Mark scheme – Redox and Electrode Potentials

Question				Answer/Indicative content	Marks	Guidance
1	a			**Comparison of E values** E of redox system **4** (MnO_4^-/Mn^{2+}) is more positive/less negative than E of redox systems **2** (HCOOH/HCHO) **OR 1** (CO_2/HCOOH)✓ **Equilibrium shift related to *E* values** More negative/less positive/system **2** (HCOOH/HCHO) **OR** system 1 (CO_2/HCOOH) shifts left **OR** Less negative/more positive/system 4 (MnO_4^-/Mn^{2+}) shifts right ✓ • **2 and 4** $2MnO_4^- + 5HCHO + 6H^+ \rightarrow 2Mn^{2+} + 5HCOOH + 3H_2O$ ✓ • **1 and 4** $2MnO_4^- + 5HCOOH + 6H^+ \rightarrow 2Mn^{2+} + 5CO_2 + 8H_2O$ ✓	4 (AO 3.1× 2) (AO 3.2× 2)	**IGNORE** higher/lower ALLOW Overall $E_{reaction}$ = (+)1.54V **OR** (+)1.62V For 'shifts left', **ALLOW** 'is oxidised' **OR** 'electrons are lost ' **OR** 'reducing agent' For 'shifts right', **ALLOW** 'is reduced' **OR** 'electrons are gained' **OR** 'oxidising agent' **IGNORE** state symbols **ALLOW** multiples **DO NOT ALLOW** un-cancelled species, e.g. H^+, on both sides **ALLOW** for 1 mark two balanced equations with uncancelled species. **ALLOW** combined equation for 2 marks: $4MnO_4^- + 5HCHO + 12H^+ \rightarrow 4Mn^{2+} + 5CO_2 +11H_2O$ **Examiner's Comments** Higher-attaining candidates described two oxidations starting from HCHO to end up with CO_2. Many candidates used the data correctly but stopped at the first oxidation to form HCOOH. Lower-attaining candidates did not state that the direction of reaction of redox equilibria is dependent on the relative negativity/positivity of the standard electrode potentials. Some candidates are still using higher/lower to compare the E cell values, and should be encouraged to instead use the phrasing 'more positive' or 'more negative'. Many candidates wrote a correct first equation, although some did not cancel down the H^+ and/or water.
	b			$2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow H_2O$ ✓ $1.34 + (-0.11) = (+)\underline{1.23}$ (V) ✓	2 (AO 2.6) (AO 2.2×1)	**IGNORE** state symbols **ALLOW** multiples
			Total		6	

2			$n(MnO_4^-)$ in titration $= 0.01 \times \dfrac{12.6}{1000} = 1.26 \times 10^{-4}$ ✓ $n(SO_3^{2-})$ in 25.0 cm^3 $= 1.26 \times 10^{-4} \times 2.5 = 3.15 \times 10^{-4}$ (mol) ✓ $n(SO_3^{2-})$ in 250 cm^3 $= 10 \times 3.15 \times 10^{-3} = 3.15 \times 10^{-3}$ (mol) ✓ mass Na$_2$SO$_3$ in 525 g meat $= 3.15 \times 10^{-3} \times 126.1 = 0.397$ (g) ✓ mass Na$_2$SO$_3$ in 1 kg of meat $= 0.397215 \times \dfrac{1000}{525} = 0.7566$ g **OR** 756.6 mg **AND** less than the maximum permitted level **OR** AW ✓	5 (AO 1.2×1) (AO 2.8×3) (AO 3.2×1)	**ALLOW** 3 SF or more throughout **ALLOW ECF** throughout Calculator = 0.397215 g **ALLOW** within range: 756 to 757 mg **ALLOW** 0.397 g<0.446 g per 525 g meat. **Examiner's Comments** This question asked the candidate to determine the amount of sodium sulfite in food. Many candidates gained full marks. Most candidates calculated the number of moles of MnO$_4$- and SO$_3^{2-}$. Some candidates calculated the mass in 525 g of meat, although some used the wrong Mr, e.g. 80, for the sulfite ion. The lower ability candidates did not process the scaling to 1 Kg.
		Total	**5**	

3			**Circuit**
			   Complete circuit **AND** voltmeter
			   AND salt bridge linking two half-cells ✓
			
			Half cells
			   Ag **AND** Ag$^+$ **AND** 1 mol dm^{-3} solution ✓
			
			   Pt **AND** H$^+$ **AND** MnO$_4^-$ **AND** Mn^{2+}
			   AND 1 mol dm^{-3} /equimolar solution ✓
				3
				(AO 3.4×1)
				
				(AO 1.2×1)
				
				(AO 1.2×1)
					Voltmeter must be shown **AND** salt bridge must be labelled
					ALLOW small gaps in circuit
					
					If species in **BOTH** half cells are correct but concentration of 1 mol dm^{-3} omitted,
					ALLOW 1 mark for **BOTH** half cells.
					
					ALLOW acidified as an alternative for H$^+$
					
					IGNORE stated pressure
					Not relevant here as no gas
					
					Examiner's Comments
					
					Most candidates drew a circuit containing a voltmeter and the silver half cell but very few candidates included the H+ in the MnO$_4$-/Mn^{2+} cell.

		Total	**3**	
4	i			3 (AO 2.6×3)	**All 3 marks are independent.** **IGNORE** charges/oxidation numbers shown around overall *equation*. *Treat as rough working* **ALLOW** overall equation shown with some or all ions that are present

			Overall equation AND state symbols: $M(s) + 2HCl(aq) \rightarrow MCl_2(aq) + H_2(g)$ ✓ **STATE SYMBOLS required in overall equation ONLY** **Half equations:** Oxidation $M \rightarrow M^{2+} + 2e^-$ ✓ Reduction $2H^+ + 2e^- \rightarrow H_2$ **OR** $H^+ + e^- \rightarrow \frac{1}{2}H_2$ ✓		e.g. (**with state symbols**) $M + 2H^+ \rightarrow M^{2+} + H_2$ $M + 2HCl \rightarrow M^{2+} + 2Cl^- + H_2$ $M + 2H^+ + 2Cl^- \rightarrow M^{2+} + 2Cl^- + H_2$ In half equations, **IGNORE** state symbols even is wrong BUT half equations MUST only have species that change. For charges on half equations, **ALLOW** M^{+2} for M^{2+} **OR** H^{+1} for H^+ **ALLOW** $M - 2e^- \rightarrow M^{2+}$ If **BOTH** half equations are correct but shown with oxidation and reduction the wrong way around, award 1 mark from the 2 marks for half equations **Examiner's Comments** This question required candidates to write an overall equation and half equations for oxidation and reduction. Many candidates made errors within one or more equations. The overall equation was often written without state symbols, despite the question instruction 'with state symbols'. The oxidation half equation was more likely to be correct than the reduction half equation, which often used Cl instead of H^+. When H^+ was used, the half equation was often unbalanced or electrons had been omitted. It is recommended that candidates carefully use the chemical information in the question.
		ii	Bubbles/effervescence/fizzing stops ✓ **M**/metal/solid has disappeared/dissolved ✓	2 (AO 3.3×2)	Responses must imply that all fizzing has stopped and that all the solid has dissolved **i.e.** 'metal disappears' is not quite enough. 'All the metal disappears' is enough **IGNORE** constant mass **IGNORE** no increase in temperature **Examiner's Comments** Most candidates identified that all the metal would have reacted when it had all disappeared and that gas bubbles from the reaction would have stopped. Some responses did not emphasise that these observations would have stopped and this prevented credit being given.
		iii	$H^+ + OH^- \rightarrow H_2O$ ✓	1 (AO 2.5)	**ALLOW** multiples e.g. $2H^+ + 2OH^- \rightarrow 2H_2O$ **IGNORE** state symbols, even if wrong **Examiner's Comments**

					The ionic equation for neutralisation of an acid with an alkali was well known and this question was answered correctly by most candidates.
			Mean titre 1 mark $=\dfrac{(27.30 + 27.20)}{2} = 27.25$ (cm³) ✓ **Analysis of results 5 marks** n(NaOH) = $27.25 \times \dfrac{0.320}{1000} = 8.72 \times 10^{-3}$ (mol) ✓ n(HC*l*) in 25.0 cm³ = n(NaOH) n(HC*l*) in 250 cm³ = $8.72 \times 10^{-3} \times 10 = 8.72 \times 10^{-2}$ (mol) ✓ n(HC*l*) that reacted with **M** = $0.210 - 8.72 \times 10^{-2} = 0.1228$ (mol) ✓ n(**M**) that reacted = $\dfrac{0.1228}{2} = 0.0614$ (mol) ✓ A_r of **M** = $\dfrac{6.90}{0.0614} = 112.4$ **AND M** = cadmium/Cd ✓			***FULL ANNOTATIONS MUST BE USED*** -- **Common error:** Incorrect mean from all 3 titres = 27.35 cm³ **Use ECF throughout** Intermediate values for working to **at least 3 SF**. **TAKE CARE**: Value written down may be truncated calculator value. Depending on rounding, either can be credited. **ALLOW** 0.123 (mol) i.e. 3SF **ALLOW** 0.0615 (mol) **IF** 0.1228 rounded to 0.123

		i
		v
			COMMON ERRORS:
			Mean of 27.35 (use of all 3 titres)
			     → 8.752×10^{-3} → 8.752×10^{-2} → 0.12248
			     → 0.06124 → 112.7 **AND** Cd: *5 marks*
			No ÷2 to *obtain n(M)*
			     → 56.2 **AND** Fe (from 27.25) *5 marks*
			     → 56.3 **AND** Fe (from 27.35) *4 marks*
			No subtraction from 0.210
			     A_r of **M** = $\dfrac{6.90}{0.0614} = 112.4$ **AND M** = cadmium/Cd ✓
			     → 158.2 to 158.3 **AND** Tb *5 marks*
			No ×10 to *obtain n(HCl) in 250 cm³* *5 marks*
			     $0.210 - 8.72 \times \mathbf{10^{-3}} = 0.20128$ **OR** 0.201
			     $n(M) = 0.20128/2 = 0.10064$
			     Ar = 6.90/0.10064 = 68.56 → Zn
			No ×10 and no ÷ 2 *4 marks*
			     $0.210 - 8.72 \times \mathbf{10^{-3}} = 0.20128$
			     Ar = 6.9/0.20128 = 34.28 → Ca
			Omitting initial titration calculation Zero marks
			     0.210/2 = 0.105 → 6.9/0.105 = 65.71 → Zn
				6
				
