Mark scheme – Transition Elements

Question	Answer/Indicative content	Marks	Guidance
1	*Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.* **Level 3 (5–6 marks)** All three tests are covered in detail, with at least **six** of **B** to **H** identified correctly and equations mostly correct. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** All three tests are covered with at least **four** of **B** to **H** identified correctly. Some attempt at writing equations, but with several omissions or incorrect formulae. *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1–2 marks)** Only two tests covered with at least **two** of **B** to **H** identified correctly, and little attempt at writing equations. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	6 (AO 3.3×3) (AO 3.4×3)	**Indicative scientific points may include:** **Identification of unknowns** Can be identified within labelled equation. **B** is $FeSO_4$ **OR** Iron(II) sulfate • Test 1: Fe^{2+} present • Test 2: SO_4^{2-} present **D** is $Fe(OH)_2$ **OR** $[Fe(H_2O)_4(OH)_2]$ **OR** iron(II) hydroxide **G** is $BaSO_4$ OR barium sulfate **C** is $CrCl_3$ **OR** chromium(III) chloride • Test 1: Cr^{3+} present • Test 3: Cl^- present **E** is $Cr(OH)_3$ **OR** $[Cr(H_2O)_3(OH)_3]$ **OR** chromium(III) hydroxide **F** is $[Cr(NH_3)_6]^{3+}$ **H** is silver chloride OR $AgCl$ **Equations** **D**: $[Fe(H_2O)_6]^{2+} + 2OH^- \rightarrow Fe(OH)_2 + 6H_2O$ **OR** $Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$ **OR** $[Fe(H_2O)_6]^{2+} + 2OH^- \rightarrow [Fe(H_2O)_4(OH)_2] + 2H_2O$ **OR** $[Fe(H_2O)6]^{2+} + 2NH_3 \rightarrow [Fe(H_2O)_4(OH)_2] + 2NH_4^+$ **OR** $[Fe(H_2O)_6]^{2+} + 2NH_3 \rightarrow Fe(OH)_2 + 4H_2O + 2NH_4^+$ **E**: $[Cr(H_2O)6]^{3+} + 3OH^- \rightarrow Cr(OH)_3 + 6H_2O$ **OR** $Cr^{3+} + 3OH^- \rightarrow Cr(OH)_3$ **OR** $[Cr(H_2O)_6]^{3+} + 3OH^- \rightarrow [Cr(H_2O)_3(OH)_3] + 3H_2O$ **OR** $[Cr(H_2O)_6]^{3+} + 3NH_3 \rightarrow [Cr(H_2O)_3(OH)_3] + 3NH_4^+$ **OR** $[Cr(H_2O)_6]^{3+} + 3NH_3 \rightarrow Cr(OH)_3 + 3H_2O + 3NH_4^+$

					F: $[Cr(H_2O)_6]^{3+} + 6NH_3 \rightarrow [Cr(NH_3)_6]^{3+} + 6H_2O$ **OR** $Cr(OH)_3 + 6NH_3 \rightarrow [Cr(NH_3)_6]^{3+} + 3OH^-$ **OR** $[Cr(H_2O)_3(OH)_3] + 6NH_3 \rightarrow [Cr(NH_3)_6]^{3+} + 3H_2O + 3OH^-$ **G**: $Ba^{2+} + SO4^{2-} \rightarrow BaSO_4$ **H**: $Ag^+ + Cl^- \rightarrow AgCl$
			Total	**6**	
2			*Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.* **Level 3 (5-6 marks)** Comprehensive explanation of the terms, ligand and coordination number and ligand substitution **AND** 3D diagrams of suitable examples of 6 **AND** 4 coordinate complex ions with different shapes **AND** Ligand substitution illustrated with a balanced equation *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3-4 marks)** Explanation of the terms, ligand and coordination number and ligand substitution with some errors or omissions **AND**: Diagrams of suitable examples of 6 **AND** 4 coordinate complex ions with different shapes **OR** A 3D wedged diagram of a suitable example of 6 **OR** 4 coordination **OR** A diagram of a suitable example of 6 **OR** 4 coordination **AND** ligand substitution illustrated with an equation **OR** Ligand substitution illustrated with a balanced equation *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence* **Level 1 (1-2 marks)** Explanation of some terms: ligand, coordination number and ligand substitution with some errors or omissions. **AND** A suitable example of a complex ion **OR** Ligand substitution illustrated with an equation with some errors *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.	6 (AO 1.1× 4) (AO 2.1× 2)	**Indicative scientific points may include:** **Terms** • **Ligand**: Donates a lone pair to metal ion Forms dative covalent (coordinate) bond with metal ion • **Coordination number**: Number of coordinate bonds to metal ion. Could be implicit in annotated diagrams **NOTE**: For monodentate ligands, 'number of ligands' is the same as the number of coordination number • **Ligand substitution**: One **ligand** replacing another **Suitable examples of complex ions with different shapes** • ***Coordination no 6*** **Octahedral** e.g. $[Cu(H_2O)_6]^{2+}$, $[Fe(H_2O)_6]^{3+}$ • ***Coordination no 4*** **Tetrahedral** e.g. $CuCl_4^{2-}$, $CoCl_4^{2-}$ **OR Square planar** Pt complexes, e.g. $Pt(NH_3)_2Cl_2$ **Diagrams and equations** • ***Diagrams of complex ions (may be 3D)***

- ***Equation for ligand substitution***

  e.g. $[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow CuCl_4^{2-} + 6H_2O$
  $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$

***NOTE**: A clear and logically structured response would link shapes with some of: coordination number, names of shapes, connectivity, involvement of lone pairs, bond angles, etc. (not inclusive)*

ALLOW minor slips

NOTE: Levels and the mark within a level is a 'best-fit', not perfection

Examiner's Comments

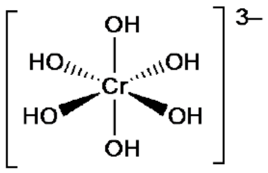
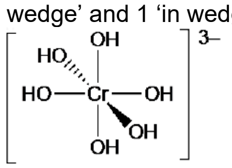
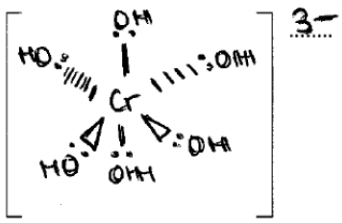
This question was assessed by level of response (LoR). The question required candidates to demonstrate their knowledge and understand of some important terms used in transition metal chemistry.

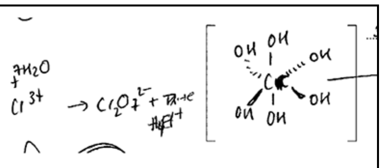
Level 3 candidates showed complete definitions of ligand, coordination number and ligand substitution, supported by suitable equations with clear diagrams of complex ions. The responses were concise with 3D diagrams of 6- and 4-coordinate complex ions displayed with wedges, correct connectivity to ligand atoms and showing the role of lone pairs in the formation of the coordinate bonds. 4-coordination was shown as either or both of tetrahedral (usually $CuCl_4^{2-}$) or square planar (e.g. platin). Ligand substitution was accompanied by a correct balanced equation, most commonly between $[Cu(H_2O_6]^{2+}$ and NH_3.

					Level 2 candidates usually gave definitions of ligand, coordination number and ligand substitution. There was usually a balanced equation for ligand substitution and one correct 3D diagram. A second diagram often had an unsuitable shape for the complex ion chosen (often $CuCl_4^{2-}$ shown as square planar). Level 1 candidates did produce definitions, but these were often incomplete. There was usually an attempt to show a 3D diagram or equation, but these often contained unsuitable examples. This question rewarded the candidates who had learnt their chemistry and the levels enabled the amount of knowledge and understanding to be assessed. The question discriminated well.
			Total	**6**	
3		i	(0.00200 mol dm^{-3} solution gives) a large titre which leads to a small (percentage) error / uncertainty ✓	1 (AO 3.4)	**ALLOW** (0.0200 mol dm^{-3} solution gives) a small titre which leads to a large (percentage) error / uncertainty Assume 'it' means dilute solution **ALLOW** 13.50 cm^3 gives a lower percentage error than 1.35 cm^3 __**Examiner's Comments**__ Only a very small minority of candidates appreciated that a larger titre reduces percentage error in titre values. Most erroneously described a reading of 1.35 cm^3 as being less accurate than a reading of 13.5(0) cm^3. The accuracy of these is equal in the same scaled apparatus.
		ii	**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = 301 mg award 5 marks** $n(MnO_4^-) = \frac{13.50}{1000} \times 0.00200 = 2.7(0) \times 10^{-5}$ (mol) ✓	5 (AO 2.8 ×5)	**ALLOW ECF** throughout **ALLOW** working to 3SF **minimum** throughout Common errors 602 (mg) (not dividing by 2) = 4

			$n(Fe^{2+})$ (in.25.0 cm^3) = 2.7(0) × 10^{-5} × 5 = 1.35 × 10^{-4} (mol) ✓ $n(Fe^{2+})$ (in 250 cm^3) = 1.35 × 10^{-4} × 10 = 1.35 × 10^{-3} ✓ Mass $C_{12}H_{22}FeO_{14}$ in 2 tablets = 1.35 × 10^{-3} × 445.8 = 0.6018 (g) ✓ Mass $C_{12}H_{22}FeO_{14}$ in 1 tablet = 301 (mg) **AND** to **3 SF** ✓		marks 37.7 (using 55.8 instead of 445.8) = 4 marks Last mark involves dividing by two and converting g to mg. These steps may be seen earlier **<u>Examiner's Comments</u>** Many candidates coped well with this multi-step calculation. The common errors were: • determining the mass of $C_{12}H_{22}FeO_{14}$ in two tablets instead of just one tablet as required in the question • determining the mass of Fe in a tablet instead of the mass of $C_{12}H_{22}FeO_{14}$ • failing to convert from grams to milligrams
		iii	A: Mass Fe = $\frac{180 \times 55.8}{151.8}$ = 66 mg B: Mass Fe = $\frac{210 \times 55.8}{169.8}$ = 69 mg **Iron supplement:** **B** provides more Fe per tablet ✓	1 (AO 3.1 ×1)	**ALLOW** correct working if iron supplement is not named **ALLOW** iron(II) fumarate or $C_4H_2FeO_4$
			Total	**7**	
4			*Coordinate bond mark* O_2 (coordinately or datively) bonds with Fe^{2+}/Fe(II)/Fe/Iron ✓ Ligand substitution mark (When required) O_2 is replaced by H_2O **OR** CO_2 **OR** O_2 is replaced by CO **OR** H_2O **OR** CO_2 is replaced by O_2 ✓ *Ligand strength mark* CO forms strong(er) bonds (than O_2) ✓	3 (AO 1.1 ×2) (AO	**ALLOW** names or symbols of ligands **ALLOW** H_2O/CO/CO_2 (coordinately or datively) bonds with Fe^{2+}/Fe(II)/Fe/Iron **ALLOW** oxygen donates electron pair to **OR** binds with Fe^{2+}/Fe(II)/Fe/Iron **DO NOT ALLOW** Fe^{3+} **ALLOW** other words for replaced

				2.1 ×1)	**ALLOW** K_{stab} for CO (much) higher (than for O_2) **ALLOW** CO bonds irreversibly **OR** CO is a strong(er) ligand **IGNORE** affinity **Examiner's Comments** The key chemistry that candidates needed to discuss in their response was as follows: • O_2 molecules forming ***coordinate bonds*** with and Fe^{2+} ions in haemoglobin. • O_2 **molecules** being replaced by another **ligand** (e.g. H_2O or CO) • CO ligands forming very **strong** coordinate bonds The mark scheme allowed 'oxygen binding' but candidates did need to specify what the oxygen was binding to. Loose terminology, such as CO having a 'greater affinity' should be avoided.
			Total	**3**	
5	a	i	$[Cr(NH_3)_6]^{3+}(aq)$ ✓	1 (AO 1.1)	**IGNORE** state symbols **Examiner's Comments** Most candidates knew the correct formula. There was some confusion with ammoniacal copper ions and $[Cr(NH_3)_4(H_2O)_2]^{2+}$ was a frequently seen incorrect answer.
		ii	$CrCl_3(aq) + 3NaOH(aq) \rightarrow Cr(OH)_3(s) + 3NaCl(aq)$ or $Cr^{3+}(aq) + 3OH^-(aq) \rightarrow Cr(OH)_3(s)$ ✓ state symbols required	1 (AO 2.8)	**IGNORE** square brackets around precipitate formulae **ALLOW** $[Cr(H_2O)_6]^{3+}(aq) + 3OH^-(aq) \rightarrow Cr(OH)_3(H_2O)_3(s)+3H_2O(l)$ **ALLOW** 'hybrid' equations, Eg $Cr^{3+}(aq) + 3NaOH(aq) \rightarrow Cr(OH)_3(s) + 3Na^+(aq)$ $[Cr(H_2O)_6]^{3+}(aq) + 3OH^-(aq) \rightarrow Cr(OH)_3(s) + 6H_2O(l)$ $[Cr(H_2O)]_6^{3+}(aq)+ 3NaOH(aq) \rightarrow$

