Question Number	Answer	Mark
4	**The only correct answer is D** (Fe^{2+} < V^{2+} < Cr^{2+}) *A is incorrect because* V^{2+} ($V^{3+} + e^- \rightleftharpoons V^{2+} = -0.26V$) *has a greater reducing strength than* Fe^{2+} ($Fe^{3+} + e^- \rightleftharpoons Fe^{2+} = +0.77V$) *B is incorrect because* Cr^{2+} ($Cr^{3+} + e^- \rightleftharpoons Cr^{2+} = -0.41V$) *has the greatest reducing strength* *C is incorrect because this is the reverse order to the correct one*	(1)

Question Number	Answer	Mark
1(a)	**The only correct answer is D** (zinc platinum) *A is incorrect because zinc is part of the reaction equation so the electrode must be zinc* *B is incorrect because zinc is needed in electrode 1 and chromium metal is not inert in electrode 2 so cannot be used* *C is incorrect because chromium metal is not inert in electrode 2*	(1)

Question Number	Answer	Mark
1(b)	**The only correct answer is C** (358 g) *A is incorrect because this is the mass of chromium ions required for a 1 mol* dm^{-3} *solution* *B is incorrect because this is the mass of the anhydrous solid required* *D is incorrect because this mass of the hydrate gives a 2 mol* dm^{-3} *solution of* Cr^{3+}	(1)

Question Number	Answer	Mark
1(c)	**The only correct answer is A** (ΔS_{total} and ln K are positive) *B is incorrect because both are directly proportional to* E^o_{cell} *C is incorrect because both are directly proportional to* E^o_{cell} *D is incorrect because both are directly proportional to* E^o_{cell}	(1)

Question number	Answer	Mark
10	**The only correct answer is B** (negative; positive) *A* *is incorrect because* $E^o_{cell} = E_{rhs} - E_{lhs}$ *so* $0.17 - (-0.40) = +0.57$ *V or* $0.40 - (-0.17) = +0.57$ *V* *C* *is incorrect because* $E^o_{cell} = E_{rhs} - E_{lhs}$ *so* $0.17 - (-0.40) = +0.57$ *V or* $0.40 - (-0.17) = +0.57$ *V* *D* *is incorrect because* $E^o_{cell} = E_{rhs} - E_{lhs}$ *so* $0.17 - (-0.40) = +0.57$ *V or* $0.40 - (-0.17) = +0.57$ *V*	(1)

Question Number	Answer	Mark
2	**The only correct answer is D** ($Mg + 2Ce^{4+} \rightarrow Mg^{2+} + 2Ce^{3+}$) *A is not correct because Ce is a weaker reducing agent than Mg* *B is not correct because* Ce^{3+} *is a weaker reducing agent than Ce* *C is not correct because* Mn^{2+} *is a weaker reducing agent than Mn*	(1) **Computer**

Question Number	Answer	Mark
4	**The only correct answer is C** (the reactants are thermodynamically unstable with respect to the products) ***A*** *is not correct because the reaction is thermodynamically feasible so will occur under certain conditions* ***B*** *is not correct because the* $E^{\ominus}_{cell}$ *value is a thermodynamic and not a kinetic property* ***D*** *is not correct because the reaction may be kinetically inert and the conditions may be non-standard*	**(1)** **Computer**

Question number	Answer	Mark
11	**The only correct answer is C** (magnesium) ***A*** *is incorrect because 1.635 ÷ 65.4 = 0.025 mol of zinc produced which gives a relative atomic mass of 24.3 for G* ***B*** *is incorrect because 1.635 ÷ 65.4 = 0.025 mol of zinc produced which gives a relative atomic mass of 24.3 for G* ***D*** *is incorrect because 1.635 ÷ 65.4 = 0.025 mol of zinc produced which gives a relative atomic mass of 24.3 for G*	**(1)**