				(AO 2.8×5)
				
				(AO 3.2)
					ALLOW 112.2 from 0.0615 **AND** Cd
					
					ALLOW A_r to nearest whole number
					ALLOW ECF for metal closest to calculated A_r
					
					DO NOT ALLOW Ga **OR** Sc (Form 3+ ions only)
					
					Examiner's Comments
					
					Candidates were presented with information about a back titration, a technique that they would be unlikely to have encountered during their course. The question stem to (iv) suggested a three-step strategy. Many candidates followed this guidance and were credited with many of the available marks. Marks were given for a correct method (by error carried forward) even if there was an error or omission in the multi-step calculation. This emphasises the importance of clear working.
					
					Most candidates determined the correct mean titre of 27.25 cm³. A few candidates did take the mean of all three titres rather than the closest. Most calculated that 8.72×10^{-3} mol of NaOH reacted with the same number of moles of HC*l* in the titration and then scaled up the HC*l* by a factor of 10 to 8.72×10^{-2} mol in the 250 cm³ volumetric flask. These steps are standard for many titration calculations and gave a route to three of the six available marks. The more difficult back titration steps then followed and the higher-attaining candidates recognised the need to subtract this amount of HC*l* from the original amount of HC*l*

					used to react with metal M. These candidates then divide this value by two to find the moles of M that reacted (from the 1 : 2 stoichiometry of M : HC*l*). The correct calculation then gave a relative atomic mass of M as 112 and its identity as cadmium. It was common for candidates to omit the division by two and to arrive at a relative atomic mass of 56 for iron. The mark scheme shows the variety of metals that candidates identified from their calculations, the errors made, and the error carried forward marks that resulted. Many lower-attaining candidates did not follow the 3 steps in the stem, using only the original amount of HCl and ignoring the titration. This approach was not credited with marks. A large range of marks was seen, and the question discriminated extremely well.
		Total		**12**	

5		**TAKE CARE: Correct final answer of −52.3 OR −52.25 can be obtained from two cancelling errors:** • Use of 50 for energy released (no ×2 of 50 for two solutions mixed) • No ÷ 2 in final step **−52.3 OR −52.25 would then be awarded 2 marks out of 4** ―――――――――――――――――― *Correctly calculates n(succinic acid)* $= 0.400 \times \dfrac{50.0}{1000} = 0.02(00)$ (mol) ✓ *Energy released in J OR kJ* $= 100.00 \times 4.18 \times 5.0 = 2090$ (J) **OR** 2.090 (kJ) ✓ **Energy released, in kJ or J, for formation of 2 mol H_2O** $\pm \dfrac{2090}{0.0200} = \pm 104500$ (J) **OR** $\pm \dfrac{2.090}{0.0200} = \pm 104.5$ **OR** ± 105 (kJ) ✓ **$\Delta_{neut}H$ to 3 or more SF AND correct – sign** $= -\dfrac{104.5}{2} = -52.3$ **OR** -52.25 kJ mol^{-1} ✓		4	**ALLOW ECF throughout** **DO NOT ALLOW** less than 3 SF **IGNORE** units ―――――――――――――――――― **ALTERNATIVE METHOD** *n(succinic acid)* = 0.02(00) (mol) ✓ *Energy released* = 2090 (J) **OR** 2.090 (kJ) ✓ *n(H_2O) formed* = 2 × 0.02(00) = 0.04(00) (mol) ✓ $\Delta_{neut}H = -\dfrac{2.090}{0.0400} = -52.3$ **OR** -52.25 kJ mol^{-1} ✓ **Examiner's Comments** The direct determination of an enthalpy change is a common practical procedure. Most candidates were able to calculate the energy

change in the reaction as 2.09 kJ, with comparatively few not adding the two 50 cm^3 volumes in their calculation. Common errors were using the mass or moles of succinic acid in the $mc\Delta T$ calculation or to use 278 K, rather than 5°C for ΔT.

Most candidates calculated that 0.02 mol of succinic acid had reacted.

The best responses recognised that the enthalpy change of neutralisation (i.e. formation of 1 mol of H_2O) was required and that 0.02 mol succinic acid produced 2 × 0.02 = 0.04 mol H_2O. 2.09 kJ was then scaled up to give the correct ΔH value of −52.25 kJ mol^{-1}. Example 1 follows this approach and each stage in the working can be followed easily.

Most candidates scaled up using 0.02 mol to obtain −104.6 kJ mol^{-1} and then thought that this was the final answer.

Lower ability candidates often calculated the moles of succinic acid as 0.02 but also calculated the moles of NaOH as 0.05 mol. They often then went on to scale up their energy change by 0.05 or 0.07.

Many responses were disorganised and poorly presented with unsubstantiated numbers across the answer space. Imperfect calculations may be partially credited by applying error carried forward but this is only possible if sense can be made of the response.

Compare the responses in Exemplar 13 and Exemplar 14. In Exemplar 14, there is no labelling to show what each stage refers to. It looks as if the candidate has calculated the moles of NaOH rather than succinic acid and has used this in the subsequent stage. Error carried forward has been applied generously on this assumption.

Answer = −52.25 kJ mol^{-1}.

Exemplar 13

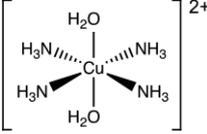|					
					mixture are the same as for water. $\Delta t = 26.5 - 21.5 = 5$ $q = mc\Delta t$ $= (50 + 50) \times 4.18 \times 5 = 2090\ J$ ✓ $= 2.09\ kJ$ moles of acid used $= \frac{50}{1000} \times 0.4 = 0.02\ mol$ ✓ moles of NaOH used $= \frac{50}{1000} \times 1 = 0.05\ mol$ acid is the limiting reagent. ✓ moles of H_2O formed $= 0.02 \times 2 = 0.04\ mol$ $\Delta_{neut} H = \dfrac{-2.09}{0.04} = -52.25$ $\Delta_{neut}H = \underline{\quad -52.25 \quad}$ kJ mol⁻¹ **[4]** **Exemplar 14** $q = mc\Delta T$ $\qquad 26.5 - 21.5$ $100 \times 4.18 \times 5 = 2090$ ✓ $\div 1000 = 2.09$ mol conc x vol $50/1000 \times 1 = 0.05$ ✗ $\quad \dfrac{q}{n}\quad \dfrac{2.09}{0.05} = 41.8$ ecf ✓ $\Delta_{neut}H = \underline{\quad -41.8 \quad}$ ✗ kJ mol⁻¹ **[4]**
		Total		**4**	
6			2MnO₄⁻ + 5H₂O₂ + 6H⁺ → 2Mn²⁺ + 8H₂O + 5O₂ Correctly balanced equation for MnO₄⁻/H₂O₂ reaction but no cancelling of H⁺ and/or e⁻ ✓ Overall equation correct with all species cancelled ✓	2	**ALLOW** multiples **ALLOW** ⇌ instead of → sign **ALLOW** 1 mark for final equation with correct balancing numbers **AND** **ONE** small slip in a formula **OR** charge **IGNORE** annotations around equations, i.e. treat as rough working **ALLOW** 1 mark for: 2H₂O₂ → 2H₂O + O₂ (*H₂O₂ is acting as both reducing and oxidising agent*) **Examiner's Comments** This part discriminated extremely well with many candidates obtaining either both marks or zero marks. Candidates needed to select the correct redox pairs, combine them and cancel H⁺ and H₂O. Many otherwise correct equations did not receive credit as they contained basic balancing errors. As a final step in constructing an equation, candidates are recommended to check the formulae of their species and that the equation is balanced.
		Total		**2**	

7	i	Colourless to yellow ✓	1	**IGNORE** clear for colourless **Examiner's Comments** Candidates were expected to apply their knowledge of the colour change in a manganate(VII) titration to this novel situation. Most candidates incorrectly showed the inverse colour change of yellow → colourless.
	ii	**Mean titre** $= \dfrac{(23.15 + 23.25)}{2}$ = 23.2(0) (cm^3) ✓ **Analysis of results**　　　　　　**5 marks** $n(Ce^{4+})$ = 23.20 $\times \dfrac{0.0500}{1000}$ = 1.16 $\times 10^{-3}$ (mol) ✓ $n((COOH)_2)$ in 25.0 cm^3 = $\dfrac{1.16 \times 10^{-3}}{2}$ = 5.8(0) $\times 10^{-4}$ (mol) ✓ $n((COOH)_2)$ in 250 cm^3 　　= 5.8(0) $\times 10^{-4} \times 10$ = 5.8(0) $\times 10^{-3}$ (mol) ✓ Mass $(COOH)_2$ = 5.8(0) $\times 10^{-3} \times 90.0$ = 0.522 g ✓ % oxalic acid = $\dfrac{0.522 \times 100}{82.68}$ = 0.631% ✓ Percentage **MUST** be expressed to **3 SF**	6	**Common error:** Incorrect mean from all 3 titres = 23.30 cm^3 **Use ECF throughout** Intermediate values for working to **at least 3 SF**. **TAKE CARE** as value written down may be truncated value stored in calculator. Depending on rounding, either can be credited. ——————————————————————— **COMMON ERRORS:** Mean of 23.30 (use of all 3 titres) → 0.634%:　　5 marks **TAKE CARE** for final answer of 0.63 seen. • No final mark as only 2 SF 　0.63 may have been rounded from 0.631 (from • correct mean) 　**OR** from 0.634 (using mean from all 3 titres) Check back to mean titre. No ÷2 to *obtain n((COOH)₂)* → 1.26%:　　　　5 marks from 23.20 → 1.27%　　　　　4 marks from 23.30 **Examiner's Comments** Most candidates answered this unstructured titration calculation well, with almost all responses gaining some credit. Most coped well with the 1:2 reaction stoichiometry and the need to scale up to 250 cm^3. Common errors included the following. • Taking the mean of all three titres (23.30 cm^3) instead of the closest titres (23.20 cm^3). • Not considering the 1:2 stoichiometry. • Not scaling up to 250 cm^3. • Giving the final answer to two rather than three significant figures; this was the most common error.
	i		1	