						$Cr(OH)_3(s) + 6H_2O(l) + 3Na^+(aq)$ **<u>Examiner's Comments</u>** The most common error for this question was to omit the state symbols, sometimes on only one species. Both a correct equation and the correct state symbols were required for the mark.
		iii	 3-D diagram with all bonds through O in OH ✓ 3– charge ✓	2 (AO 1.1) (AO 2.3)	Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper **OR** 4 lines, 1 'out wedge' and 1 'in wedge':  **ALLOW** dotted line **OR** unfilled wedge as alternatives for dotted wedge **IGNORE** charges inside brackets **<u>Examiner's Comments</u>** The drawing of simple 3-D diagrams of relevant shapes is a skill that is assessed in A Level chemistry. Common errors are listed in the exemplars. **Exemplar 6**  Some candidates drew in pencil then over-wrote in ink. Candidates need to remember that the scanned image does not differentiate between pencil and ink, so it is not necessary for them to do this. **Exemplar 7**

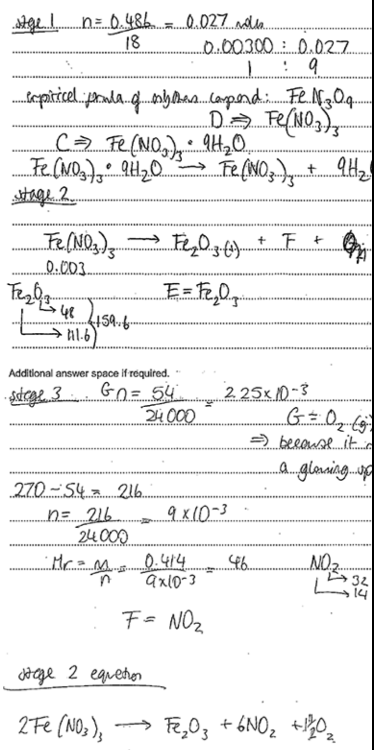
					 Candidates should avoid incorrect connectivity between the ligand and the central metal ion. Candidates should be taught which atom within the ligand supplies the lone pair to form the coordinate bond. In this case oxygen has lone pairs, not hydrogen as suggested by the candidate in the bonding involving the bottom left hand ligand.
		iv	CrO_4^{2-} ✓	1 (AO 3.1)	**IGNORE** compounds e.g. Na_2CrO_4 **<u>Examiner's Comments</u>** Very few candidates correctly identified the CrO_4^{2-} ion here. Candidates should be aware that oxidation of $Cr(OH)_3$ produces CrO_4^{2-} (which can then be acidified to produce $Cr_2O_7^{2-}$).
		v	orange ✓	1 (AO 1.1)	**<u>Examiner's Comments</u>** Invariably, the answer given by candidates here was either orange or green, indicating some knowledge of the colours of chromium ions. Those who stated orange received credit
	b	i	$(1s^2)2s^22p^63s^23p^63d^2$ ✓	1 (AO 1.1)	**ALLOW** upper case D, etc. and subscripts, e.g. $3D_2$ If included, **ALLOW** $4s^0$ **<u>Examiner's Comments</u>** Many candidates did not realise that when transition metal ions are formed, the first electrons removed from atoms are the 4s electrons and so wrote $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^1$ $4s^2$.
		ii	*Explanation of colours* VO^{2+} goes to V^{3+} (green) **AND** then V^{3+} goes to V^{2+} (violet) ✓	3 (AO 3.2	

			Explanation using E⦵ values (*E*⦵ of) system 4 (VO^{2+}/V^{3+}) is more positive / less negative than system 2 (Fe^{2+}/Fe) **OR** (*E*⦵ of) system 3 (V^{3+}/V^{2+},) is more positive / less negative than system 2 (Fe^{2+}/Fe) ✓ *Equilibrium shift related to E⦵ values* More positive/less negative system 4 (VO^{2+}/V^{3+}) shifts right **AND** More positive/less negative system 3 (V^{3+}/V^{2+}) shifts right	×2) (AO 3.2× 1)	**IGNORE** 'lower/higher' **ALLOW** reverse argument System 2 more negative than system 4 etc *E* = (+)0.78 V for system 4 + system 2 reaction **OR** *E* = (+)0.18 V for system 3 + system 2 reaction For shifts right' **ALLOW** (VO^{2+}) is reduced **OR** gains electrons (maybe seen as an equation) **AND** 'For shifts right' **ALLOW** (V^{3+}) is reduced **OR** gains electrons (maybe seen as an equation) **IGNORE** Fe oxidised **<u>Examiner's Comments</u>** Most candidates did not state that the direction of reaction of redox equilibria is dependent on the relative negativity/positivity of the standard electrode potentials. Higher ability candidates described two reductions of the relevant vanadium ions to end up with V^{2+} ions.
		iii	$Fe + 4H^+ + 2VO^{2+} \rightarrow Fe^{2+} + 2H_2O + 2V^{3+}$	1 (AO 2.8)	**IGNORE** state symbols **ALLOW** multiples **ALLOW** '⇌'
			Total	**11**	
6	a	i	**A**: $Fe(OH)_3(s)$ ✓ **B**: $Ag_2S(s)$ ✓✓	2 AO3.1x2	**ALLOW** $Fe(OH)_3(H_2O)_3$ **IGNORE** state symbols **<u>Examiner's Comments</u>** Most candidates were given 1 or 2 marks for this part. The black precipitate **B** (Ag_2S) was identified correctly more often the orange precipitate **A**, which was often shown as $Fe(OH)_2$ instead of $Fe(OH)_3$ or $Fe(OH)_3(H_2O)_3$. Significantly, identification of **B**

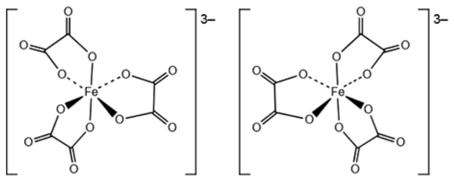
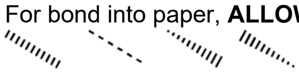
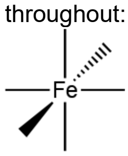
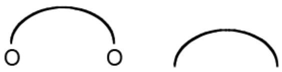
					required interpretation of new information whereas **A** required knowledge of transition element chemistry.
		ii	Student is incorrect **AND** No oxidation numbers change **OR** example, e,g, Fe stays as +2 ✓	1 AO3.2	**ALLOW** no electron transfer **<u>Examiner's Comments</u>** Just over half the candidates identified that the student was incorrect, and that the reaction is not redox. Candidates were expected to provide some evidence to support their statement, in terms of no oxidation number changes. Some candidates claimed that the reaction was not redox because only sulfur changed oxidation number, suggesting a misunderstanding of redox.
		iii	$2[Fe(H_2O)]^{2+} + Cl_2 \rightarrow 2[Fe(H_2O)_6]^{3+} + 2Cl^-$ ✓	1 AO3.1	**ALLOW multiples** **e.g.** $[Fe(H_2O)_6]^{2+} + ½Cl_2 \rightarrow [Fe(H_2O)_6]^{3+} + Cl^-$ **ALLOW** $2[Fe(H_2O)_6]^{2+} + Cl_2 \rightarrow 2[Fe(H_2O)_5OH]^{2+} + 2HCl$ OR $2[Fe(H_2O)_6]^{2+} + Cl_2 \rightarrow 2[Fe(H_2O)_5Cl]^{2+} + 2H_2O$ **NOTE**: equation **MUST** be balanced by charge and oxidation number **IGNORE** state symbols **<u>Examiner's Comments</u>** Candidates found this equation extremely difficult with only a small number of candidates writing a correct equation. The problem lies with balancing the oxidation numbers and charges. Many wrote an equation with a 1:1 ratio or 1:2 ratio for $[Fe(H_2O)_6]^{2+} : Cl_2$. An equation balanced in oxidation number and charge required a 2:1 ratio. When writing equations for redox reactions, candidates are

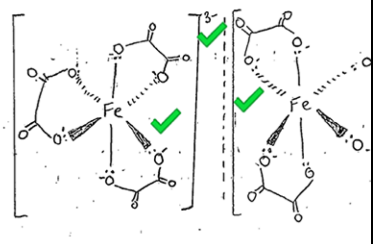
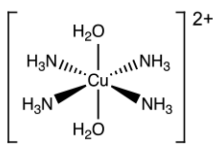
					recommended to check that oxidation changes and charges are balanced as well as atoms.
		iv	$5H_2S + 2MnO_4^- + 6H^+ \rightarrow 2Mn^{2+} + 5S + 8H_2O$ ✓✓ **1st mark** **ALL** Correct species (**SIX**) **OR** Equation containing Mn and S species correctly balanced i.e. $5\ H_2S + 2\ MnO_4^-$ ……. → $2\ Mn^{2+} + 5\ S$ …….. **2nd mark** Complete correct balanced equation	2 AO3.1×2	**ALLOW** multiples, e.g. $2\frac{1}{2}\ H_2S + MnO_4^- + 3H^+ \rightarrow Mn^{2+} + 2\frac{1}{2}\ S + 4H_2O$ **ALLOW** equation with S^{2-}, e.g. $5S^{2-} + 2MnO_4^- + 16^{H+} \rightarrow 2Mn^{2+} + 5S + 8H^2O$ **IGNORE** extra electrons for 1st mark __**Examiner's Comments**__ Candidates needed to interpret the information in the flowchart and to use this as the basis for their redox equation. The clue that a yellow solid is a product proved to be very difficult to interpret as being sulfur. The equation then required H_2O to be added as the other product. Candidates found this equation difficult and relatively few correct equations were seen. As with (iii), many equations were not balanced by oxidation number or charge. Some candidates omitted this part entirely.
	b		*Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** Reaches a comprehensive conclusion to determine the correct formulae of **almost all** of **C, D, E, F, G AND 9H_2O** *There is a well-developed line of reasoning which is clear and logically structured.* *The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Reaches a sound conclusion to determine the correct formulae of **at least half** of **C, D, E, F, G AND 9H_2O.** *There is a line of reasoning presented with some structure.* *The information presented is relevant and supported by some evidence.*	6 AO1.2×2 AO3.1×2 AO3.2×2	**Indicative scientific points may include:** **Formula of C, D, E, F and G** • **C**: $Fe(NO_3)_3{\bullet}9H_2O$ **OR** $FeN_3O_9{\bullet}9H_2O$ • **D**: FeN_3O_9 **OR** $Fe(NO_3)_3$ • **E**: Fe_2O_3 • **F**: NO_2 • **G**: O_2 • $9H_2O$ *Examples of evidence* $n(H_2O) = \frac{0.486}{18.0} = 0.027$ (mol)

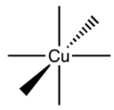
			Level 1 (1–2 marks) Reaches a simple conclusion to determine the correct formulae of **some** of **C, D, E, F, G AND 9H$_2$O.** *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		0.027 : 0.003 = 1 : 9 → **9H$_2$O** $n(\mathbf{F}) = \frac{270-54}{24000} = \frac{216}{24000} = 0.009(00$ M(**E**) = 55.8 × 2 + 16.0 × 3 = 159.6 $M(\mathbf{F}) = \frac{0.414}{0.009(00)} = 46$ (g mol^{-1}) **G**: oxygen linked to relighting glowing split **NOTE**: *Equations could include evidence* e.g $Fe(NO_3)_3{\bullet}9H_2O \rightarrow Fe(NO_3)_3 + 9H_2O$ $FeN_3O_9{\bullet}9H_2O \rightarrow FeN_3O_9 + 9H_2O$ $2Fe(NO_3)_3 \rightarrow Fe_2O_3 + 6NO_2 + 1\frac{1}{2}O_2$ **<u>Examiner's Comments</u>** This question presented a practical scenario in which candidates were asked to identify 5 unknown chemicals. There are many routes that lead to correct identifications of the unknowns. Most candidates identified **G** as oxygen and made some headway towards identifying **C** and **D** by determining that 9 waters of crystallisation were present in **C**. The formulae of **C** and **D** sometimes followed but many candidates found it difficult to link 9H$_2$O to their formulae. The best responses showed the nitrate ion separately in the formula, e.g. $Fe(NO_3)_3$, but many showed the empirical formula instead, e.g. FeN_3O_9. Gas **G** (NO_2) proved to be the most difficult unknown to identify as it required two pieces of data for its determination. There were some very competent attempts at writing equations, with the decomposition of compound **D** in Stage 2 to form **E, F** and **G** being the most difficult.