Question Number	Answer	Mark
3	**The only correct answer is D** ($\Delta S^{\ominus}_{total}$) ***A*** *is not correct because* $E^{\ominus}_{cell}$ *is directly proportional to* $\ln K_c$ ***B*** *is not correct because* $E^{\ominus}_{cell}$ *is directly proportional to* $\Delta S^{\ominus}_{total}$ *and not* $\Delta H^{\ominus}$ ***C*** *is not correct because* $E^{\ominus}_{cell}$ *is directly proportional to* $\Delta S^{\ominus}_{total}$ *and not* $\Delta S^{\ominus}_{system}$	**(1)** **Computer**

Question number	Answer	Mark
8	**The only correct answer is B** ($Fe^{2+}(aq) \rightleftharpoons Fe^{3+}(aq) + e^{-}$ and $Br_2(aq) + 2e^{-} \rightleftharpoons 2Br^{-}(aq)$) ***A*** *is incorrect because both half-equations cannot be oxidation* ***C*** *is incorrect because these half-equations would give* $E^{\ominus}_{cell} = -0.32$ *V* ***D*** *is incorrect because both half-equations cannot be reduction*	**(1)**

Question Number	Answer	Mark
1	**The only correct answer is D** ($Pt(s) \vert V^{2+}(aq), V^{3+}(aq) \vert\vert Cu^{2+}(aq) \vert Cu(s)$) ***A*** *is not correct because the* $V^{3+}(aq)/V^{2+}(aq)$ *half-cell should have a platinum electrode and should show oxidation and the* $Cu^{2+}(aq)/Cu(s)$ *half-cell should show reduction* ***B*** *is not correct because the* $V^{3+}(aq)/V^{2+}(aq)$ *half-cell should have a platinum electrode* ***C*** *is not correct because the* $V^{3+}(aq)/V^{2+}(aq)$ *half-cell should show oxidation and the* $Cu^{2+}(aq)/Cu(s)$ *half-cell should show reduction*	**(1)** **Computer**

Question number	Answer	Mark
8	**The only correct answer is A** (standard reduction potential; most negative to most positive) ***B*** *is incorrect because the electrochemical series has the most negative standard electrode potential first* ***C*** *is incorrect because standard cell potentials are determined from two standard electrode potentials* ***D*** *is incorrect because standard cell potentials are determined from two standard electrode potentials and the electrochemical series has the most negative standard electrode potential first*	**(1)**

Question number	Answer	Mark
7	**The only correct answer is C** (ΔS_{total} and ln K) ***A*** *is incorrect because* E^{o}_{cell} *is not directly proportional to* $\Delta_r H$ ***B*** *is incorrect because* E^{o}_{cell} *is not directly proportional to* $\Delta_r H$ *or to ln RT* ***D*** *is incorrect because* E^{o}_{cell} *is not directly proportional to ln RT*	**(1)**

Question Number	Answer	Additional Guidance	Mark
21(a)	An explanation that makes reference to the following points: • (Hg^{+} is [Xe]$4f^{14}$) $5d^{10}6s^{1}$ **and** (Hg^{2+} is [Xe]$4f^{14}$) $5d^{10}(6s^{0})$ **(1)** • (d-block element as last) electron goes into a (5)d-orbital(s) (when the electronic configuration is written according to the Aufbau principle) **(1)** • (not transition element as) Hg^{+} and Hg^{2+}/(stable) ions do not have incompletely filled (5)d-orbital(s) **(1)**	Accept use of d-subshell for d-orbital(s) Allow use of d-shell for d-subshell Penalise use of just d-block for d-shell once only Penalise use of 3d/4d for 5d once only Allow Hg loses (only) its **6s** electrons (when forming ions/compounds) Do not award answer in terms of the electronic configuration of an ion of mercury Allow Hg^{+} and Hg^{2+}/(stable) ions have completely full (5)d-orbital(s) Ignore any reference to d-d transitions / other transition element properties Do not award answer in terms of the electronic configuration of the element / an Hg atom	**(3)** **Expert**