					The question required the final answer to be given to an appropriate number of significant figures. Many candidates seemed to be unaware that this reflects the least significant figures provided in the data, in this case three significant figures. Candidates are also advised to only round at the end of a multi-step calculation. Rounding of intermediate values introduces rounding errors in the final answer. The example shows a perfect response with each step clearly described, leading to the correct concentration of ethanedioic acid. Candidates should present their calculations clearly. If there is a mistake at any stage, this can be easily identified, allowing for error carried forward to be applied for any subsequent good method. **Exemplar 6**
		Total		**7**	
8	i	Titres correct and **ALL** recorded to **2 decimal places** | Titre:	24.00	23.40	23.75	23.85 ✓ | | mean titre = 23.80 (cm^3) ✓		**2**	**ALLOW** 23.8 cm^3 **Examiner's Comments** It is clear candidates are not as experienced at filling in titration tables as might be expected. Every value in a titration table should be recorded to a second decimal place to an accuracy of ± 0.05 cm^3. The average titre should be calculated by

					averaging concordant titres, i.e. those within 0.10 cm^3 of each other.
		ii	Percentage uncertainty $= \dfrac{0.05 \times 2}{23.40} \times 100 = 0.43 \, (\%)$ ✓	1	**ALLOW ECF** from incorrect subtraction in **(i)** or incorrect mean **ALLOW** 0.42% from titre values 2, 3 or 4 or mean titre or trial titre. **2 DP required** **Examiner's Comments** Candidates are unfamiliar with determination of percentage uncertainty. Marks were credited for any percentage uncertainty calculation correctly determined from any titre value, as many opted to choose the trial value as titre 1 or used an average titre.
		iii	Add starch (near the end point) ✓ Blue to colourless ✓	2	**ALLOW** blue/black **OR** black **OR** purple for colour of mixture **ALLOW** blue colour disappears (to colourless) **IGNORE** 'clear' **IGNORE** 'colorimetry' **Examiner's Comments** Only the higher ability candidates realised starch needed to be added close to the end-point and this made the resulting colour change (blue-black to colourless) easier to see. The common error was to assume this was an acid-base titration and indicators such as methyl orange or phenolphthalein should be added.
		i v	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF B = RbIO₃ AND relative formula mass = 260.5 award 5 marks** **IF relative formula mass = 260.5 award 4 marks** -- $n(S_2O_3^{2-})$ **in titration** $= \dfrac{0.150 \times 23.80}{1000} = 3.57 \times 10^{-3}$ (mol) ✓ $n(IO_3{}^{✓})$ **in titration** $= 10 \times 5.95 \times 10^{-4} = 5.95 \times 10^{-3}$ (mol) ✓ $n(IO_3{}^{✓})$ **in original 250 cm³** $= \dfrac{3.57 \times 10^{-3}}{6} = 5.95 \times 10^{-4}$ (mol) ✓	5	**ALLOW ECF** from incorrect mean titre in **(a)(i)** **ECF** from $n(S_2O_3^{2✓})$ in titration **ALLOW** a two-step calculation $n(I_2) = n(S_2O_3^{2-}) \div 2$ and $n(IO_3{}^-) = n(I_2) \div 3$ **ECF** from $n(IO_3{}^-)$ in titration

			Relative formula mass of B $= \dfrac{1.55}{5.95 \times 10^{-3}} = 260.5$ (g mol^{-1}) ✓ **Formula of B (must be derived from relative formula mass)** | Iodate of Group 1 metal that most closely matches calculated molar mass of **B** Formula from 260.5 = RbIO$_3$ ✓ | 		**ECF** from $n(IO_3^-)$ in original 250 cm^3 **IF** scaling × 10 is omitted, **ALLOW ECF** from $n(IO_3^-)$ in titration **ALLOW ECF** from incorrect RFM of **B** provided metal is from Group 1 **ALLOW** RbIO$_3$$^-$ **DO NOT ALLOW** RbIO$_3$ without relative formula mass value. **DO NOT ALLOW** 260.4 (without working) and RbIO$_3$ **IF B** = RbIO$_3$ **AND** relative formula mass = 261 award 5 marks **Examiner's Comments** This unstructured calculation was done well by the higher ability candidates. Lower ability candidates struggled to show what they were attempting to calculate and in particular did not appreciate the 1 : 6 ratio of $S_2O_3^{2-}$(aq) to IO_3^-(aq). Candidates might be advised to start n(formula) = … at the start of each line of calculation eg $n(S_2O_3^{2-})$ = … mol No credit was given to candidates who grasped the identity of the Group 1 iodate from nowhere and calculated the theoretical relative formula mass.
			Total	**10**	

9	a	i	*Circuit:* complete circuit **AND** voltmeter **AND** salt bridge linking two half-cells ✓
			
			Half cells: Pt **AND** I$^-$ **AND** I$_2$ ✓
			
			            Ni **AND** Ni^{2+} ✓
			
			Standard conditions:
			
			     1 mol dm^{-3} solutions
			     AND 298 K / 25°C ✓
				4	Voltmeter must be shown **AND** salt bridge must be labelled
					ALLOW small gaps in circuit
					
					ALLOW half cells drawn either way around
					IGNORE 2 before I$^-$(aq)
					DO NOT ALLOW I$_2$(g) **OR** I$_2$(s) **OR** I$_2$(l)
					
					ALL conditions required
					BUT ALLOW 1 mol dm^{-3}/1M if omitted here but shown for just one solution in diagram
					Look on diagram in addition to answer lines
					
					IGNORE pressure
					Not relevant for this cell
					
					DO NOT ALLOW 1 mol for concentration

					Examiner's Comments A significant number of candidates did not draw a simple circuit. Most candidates scored the mark for the Ni electrode but fewer scored the mark for the Pt electrode in the $I^-(aq)/I_2(aq)$ mixture. The last mark, for the conditions (including concentrations of $1.00\ mol\ dm^{-3}$), was almost universally scored even by those who omitted the solutions in their diagram. Common errors were: diagrams with electrodes not entering solutions; salt bridges not labelled or not entering solutions; making solid iodine an electrode; and assuming iodine to be a gas and adapting a standard hydrogen electrode to accommodate this.
		ii	$E = 0.79$ (V) ✓	**1**	**IGNORE** sign **Examiner's Comments** This was the most successfully answered single mark question on the paper.
	b	i	$H_2O_2(aq) + 2H^+(aq) + 2Fe^{2+}(aq) \rightarrow 2Fe^{3+-}(aq) + 2H_2O(l)$ ✓	**1**	**ALLOW** multiples **IGNORE** state symbols, even if wrong **Examiner's Comments** Most candidates got the equation correct. Occasionally a number was omitted causing incorrect stoichiometry and occasionally the equation was reversed.
		ii	**Equations** $3Zn(s) + Cr_2O_7^{2-}(aq) + 14H^+(aq)$ $\rightarrow 3Zn^{2+}(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$ ✓ $Zn(s) + 2Cr^{3+}(aq) \rightarrow Zn^{2+}(aq) + 2Cr^{2+}(aq)$ ✓ **Comparison of *E* values (seen once)** *E* of Zn is more negative/less positive than *E* of $Cr_2O_7^{2-}$ **OR** *E* of Zn is more negative/less positive than *E* of Cr^{3+} ✓ **Equilibrium shift related to *E* values**	**4**	**ALLOW** multiples **IGNORE** state symbols, even if wrong **ALLOW** E_{cell} is (+) 2.09V for $Zn/Cr_2O_7^{2-}$ cell **OR** **ALLOW** E_{cell} is (+) 0.34V for Zn/Cr^{3+} cell **IGNORE** 'lower/higher'

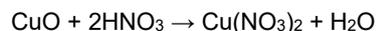|				
			More negative/less positive **OR** Zn system shifts left **OR** Less negative/more positive $Cr_2O_7^{2-}$ system shifts right **OR** Less negative/more positive Cr^{3+} system shifts right ✓		For 'shifts left': **ALLOW** '(Zn) is oxidised' **OR** 'electrons are lost (from Zn)' For 'shifts right', **ALLOW** '(Cr) is reduced' **OR** 'electrons are gained' **Examiner's Comments** Only the higher ability candidates achieved full marks. Most candidates were able to come up with both redox equations and some could state that zinc was oxidised or chromium was reduced as a result of zinc having a more negative electrode potential than either chromium species. Common errors were: stating that zinc had a lower (not more negative) electrode potential; stating that zinc was an oxidising agent (as well as being oxidised); confusing the direction of change of equilibria shown; and not balancing the overall redox equations.