					Exemplar 6 is a Level 3 response. The candidate has first identified **C** and **D**, having first determined the 1:9 molar ratio of **C**: H_2O. The candidate then writes the correct equation for Stage 1, using NO_3 for the nitrate ion. The candidate then identifies **E**, **F** and **G** using a methodical approach with clear working throughout. Finally, the candidate writes the correct equation for the reaction in Stage 2. This is an excellent Level 3 response, given 6/6 marks. **Exemplar 6**  stage 1 n = 0.486 / 18 = 0.027 mols 0.00300 : 0.027 1 : 9 empirical formula of anhydrous compound: FeN_3O_9 D ⇒ $Fe(NO_3)_3$ C ⇒ $Fe(NO_3)_3 \cdot 9H_2O$ $Fe(NO_3)_3 \cdot 9H_2O \longrightarrow Fe(NO_3)_3 + 9H_2O$ stage 2 $Fe(NO_3)_3 \longrightarrow Fe_2O_3(s) + F + G$ 0.003 Fe_2O_3 48, 111.6, 159.6 E = Fe_2O_3 Additional answer space if required. stage 3 G n = 54 / 24000 = 2.25×10⁻³ — G = $O_2(g)$ ⇒ because it ... a glowing sp... 270 − 54 = 216 n = 216 / 24000 = 9×10⁻³ Mr = m/n = 0.414 / 9×10⁻³ = 46 NO_2 32, 14 F = NO_2 stage 2 equation $2Fe(NO_3)_3 \longrightarrow Fe_2O_3 + 6NO_2 + 1\frac{1}{2}O_2$
			Total	**12**	
7		i	**Equation** $[Co(H_2O)_6]^{2+} + 4Cl^- \rightleftharpoons [CoCl_4]^{2-} + 6H_2O$ **OR** $[Co(H_2O)_6]^{2+} + 4HCl \rightleftharpoons [CoCl_4]^{2-} + 6H_2O + 4H^+$ ✓	1	**ALLOW** reverse equation: $[CoCl_4]^{2-} + 6H_2O \rightleftharpoons [Co(H_2O)_6]^{2+} + 4Cl^-$ but take care for subsequent explanations **IGNORE** state symbols (even if wrong) For $[CoCl_4]^{2-}$, **ALLOW** $CoCl_4^{2-}$, $(CoCl_4)^{2-}$ For other representations, contact TL **<u>Examiner's Comments</u>**

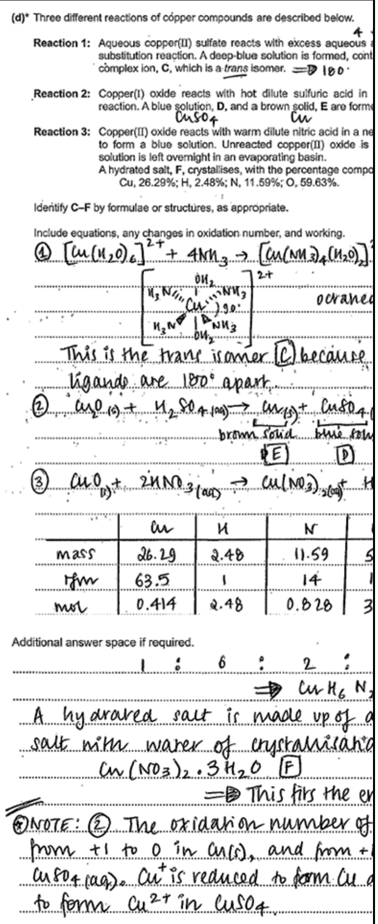
					In this part, candidates needed to apply their knowledge and understanding of ligand substitution and equilibrium to a novel situation. The best equations used Cl^- ions to form $CoCl_4^{2-}$. Some candidates used HCl instead and then H+ was often omitted in the equation. As with 2b, candidates are recommended to check that their completed equations are balanced.
		ii	**Equilibrium shift** • equilibrium (shifts) **to right** at high **temperature**/100°C **OR** equilibrium shifts to left at low temperature/0°C ✓ **CARE: Direction of shift** depends on direction of equilibrium equation from 2c(i). Either look back or see the equation copied at bottom of 2c(ii) marking zone. **Enthalpy change** • Endothermic ✓	2	**Mark independently** **ALLOW** suitable alternatives for 'to right' e.g. towards products **OR** in forward direction **OR** 'favours the right' **ORA** for 'to left' **Temperature** required but **ALLOW** 'in ice for low temperature **OR** 'in boiling/hot water' for high temperature **IGNORE** shift to blue side or pink side **Examiner's Comments** Candidates were expected to determine the type of energy change by linking their equilibrium equation in 2b(i) with the colour changes at different temperatures. Most candidates correctly concluded that the formation of a blue colour is endothermic. Many candidates did not explain this in terms of a shift in equilibrium position, considering bond breaking and bond making instead.
			Total	**3**	

8			Overall 3− charge shown (outside brackets) for at least **ONE** isomer ✓ *3− must apply to the overall charge of structures*  *1 mark for each isomer ✓✓* • *Bonds **must** go to O ligand atoms on **EACH** structure* • ***ALLOW** unambiguous structures; ethanedioate ions can include C atoms* **For other structures that might be creditworthy, contact TL**	3	**ALLOW** −3 for 3− **IGNORE** charges or dipoles on atoms within diagrams (even if wrong) Square brackets **NOT** required ______________________________ **3D** Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper **OR** 4 lines, 1 'out wedge' and 1 'in wedge': For bond into paper, **ALLOW**:  **ALLOW** following geometry throughout:  **NOT ALLOW** structures showing a simplified loop for ethanedioate ligands e.g.  __**Examiner's Comments**__ Most candidates were able to draw clear octahedral 3D shapes of the optical isomers, with good use made of wedges. The best candidates showed an overall 3− charge on each isomer but lower ability candidates did not always cancel down the charges in the Fe^{3+} and $(COO^-)_2$ ions, showing a 3+ charge instead of the overall charge of 3−. (See Exemplar 5) **Exemplar 5**

					
			Total	**3**	
9	a		Ni: $1s^22s^22p^63s^23p^63d^84s^2$ ✓ Ni^{2+}: $1s^22s^22p^63s^23p^63d^8$ ✓	**2**	**ALLOW** 4s before 3d, ie $1s2^2s2^2p^63s^23p^64s^23d^8$ **ALLOW** 1^2 written after answer prompt (*ie* $1s^2$ twice) **ALLOW** upper case D, etc and subscripts, e.g. ……$4S_23D_8$ **ALLOW** for Ni^{2+} ……….4s0 **DO NOT ALLOW** [Ar] as shorthand for $1s^22s^22p^63s^23p^6$ Look carefully at $1s^22s^22p^63s^23p^6$ – there may be a mistake **Examiner's Comments** Most candidates knew the electron configuration of an Ni atom but the number knowing the electron configuration of the Ni^{2+} ion was considerably fewer. The common error was the failure to remove the two 4s electrons.
	b		*Please refer to the marking instructions on page 5 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** All three reactions are covered in detail with **C**, **D**, **E** and **F** identified with clear explanations. *There is a well-developed line of reasoning which is clear and logically structured with clear chemical communication and few omissions. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** All three reactions are covered but explanations may be incomplete **OR** Two reactions are explained in detail. *There is an attempt at a logical structure with a line of reasoning. The information is relevant e.g. formulae may contain missing brackets or numbers and supported by some evidence.* **Level 1 (1–2 marks)** Make two simple explanations from any one reaction. **OR**	**6**	**Indicative scientific points may include:** **REACTION 1 ($CuSO_4/NH_3$)** ***Product*** C : $[Cu(NH_3)_4(H_2O)_2]^{2+}$ ***Equation*** $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$ ***Structure of trans stereoisomer***  Correct connectivity

			Makes one simple explanation from each of two reactions *There is an attempt at a logical structure with a line of reasoning The information is in the most part relevant.* **0 marks** No response worthy of credit.		**REACTION 2 (Cu_2O/H_2SO_4)** ***Products*** **D** : $CuSO_4$ **OR** $[Cu(H_2O)_6]^{2+}$ **E**: Cu **Equation** $Cu_2O + H_2SO_4 \rightarrow CuSO_4 + Cu + H_2O$ ***Oxidation numbers*** Cu(+1) → Cu(+2) + Cu(0) **REACTION 3 (CuO/HNO_3)** ***Equation*** $CuO + 2HNO_3 \rightarrow Cu(NO_3)_2 + H_2O$ ***Molar ratios*** Cu : H : N : O $= \frac{26.29}{63.5} : \frac{2.49}{1.0} : \frac{11.59}{14.0} : \frac{59.63}{16.0}$ ***Formula of F*** $CuH_6N_2O_9$ **F**: $Cu(NO_3)^2 \bullet 3H_2O$ (**OR** $Cu(NO_3)_2(H_2O)_3$) -- **Further guidance on use of wedges** • Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper **OR** 4 lines, 1 'out wedge' and 1 'in wedge': • For bond into paper, **ALLOW**:  • **ALLOW** following geometry:  <u>**Examiner's Comments**</u> Many candidates had a stab at identifying **C−F** but neglected to include equations for the three reactions described or to show

					relevant working. Most candidates recognised **C** as the ammoniacal copper(II) ion but the formula was frequently incorrect and correct attempts at a ligand substitution equation from $[Cu(H_2O)_6]^{2+}$ was rarely seen. Diagrams showing the *trans* isomer were attempted but often of poor quality due to incorrect linking. Candidates recognised **D** as being $CuSO_4$ but often did not identify **E** as Cu due to a lack of familiarity with this common disproportionation reaction. $Cu(OH)_2(s)$ was a common incorrect identification of **E**. Only the best responses described the oxidation number changes which made this a disproportionation reaction. **F** was identified by a percentage by mass calculation to determine an empirical formula and then by deduction to produce $Cu(NO_3)_2.3H_2O$. Having done this, many candidates did not give the relatively simple equation for reaction **3** between copper(II) oxide and dilute nitric acid. **Exemplar 2**

					 (d)* Three different reactions of copper compounds are described below. Reaction 1: Aqueous copper(II) sulfate reacts with excess aqueous … substitution reaction. A deep-blue solution is formed, cont… complex ion, C, which is a *trans* isomer. Reaction 2: Copper(I) oxide reacts with hot dilute sulfuric acid in … reaction. A blue solution, D, and a brown solid, E are form… Reaction 3: Copper(II) oxide reacts with warm dilute nitric acid in a ne… to form a blue solution. Unreacted copper(II) oxide is … solution is left overnight in an evaporating basin. A hydrated salt, F, crystallises, with the percentage compo… Cu, 26.29%; H, 2.48%; N, 11.59%; O, 59.63%. Identify C–F by formulae or structures, as appropriate. Include equations, any changes in oxidation number, and working. Additional answer space if required. This exemplifies how considered structuring of candidate responses can enhance their clarity. The clear labelling of C-F in the response, along with numbering which corresponds to the reactions in the question stem, make the candidate's line of reasoning easy to follow. The underlining and annotations in the question stem show good practice in picking out and interpreting key information.
			Total	**8**	
1 0	a		*Please refer to the marking instructions on page 5 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** A comprehensive conclusion using all data to obtain correct formulae for **A, B, C** and **D** **AND** optical isomers shown *There is a well-developed line of reasoning which is clear and logically structured with use of 3D structures for both optical isomers of* ***C****, use of wedges and bonding to N.* *The information presented is relevant and substantiated.*	6	**Indicative scientific points may include:** **1. Formula of anhydrous complex B** $NiC_6N_6H_{24}Cl_2$ *Example of working* Ni : C : N : H : C… $= \frac{18.95}{58.7} : \frac{23.25}{12.0} : \frac{27.12}{14.0} : \frac{7.75}{1.00} : \frac{2…}{3…}$ ***There may be other methods***

Level 2 (3–4 marks)
Reaches a sound conclusion for the formula of **B**
AND
obtains the correct formula of the hydrated complex **A**
OR a 3D diagram of one optical isomer of cation **C**

There is a line of reasoning and supported by some evidence. Calculations are clear and can be followed to obtain correct conclusions. 3D diagram, if present, should use wedges mostly correctly.
*Formula of **A** to show water separately or formula of **C** to show ligands separately, as appropriate.*

Level 1 (1–2 marks)
Reaches a simple conclusion to obtain the correct formula of anhydrous complex **B** **OR** shows that **A** contains $2H_2O$

There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant. Attempts more than one part of the problem.

