**4**

Q42.

(b)	C*l*-Cu-C*l*	1
	one minus charge	1
(c)		1
	octahedral **and** 90° or 180° labelled correctly on diagram as appropriate	1

(d)	reaction 1: blue ppt / blue **solid**	1
	$[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow Cu(OH)_2 + 6H_2O$ or $[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow Cu(OH)_2(H_2O)_4 + 2H_2O$ or $[Cu(H_2O)_6]^{2+} + 2NH_3 \rightarrow Cu(OH)_2(H_2O)_4 + 2NH_4^+$	1
	reaction 2: deep / dark / royal blue solution	1
	$Cu(OH)_2 + 4NH_3 + 2H_2O \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 2OH^-$ or $Cu(OH)_2 + 4NH_3 \rightarrow [Cu(NH_3)_4]^{2+} + 2OH^-$ or $Cu(OH)_2(H_2O)_4 + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 2OH^- + 2H_2O$	1

(f)(i)	donates lone pairs / forms dative / co-ordinate bonds to (central) metal atom / metal ion	1
	donates two lone pairs / forms two (dative or coordinate) bonds	1
(f)(ii)	$[Zr(C_2O_4)_4]^{4-}$	1
	not octahedral because 8 dative bonds to Zr **or** not octahedral because not 6 dative bonds to Zr **or** not octahedral because co-ordination number is 8 / is not 6	1