	c		*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
			Makes one simple explanation from each of two reactions
				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
					
					REACTION 2 (Cu_2O/H_2SO_4)
					Products
					
					    D : $CuSO_4$ **OR** $[Cu(H_2O)_6]^{2+}$
					    E: Cu
					
					Equation
					
					    $Cu_2O + H_2SO_4 \rightarrow CuSO_4 + Cu + H_2O$

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.
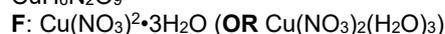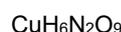
Oxidation numbers

$Cu(+1) \rightarrow Cu(+2) + Cu(0)$

REACTION 3 (CuO/HNO₃) *Equation*

$CuO + 2HNO_3 \rightarrow Cu(NO_3)_2 + H_2O$

Molar ratios

$$= \begin{array}{ccccccc} Cu & : & H & : & N & : & O \\ \dfrac{26.29}{63.5} & : & \dfrac{2.49}{1.0} & : & \dfrac{11.59}{14.0} & : & \dfrac{59.63}{16.0} \end{array}$$

Formula of F

$CuH_6N_2O_9$
F: $Cu(NO_3)^2 \cdot 3H_2O$ (**OR** $Cu(NO_3)_2(H_2O)_3$)

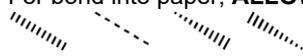**Further guidance on use of wedges**

- 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:

Examiner's Comments

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

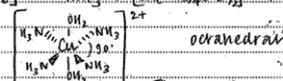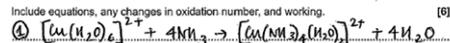(d)* Three different reactions of copper compounds are described below.

Reaction 1: Aqueous copper(II) sulfate reacts with excess aqueous ammonia in a ligand substitution reaction. A deep-blue solution is formed, containing an octahedral complex ion, **C**, which is a *trans* isomer.

Reaction 2: Copper(I) oxide reacts with hot dilute sulfuric acid in a disproportionation reaction. A blue solution, **D**, and a brown solid, **E**, are formed.
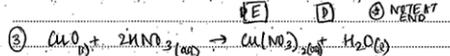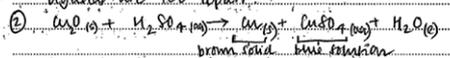
Reaction 3: Copper(II) oxide reacts with warm dilute nitric acid in a neutralisation reaction, to form a blue solution. Unreacted copper(II) oxide is filtered off, and the solution is left overnight in an evaporating basin.
A hydrated salt, **F**, crystallises, with the percentage composition by mass:
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. [6]

① $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$

octahedral

This is the trans isomer Ⓒ because my H_2O ligands are 180° apart.

② $Cu_2O_{(s)} + H_2SO_{4\,(aq)} \rightarrow Cu_{(s)} + CuSO_{4\,(aq)} + H_2O_{(l)}$
    brown solid   blue solution
    Ⓔ   Ⓓ

③ $CuO_{(s)} + 2HNO_{3\,(aq)} \rightarrow Cu(NO_3)_{2\,(aq)} + H_2O_{(l)}$

	Cu	H	N	O
mass	26.29	2.48	11.59	59.63
rfm	63.5	1	14	16
mol	0.414	2.48	0.828	3.73

Additional answer space if required.

1 : 6 : 2 : 9
$\Rightarrow Cu H_6 N_2 O_9$

A hydrated salt is made up of an anhydrous salt with water of crystallisation.
$Cu(NO_3)_2.3H_2O$ Ⓕ   and molecular
$\Rightarrow$ This fits the empirical formula.
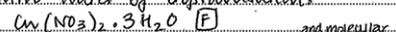
ⓃOTE: ② The oxidation number of Cu goes from +1 to 0 in Cu(s), and from +1 to +2 in $CuSO_{4\,(aq)}$. Cu is reduced to form Cu and oxidised to form Cu^{2+} in $CuSO_4$.

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		**16**	
10		i	sodium nitrate(III)		**1**	**ALLOW** sodium nitrite **OR** sodium nitrite(III) **Examiner's Comment:** This part was very poorly answered, the most common answer being sodium nitrate. The examiners were expecting sodium nitrate(III) but the mark scheme was extended to also allow sodium nitrite. Sodium(III) nitrate was sometimes seen, indicating that candidates are not fully conversant with rules for showing oxidation states in names.
		ii	Sodium / Na oxidised from 0 to +1 ✓ Nitrogen / N reduced from +3 to 0 ✓		**2**	**ALLOW** 1+ for +1 and 3+ for +3 **ALLOW** N_2 for nitrogen **ALLOW** 1 mark for elements **AND** all oxidation numbers correct, but N on oxidised line and Na on reduced line '+' is required in +3 and +1 oxidation numbers **Examiner's Comment:** This part was generally answered well although a significant number of candidates managed to get one of the oxidation numbers wrong, usually for N. It was rare to see the sign for an oxidation number omitted.
		iii	$2NaNO_2 + 6Na \rightarrow 4Na_2O + N_2$ ✓ **IGNORE** state symbols		**1**	**ALLOW** multiples, e.g. $NaNO_2 + 3Na \rightarrow 2Na_2O + \frac{1}{2}N_2$ ✓ **Examiner's Comment:** The examiners were impressed with the responses for this part with just over half the candidates producing a correct balanced equation for this unfamiliar reaction. Most used whole numbers for balancing but it was common to also see the half-multiple version including $\frac{1}{2}N_2$.
			Total		**4**	
11			**ALLOW** equilibrium sign in equations provided reactants on left		**4**	**ALLOW** correct multiples **IGNORE** state symbols ………………………………………………… . **ALLOW** uncancelled H_2O and H^+ $H_2O_2 + MnO_2 + \mathbf{4}H^+ \rightarrow O_2 + Mn^{2+} + 2H_2O$ **+ 2H⁺**

			Reaction of H_2O_2 with MnO_2: $H_2O_2 + MnO_2 + 2H^+ \rightarrow O_2 + Mn^{2+} + 2H_2O$ ✓ **Reaction of H_2O_2 with Mn^{2+}:** $H_2O_2 + Mn^{2+} \rightarrow MnO_2 + 2H^+$ ✓ **Use of *E* data** Use of *E* data to support equation(s) above or half direction of provided half equations (one including MnO_2) ✓ *Also look for evidence around half equations* MnO_2 regenerated / reformed ✓ *Must be linked to an equation showing MnO_2 as reactant and an equation showing MnO_2 as product*		$H_2O_2 + Mn^{2+}$ **+ 2H₂O + 2H⁺** $\rightarrow MnO_2 +$ **4H⁺** **+ 2H₂O** *Examples* • More negative *E* moves to left **ORA** • Reduction half equation to the right **ORA** • Most positive *E* is reduced **ORA** • Calculated *E* cell = +0.81 V (*from top* 2) **OR** +0.27 V (*from bottom 2*) **ALLOW** combining of equations above to show that MnO_2 is used and reformed **Examiner's Comment:** Many candidates found this part challenging and there was a wide variety of answers and marks awarded. There were two equations to construct showing how MnO_2, and Mn^{2+} react with H_2O_2. Many combined the two equations involving H_2O_2 to obtain the overall equation for the decomposition of H_2O_2 which was given at the top of the paper. Of the equations seen, many had species uncancelled. Many candidates only tackled one of the equations. Candidates were expected to provide evidence for their equations based on the electrode potentials provided. Use of this data was patchy and only the best candidates linked the relative *E* values to the direction of movement or redox details. A significant number gave cell potentials. Regeneration of MnO_2 was well understood but often just stated with no reference to the equations. This part discriminated very well.
		Total	**4**	
1 2	a		**AWARD 2 marks** for correct balancing **AND** all species cancelled on both sides of equation: $2MnO_4^- + 6H^+ + 5SO_3^{2-} \rightarrow 2Mn^{2+} + 3H_2O + 5SO_4^{2-}$ ✓ ✓ **AWARD 1 mark** for correct balancing but **not** all species (H_2O, H^+) cancelled on both sides of equation ✓ e.g. $2MnO_4^- + 16H^+ + 5SO_3^{2-} + 5H_2O$	2	**ALLOW** correct multiples e.g. $MnO_4^- + 3H^+ + 2½SO_3^{2-}$ $\rightarrow Mn^{2+} + 1½H_2O + 2½SO_4^{2-}$ **IGNORE** state symbols e.g. $MnO_4^- + 8H^+ + 2½SO_3^{2-} + 2½H_2O$

			$\rightarrow 2Mn^{2+} + 8H_2O + 5SO_4^{2-} + 10H^+$	9	$\rightarrow Mn^{2+} + 4H_2O + 2\frac{1}{2}SO_4^{2-} + 5H^+$
					Examiner's Comments This was successfully answered by the majority of candidates.
	b	i	*Circuit:* complete circuit **AND** voltmeter **AND** *labelled* salt bridge linking two half-cells ✓ *Half cells:* Pt **AND** Fe²⁺ **AND** Fe³⁺ ✓ Zn **AND** Zn²⁺ ✓ *Standard conditions:* 1 mol dm⁻³ (solution(s)) **AND** 298 K / 25°C ✓	4	Electrodes / salt bridge must at least touch the surface **ALLOW** small gaps in circuit wires **ALLOW** half cells drawn either way around **ALLOW** 1 mol / dm³ **OR** 1 M **ALLOW** 1 mol dm⁻³/1M if omitted here but shown for just one solution in diagram **IGNORE** pressure **DO NOT ALLOW** 1 mol(e) for concentration **Examiner's Comments** A significant number of candidates handicapped themselves by failing to draw a simple circuit. Diagrams with electrodes not entering solutions, salt bridges not labelled or not entering solutions were frequently seen. Most candidates scored the mark for the Zn electrode but less scored the mark for the Pt electrode in the Fe²⁺(aq)/Fe³⁺(aq) mixture. The last mark, for the conditions (including concentrations of 1.00 mol dm⁻³), was almost universally scored even by those who omitted the solutions in their diagram.
		ii	1.53 (V) ✓	1	**IGNORE** sign **Examiner's Comments** This was the most successfully answered one mark question on the paper.
	c		*strongest reducing agent:* Zn ✓ *strongest oxidizing agent:* MnO₄⁻ ✓	2	**NOTE:** H⁺ has been ignored **Examiner's Comments** Most candidates were able to use the standard electrode potentials given in the question to work out that zinc (Zn(s)) was the strongest reducing agent and that manganate(VII) ions were the strongest oxidising agent.
			Total	9	
13			H₂SO₄ + 8HI → 4I₂ + H₂S + 4H₂O All species correct	2	