0 marks *No response or no response worthy of credit.*

2. Formula of hydrated complex A
$NiC_6N_6H_{24}Cl_2{\bullet}2H_2O$ **OR**
$NiC_6N_6H_{24}Cl_2(H_2O)_2$
Example of working

n(anhydrous salt) = $\frac{7.433}{309.7}$ = 0.02400

$n(H_2O)$ = $\frac{0.864}{18.0}$ = 0.04800 (mol) ✓

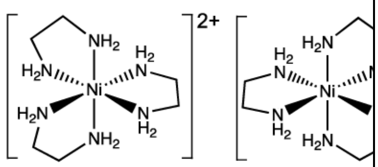
There may be other methods

3. Formula of cation C
$[NiC_6N_6H_{24}]^{2+}$ **OR**
$[Ni(H_2NCH_2CH_2NH_2)_3)]^{2+}$
(could be in structures
2+ charge can be shown on cation **OR** optical isomers (i.e. seen somewhere)

- **Bidentate ligand D**

$H_2NCH_2CH_2NH_2$ or displayed so that structure is clearly unambiguous.

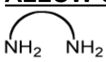
- **Optical isomers**

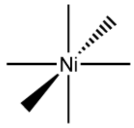
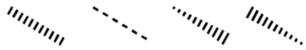


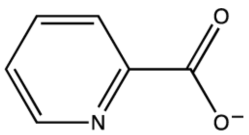
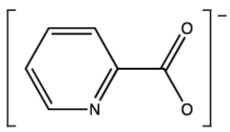
Accuracy of structures

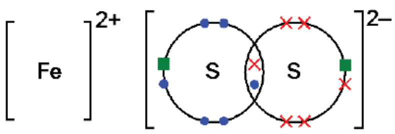
Bonding shown from Ni to N of $H_2NCH_2CH_2NH_2$
ALLOW $CH_3CH(NH_2)_2$ for ligand
For $H_2NCH_2CH_2NH_2$ in optical isomers,

<u>**ALLOW** C–C without Hs and</u>

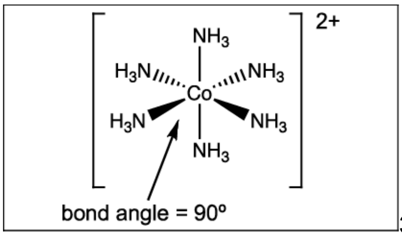
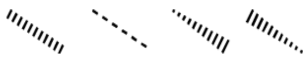
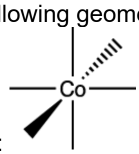


					Each structure to contain 2 ‘out wedges’, 2 ‘in wedges’ and 2 lines in plane of paper **OR** 4 lines, 1 ‘out wedge’ and 1 ‘in wedge’:  Bond into paper can be shown as:  **Examiner’s Comments** This was the second extended response question. Most candidates were able to make a start on this response and found the formula of **B.** A significant number of candidates assumed the bidentate ligand **D** to be $H_2NCH_2CH_2NH_2$ and worked backwards to identify **C.** Having identified **C,** the drawing of optical isomers proved relatively straightforward. Many strong candidates omitted to determine the formula of **A** or realised quite late on within their extended response that this was required.
	b	i	$CuCl_4^{2-}$ **OR** $[CuCl_4]^{2-}$ ✓ *yellow solution* $Cu(OH)_2$ ✓ *pale blue precipitate* $[Cu(NH_3)_4(H_2O)_2]^{2+}$ ✓ *deep blue solution* CuI ✓ *white solid* I_2 ✓ *brown solution*	5	**ALLOW** $Cu(Cl)_4^{2-}$ **ALLOW** $Cu(OH)_2(H_2O)_4$ Brackets required for $[Cu(NH_3)_4(H_2O)_2]^{2+}$ **NOTE:** Take great care to check that subscripted numbers and brackets are correct **Examiner’s Comments** The identification and recall of transition element compounds

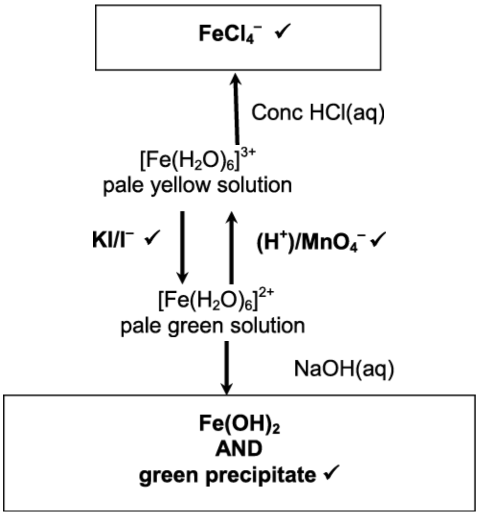
					and ions was not done well. Most candidates knew the yellow solution to be $CuCl_4^{2-}$ and the majority suggested the brown solution was I_2. The formula of the blue precipitate $Cu(OH)_2$ was less well known and only a small minority were able to identify the deep blue solution and white solid as $[Cu(NH_3)_4(H_2O)_2]^{2+}$ and CuI respectively.
		ii	*Reaction 1:* ligand substitution ✓ *Reaction 2:* redox ✓	2	**ALLOW** ligand exchange **ALLOW** reduction **AND** oxidation **ALLOW** precipitation **Examiner's Comments** Ligand substitution was well known but redox was less frequently seen. However, as reaction 2 formed a precipitate, precipitation was accepted as an alternative answer.
			Total	**13**	
11		i	 ✓	**1**	**ALLOW** brackets around structure with negative charge outside, i.e.  **ALLOW** ring (Kekulé structure) **Examiner's Comment:** Most candidates identified the skeleton of the ligand. However, this was often drawn without the minus sign on the COO^- or with an additional minus sign on the nitrogen.
		ii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **If answer = 1.61×10^{-3} award 2 marks** M = 418(.0) (g mol^{-1}) **OR** n(Cr) = 3.85×10^{-6} (mol) ✓ Mass = $3.85 \times 10^{-6} \times 418.0 = 1.61 \times 10^{-3}$ g ✓	**2**	**Note:** $\frac{200 \times 10^{-6}}{52.0} = 3.85 \times 10^{-6}$ (at least 3 SF) **ALLOW ECF** from incorrect M **OR** n(Cr)

					ALLOW 3 SF up to calculator value correctly rounded **For 5a(i)–(iv) IGNORE** poor connectivity to SH groups *Given in question* **Examiner's Comment:** Most candidates calculated the amount of chromium correctly as 3.85×10^{-6} mol. The second mark required this value to be multiplied by the molar mass of the complex. Success here was dependent on obtaining the correct molar mass of 418 g mol^{-1}. Candidates scored better here than in 4(c)(i). Answer: 1.61×10^{-3} g
			Total	**3**	
12		i	$1s^22s^22p^63s^23p^63d^6$ ✓	1	
		ii	 • Electrons for each S atom must be shown differently, e.g. • for left–hand S and × for right hand S • Two 'extra' electrons shown with different symbol (as a square in diagram above) with one square on each S atom. **MARKING** 1 covalent bond between two S atoms with • **AND** × ✓ Rest of structure correct including 2 extra electrons ✓	2	**IGNORE any outer electrons shown on Fe** Electrons donated by Fe **must** be different. **ALLOW** dative covalent bond for covalent bond using two dots **OR** 2 crosses for 1st mark 2nd mark will then have the 2 extra electrons on the S atom that has donated the electrons for the dative covalent bond.

			Total	**3**	
13	a		$n(H_2O)$ = 27.55/18.0 = 1.5306 (mol) ✓ $n((NH_4)_2Fe(SO_4)_2)$ = 72.45/284.0 = 0.2551 (mol) ✓ whole number ratio of $(NH_4)_2Fe(SO_4)2$: H_2O = 0.2551 : 1.5306 = 1 : 6 **OR** x = 6 ✓	3	**If there is an alternative answer, check to see if there is any ECF credit possible** **ALLOW** calculator value or rounding to two significant figures or more but **IGNORE** 'trailing zeroes' if wrong *M* produces such numbers throughout. **ALLOW ECF** If no working, **ALLOW** 1 mark for *x* = 6.
	b	i	To neutralise acidic soil ✓	1	
		ii	*Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** Describes practical details of tests and observations that allows all four ions to be identified **AND** Attempts associated equations, with most correct. *There is a well-developed line of reasoning and the method is clear and logically structured. The information presented is relevant and substantiated by observations from the tests described and practical details.* **Level 2 (3–4 marks)** Describes most practical details of tests including the observations that allows most ions to be identified **AND** Attempts associated equations, with some correct. *There is a line of reasoning presented and the method has some structure. The information presented is in the most-part relevant and supported by some evidence of observations from the tests described but practical details may be absent.* **Level 1 (1–2 marks)** Describes some of the practical details of tests and observations would only allow some ions to be identified. **OR** Attempts associated equations, with some correct. *The information is basic and the method lacks structure. The information is supported by limited evidence of the observations, the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	6	**Indicative scientific points may include** **Practical details:** • Sample stirred with water and mixture filtered. • SO_4^{2-}, Fe^{2+}, NH_4^+ tests on filtrate. • CO_3^{2-} test on residue or garden product **Tests and associated equations:** CO_3^{2-} test: *Test:* Add nitric acid. *Observation:*effervescence. *Equation:* $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$ ***ALLOW*** $CO_3^{2-} + 2H^+ \rightarrow CO_2 + H_2O$ ***OR*** overall equation of $CaCO_3$ and an acid. SO_4^{2-}test: Add $BaCl_2(aq)/Ba(NO_3)_2(aq)/Ba^{2+}(aq)$. Observation: white precipitate. Equation: $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$ Fe^{2+} test: Test: Add NaOH(aq) Observation: green precipitate

					Equation: Fe^{2+} + $2OH^-$ → $Fe(OH)_2$ NH_4^+ test: *Test:* Add NaOH(aq) and warm *Observation:* gas turns red litmus indicator blue *Equation:* $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$
	c	i	Equation: $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$ ✓ *State symbols required* Observation: Blue precipitate ✓	2	**ALLOW** $[Cu(H_2O)_6]^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(H_2O)_4(OH)_2(s) + 2H_2O(l)$ **ALLOW** blue solid
		ii	Coordinate/dative covalent bonds between protein and Cu^{2+}/Cu ✓ N atoms **OR** O atoms in protein donate electron pairs ✓	2	
			Total	**14**	
14		i	$[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H^2O$ ✓ ligand substitution ✓	2	**ALLOW** ligand exchange
		ii	 3 −D Shape ✓ bond angle 90 ° ✓ Bonds **must** be to N of NH_3 ligands	2	**IGNORE** charges (**anywhere**) and labels (even if wrong) Square brackets **NOT** required Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper **OR** 4 lines, 1 'out wedge' and 1 'in wedge': For bond into paper, **ALLOW:**  **ALLOW** following geometry throughout: 
		iii	**Empirical formula of complex D** Co : N : H : Cl $\frac{22.03}{58.9} : \frac{31.41}{14.0} : \frac{6.73}{1.00} : \frac{39.83}{35.5}$ **OR** 0.374 : 2.24 : 6.73 : 1.12 ✓	4	

			= 1 : 6 : 18 : 3 = $CoN_6H_{18}Cl_3$ ✓ **complex ion C** $[Co(NH_3)_6]^{3+}$ ✓ **complex D** $[Co(NH_3)_6]^{3+}[Cl^-]_3$ ✓		Correct empirical formula subsumes previous mark **ALLOW** $[Co(NH_3)_6]^{3+}$ $3Cl^-$
		iv	**Half equations** $[Co(NH_3)_6]^{2+} \rightarrow [Co(NH_3)_6]^{3+} + e^-$ ✓ $H_2O_2 + 2e^- \rightarrow 2OH^-$ ✓ **Overall equation** $2[Co(NH_3)_6]^{2+} + H_2O_2 \rightarrow 2[Co(NH_3)_6]^{3+} + 2OH^-$ ✓	1	**ALLOW** multiples throughout **ALLOW** $H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$ **ALLOW** $2[Co(NH_3)_6]^{2+} + H_2O_2 + 2H^+ \rightarrow$ 2[Co(N
			Total	**11**	
15		i	**3** MnO_4^{2-} + **4** $H^+ \rightarrow 2\ MnO_4^-$ + MnO_2 + **2** H_2O ✓	1	**ALLOW** 1 in front of MnO_2
		ii	**In acidic conditions** (Concentration of) H^+ increases **AND** equilibrium (position) shifts to the right to reduce concentration of H^+/remove H^+ ✓ **In alkaline conditions** OH^- reacts with H^+ **AND** equilibrium (position) shifts to the left to increase concentration of H^+/add H^+ ✓	2	**ALLOW** $H^+ + OH^- \rightarrow H_2O$
			Total	**3**	
16		i	$1s^22s^22p^63s^23p^63d^6$ ✓ Look carefully at $1s^22s^22p^63s^23p^6$ − there may be a mistake	1	**ALLOW** $4s^0$ before or after 3d, i.e. $1s^22s^22p^63s^23p^6$**$4s^03d^6$** **DO NOT ALLOW** [Ar] as shorthand for $1s^22s^22p^63s^23p^6$ **ALLOW** upper case D, etc and subscripts, e.g. ......$3D_{10}$