Question Number	Answer	Additional Guidance	Mark
21(b)(i)	An explanation that makes reference to the following points: • Hg/mercury oxidised **and** from 0 (in Hg) to +2 (in $Hg(NO_3)_2$) **(1)** • N/nitrogen is reduced **and** from +5 (in HNO_3) to +2 (in NO) **(1)**	Allow oxidation numbers from annotation to the equation Ignore any reference to electron loss/gain Do not award reference to oxidation of any other element Do not award HNO_3 is reduced Do not award reference to reduction of any other element If no other mark awarded, Hg/mercury oxidised **and** N/nitrogen reduced OR Hg/mercury from 0 to +2 **and** N/nitrogen from +5 to +2 scores (1)	**(2)** **Expert**

Question Number	Answer	Additional Guidance	Mark
21(b)(ii)	An answer that makes reference to the following points: • ionic half-equation for oxidation of mercury **(1)** • ionic half-equation for reduction of nitrate **(1)**	Allow multiples and $\rightleftharpoons$ for $\rightarrow$ Ignore state symbols, even if incorrect Examples of ionic half-equations: $Hg \rightarrow Hg^{2+} + 2e^{(-)}$ Allow $Hg - 2e^{(-)} \rightarrow Hg^{2+}$ Do not award half-equation including HNO_3/NO_3^- $4H^{+} + NO_3^{-} + 3e^{(-)} \rightarrow NO + 2H_2O$ Allow $3H^{+} + HNO_3 + 3e^{(-)} \rightarrow NO + 2H_2O$ Allow $4HNO_3 + 3e^{(-)} \rightarrow NO + 2H_2O + 3NO_3^{-}$	**(2)** **Expert**

Question Number	Answer	Additional Guidance	Mark
21(b)(iii)	An answer that makes reference to the following point: • balanced equation	Example of completed equation: $\underline{3}Hg(l) + \underline{8}HNO_3(aq) \rightarrow \underline{3}Hg(NO_3)_2(aq) + \underline{2}NO(g) + \underline{4}H_2O(l)$ Allow multiples	**(1)** **Clerical**

Question Number	Answer		Additional Guidance	Mark
21(c)(i)	An answer that makes reference to the following point: • correct species • balanced equation	 (1) (1)	Example of completed equation: $Hg(NO_3)_2 + 3C_2H_5OH \rightarrow Hg(CNO)_2 + 2CH_3CHO + 5H_2O$ Ignore state symbols even if incorrect Do not award molecular formulae eg C_2H_4O for CH_3CHO Do not award CH_3COH for CH_3CHO Allow multiples No TE on M1 except on correct molecular formulae and on CH_3COH	(2) **Graduate**

Question Number	Answer		Additional Guidance	Mark
21(c)(ii)	• moles of $Hg(CNO)_2$ • moles of gas produced • volume of gas produced	(1) (1) (1)	Correct answer with some working scores (3) Ignore SF except 1SF throughout Example of calculation: $n = \frac{1.00}{284.6} = 0.0035137 / 3.5137 \times 10^{-3}$ $n = 0.0035137 \times 2 = 0.0070274 / 7.0274 \times 10^{-3}$ TE on M1 $v = 0.0070274 \times 24000 = 168.66\ (cm^3)$ Accept 0.16866 $\mathbf{dm^3}$ TE on M2	(3) **Expert**

Question Number	Answer	Additional Guidance	Mark
21(d)(i)	An answer that makes reference to the following point: • (to provide a) constant concentration (of Cl^-)	Allow KCl for Cl^- throughout Allow to keep the solution / Cl^- saturated Allow to replace Cl^- Ignore just to provide Cl^- Ignore stated concentrations Do not award salt bridge / to complete the circuit Do not award catalyst	(1) **Expert**

Question Number	Answer	Additional Guidance	Mark
21(d)(ii)	An answer that makes reference to the following point: • (0.24 – 0.37 =) –0.13 (V)	Ignore working, even if incorrect	(1) **Expert**