			OR H_2SO_4 : HI ratio = 1 : 8 ✓ Equation complete and balanced ✓		
			Total	**2**	
14	a	i	**3** MnO_4^{2-} + **4** H^+ → 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** $H^+ + OH^- → H_2O$

	b		**In acid:**
			  $H_2(g) → 2H^+(aq) + 2e^-$
			  AND
			  $O_2(g) + 4H^+(aq) + 4e^- → 2H_2O(l)$ ✓
			
			  $2H_2 + O_2 → 2H_2O$
			  AND
			  Cell potential = 1.23 − 0.00 = 1.23 (V) ✓
			
			In alkali:
			$2OH^-(aq) + H_2(g) → 2H_2O(l) + 2e^-$
			AND
			$O_2(g) + 2H_2O(l) + 4e^- → 4OH^-(aq)$ ✓
			$2H_2 + O_2 → 2H_2O$
			
			AND
			Cell potential = 0.40 − (−0.83) = 1.23 (V) ✓
				4	**ALLOW** $H_2 + \frac{1}{2}O_2 → H_2O$
					
					ALLOW $H_2 + \frac{1}{2}O_2 → H_2O$

			Total	**7**	
15	a		Cu^{2+}: ($1s^2$) $2s^2 2p^6 3s^2 3p^6 3d^9$ ✓ Cu^+: ($1s^2$) $2s^2 2p^6 3s^2 3p^6 3d^{10}$ ✓	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.......$3S_2 3P^6$ **DO NOT ALLOW** [Ar] as shorthand for $1s^2 2s^2 2p^6 3s^2 3p^6$ **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** $Cu(OH)_2 + 2HCOOH \rightarrow Cu(HCOO)_2 + \mathbf{2}H_2O$ ✓	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	$2Cu^{2+} + 4I^- \rightarrow 2CuI\mathbf{(s)} + I_2$ ✓ State symbol for CuI(s) **ONLY** required	1	**ALLOW** multiples, e.g. $Cu^{2+} + 2I^- \rightarrow CuI\mathbf{(s)} + \frac{1}{2}I_2$ **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}) ✓ $x(H_2O)$ has mass of $225.5 - M(Cu(HCOO)_2)$ $= 225.5 - 153.5$ $= 72(.0)$ ✓ $x = \frac{72(.0)}{18(.0)} = 4$ **WHOLE NUMBER** needed **AND** evidence of working ✓	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 ✓ $n(H_2O) = \frac{2.226 - 1.515}{18(.0)} = \frac{0.711}{18(.0)} = 0.0395$ (mol) ✓ $x = \frac{0.0395}{9.87 \times 10^{-3}} = 4$ ✓ **ALLOW** $Cu(HCOO)_2 \cdot 4H_2O$ .... **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 $0.5 \times 9.87 \times 10^{-3}$)* 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**	
1 6		i	linear ✓		1	**IGNORE** planar **Examiner's Comments** Most candidates identified the shape as linear.

		ii	Au / Gold has been **oxidised** from 0 to +1 ✓ O / Oxygen / O$_2$ has been **reduced** from 0 to −2 ✓	2	**IF** Ag referred to, rather than Au, treat as a slip and apply **BOD** **ALLOW** 0 to 1 (i.e. no + sign for +1) **ALLOW** 1 mark for **ALL** oxidation numbers correct with no oxidised or reduced **OR** oxidation and reduction wrong way round, e.g. Au goes from 0 to +1 and O goes from 0 to −2 ✓ Au is reduced from 0 to +1 and O is oxidised from 0 to −2 ✓ **Examiner's Comments** Although most identified correct oxidation numbers, a significant number thought that the CN$^-$ ion was reduced. Overall though, candidates demonstrated a good understanding of basic redox.
		iii	**IGNORE** any charges shown within complexes (treat as rough working) 4Au + 8CN$^-$ + 2H$_2$O + O$_2$ → 4[Au(CN)$_2$]$^-$ + 4OH$^-$ ✓ ✓ First mark for all 6 species Second mark for balancing	2	**IF** Ag referred to, rather than Au, treat as a slip and apply **BOD** **IGNORE** state symbols **CARE**: In [Au(CN)$_2$]$^-$, − sign is **OUTSIDE** square brackets **For 1st mark, IGNORE** e$^-$ present **ALLOW** 1 mark for balanced equation with CN$^-$ missing, i.e. 4Au + 2H$_2$O + O$_2$ → 4Au$^+$ + 4OH$^-$ **ALLOW** 1 mark rogue e$^-$ on either side **ALLOW** multiples, e.g. 2Au + 4CN$^-$ + H$_2$O + ½O$_2$ → 2[Au(CN)$_2$]$^-$ + 2OH$^-$ Au + 2CN$^-$ + ½ H$_2$O + ¼ O$_2$ → [Au(CN)$_2$]$^-$ + OH$^-$ **Examiner's Comments** Almost all candidates wrote the correct species but balancing the equation was much more demanding. It was often balanced by species but not by charge and oxidation number.
		iv	ClO$^-$ + 2H$^+$ + 2e$^-$ → Cl$^-$ + H$_2$O ✓	1	**IGNORE** state symbols **ALLOW** e for electron **ALLOW** multiples **Examiner's Comments** Candidates found it easy to derive the correct half equation.
			Total	**6**	

17	a		**Definition** The e.m.f. (of a half-cell) compared with / connected to a (standard) hydrogen half-cell / (standard) hydrogen electrode ✓ **Standard conditions** *Units essential* Temperature of 298 K / 25°C **AND** (solution) concentrations of 1 mol dm^{-3} **AND** pressure of 100kPa **OR** 10^5 Pa **OR** 1 bar ✓	2	For e.m.f., **ALLOW** voltage **OR** potential difference / p.d. **OR** electrode / reduction / redox potential **ALLOW** e.m.f. of a cell..... **ALLOW** /(standard) hydrogen cell **IGNORE** S.H.E. (as abbreviation for standard hydrogen electrode) **DO NOT ALLOW** hydrogen fuel cell **ALLOW** 1M **OR** 1 mol/dm^3 **DO NOT ALLOW** 1 mol **OR** 1 mole **ALLOW** 1 atmosphere / 1 atm **OR** 101 kPa **OR** 101325 Pa **Examiner's Comments** This definition was well known with most candidates achieving both marks. An error was more likely for the units of the standard conditions, usually 1 mol and 1 mol dm^3 for concentration. A less common error was comparison with a hydrogen fuel cell.
	b	i	**Complete** circuit with voltmeter **AND** labelled salt bridge linking two half-cells ✓ Cu electrode in Cu^{2+} ✓ Pt electrode in V^{2+} **AND** V^{3+} ✓ Cu shown as + **AND** Pt shown as − ✓ electrons in wire **AND** ions in salt bridge ✓ *On diagram or stated*	5	Half cells can be drawn in either order Half cells must show electrodes dipping into solutions **ALLOW** small gaps in circuit **DO NOT ALLOW** half-cell with H$_2$ added **IGNORE** any stated concentrations **IGNORE** 'anode' and 'cathode' In salt bridge, **ALLOW** any stated ion that may be present, e.g. K^+, NH_4^+, NO_3^-, Cu^{2+}, V^{2+}, V^{3+} **IGNORE** direction of travel of ions and electrons. **ALLOW** Cu half cell as + **AND** V half cell as− **Examiner's Comments** Most candidates drew a full circuit with half cells containing the correct species in a suitably labelled diagram. The signs of the electrodes were usually correct but the charge carriers were omitted much more often than they were included. The overall quality of the diagrams was poor, usually resembling drawings or even rough sketches.
		ii	0.60 **OR** 0.6 (V) ✓	1	**IGNORE** any sign
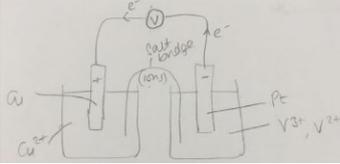
					Examiner's Comments
					This part was answered correctly be almost all candidates. Answer: standard cell potential = 0.60 V
c			**Definitions: *1 mark*** Oxidising agent removes / accepts / gains electrons **OR** increases oxidation number (of another species) **AND** Reducing agent adds / donates / loses electrons **OR** decreases oxidation number (of another species) ✓ **Oxidising agent: *2 marks*** Cr^{3+} oxidises Al **OR** Cr^{3+} acts as oxidising agent **AND** $3Cr^{3+} + Al \rightarrow 3Cr^{2+} + Al^{3+}$ ✓ ***Explanation (dependent on Cr^{3+} oxidising Al above)*** E of redox system 2 (Cr^{3+}/Cr^{2+}) is **more** positive /**less** negative (than E of system 1 (Al^{3+}/Al)) **ORA**, i.e. in terms of 1 being more negative (than 2) ✓ **Reducing agent: *3 marks*** Cr^{3+} reduces $FeO_4^{2-}(/H^+)$ ✓ $2Cr^{3+} + 2FeO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + 2Fe^{3+} + H_2O$ ✓ ***Explanation (dependent on Cr^{3+} reducing FeO_4^{2-} above)*** E of redox system 5 ($Cr_2O_7^{2-}/Cr^{3+}$) is **less** positive / **more** negative (than E of system 6 (FeO_4^{2-}/Fe^{3+})) **ORA**, i.e. in terms of 6 being more positive (than 5) ✓	6		***FULL ANNOTATIONS MUST BE USED*** .... **ALLOW** oxidising agent decreases its oxidation number **AND** reducing agent increases its oxidation number **IGNORE** oxidising agent oxidises / is reduced **OR** reducing agent reduces / is oxidised **In equations,** • **IGNORE** state symbols (even if incorrect) • **ALLOW** ⇌ in equation **IF** more than one equation shown for **Cr^{3+} as oxidising agent**, **CON** and **zero marks** for 2 oxidising agent marks **IGNORE** equations with Cr^{2+} as reactant Explanations **MUST** be in terms of positive / negative: **IGNORE** 'higher' E **OR** 'greater' **ALLOW** E_{cell} = +1.25 V (+ sign required) **IF** more than one equation shown for **Cr^{3+} as a reducing agent**, **CON** and **zero marks** for 3 reducing agent marks **IGNORE** equations with Cr^{2+} as reactant Explanations **MUST** be in terms of positive / negative: **IGNORE** 'higher' E **OR** 'greater' **ALLOW** E_{cell} = +0.87 V (+ sign required) **Examiner's Comments** Although most candidates produced lengthy answers to this part, there was often little that could be rewarded. The terms oxidising agent and reducing agent were usually described but the expected response needed to be in terms of electrons or oxidation number. An alarming number of candidates claimed that an oxidising agent is oxidised and a reducing agent reduced. Many candidates went on to discuss the role of Cr^{3+} ions in oxidising aluminium, with a correct