					IGNORE an extra $1s^2$ after prompt on answer line
		ii		4	Check correct 1− charge **ALLOW** brackets, e.g. $[FeCl_4]^-$ **For** I^-, **ALLOW** SO_2 , $(H^+)/Zn$ **For** MnO_4^-, **ALLOW** H_2O_2 , $(H^+)/Cr_2O7^{2-}$, Cl_2 **For** $Fe(OH)_2$ **ALLOW** $Fe(OH)_2(H_2O)_4$ For colour, **ALLOW** any colour that describes green
			Total	**5**	
17		i	**IGNORE** any charges shown within complexes (treat as rough working) **Complex ion C**: $[Ni(H_2O)_6]^{2+}$ ✓ **Solid D**: $Ni(OH)_2$ ✓ **Complex ion E**: $[Ni(CN)_4]^{2-}$ ✓	3	**ALLOW** +2 and −2 for charges Square brackets required **ALLOW** $Ni(H_2O)_4(OH)_2$ $(H_2O)_4$ and $(OH)_2$ in any order **IGNORE** any square brackets Square brackets required **TAKE CARE** for round brackets within complex ion, i.e. (H_2O), (OH) and (CN) **Examiner's Comments** The majority of candidates obtained all three marks. Where marks were lost, it was often for

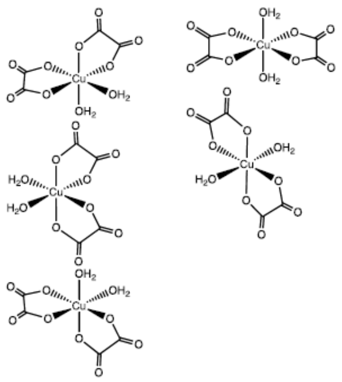
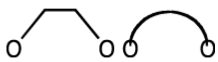
					missing or incorrect charges (e.g. $[Ni(CN)_4]^{2+}$), and poor use of brackets (e.g. $Ni(OH_2)$ and $[NiCN_4]^{2+}$). $Ni(OH)_2(H_2O)_4$ was often seen and was credited.
		ii	**Mark independently of 7(a)(i)** **ALLOW** +2 and −2 for charges **IGNORE** any charges shown within complexes (treat as rough working) $Ni^{2+} + 2OH^- \rightarrow Ni(OH)_2$ ✓ Type of reaction: precipitation ✓ **INDEPENDENT of equation** $[Ni(H_2O)_6]^{2+} + 4CN^- \rightarrow [Ni(CN)_4]^{2-} + 6H_2O(l)$ ✓ Type of reaction: ligand substitution ✓ **INDEPENDENT of equation**	4	**For equations: IGNORE** state symbol (even if wrong) Square brackets **not** required for $Ni(OH)_2$ **ALLOW** $[Ni(H_2O)_6]^{2+} + 2OH^- \rightarrow [Ni(H_2O)_4(OH)_2] + 2H_2O$ **ALLOW** $[Ni(H_2O)_6]^{2+} + 2OH^- \rightarrow Ni(OH)_2 + 6H_2O$ **ALLOW** $NiSO_4(aq) + 2OH^-(aq) \rightarrow Ni(OH)_2(s) + SO_4^{2-}(aq)$ **ALLOW** $NiSO_4(aq) + 2KOH(aq) \rightarrow Ni(OH)_2(s) + K_2SO_4(aq)$ **ALLOW** acid / base **OR** neutralisation **OR** deprotonation **ONLY IF** $[Ni(H_2O)_6]^{2+}$ **AND** $[Ni(H_2O)_4(OH)_2]$ used **ALLOW** precipitate **ALLOW** $[Ni(H_2O)_6]^{2+} + 4KCN \rightarrow [Ni(CN)_4]^{2-} + 6H_2O + 4K^+$ **LOOK** at formulae for **E** from **7(a)(i)** (copied at bottom) **ALLOW ECF** in **7aii** Equation for no round brackets around CN, i.e. $[NiCN_4]^{2-}$ in **7a(i)** This is the only **ECF** allowed from **7ai** structures. **ALLOW** ligand exchange **Examiner's Comments** Provided that correct formulae had been obtained in (a)(i), correct equations often followed, although marks were again lost by careless uses of charge and brackets, and unbalanced equations. The types of reaction were usually correct.
			Total	**7**	

18	a		Cu^{2+}: ($1s^2$) $2s^22p^63s^23p^63d^9$ ✓ Cu^+: ($1s^2$) $2s^22p^63s^23p^63d^{10}$ ✓	2	**IGNORE** repeated $1s^2$ after $1s^2$ prompt on answer line **ALLOW** $4s^0$, either before or after 3d **ALLOW** upper case D, etc and subscripts, e.g.......$3S_23P^6$ **DO NOT ALLOW** [Ar] as shorthand for $1s^22s^22p^63s^23p^6$ **Examiner's Comments** The responses seen were very mixed. Able candidates scored the two marks easily but many errors were seen, particularly by removal of 3d electrons rather than 4s electrons from copper atoms to give the electron configurations of the ions (especially for Cu^+ in CuI).
	b		**IGNORE** any charges shown within formulae (treat as rough working) $CuCO_3 + 2HCOOH \rightarrow Cu(HCOO)_2 + H_2O + CO_2$ **OR** $CuO + 2HCOOH \rightarrow Cu(HCOO)_2 + H_2O$ **OR** $Cu(OH)_2 + 2HCOOH \rightarrow Cu(HCOO)_2 +$ **2**H_2O ✓	1	**IGNORE** state symbols In formula of HCOOH / HCOO, **ALLOW** H, C and O in **ANY** order **ALLOW** H_2CO_3 for H_2O and CO_2 in carbonate equation **ALLOW** $(HCOO)_2Cu$ for $Cu(HCOO)_2$ **DO NOT ALLOW** equation with $CuSO_4$ **Examiner's Comments** Most candidates attempted an equation using CuO, $Cu(OH)_2$ or $CuCO_3$. Marks were then sometimes lost by not balancing the equation. It was not uncommon to see equations using $CuSO_4$ or $CuCl_2$ as reactant and consequently this mark was often not awarded.
	c		$2Cu^{2+} + 4I^- \rightarrow 2CuI$**(s)** $+ I_2$ ✓ State symbol for CuI(s) **ONLY** required	1	**ALLOW** multiples, e.g. $Cu^{2+} + 2I^- \rightarrow CuI$**(s)** $+ \frac{1}{2}I_2$ **IGNORE** other state symbols, even if incorrect **Examiner's Comments**

					This equation proved to be much more difficult than in **8(b)**, with only the best candidates producing a correctly balanced equation. As with **4(c)** and **7(b)(iii)**, equations were often unbalanced in terms of charge and oxidation number.
	d		Starch ✓ Blue / black to colourless / white ✓ **MARK INDEPENDENTLY**	2	**IGNORE** 'brown' in composite colour with blue or black, i.e. **ALLOW** blue / brown to colourless **ALLOW** black / brown to colourless **DO NOT ALLOW** just 'it turns colourless / is decoloured' *Initial colour required* **IGNORE** clear for colourless **Examiner's Comments** Most candidates seemed unaware that starch is used to identify the end point in iodine–thiosulfate titrations. Even when starch was given, the colour change was often incorrect. Random responses were seen to this part, e.g. methyl orange, phenolphthalein, potassium manganate and sodium thiosulfate.
	e		**WORKING REQUIRED** Correct answer: x = 4 required evidence of working .... $n(S_2O_3^{2-})$ **OR** $n(Cu^{2+}) = \frac{0.0420 \times 23.5}{1000} = 9.87 \times 10^{-4}$ (mol) ✓ In 250.0 cm^3 solution, $n(Cu^{2+}) = 9.87 \times 10^{-3}$ (mol) ✓ $M(Cu(HCOO)_2 \cdot 4H_2O) = \frac{2.226}{9.87 \times 10^{-3}} = 225.5$ ($g\ mol^{-1}$) ✓ $\boldsymbol{x}(H_2O)$ has mass of 225.5 − $M(Cu(HCOO)_2)$ = 225.5 − 153.5 = 72(.0) ✓ $\boldsymbol{x} = \frac{72(.0)}{18(.0)} = \mathbf{4}$ **WHOLE NUMBER** needed	5	***FULL ANNOTATIONS MUST BE USED*** .... At least **3 SF** required throughout *Alternative approach for final 3 marks based on mass:* mass $Cu(HCOO)_2 = 9.87 \times 10^{-3} \times 153.5 = 1.515$ g ✓ $n(H_2O) = \frac{2.226 - 1.515}{18(.0)} = \frac{0.711}{18(.0)} = 0.$ $\boldsymbol{x} = \frac{0.0395}{9.87 \times 10^{-3}} = 4$ ✓

			AND evidence of working ✓		**ALLOW** $Cu(HCOO)_2 \bullet 4H_2O$ .... **COMMON ERRORS for 4 marks** ***x*** = 117 (calc 116.78) *Use of 9.87 × 10⁻⁴ (no scaling × 10) → M* = 2255.319 ***x*** = 17 (calc 16.53) 4 marks *Use of 4.935 × 10⁻⁴ (Use of 0.5 × 9.87 × 10⁻³)* Check $n(Cu^{2+})$ for other **ECF**s Check for **ECF**s from incorrect *M*(anhydr salt) Actual = 153.5 **Examiner's Comments** Many candidates were on firm territory with a redox titration problem. The majority went through a well-rehearsed sequence of steps to obtain all five marks for showing that x was 4. Where '4' had not been obtained, marks could still be awarded for intermediate working if correct. Answer: x = 4
			Total	**11**	
19	a		**IGNORE** any charges shown within complexes (treat as rough working) **Formulae** **2 marks** $[Cu(NH_3)_4(H_2O)_2]^{2+}$ ✓ $[CuCl_4]^{2-}$ ✓ **Colours** **1 mark** blue **AND** yellow ✓ *Mark independently of formulae*	3	For charges, **ALLOW** +2 and −2 Square brackets **required**, i.e. **DO NOT ALLOW** $Cu(NH_3)_4(H_2O)_2^{2+}$ **ALLOW** Ligands in any order **ALLOW** $CuCl_4^{2-}$ i.e. no brackets **OR** $Cu(Cl)_4^{2-}$ For $CuCl_4^{2-}$, **ALLOW** green—yellow **OR** yellow—green **DO NOT ALLOW** green For $[Cu(NH_3)_4(H_2O)_2]^{2+}$ **DO NOT ALLOW** pale blue, light blue **DO NOT ALLOW** precipitate with blue **OR** yellow

					Examiner's Comments This question assessed complex ions of transition elements. Although a relatively gentle introduction to the paper, the question discriminated well. This question required knowledge and understanding of complex ions formed in ligand substitution reactions of aqueous Cu^{2+} ions. Well-prepared candidates usually collected the three marks with comparative ease. For the complex ions, common errors included $[Cu(NH_3)_6]^{2+}$ instead of $[Cu(NH_3)_4H_2O)_2]^{2+}$ and incorrect charges (e.g. $CuCl_4^-$). The observations were well known although green, rather than yellow, was often seen for $CuCl_4^{2-}$.
	b	i	**Donates two** electron **pairs** to a metal ion / metal / Cu^{2+} **AND** forms **two** coordinate **bonds** to a metal ion / metal / Cu^{2+} ✓	1	**ALLOW** lone pairs for electron pairs **ALLOW** molecule / atom / ion / substance for 'ligand' **ALLOW** dative (covalent) bonds for coordinate bonds **ALLOW** transition element for metal **Two is needed once only** e.g. **Donates two** electron **pairs** to form coordinate **bonds** to a metal ion / metal / Cu^{2+} **Donates** electron **pairs** to form **two** coordinate **bonds** to a metal ion / metal / Cu^{2+} **DO NOT ALLOW** donates **two** electron pairs to form **one / a** coordinate bond **Examiner's Comments** This question assessed complex ions of transition elements. Although a relatively gentle introduction to the paper, the question discriminated well.