Question Number	Answer	Additional Guidance	Mark
21(d)(iii)	An answer that makes reference to the following point: • $Hg_2Cl_2 + Sn \rightarrow 2Hg + Sn^{2+} + 2Cl^-$	Allow $Hg_2Cl_2 + Sn \rightarrow 2Hg + SnCl_2$ Allow multiples Allow $\rightleftharpoons$ for $\rightarrow$ Ignore state symbols even if incorrect Ignore half-equations even if incorrect Ignore use of cell diagrams Do not award uncancelled electrons Do not award $2Hg^+$ (+ $2Cl^-$) for Hg_2Cl_2 **If answer to (d)(ii) is +0.61 (V) / +0.37 (V) / greater than +0.24 (V), equation must be reversed:** $2Hg + Sn^{2+} + 2Cl^- \rightarrow Hg_2Cl_2 + Sn$ OR $2Hg + SnCl_2 \rightarrow Hg_2Cl_2 + Sn$	(1) **Expert**

Question Number	Answer	Additional Guidance	Mark
21(d)(iv)	An answer that makes reference to the following points:	Example of completed diagram: 	(3)

Question Number	Answer	Additional Guidance	Mark
16(a)(i)	An answer that makes reference to the following point: • oxygen is -2 / total for oxygen is -8 **and** hydrogen is +1 / total for hydrogen is +3 **and** a compound must be 0 overall (so Mn is +5)	Values may be seen in a calculation Values may be seen as labels on equation in the question Allow just the totals or the values for each atom for oxygen and hydrogen This can be scored by a statement or by a mathematical justification through a suitable calculation which assumes overall is 0.	(1)

Question Number	Answer	Additional Guidance	Mark
16(a)(ii)	An answer that makes reference to the following point: • correct formula for all three manganese compounds (1) • balanced equation (1)	$2H_3MnO_4 \rightarrow HMnO_4^- + MnO_2 + 2H_2O + H^+$ Accept $2MnO_4^{3-} + 4H^+ \rightarrow MnO_4^{2-} + MnO_2 + 2H_2O$ Dependent on M1 Do not award uncancelled electrons Allow multiples Ignore state symbols even if incorrect	(2)

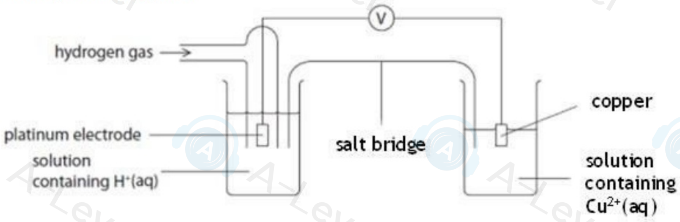
Question Number	Answer	Additional Guidance	Mark
16(a)(iii)	An answer that makes reference to the following points: • selection of correct values for equation (1) • calculation of $E^⦵$ and statement regarding thermodynamic feasibility (1)	Example of calculation $E^⦵ = 2.90 - 1.28$ Allow (+)1.62(V) with no indication of electrode values $E^⦵ = (+)1.62(V)$ Value is positive so (thermodynamically) feasible Allow TE on calculation Allow > 0 for positive If no calculation is attempted allow a positive value of $E^⦵$ is feasible Or A negative value for $E^⦵$ is unfeasible	(2)

Question Number	Answer	Additional Guidance	Mark
16(b)(i)	An answer that makes reference to the following points: • (pale) pink to colourless	Do not award purple Do not award colourless to pink	(1)