			equation. The expected explanation in terms of electrode potentials was seen more rarely. The role of Cr^{3+} in reducing FeO_4^{2-} was seen much more rarely. The commonest responses showed a list of equations, all showing reactions of Cr^{2+} rather than Cr^{3+}. The best candidates produced superb answers demonstrating excellent understanding of electrode potentials. When comparing electrode potentials, candidates are advised to use terms such 'more negative' or 'more positive, rather than 'greater' or 'higher', which are ambiguous when comparing negative numbers. An alternative approach in terms of positive cell potentials were seen and credited, although the positive sign was required.		
		Total	**14**	
1 8		**in all equations ALLOW equilibrium signs** **IGNORE** state symbols .... **Reaction 1: 1 mark** $2I_2 + 5O_2 \rightarrow 2I_2O_5$ ✓ .... **Reaction 2: 2 marks** **1st mark: ALL CORRECT species** e.g.: $I_2 + OH^- \rightarrow I^- + IO_3^- + H_2O$ **2nd mark** for **CORRECT balanced equation** $3I_2 + 6OH^- \rightarrow 5I^- + IO_3^- + 3H_2O$ ✓✓	3	***FULL ANNOTATIONS MUST BE USED*** .... **ALLOW** correct multiples throughout, e.g. $I_2 + 2\frac{1}{2}O_2 \rightarrow I_2O_5$ .... **For 1st mark, IGNORE** e^- present **ALLOW** species / equation with NaOH or KOH, e.g. $3I_2 + 6NaOH \rightarrow 5I^- + IO_3^- + 3H_2O + 6Na^+$ $3I_2 + 6NaOH \rightarrow 5NaI + NaIO_3 + 3H_2O$ **ALLOW** Species: $I_2 + OH^- \rightarrow I^- + IO_2^+ + H_2O$ ✓ **OR** Equation: $3I_2 + 4OH^- \rightarrow 5I^- + IO_2^+ + 2H_2O$ ✓ ✓ Species: $I_2 + OH^- \rightarrow I^- + IO^{3+} + H_2O$ ✓ **OR** Equation: $3I_2 + 2OH^- \rightarrow 5I^- + IO^{3+} + H_2O$ ✓ ✓ **Examiner's Comments** This question was about equilibrium, set in the context of the solubility of iodine. This part required candidates to interpret unfamiliar information to construct reactions for redox reactions of iodine. Candidates were far more successful with the first equation than the more demanding second equation. For the second equation, the key difficulty was the formula of the iodate(V) ion, IO_3^-, with I^{5+} or the formula of I_2O_5 often being shown. The most difficult skill was balancing the second redox equation, suggesting that many candidates need more practice in this area.

			Total	3	
1 9	a		**Equations can be in either order** $Na_2O + H_2O \rightarrow 2NaOH$ ✓ $NaFeO_2 + 2H_2O \rightarrow Fe(OH)_3 + NaOH$ ✓	2	**ALLOW** multiples throughout **IGNORE** state symbols **ALLOW** $Na_2O + H_2O \rightarrow 2Na^+ + 2OH^-$ **DO NOT ALLOW** equations with uncancelled species. e.g. $Na_2O + 2H_2O \rightarrow 2NaOH + H_2O$ **ALLOW** $2NaFeO_2 + H_2O \rightarrow Fe_2O_3 + 2NaOH$ **OR** $2NaFeO_2 + H_2O \rightarrow Fe_2O_3 + 2Na^+ + 2OH^-$ **Examiner's Comments** The information needed to write the equation was within the information provided for step 1 and the stem. Candidates were much more successful with the first than the second equation. The clue that an alkaline solution had been formed should have helped with the identification of NaOH as a product of both reactions. The brown precipitate provided a clue that $Fe(OH)_3$ had been formed although the examiners also credited an equation producing Fe_2O_3.

	b		**FIRST, CHECK THE ANSWER ON ANSWER LINE**
			IF answer = 33.7%, award **6 marks**.
			IF there is an alternative answer, check to see if there is any **ECF** credit possible using working below
			....
			amount $S_2O_3^{2-}$ used = $0.1000 \times \frac{25.50}{1000}$
			  = **2.550 × 10^{-3}** (mol) ?
			amount I_2 = $2.550 \times 10^{-3} \div$ **2**
			  1.275 × 10^{-3} (mol) ✓
			
			amount CrO_4^{2-}
			2/3 × 1.275×10^{-3} **OR** $1.275 \times 10^{-3} \div$ **1.5**
			  = **8.5(00) × 10^{-4}** (mol) ✓
			
			amount CrO_4^{2-} in original 1000 cm^3 = **40 ×** 8.5(00) × 10^{-4}
			  = **3.4(00) × 10^{-2}** mol ✓
			
			Mass of Cr / Cr^{3+} in ore = **52.0** × 3.4(00) × 10^{-2} g
			
			  1.768 g ✓
			
			percentage Cr in ore = $\frac{1.768}{5.25} \times 100$
			
			  = **33.7%** ✓
			
			MUST be to **one** decimal place (in the question)
				6	*FULL ANNOTATIONS MUST BE USED*
					
					IF a step is omitted but subsequent step subsumes previous, then award mark for any missed step
					Working: at least 3 SF throughout until final % mark
					BUT ignore trailing zeroes, ie for 0.490 allow 0.49
					....
					
					ECF answer above **÷ 2**
					
					ECF answer above **÷ 1.5**
					
					ECF answer above **× 40**
					
					ECF answer above × 52.0
					IMPORTANT: The last two marks are **ONLY** available by using 52.0 for Cr
					....
					Common ECFs:
					
					0.8% × 40 missing 5 marks (scaling error)

					0.84% × 40 missing 4 marks (scaling error and 2 DP) **33.68%** 5 marks (2 DP) **16.8%** 5 marks (divide Cr somewhere by 2) **144.9%; 72.5%** 4 marks (**Final 2 marks unavailable**) Use of $M(Fe(CrO_2)_2) = 223.8$ instead of $M(Cr)$. **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 four marks for reaching the amount of CrO_4^{2-} ions in the original solution. Sometimes, candidates used the 1:1.5 molar ratio for CrO_4^{2-} : I_2 the wrong way around to obtain 1.9125×10^{-3} rather than 8.50×10^{-4} mol CrO_4^{-4}. More candidates had problems in scaling up by 40 to obtain the original amount of CrO_4^{2-} as 3.40×10^{-2} mol. Strangely many used a factor of 4 instead. The last two marks proved to be more elusive, with many candidates calculating the percentage of $Fe(CrO_2)_2$ rather than Cr in the sample of chromite. The responses seen show just how far candidates have travelled since early structured titration calculations for AS to complex unstructured calculations at the end of the A-level course. Answer: 33.7%
	c		*Overall*: $_4{}^{2-}$ + 3I⁻ + 4H₂O → Cr³⁺ + 1½ I₂ + 8OH⁻ ✓ CrO *Half equations*: $_4{}^{2-}$ + 4H₂O + 3e⁻ → Cr³⁺ + 8OH⁻ ✓ CrO 2I⁻ → I₂ + 2e⁻ ✓	3	**ALLOW multiples and equilibrium signs throughout** **IGNORE** state symbols throughout e.g. $2CrO_4^{2-}$ + $6I^-$ + $8H_2O$ → $2Cr^{3+}$ + $3I_2$ + $16OH^-$ **ALLOW** equation using H⁺. i.e. CrO_4^{2-} + $3I^-$ + $8H^+$ → Cr^{3+} + 1½ I_2 + $4H_2O$ **OR** $2CrO_4^{2-}$ + $6I^-$ + $16H^+$ → $2Cr^{3+}$ + $3I_2$ + $8H_2O$ **ALLOW** CrO_4^{2-} half equation using H⁺. i.e. CrO_4^{2-} + $8H^+$ + $3e^-$ → Cr^{3+} + $4H_2O$ **Examiner's Comments** This part required candidates to construct three equations for an unfamiliar reaction. The examiners allowed equations using H⁺ rather than OH⁻. It was then possible to credit many candidates with the full three marks with many excellent responses seen. Predictably the