					Most candidates obtained this mark in terms of donation by two electron pairs to a metal ion to form two coordinate or dative covalent bonds. Some candidates omitted donation, reference to a metal ion, or the formation of coordinate bonds.
		ii		3	***FULL ANNOTATIONS MUST BE USED*** .... **2 marks**: one for each correct isomer ✓ ✓ **TAKE CARE**: structures may be in different orientations and in different order **IF BOTH** isomers are 'correct', but O connectivity wrong, **AWARD** 1 mark for both structures **Check** H_2O ligands carefully for connectivity **ALLOW** H_2O reversed shown as — O_2H **IGNORE** charges (**anywhere**) .... **NOTE**: For each structure, **ALL** O atoms must be shown **AND** For $(COO^-)_2$, **ALLOW** skeletal, structural or displayed formula **DO NOT ALLOW** structures such as those shown below  ....
		ii			**1 mark**: for whole of 2nd row for whole of 'Type' row i.e. (cis **AND** optical) **AND** trans only **Examiner's Comments** This question assessed complex

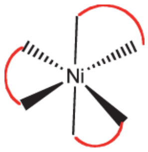
					ions of transition elements. Although a relatively gentle introduction to the paper, the question discriminated well. Candidates were required to draw accurate diagrams of stereoisomers of $[Cu(COO)_2(H_2O)_2]^{2-}$ and to classify these. The examiners were impressed with the accuracy of the diagrams seen. The inclusion of a 3D template and structure of one of the stereoisomers gave candidates a good indication of what was required. Unfortunately, marks were lost by showing the same stereoisomer twice, omitting O atoms from the COO^{2-} ligands or poor connectivity of the H_2O ligands. Many candidates did not identify one of the stereoisomers as being both *cis* and optical.
		iii	$CuC_4H_4O_{10}{}^{2-}$ Formula ✓ 2— charge ✓ **MARK formula and charge INDEPENDENTLY**	2	**Empirical** formula essential, e.g. **DO NOT ALLOW** $Cu(COO)_2(H_2O)_2$ for formula mark **ALLOW** any order of elements in formula **ALLOW –** 2 for charge **Examiner's Comments** This question assessed complex ions of transition elements. Although a relatively gentle introduction to the paper, the question discriminated well. In the formula, the majority of candidates showed the correct 2− charge but many failed to show an empirical formula. The main problem was use of a structural formula instead of the empirical formula: $CuC_4H_4O_{10}$. Candidates showing an empirical formula often omitted one of the ligand atoms, with C the commonest omission. The

					number of each atom also proved problematic, especially the O atoms.
			Total	**9**	
20	a	i i	Fe^{2+}: $1s^22s^22p^63s^23p^63d^6$ ✓ Br^-: $1s^22s^22p^63s^23p^63d^{10}4s^24p^6$ ✓	2	**ALLOW** 4s before 3d, ie $1s^22s^22p^63s^23p^64s^23d^{10}4p^6$ **ALLOW** $1s^2$ written after answer prompt (*ie* $1s^2$ twice) **ALLOW** upper case D, etc and subscripts, e.g. ……$4S_23D_1$ **ALLOW** for Fe^{2+} ……….$4s^0$ **DO NOT ALLOW** [Ar] as shorthand for $1s^22s^22p^63s^23p^6$ Look carefully at $1s^22s^22p^63s^23p^6$ − there may be a mistake **Examiner's Comments** Few candidates produced two incorrect electron configurations but there were many mistakes seen for either species. For Fe^{2+}, the commonest error was for loss of electrons from the 3d rather than 4s sub-shell of an Fe atom. For a Br^- ion, it was common to see the electron configuration of a Br atom. Surprisingly a common error was to see $4p^4$ rather than $4p^6$ from loss rather than gain of an electron. Only just over half the candidates showed two correct configurations so clearly more care is needed when answering.
		ii	With Cl_2 **AND** Br_2 **AND** I_2 products are Fe^{2+} (AND halide ion) $FeCl_2$ **AND** $FeBr_2$ **AND** FeI_2 ✓ **OR** Evidence that **two** electrode potentials have been compared for at least **ONE** reaction, ✓ e.g. Fe −0.44 **AND** Cl_2 +1.36 e.g. Iron has more / most negative electrode potential With Cl_2 **AND** Br_2, products are Fe^{3+} (AND halide ion) $FeCl_3$ AND $FeBr_3$?	3	**FULL ANNOTATIONS NEEDED** **ALLOW** products within equations (even if equations are not balanced) **IF stated, IGNORE reactants** **ALLOW** response in terms of positive 'cell reactions', e.g Fe + Cl_2 → Fe^{2+} + $2Cl^-$ E = (+)1.80 V **IGNORE** comments about reducing and oxidising agents and electrons

					Examiner's Comments The majority of candidates predicted that Fe would react with all three halogens to form Fe^{2+} ions, supported by equations and electrode potential data. Many simply stated that Fe has the more negative *E* value (or the halogens the more positive value). It was also common to see cell voltages used, such as +0.98 V for a reaction between iron and iodine. Both approaches were credited. The most able candidates correctly predicted that Fe^{2+} ions, initially formed from the reaction of iron with bromine and chlorine, would then be oxidised to Fe^{3+}. The best answers showed exceptional understanding. Candidates are advised to consider all the information supplied in a question as the majority had ignored completely the Fe^{3+}/Fe^{2+} data.
	b		**BOTH EQUATIONS REQUIRE IONS PROVIDED IN QUESTION** **Reaction 1: 2 marks** **1st mark** for **ALL CORRECT species** e.g.: $Fe^{2+} + NO_3^- + H^+ \rightarrow Fe^{3+} + NO + H_2O$ **2nd mark** for **CORRECT balanced equation** $3Fe^{2+} + NO_3^- + 4H^+ \rightarrow 3Fe^{3+} + NO + 2H_2O$ ✓✓ .... **Reaction 2: 1 mark** $[Fe(H_2O)_6]^{2+} + NO \rightarrow [Fe(H_2O)_5NO]^{2+} + H_2O$ ✓	3	**ALLOW** correct multiples throughout **ALLOW equilibrium signs in all equations** **For 1st mark, IGNORE** e^- present **Check** carefully for correct **charges** **Examiner's Comments** This part required candidates to interpret unfamiliar information to construct reactions for redox and ligand substitution reactions. Marks were sometimes wasted

					by incorrect balancing of equations or careless positioning of numbers. This part discriminated extremely well. For the redox equation, common mistakes were omission of species (such as H^+) failure to balance the redox reaction by charge (with the '3' balancing numbers for Fe^{2+} and Fe^{3+} being omitted) or inclusion of e^- on one side of the equation. For the ligand substitution equation, H_2O was sometimes omitted on the right-hand side and careless positioning of numbers, such as (H_2O_5) was sometimes seen. Candidates are recommended to check all species very carefully for any such slips.
			Total	**8**	
21	a	i	**Donates two** electron **pairs** (to a metal ion) **AND** forms **two** coordinate **bonds** (to a metal ion) ✓ ***NOTE****: Metal ion not required as Ni^{3+} is in the question*	1	**ALLOW** lone pairs for electron pairs **ALLOW** dative (covalent) bonds for coordinate bonds **TWO** is only needed once, e.g. **Donates two** electron **pairs** to form coordinate **bonds** **Donates** electron **pairs** to form **two** coordinate **bonds** **Examiner's Comments** Most candidates obtained this mark in terms of donation by two electron pairs to form two coordinate or dative covalent bonds. Some candidates omitted donation or formed one coordinate bond only.
		ii	$C_3H_{10}N_2$ ✓	1	**ALLOW** in any order **IGNORE** structure **Examiner's Comments** Most candidates were able to identify the three bidentate ligands in $C_9H_{30}N_6Ni^{3+}$ and the

					correct response of $C_3H_{10}N_2$ was commonly seen. The question asked for a molecular formula and structural or other formulae were not credited. Weaker candidates often responded with $C_9H_{30}N_6$.
		iii	**MARK INDEPENDENTLY** ……………………………………………………… $H_2NCH_2CH_2CH_2NH_2$ ✓ Each N **OR** each NH_2 **OR** amine group has a lone pair / electron pair **OR** lone pairs shown on N atoms in structure ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **ALLOW** $H_2NCH_2CH(CH_3)NH_2$ **OR** $H_2NCH(CH_2CH_3)NH_2$ **ALLOW** secondary or tertiary diamines or mixture **IGNORE** complex ion FOR other examples, **CHECK** with TL **Examiner's Comments** Most candidates were able to produce a diamine of $C_3H_{10}N_2$. A displayed or semi-displayed formula was the commonest response seen with propane-1,3-diamine being the commonest isomer seen (any possible diamine of $C_3H_{10}N_2$ was credited). The role of the two nitrogen atoms in providing the electron pairs was usually described, although examiners also credited this feature if seen in the structure.
		iv	6 ✓	1	**Examiner's Comments** Most candidates responded correctly with a coordination number of 6 although there was the usual incorrect response seen of '3' from counting each bidentate ligand instead of the number of the coordinate bonds.
		v	3–D diagrams of **BOTH** optical isomers required for the mark	1	In this part, Charge **AND** Square brackets **NOT** required **IGNORE** N or attempts to draw structure of bidentate ligand

			 **AND**  ✓		Other orientations possible but all follow same principle with 2nd structure being a mirror image of the first **Examiner's Comments** In past sessions, candidates have been required to draw out stereoisomers and this question proved to be much more straightforward. Only the very weakest candidates were unable to complete the diagrams to provide two mirror image forms.
	b		*Quality of written communication* Observation must be linked to the correct **reaction** ***REACTIONS OF AQUEOUS Cu^{2+}*** ………………………………………………………… **REACTION OF Cu^{2+} with NaOH(aq)** **Correct balanced equation** $Cu^{2+}(aq) + 2OH^{-}(aq) \rightarrow Cu(OH)_2(s)$ ✓ state symbols **not** required **Observation** blue precipitate / solid ✓	2	***FULL ANNOTATIONS MUST BE USED THROUGHOUT*** **ALLOW some reactions for Cu^{2+} and some for Co^{2+}** **ALLOW equilibrium signs in all equations** **IGNORE any incorrect initial colours** **IGNORE state symbols** **IGNORE an incorrect formula for an observation** …………………………………… …………………… **ALLOW** $[Cu(H_2O)_6]^{2+} + 2OH^{-} \rightarrow Cu(OH)_2(H_2O)_4 + 2H_2O$ **ALLOW** full or 'hybrid' equations, e.g. $Cu^{2+} + 2NaOH \rightarrow Cu(OH)_2 + 2Na^{+}$ $[Cu(H_2O)_6]^{2+} + 2OH^{-} \rightarrow Cu(OH)_2 + 6H_2O$ $CuSO_4 + 2NaOH \rightarrow Cu(OH)_2 + Na_2SO_4$ **ALLOW** any shade of blue
			REACTION OF Co^{2+} WITH excess $NH_3(aq)$ **Correct balanced equation** $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$ ✓ **Observation** deep / dark blue (solution) ✓	2	**IGNORE initial precipitation of $Cu(OH)_2$** **IGNORE** $[Cu(NH_3)_4]^{2+}$ **ALLOW** royal blue, ultramarine blue or any blue colour that is clearly darker than for $[Cu(H_2O)_6]^{2+}$ **DO NOT ALLOW** deep blue precipitate for observation

			REACTION OF Cu^{2+} WITH HCl(aq) **Correct balanced equation** $[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$ ✓ **Observation** yellow (solution) ✓	2	**IGNORE** mention of different concentrations of HCl **ALLOW** $CuCl_4^{2-}$ i.e. no brackets **OR** $Cu(Cl)_4^{2-}$ **ALLOW** $[Cu(H_2O)_6]^{2+} + 4HCl \rightarrow [CuCl_4]^{2-} + 6H_2O + 4H^+$ **IGNORE** $Cu^{2+} + 4Cl^- \rightarrow CuCl_4^{2-}$ **ALLOW** green−yellow **OR** yellow−green **DO NOT ALLOW** yellow precipitate for observation
			Quality of written communication Observation must be linked to the correct **reaction** ***REACTIONS OF AQUEOUS Co^{2+}*** ……………………………………………………… **REACTION OF Co^{2+} with NaOH(aq)** **Correct balanced equation** $Co^{2+}(aq) + 2OH^-(aq) \rightarrow Co(OH)_2(s)$ ✓ state symbols **not** required **Observation** blue precipitate / solid ✓		***FULL ANNOTATIONS MUST BE USED THROUGHOUT*** **ALLOW some reactions for Cu^{2+} and some for Co^{2+}** **ALLOW equilibrium signs in all equations** **IGNORE any incorrect initial colours** **IGNORE state symbols** **IGNORE an incorrect formula for an observation** ……………………………………………………… **ALLOW** $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2(H_2O)_4 + 2H_2O$ **ALLOW** full or 'hybrid' equations, e.g. $Co^{2+} + 2NaOH \rightarrow Co(OH)_2 + 2Na^+$ $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2 + 6H_2O$ $CoSO_4 + 2NaOH \rightarrow Co(OH)_2 + Na_2SO_4$ **ALLOW** any shade of blue **IGNORE** changes in colour over time
			REACTION OF Co^{2+} WITH excess NH_3(aq) **Correct balanced equation** $[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$ ✓ **Observation** brown / yellow (solution) ✓		**IGNORE initial precipitation of $Co(OH)_2$** **ALLOW** any shade of brown or yellow **DO NOT ALLOW** brown / yellow precipitate for observation
			REACTION OF Co^{2+} WITH HCl(aq) **Correct balanced equation**		**IGNORE** mention of different concentrations of HCl

			$[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$ ✓ **Observation** blue (solution ✓		**ALLOW** $CoCl_4^{2-}$ i.e. no brackets **OR** $Co(Cl)_4^{2-}$ **ALLOW** $[Co(H_2O)_6]^{2+} + 4HCl \rightarrow [CoCl_4]^{2-} + 6H_2O + 4H^+$ **IGNORE** $Co^{2+} + 4Cl^- \rightarrow CoCl_4^{2-}$ **ALLOW** any shades of blue **DO NOT ALLOW** blue precipitate for observation **Examiner's Comments** This question assessed knowledge and understanding of precipitation and ligand substitution reactions of transition metal ions. The question discriminated extremely well between well-prepared and poorly-prepared candidates. The well-prepared often collected the full six marks with comparative ease. However, marks were sometimes squandered by incorrect balancing of equations (e.g. formation of $2H_2O$ rather than $4H_2O$ with NH_3), careless positioning of numbers (such as $Cu(OH_2)$ and $[Cu(H_2O_6)]^{2+}$) or omission of charges (such as $[Cu(NH_3)_4(H_2O)_2]$). The observations were very well known with yellow, rather than green, usually seen for $CuCl_4^{2-}$. It was sad to see the responses of poorly-prepared candidates that had clearly been invented in the exam. Often these scored no marks or perhaps one for remembering that copper(II) hydroxide is a blue precipitate. Cobalt tended to be the choice of weaker candidates. Some candidates mixed and matched between copper and cobalt and this approach was fully credited. For precipitation, the specification allows a simple equation in terms of $Cu^{2+}(aq)$ rather than complex ions. It was relatively common to see an equation for the precipitation reaction of $[Cu(H_2O)_6]^{2+}$ with hydroxide ions forming

					$[Cu(OH)_2(H_2O)_4]$ and this approach gained full credit if the equations were correctly balanced. The two equations for ligand substitution required complex ions throughout. It should be noted that the specification requires the complex ion $[Cu(NH_3)_4(H_2O)_2]^{2+}$ and the simpler representation of $[Cu(NH_3)_4]^{2+}$ was not credited. $[Cu(NH_3)_6]^{2+}$ was a common incorrect complex ion seen.
			Total	**12**	
2 2	a		$Fe_2O_3 + 3Cl_2 + 10OH^- \rightarrow 2FeO_4^{2-} + 6Cl^- + 5H_2O$ ✓✓ First mark for all 6 species Second mark for balancing	2	**ALLOW** multiples **ALLOW** oxidation half equation for two marks $Fe_2O_3 + 10OH^- \rightarrow 2FeO_4^{2-} + 5H_2O + 6e^-$ Correct species would obtain 1 mark − *question: equation for oxidation* **ALLOW variants forming H^+ for 1 mark, e.g:** $Fe_2O_3 + 3Cl_2 + 5OH^- \rightarrow 2FeO_4^{2-} + 6Cl^- + 5H^+$ $Fe_2O_3 + 3Cl_2 + 5OH^- \rightarrow 2FeO_4^{2-} + 5HCl + Cl^-$ **Examiner's Comments** The information needed to write the equation was largely within the information provided for step 1. In step 1, candidates were provided with three reactants and two of the products. They were also told that the reaction was carried out using an excess of hydroxide ions, so any potential H^+ ions produced would be neutralised to water. Only the very best candidates were able to interpret this information to score both marks for the correct equation. Many attempts seen did not start with iron(III) oxide. When arriving at a complete equation, candidates are recommended to check the overall charge on either side. This must balance, a feature not seen in the majority of

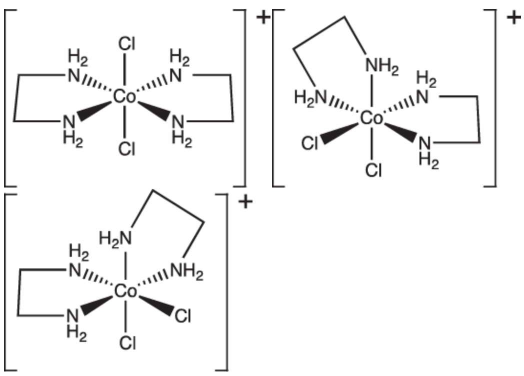
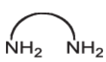
					responses. One mark was available for an equation with all species correct, including water as the third product, or a ‘correct’ equation but with H^+ produced.
	b		$Ba^{2+}(aq) + FeO_4^{2-}(aq) \rightarrow BaFeO_4(s)$ ✓	1	Balanced **ionic** equation **AND** state symbols required **DO NOT ALLOW** +2 or −2 for ionic charges **Examiner's Comments** As with 8(a), the relevant information was mostly included within the referenced part: step 2. The responses were very disappointing as the required equation is very similar to a simple precipitation reaction between silver and halide ions. The requirement for state symbols was clearly stated but often omitted from otherwise correct equations.
	c		**Reason can ONLY be correct from correct reducing agent** …………………………………… ***reducing agent***: I^- **OR** KI ✓ I^- adds / donates / loses electrons **AND** to FeO_4^{2-} **OR** to $BaFeO_4$ **OR** to Fe(VI) or to Fe(+6) ✓ ***ALLOW*** *Fe(6+)* ***OR*** *Fe^{6+}*	2	**IGNORE** H^+ **OR** acidified **ALLOW** iodide / potassium iodide but **DO NOT ALLOW** iodine **ALLOW** I^- loses electrons **AND** to form I_2 **ALLOW** Fe(6+) **OR** Fe^{6+} **Examiner's Comments** The majority of candidates identified iodide ions or potassium iodide as the oxidising agent. Iodine was often recognised as the product but the explanation was usually in terms of oxidation number despite the question asking for electrons – very much a case of reading the question. Precise language was also required as iodine and iodide are rather different, especially as iodine is the product. The best responses

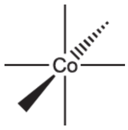
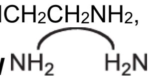
					discussed the species being reduced, $BaFeO_4$ or Fe(VI).
d			**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 51.8%, award **4 marks.** …………………………………… $n(S_2O_3^{2-})$ used = $0.1000 \times \frac{26.4}{1000} = 2.64 \times 10^{-3}$ (mol) ✓ $n(FeO_4^{2-})$ = ½ x 2/3 x $2.64 \times 10^{-3} = 8.8(0) \times 10^{-4}$ (mol) ✓ Mass $BaFeO_4$ in sample $= 8.8 \times 10^{-4} \times 257.1$ g = 0.226248 g ✓ % purity = $\frac{0.226248}{0.437} \times 100 = 51.8\%$ ✓ **MUST** be to **one** decimal place (in the question) …………………………………… As an alternative for the final two marks, **ALLOW**: Theoretical amount of $BaFeO_4 = \frac{0.437}{257.1} = 0.00170$ (mol) ✓ % purity = $\frac{8.8 \times 10^{-4}}{1.70 \times 10^{-3}} \times 100 = 51.8\%$ ✓	4	***FULL ANNOTATIONS MUST BE USED*** …………………………………… For alternative answers, look first at common **ECFs** below. Then check for **ECF** credit possible using working below **IF** a step is omitted but subsequent step subsumes previous, then award mark for any missed step …………………………………… **Working must be to at least 3 SF throughout until final % mark** **BUT** ignore trailing zeroes, ie for 0.880 allow 0.88 **ECF** answer above × ½ × 2/3 This mark may be seen in 2 steps via I_2 but the mark is for both steps combined **ECF** 257.1 × answer above **ECF** $\frac{\text{answer above}}{0.437} \times 100$ **ALLOW** 51.7% FROM 0.226 g $BaFeO_4$ (earlier rounding) …………………………………… **Common ECFs:** No × 2/3 for $n(FeO_4^{2-})$: % purity = 77.7%/77.6% 3 marks No ÷ 2 for $n(FeO_4^{2-})$: % purity = 25.9% 3 marks 24.6 used instead of 26.4: % purity = 48.2% 3 marks **Examiner's Comments** After the information-finding demands of parts (a)–(c), candidates were on much firmer territory here with a stock redox titration problem. Many candidates secured all 4 marks and most were able to obtain some marks along the way. The

					hardest mark was the step from the initial amount of $Na_2S_2O_3$ to the amount of $BaFeO_4$. Answer: 51.8%
	e		**gas**: O_2 ✓ **precipitate**: $Fe(OH)_3$ ✓ **equation**: $2FeO_4^{2-} + 5H_2O \rightarrow 1½O_2 + 2Fe(OH)_3 + 4OH^-$ **OR** $2FeO_4^{2-} + H_2O + 4H^+ \rightarrow 1½O_2 + 2Fe(OH)_3$ ✓	3	**DO NOT ALLOW** names **IGNORE** a balancing number shown before a formula **ALLOW** $Fe(OH)_3(H_2O)3$ **ALLOW** multiples **ALLOW** $2FeO_4^{2-} + 11H_2O \rightarrow 1½O_2 + 2Fe(OH)$ **Examiner's Comments** This part required candidates to construct an equation for an unfamiliar reaction. Candidates were reasonably competent in identifying the gas as O_2 and precipitate as $Fe(OH)_3$. Unfortunately, some responded with 'oxygen' despite the formulae being asked for in the question. The correct equation proved to be the hardest mark on the paper, being seen extremely rarely. As with the equation in 8(a), often the overall charge didn't balance on either side of the equation, a consideration that would have led to many more correct responses.
			Total	**12**	
23	a		(Transition element) has **an ion** with an incomplete / partiallyfilled d **sub-shell** / **d-orbital** ✓ Scandium / Sc and zinc / Zn are not transition elements ✓ *Electron configurations of ions* Sc^{3+} **AND** $1s^22s^22p^63s^23p^6$ ✓	6	***FULL ANNOTATIONS MUST BE USED*** .... **ALLOW** capital 'D' within definition **DO NOT ALLOW** d shell **ALLOW** if **ONLY** Sc and Zn are used to illustrate d block elements that are **NOT** transition elements This can be from anywhere in the overall response in terms of

			Zn^{2+} **AND** $1s^22s^22p^63s^23p^63d^{10}$ ✓ Sc^{3+} **AND** d **sub-shell** empty / **d orbital(s) empty** ✓ ***Note**: Sc^{3+} must be the **ONLY** scandium ion shown for this mark* Zn^{2+} **AND** d **sub-shell** full / **ALL d-orbitals** full ✓ ***Note**: Zn^{2+} must be the **ONLY** zinc ion shown for this mark*		Sc, Sc^{3+}, Zn, Zn^{2+} **OR** incorrect charges, i.e. only Sc^+, Sc^{2+}, Zn^+ In electron configurations, **IF** subscripts **OR** caps used, **DO NOT ALLOW** when first seen but credit subsequently **ALLOW** $4s^0$ in electron configurations **IGNORE** [Ar] **IGNORE** electron configurations for other Sc and Zn ions **ALLOW** for Sc^{3+}: Sc forms a 3+ ion; **ALLOW** Sc^{+3} **ALLOW** for Zn^{2+}: Zn forms a 2+ ion; **ALLOW** Zn^{+2} **ALLOW** Sc^{3+} has no d sub-shell **DO NOT ALLOW** 'd sub-shell is incomplete' *(in definition)* **DO NOT ALLOW** 'd sub-shell is incomplete' *(in definition)* **Examiner's Comments** The position of scandium as zinc and d-block elements that are not transition elements has been rarely assessed and some candidates had clearly not learnt this part of the specification. The examiners required a standard definition of a transition elements and an explanation of why scandium and zinc do not comply with this definition in terms of the electron configurations of the Sc^{3+} and Zn^{2+} ions and the empty and full d sub-shell of these two ions respectively. The well-prepared easily collected all 6 marks but it was sad to see marks wasted by responses that were clearly being made up during the examination (often in terms of any of the d- block elements in Period 4). Reasons for not obtaining marks included a definition in terms of elements