					equations involving CrO_4^{2-} were more difficult but even some weaker candidates were able to construct an equation for the oxidation of iodide ions. The very best candidates did manage to construct the equations in alkaline conditions.
		Total		**11**	
20	i	Fe^{2+}: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$ ✓		2	**ALLOW** 4s before 3d, ie $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6$ **ALLOW** $1s^2$ written after answer prompt (*ie* $1s^2$ twice)
	i	Br^-: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$ ✓			**ALLOW** upper case D, etc and subscripts, e.g. ......$4S_2 3D_1$ **ALLOW** for Fe^{2+} ....$4s^0$ **DO NOT ALLOW** [Ar] as shorthand for $1s^2 2s^2 2p^6 3s^2 3p^6$ Look carefully at $1s^2 2s^2 2p^6 3s^2 3p^6$ – 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.
		Total		**5**		
2 1	a	i	pH = 0 ✓		1	**Guidance** **Examiner's Comments** Surprisingly, this part caused many candidates a problem with less than half the candidates obtaining the correct answer of 0 V. The commonest incorrect responses seen were pH values of 1 or even 7. Answer: pH = 0 V

		ii	H redox system is more negative
			  (e.g. has a more −ve *E* **OR** less +ve *E* **OR** is −ve electrode)
			OR H redox system releases electrons
			  (May be in equation, e.g. $H_2 \rightarrow 2H^+ + 2e^-$) ✓
			
			Equilibrium **shifts** to increase [H⁺] **OR** H⁺
			OR standard hydrogen equation **shifts** to increase [H⁺] **OR** H⁺ ✓
					2	**ALLOW ORA**, *ie*
						Ag redox system (D) has more positive *E* / less negative *E*
						
						ALLOW equilibrium sign
						
						IGNORE H is more reactive **ORA**
						
						IGNORE direction of equilibrium shift
						
						Examiner's Comments
						
						This part discriminated well with many candidates unable to interpret the information. Although the question asked for an explanation in terms of electrode potentials and equilibrium, these were often absent in the responses. Surprisingly, many identified the incorrect polarity for the hydrogen half-cell and then concluded that a decease in pH is a result of a decrease, rather than an increase in [H⁺(aq)]. To score well required a very good understanding of equilibrium in the context of electrode potentials.

		iii	$H_2 + 2Ag^+ \rightarrow 2Ag + 2H^+$ ✓		1	**ALLOW** multiples e.g. $\frac{1}{2}H_2 + Ag^+ \rightarrow Ag + H^+$ State symbols **NOT** required **ALLOW** equilibrium sign

				Examiner's Comments Perhaps influenced by incorrect polarity, many equations were shown the wrong way round. Many equations were not balanced by charge with Ag^+ and Ag often having no balancing number.
b	i	Fuel reacts with oxygen / oxidant to give **electrical energy / voltage** ✓	1	**ALLOW** named fuel. e.g. hydrogen / H_2; ethanol; methanol, etc **ALLOW** fuel cell requires constant supply of fuel **AND** oxygen / an oxidant **OR** fuel cell operates continuously as long as a fuel **AND** oxygen / an oxidant are added **IGNORE** 'reactants' 'products' and comments about pollution and efficiency **Examiner's Comments** Many responses seen here were far too vague. It was common to see answers about a fuel reacting but with no reference to oxygen. Responses in terms of less pollution or greenhouse gases gained no credit.
	ii	ethanol is a **liquid OR** is **less** volatile		Assume that '**it**' refers to ethanol
	ii	**OR** ethanol is easier to store / transport / stored more safely		**ALLOW** ORA throughout
	ii	**OR** hydrogen is explosive / more flammable		**IGNORE** ethanol has a higher boiling point
	ii	**OR** ethanol has more public / political acceptance ✓	1	**IGNORE** H_2 is a gas **IGNORE** 'produces no CO_2' **OR** less pollution **IGNORE** comments about efficiency **IGNORE** comments about biomass and renewable **Examiner's Comments** Most candidates were credited here, recognising that ethanol is a liquid and can therefore be more easily stored or transported.
	iii	$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O \rightarrow$	1	Correct species **AND** balancing needed **ALLOW** multiples **ALLOW** C_2H_6O for formula of ethanol **IGNORE** state symbols **Examiner's Comments** Almost all candidates wrote correct species but the equation was not always balanced correctly with $3\frac{1}{2}O_2$ or $2O_2$ being the commonest errors. Candidates need to take great care when balancing an equation containing an alcohol to account for the O atom with the alcohol formula.
	iv	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ ✓	1	Correct species **AND** balancing needed **ALLOW** multiples, e.g. $3O_2 + 12H^+ + 12e^- \rightarrow$

					$6H_2O$ $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$ **ALLOW** e (*ie* no − sign) **ALLOW** $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ **OR** $3O_2 + 6H_2O + 12e^- \rightarrow 12OH^-$ **IGNORE** state symbols **Examiner's Comments** The equations seen were impressive with nearly half the candidates providing an equation that could be credited. The examiners credited many different balancing numbers of $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$. The commonest seen were multiples using $\frac{1}{2}O_2$ and especially $3O_2$. As correct answers often showed no working, perhaps the oxygen half equation had been memorised by many candidates.
		v	oxidation: C from −2 to +4 '+' sign **not** required ✓ reduction: O from 0 to −2 ✓	2	**ALLOW** 2− and 4+ **ALLOW** $C^{2-} \rightarrow C^{4+}$ **ALLOW** 0 and 2− **ALLOW** $O^0 \rightarrow O^{2-}$ **ALLOW** 1 mark if correct oxidation numbers shown for **BOTH** C and O but wrong way around (*ie* C on reduction line and O on oxidation line) **IGNORE** O_2 reduced **IGNORE** any reference to electron transfer (*not in question*) **Examiner's Comments** This part required identification of oxidation and reduction in an unfamiliar context. The reduction of O was far easier than the oxidation of C and this was reflected in 1/2 being the commonest mark awarded. Discrimination was very good with able candidates collecting both marks.
		Total		**10**	
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 = $0.1000 \times \dfrac{26.4}{1000}$ = 2.64×10^{-3} (mol) ✓
	
	$n(FeO_4^{2-})$ = ½ x 2/3 x 2.64×10^{-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 = $\dfrac{0.226248}{0.437} \times 100$ = 51.8% ✓
	
	MUST be to **one** decimal place (in the question)
	……………………………………
	As an alternative for the final two marks, **ALLOW**:
	Theoretical amount of BaFeO$_4$ = $\dfrac{0.437}{257.1}$= 0.00170 (mol) ✓
	
	% purity = $\dfrac{8.8 \times 10^{-4}}{1.70 \times 10^{-3}} \times 100$ = 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 $\times$ ½ $\times$ 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 $\dfrac{\text{answer above}}{0.437} \times 100$
			
			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$_2$S$_2$O$_3$ 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$_2$O)3 **ALLOW** multiples **ALLOW** $2FeO_4^{2-} + 11H_2O \rightarrow 1½O_2 + 2Fe(OH)_3(H_2O)_3 + 4OH^-$

					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	**Definition** The e.m.f. (of a half-cell) compared with / connected to a (standard) hydrogen half-cell / (standard) hydrogen electrode ✓ **Standard conditions** *Units essential* Temperature of 298 K / 25°C **AND** (solution) concentrations of 1 mol dm^{-3} **AND** pressure of 100 kPa **OR** 10^5 Pa **OR** 1 bar ✓		2	As alternative for e.m.f., **ALLOW** voltage **OR** potential difference **OR** p.d. **OR** electrode potential OR reduction potential OR redox potential **ALLOW** / (standard) hydrogen cell **IGNORE** S.H.E. (as abbreviation for standard hydrogen electrode) **ALLOW** 1M **DO NOT ALLOW** 1 mol **ALLOW** 1 atmosphere / 1 atm **OR** 101 kPa **OR** 101325 Pa **Examiner's Comments** This definition was well known with most candidates achieving both marks. An error was more likely for the units of the standard conditions, usually 1 mol and 1 mol dm^3 for concentration. A less common error was comparison with a hydrogen fuel cell.
	b	i	$2Ag^+(aq) + Cu(s) \rightarrow 2Ag(s) + Cu^{2+}(aq)$ ✓	1	State symbols **not** required **ALLOW** ⇌ provided that reactants on LHS **Examiner's Comments** This proved to be a relatively easy mark although some showed the equation the wrong way round or did not balance the silver species on one side of the equation.
		ii	**Assume $Cu^{2+}|Cu$ OR Cu half cell unless otherwise stated.** $[Cu^{2+}]$ decreases **OR** < 1 mol dm^{-3} **AND**	3	*FULL ANNOTATIONS MUST BE USED* ……………………………… **ALLOW** $[Cu^{2+}]$ less than standard concentration / 1 mol dm^{-3} **DO NOT ALLOW** water reacts with Cu^{2+} **OR** Cu