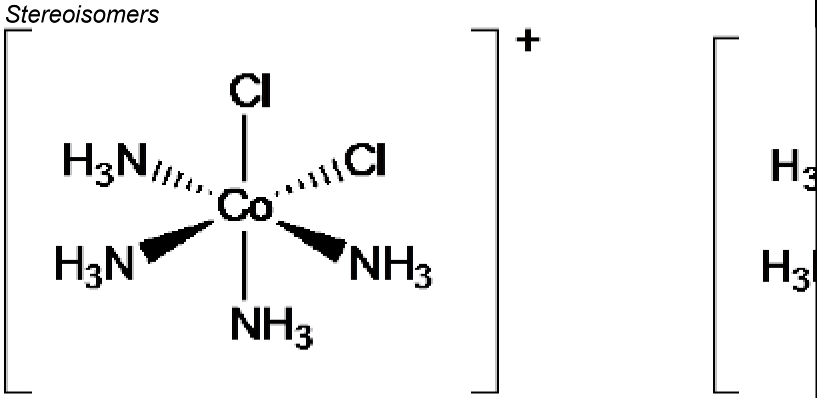
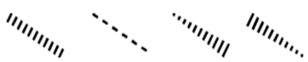
					rather than ions, shortened electron configurations using [Ar] (despite 'full' being asked for) and explanations that simply repeated the definition. Candidates are advised to prepare for the exam by learning all of the specification.
	b	i	Donates **two** electron / lone pairs to a metal ion **OR** Co^{3+} ✓ ***DO NOT ALLOW*** *metal (complex contains* Co^{3+}*)* Electron / lone pair on N **OR** NH_2 (groups) ✓	2	**ALLOW** 'forms two coordinate bonds / dative covalent / dative bonds' as an alternative for 'donates **two** electron / lone pairs' *Two is required for 1st marking point* *Two can be implied using words such as 'both' or 'each'* For metal ion, **ALLOW** transition (metal) ion Second mark is for the atom that donates the electron / lone pairs **ALLOW** both marks for a response that communicates the same using N as the focus: e.g. The two N atoms each donate an electron pair to metal ion **Examiner's Comments** Most candidates obtained at least one of the available two marks, usually for identifying the role of nitrogen, with its lone pair, as an electron pair donor. The commonest omission was the required coordinate bond formation to the transition metal ion.
		ii	$[Co(H_2NCH_2CH_2NH_2)_2Cl_2]^+$ ✓	1	Square brackets **AND** + charge required **DO NOT ALLOW** any charges included within square brackets **ALLOW** $[Co(C_2H_8N_2)_2Cl_2]^+$ **OR** $[CoC_4H_{16}N_4Cl_2]^+$ **ALLOW** structural **OR** displayed **OR** skeletal formula

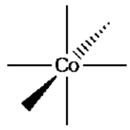
					OR mixture of the above (as long as unambiguous) **IGNORE** $[Co(en)_2Cl_2]^+$ *simplifies question* Within formula, **ALLOW** … .$(Cl)_2$, (Cl_2) **ALLOW** CO Within the context of the question, CO is Co **Examiner's Comments** Success depended on a systematic approach with both the number of ligands and the overall charge. The examiners did not allow formulae containing charges within the required square brackets as collectively the overall charge displayed would then be wrong. The commonest error seen was an incorrect overall charge, either as − or as 3+.
		iii	6 ✓	1	**Examiner's Comments** Most candidates responded correctly with a coordination number of 6 although there was the usual incorrect response seen of '4' from counting each ethanediamine ligand just once.
		iv	 Note: For each structure, **ALL** NH_2 groups must be shown **AND** bonding between Co **AND** N of NH_2. For $H_2NCH_2CH_2NH_2$, **ALLOW** C—C without Hs and  …………………………………… **IF** NH_2 shown without Hs, e.g. , penalise first time **ONLY** …………………………………… **IF ALL** 3 isomers are 'correct', but 2 x Cl **AND** no Ns, e.g.  **AWARD** 1 mark	3	***FULL ANNOTATIONS MUST BE USED*** ……………………………………… **IGNORE** charges (**anywhere**) and labels (even if wrong) Square brackets **NOT** required Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper **OR** 4 lines, 1 'out wedge' and 1 'in wedge': For bond into paper, **ALLOW**:  **ALLOW** following geometry throughout:

					 **TAKE CARE**: structures may be in different orientations. For $H_2NCH_2CH_2NH_2$, **ALLOW**  *(connectivity within 'loop' only)* **If Cl_2s are shown instead of Cl, penalise 1st time only** **Examiner's Comments** This type of question has been encountered on previous papers and candidates were generally comfortable with drawing stereoisomers. The examiners did require the connecting amine groups to be shown including bonding from the N atoms to the metal ion to full credit. Intermediate marks were available if H atoms or NH_2 groups had been omitted. In general, candidates displayed 3D diagrams very competently using 'in' and 'out' wedges. Some candidates did manage to repeat the *trans* isomer once or even twice. Most candidates displayed the cis optical isomers as clear mirror images and this strategy is recommended. A few candidates instead chose to rotate the whole structure and whether the second diagram was a different optical isomer or the same structure rotated was then largely down to luck.
	c	i	O_2 / oxygen **bonds** to Fe^{2+}/Fe(II) ✓ *Fe^{2+} / Fe(II) essential for 1st marking point*	2	**ASSUME that 'it' refers to oxygen** **ALLOW** O_2 binds to Fe^{2+} **OR** O_2 donates electron pair to Fe^{2+} **OR** O_2 is a ligand with Fe^{2+} **IGNORE** O_2 reacts with Fe^{2+} **OR**

			(When required,) O_2 substituted **OR** O_2 released ✓ *Fe^{2+} not required for 2nd marking point (e.g. **IGNORE** Fe)*		O_2 is around Fe^{2+} **ALLOW** bond to O_2 breaks when O_2 required **OR** H_2O replaces O_2 **OR** vice versa **ALLOW** CO_2 replaces O_2 **OR** vice versa **ALLOW** O_2 bonds / binds reversibly **Examiner's Comments** The majority of candidates secured one of the available two marks for describing ligand substitution between O_2 and either H_2O or CO_2. The second mark required a specific reference to the role of Fe^{2+}; this was often omitted with responses instead predominately discussing the role of haem or iron.
		ii	$(K_{stab} =)\ \frac{[HbO_2(aq)]}{[Hb(aq)]\ [O_2(aq)]}$ ✓ **ALL Square brackets essential**	1	**ALLOW** expression without state symbols *(given in question)* **Examiner's Comments** As with 3(a) the K_{stab} expression was shown correctly by almost all candidates, the only mistakes being the very occasional inverted expression or use of "+' within the denominator.
		iii	**Both marks require a comparison** Stability constant / K_{stab} value with CO is **greater** (than with complex in O_2) ✓ (Coordinate) bond with CO is **stronger** (than O_2) **OR** CO binds more strongly ✓	2	**IGNORE** (complex with) CO is more stable **ALLOW** bond with CO is less likely to break (than O_2) **OR** CO is a stronger ligand (than O_2) **OR** CO has greater affinity for ion / metal / haemoglobin (than O_2) **ALLOW** CO bond formation is irreversible **OR** CO is not able to break away **IGNORE** CO bonds more easily

					OR CO complex forms more easily **Examiner's Comments** The majority of candidates obtained both marks by following the cues in the question for an explanation in terms of CO having a greater bond strength and higher stability constant than O_2 with haemoglobin.
			Total	**18**	
24	a	i	$1s^22s^22p^63s^23p^63d^{10}4s^1$ ✓	1	**ALLOW** upper case S, P and D and subscripts, e.g. ……$3S_23P_63D_{10}$ **ALLOW** $4s^1$ before $3d^{10}$ **DO NOT ALLOW** [Ar] as shorthand for $1s^22s^22p^63s^23p^6$, i.e. **DO NOT ALLOW** [Ar]$3d^{\mathbf{8}}$ Look carefully at $1s^22s^22p^63s^23p^6$ − there may be a mistake
		ii	$n = \frac{95.0}{24000} = 3.96 \times 10^{-3}$ (mol) ✓ *Calculation of M* $M = \frac{m}{n} = \frac{254 \times 10^{-3}}{3.96 \times 10^{-3}} = 64.2$ **OR** 64.1 (g mol^{-1}) ✓ *Gas*: sulfur dioxide **OR** SO_2 ✓ *Equation* $Cu + 2H_2SO_4 \rightarrow CuSO_4 + SO_2 + 2H_2O$ ✓	4	**IF there is an alternative answer, check to see if there is any ECF credit possible using working below** Unrounded values give 64.2; Rounded to 3 SF gives 64.1 **ALLOW** $Cu + 2H^+ + H_2SO_4 \rightarrow CU^{2+} + SO_2 + 2H_2O$
	b	i	green solution: $Fe^{2+}(aq)$ **OR** $[Fe(H_2O)_6]^{2+}$ **AND** gas bubbles: $H_2(g)$ **AND** orange-brown solution: $Fe^{3+}(aq)$ **OR**$[Fe(H_2O)_6]^{3+}$ ✓ $Fe(s) + 2H^+(aq) \rightarrow Fe^{2+}(aq) + H_2(g)$ ✓ $4Fe^{2+}(aq) + O_2(g) + 4H^+(aq) \rightarrow 4Fe^{3+}(aq) + 2H_2O(l)$ ✓	3	State symbols are **not** required in this part **IGNORE**, even if incorrect **ALLOW** full equation: $Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$

		ii	orange solution: $Cr_2O_7^{2-}$ **AND** green solution (anywhere) Cr^{3+} **OR** $[Cr(H_2O)_6]^{3+}$ ✓ $2Cr^{3+}(aq) + H_2O(l) + 3H_2O_2(aq) \rightarrow Cr_2O_7^{2-}(aq) + 8H^+(aq)$ H^+, H_2O and e^- all cancelled ✓✓	3	State symbols are **not** required in this part **IGNORE**, even if incorrect **IGNORE** Cr(VI) *The question asks for species* **ALLOW** 1 mark for $H^+/H_2O/e^-$ not cancelled, e.g. $2Cr^{3+}(aq) + 7H_2O(l) + 3H_2O_2(aq) + 6H^+(aq) \rightarrow Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6H_2O(l)$ ✓
			Total	**11**	
25	a		Cr: $(1s^22s^22p^6)3s^23p^63d^54s^1$ Cr^{3+}: $(1s^22s^22p^6)3s^23p^63d^3$	2	**ALLOW** 4s before 3d, ie $1s^22s^22p^63s^23p^64s^13d^5$ **ALLOW** $1s^2$ written after answer prompt (*ie* $1s^2$ twice) **ALLOW** upper case D, etc and subscripts, e.g.…………..$4S_13D_5$ **ALLOW** for Cr^{3+} …………..$4s^0$ **DO NOT ALLOW** [Ar] as shorthand for $1s^22s^22p^63s^23p^6$ Look carefully at $1s^22s^22p^63s^23p^6$ – there may be a mistake.
	b		*Formula of complex ion **J*** Structures show correct ligands (4 NH_3 **AND** 2 Cl) **AND** 1+ charge (on at least one structure) *Stereoisomers*  *cis* **NOTE:** For each structure, bonding from Co must be to **N** of NH_3 *cis* and *trans* labels required for both structure marks. If structures are correct but labels are wrong way round or omitted, award 1 out of the 2 stereoisomer marks.	3	***FULL ANNOTATIONS MUST BE USED*** …………………………………………………… For two stereoisomer marks, **IGNORE** charges (**anywhere**) *Charge already credited within the 1st mark.* Square brackets **NOT** required Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper **OR** 4 lines, 1 'out wedge' and 1 'in wedge': For bond into paper, **ALLOW:** 

			TAKE CARE: structures may be in different orientations.		**ALLOW** following geometry throughout: 
	c	i	**A:** $Cr_2(SO_4)_3$ **B:** MnI_2 State symbols **not** required in equations (within observations). **C:** $Cr^{3+} + 3OH^- \rightarrow Cr(OH)_3$ **D:** $[Cr(H_2O)_6]^{3+} + 6NH_3 \rightarrow [Cr(NH_3)_6]^{3+} + 6H_2O$ **E:** $Mn^{2+} + 2OH^- \rightarrow Mn(OH)_2$ **F:** $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$ **G:** $Ag^+ + I^- \rightarrow AgI$	7	**Formulae required in question** **IGNORE** incorrect names **IGNORE** incorrect state symbols **ALLOW** $[Cr(H_2O)_6]^{3+} + 3OH^- \rightarrow Cr(OH)_3(H_2O)_3 + 3H_2O$ **ALLOW** $Cr(OH)_3(H_2O)_3 + 6NH_3 \rightarrow [Cr(NH_3)_6]^{3+} + 3H_2O + 3OH^-$ **ALLOW** $[Mn(H_2O)_6]^{2+} + 2OH^- \rightarrow Mn(OH)_2(H_2O)_4 + 2H_2O$
		ii	removes / reacts with carbonate / CO_3^{2-} **AND** carbonate forms a (white) precipitate	1	**Both** statements required for the mark **Note:** 2nd statement can be for Test 2 (Ba^{2+}) **OR** Test 3 (Ag^+)
		iii	**Test 2:** no difference **Test 3** gives a white precipitate by reaction with Cl^- **A:** white precipitate **AND** **B:** white / yellow ppt **OR** cream ppt **OR** paler yellow ppt	3	
		iv	Add **concentrated** ammonia / NH_3 **AND** yellow precipitate does **not** dissolve	1	**Concentrated** essential for NH_3
			Total	**17**	