		Equilibrium (shown in table) shifts to left ✓ more electrons are released by Cu ✓ The cell has a bigger **difference** in E✓		2	**ALLOW** E (for Cu^{2+}|Cu) is less positive / more negative / decreases **IGNORE standard** electrode potential (*Cell no longer standard*) **IGNORE** $E^{\ominus}$ decreases **CARE** **DO NOT ALLOW** statements about silver E changing (**CON**) **IGNORE** just 'cell potential increases' (in the question) *The final mark is more subtle and is a consequence of the less positive E value of the copper half cell* **Examiner's Comments** This part was designed to be very demanding and this proved to be the case with weaker candidates made little if any headway. The key requirements were a decreased concentration of copper ions resulting in an equilibrium shift to the left, increasing the electron flow from the copper electrode and decreasing the electrode potential of the copper half cell. This results in a larger difference in electrode potential between the two half cells and an increase in the cell potential. Even able candidates often responded in terms of the standard electrode potential changing which can never be the case. Many candidates suggested that the added water would react with copper ions forming a copper hydroxide precipitate with an equilibrium shift to the right. To score well required a very good understanding of equilibrium in the context of electrode potentials.
	c	i	$E = -2.31$ (V) ✓		1	$\mp$ sign **AND** 2.31 **required** for the mark **Examiner's Comments** In past exams, candidates have found it easy to calculate a standard cell potential. This slightly different slant on the question produced far more incorrect responses with +2.31 V (wrong sign) and 3.11 V (wrong subtraction) being common. Answer: −2.31 V
		ii	$4Al(s) + 4OH^-(aq) + 3O_2(g) + 6H_2O(l) \rightarrow 4Al(OH)_4^-(aq)$ species ✓ balance ✓		2	**IGNORE** state symbols **ALLOW** multiples **ALLOW** 1 mark for an equation in which OH^- are balanced but have not been cancelled, e.g. $4Al(s) + 16OH^-(aq) + 3O_2(g) + 6H_2O(l) \rightarrow 4Al(OH)_4^-(aq) + 12OH^-(aq)$ **ALLOW** 1 mark if charge on $Al(OH)_4$ is omitted, i.e

					$4Al(s) + 4OH^-(aq) + 3O_2(g) + 6H_2O(l) \rightarrow$ $4Al(OH)_4(aq)$ **ALLOW** 1 mark for an 'correct equation' reversed, i.e. $4Al(OH)_4^-(aq) \rightarrow 4Al(s) + 4OH^-(aq) + 3O_2(g) + 6H_2O(l)$ **Examiner's Comments** The attempts at this equation were impressive with many securing both marks for the correct balanced equation. One mark was available and awarded often for the following: a correctly balanced equation but with hydroxide ions not cancelled; the correct equation but reversed; an otherwise correct equation but with the charge missing from the $Al(OH)_4^-$ ion.
		Total		**9**	
24	a	i	 **Half-cells (2 marks)** Ag(s) and 1 mol dm^{-3} Ag$^+$(aq) 1 mol dm^{-3} Fe^{2+}(aq) **AND** 1 mol dm^{-3} Fe^{3+}(aq) **AND** Pt metal **Complete circuit (1 mark)** salt bridge **AND** voltmeter **AND** wires **Standard conditions (1 mark)** 298 K / 25 °C **AND** 100 kPa / 101 kPa pressure	4	**ALLOW** 1 atm
		ii	(Electrode potential of) Ag$^+$ / Ag becomes more positive … therefore, E_{cell} becomes smaller **OR** less positive.	2	**ALLOW** equilibrium Ag / Ag$^+$ shifts to right **ALLOW** more negative 2nd mark only available if deduced from 1st mark **ALLOW ECF** for 2nd mark
	b		Ce^{3+} and Zn^{2+}	1	
	c		Mn^{2+}, H$_2$O, Fe^{3+}, Br$_2$ Three species correct Four species correct	2	
		Total		**9**	
25	a	i	Titres correct and **ALL** recorded to **2 decimal places**	1	

			Titre: 22.50　　　　21.80　　21.15　　21.70 **AND** mean titre = 21.75 (cm^3) ✓		Working not required for mean titre
		ii	Percentage uncertainty = $\dfrac{0.05 \times 2}{21.70} \times 100 = 0.46\ (\%)$ ✓ **2 DP** required	1	**ALLOW ECF** from incorrect subtraction in **(i)**
		iii	(Excess KI) ensures that all I$_2$ is formed for titration ✓	1	**ALLOW** All Cu^{2+} converted to CuI/Cu(I)
		iv	Add starch ✓ Blue to colourless **AND** all I$_2$ has reacted ✓	2	
		v	$n(S_2O_3{}^{2-})$ in titration = $\dfrac{0.120 \times 21.75}{1000}$ = 2.61 × 10^{-3} (mol) ✓ $n(I_2)$ = 1.305 × 10^{-3} (mol) **OR** $n(Cu^{2+})$ = 2.61 × 10^{-3} (mol) **AND** $n(Cu^{2+})$ in original 250 cm^3 = 10 × 2.61 × 10^{-3} = 2.61 × 10^{-2} (mol) Mass of **A** (CuSO$_4$•xH$_2$O) used = 17.95 − 12.35 = 5.60 (g) M(CuSO$_4$•xH$_2$O) = $\dfrac{5.60}{2.61 \times 10^{-2}}$ = 214.6 (g mol^{-1}) ✓ x = $\dfrac{214.6 - 159.6}{18.0}$ = 3.05 = 3 Formula = CuSO$_4$•3H$_2$O	4	**ALLOW ECF** from incorrect mean titre in **(i)** **ECF** from $n(S_2O_3{}^{2-})$ **ECF** from $n(Cu^{2+})$ **BUT DO NOT ALLOW** incorrect mass **ECF** from M(CuSO$_4$•xH$_2$O) **AND** x = nearest whole number
	b	i	green solution: Fe^{2+}(aq) **OR** [Fe(H$_2$O)$_6$]$^{2+}$ **AND** gas bubbles: H$_2$(g) **AND** orange-brown solution: Fe^{3+}(aq) **OR** [Fe(H$_2$O)$_6$]$^{3+}$ ✓ Fe(s) + 2H$^+$(aq) → Fe^{2+}(aq) + H$_2$(g) ✓ 4Fe^{2+}(aq) + O$_2$(g) + 4H$^+$(aq) → 4Fe^{3+}(aq) + 2H$_2$O(l) ✓	3	State symbols are **not** required in this part **IGNORE**, even if incorrect **ALLOW** full equation: Fe(s) + 2HCl(aq) → FeCl$_2$(aq) + H$_2$(g)
		ii	orange solution: Cr$_2$O$_7{}^{2-}$ **AND** green solution (anywhere) Cr^{3+} **OR** [Cr(H$_2$O)$_6$]$^{3+}$ ✓	3	State symbols are **not** required in this part **IGNORE**, even if incorrect **IGNORE** Cr(VI) *The question asks for species*

			$2Cr^{3+}(aq) + H_2O(l) + 3H_2O_2(aq) \rightarrow Cr_2O_7^{2-}(aq) +$ $8H^+(aq)$ H^+, H_2O and e^- all cancelled ✓✓		**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	**15**		
26	a		$n(NH_2OH) = 4.32 \times 10^{-2} \times 0.0250 = 1.08 \times 10^{-3}$ mol $n(Fe^{3+}) = 3 \times 1.08 \times 10^{-3} = 3.24 \times 10^{-3}$ mol (assuming Equation 3) volume $= \dfrac{3.24 \times 10^{-2} \times 1000}{0.0400} = 81.0$ cm^3 Explanation: minimum amount of Fe^{3+} required is maximum amount theoretically required to react with all NH_2OH, i.e. if Equation 3 is correct (greatest amount of Fe^{3+} required) (*owtte*)	4	Factor **3** must be included in second mark for **ECF** on third mark. **ALLOW** 2 sig figs	
	b		$n(MnO_4^-) = 2.00 \times 10^{-2} \times \dfrac{21.6}{1000} = 4.32 \times 10^{-4}$ (mol) $n(Fe^{2+}) = 4.32 \times 10^{-4} \times 5 = 2.16 \times 10^{-3}$ (mol) Ratio NH_2OH: Fe^{2+} **OR** NH_2OH: Fe^{2+} $= 1.08 \times 10^{-3} : 2.16 \times 10^{-3} = 1 : 2$ **AND** Equation 2 is correct	3	**Working must be to at least 3 sig figs throughout until final numerical answer BUT** ignore trailing zeroes, e.g. for 0.490 allow 0.49 **ECF** answer above × 5 This mark is only possible from correct answers above, i.e. **no ECF**	
	c	i	Boiling speeds up the reaction **OR** Ensures that reaction is complete (Titre is less because) there is less Fe^{2+}	2		
		ii	In **Stage 1**, increase quantities so that there is sufficient solution for more than one titration	1	**ALLOW** increase scale of **Stage 1**	
			Total	**10**		
27			$..ClO^- + ..H_2O + \mathbf{2}..e^- \rightarrow ..Cl^- + \mathbf{2}..OH^-$ $Fe_2O_3 + \mathbf{10}..OH^- \rightarrow \mathbf{2}..FeO_4^{2-} + \mathbf{5}..H_2O + \mathbf{6}..e^-$ $Fe_2O_3 + \mathbf{3}..ClO^- + \mathbf{4}..OH^- \rightarrow \mathbf{2}..FeO_4^{2-} + \mathbf{3}..Cl^- + \mathbf{2}..H_2O$	3	**ALLOW** multiples throughout	
			Total	**3**		
28			Element oxidised: sulfur / S 0 to +6 Element reduced: nitrogen / N +5 to +4	4	**ALLOW** 5+, 4+ and 6+ Signs required	

			$6HNO_3 + S \rightarrow 6NO_2 + H_2SO_4 + 2H_2O$ Correct species Balance		**ALLOW** $4H^+ + 6NO_3^- + S \rightarrow 6NO_2 + SO_4^{2-} + 2H_2O$
			Total	**4**	