Question Number	Answer	Additional Guidance	Mark
16(b)(ii)	• use of two mathematical process **(1)** • use of two further mathematical process **(1)** • use of two further mathematical processes **(1)** • use of two further mathematical processes **(1)**	To mark this item look first for the final answer. Correct answer with some working scores (4). Next look for the processes. Mark according to the number of processes as shown in the Answer column. This calculation involves eight mathematical processes 1) Calculation of Mr of sodium ethanedioate 2) Divide by calculated Mr (molecular mass of sodium ethanedioate) 3) $\times 10^{-3}$ or $\div 1000$ an odd number of times 4) Divide by 250 (volume of sodium ethanedioate solution) 5) Multiply by 22.95 (mean titre volume) 6) multiply by 2/5 (mole ratio of manganate(VII) to ethanedioate) 7) divide by 25 (volume of manganate(VII) solution) 8) final answer to **2 or 3 SF** These processes can be done in any order except process 8. Volumes can be in cm^3 rather than dm^3 (as two of the powers will cancel) so do not penalise. This is covered in process 3. <u>Example of calculation</u> One common route is shown: $1.915 \div 134 = 0.014291$ / 0.0143 / 1.4291×10^{-2} / 1.43×10^{-2} (mol) $0.014291 \div 250 = 5.7164 \times 10^{-5}$ (mol cm^{-3}) (or $= 0.057164$ (mol dm^{-3})) $5.7164 \times 10^{-5} \times 22.95 = 0.0013119$ (mol) $2/5 \times 0.0013119 = 5.2477 \times 10^{-4}$ (mol) $5.2477 \times 10^{-4} \div 25 \times 10^{-3} = 0.0020991$ (mol dm^{-3}) $= 0.0210$ / 0.021 / 2.10×10^{-2} / 2.1×10^{-2} Ignore SF except for final mark Allow TE throughout	**(4)**

Question Number	Answer	Additional Guidance	Mark
16(b)(iii)	An answer that makes reference to the following points: • (brown suspension is) MnO_2 **(1)** • because only three electrons are required in forming MnO_2 (while five are required on forming Mn^{2+}) or because only three electrons are required to convert Mn(VII) to Mn(IV) (while five are required to convert Mn(VII) to Mn(II)) **(1)** • this results in a smaller titration volume / less ethanedioate required **(1)**	Allow any identification of MnO_2 including in an equation. May be shown in an ionic half-equation Allow formation of MnO_2 / Mn(IV) / requires less electrons Allow the ratio of manganese species:ethanedioate is 2:3 for Mn(IV) (but 2:5 for Mn(II)) Dependent on one of the previous two marks	**(3)**

(Total for Question 16 = 13 marks)

Question Number	Answer	Additional Guidance	Mark
18(a)	**Hydrogen half-cell:** • (**M1**) 1 mol dm^{-3} $H^+(aq)$ **and** platinum (black) electrode **(1)** • (**M2**) hydrogen gas in suitable apparatus at 100 kPa / 1×10^5 Pa (at 298 K) **(1)** **Copper half-cell:** • (**M3**) copper (electrode) dipping into solution **(1)** • (**M4**) 1 mol dm^{-3} Cu^{2+} (solution) **(1)** **Connections:** • (**M5**) salt bridge (dipping into /touching both solutions) **and** voltmeter **and** complete circuit **(1)**	Example of diagram:  Allow hydrogen half-cell drawn on the right Concentration only needed once in M1 and M4 if both are 1 mol dm^{-3} Allow 1 mol dm^{-3} hydrochloric acid / HCl / nitric acid / HNO_3 Allow 0.5 mol dm^{-3} sulfuric acid / H_2SO_4 Do not award just 1 mol but only penalise once in M1 and M4 Accept 101 kPa / 1.01×10^5 Pa / 1 atmosphere pressure Allow 1 bar pressure Do not award other temperatures Ignore references to anode/cathode Allow any soluble named copper(II) salt e.g. copper(II) sulfate / $CuSO_4$ / copper(II) nitrate / $Cu(NO_3)_2$ / copper(II) chloride / $CuCl_2$ Allow salt bridge drawn and labelled just with the electrolyte e.g. potassium, sodium or ammonium nitrate, chloride or sulfate Do not award M5 if the circuit is incorrect e.g. a cell or ammeter instead of voltmeter or incorrect compounds such as KOH/HNO_3 in salt bridge	**(5)**

Question Number	Answer	Additional Guidance	Mark
18(b)(i)	An explanation that makes reference to the following points: (concentrated hydrochloric acid) • increases the concentration of H^+ ions in the first equilibrium (and displaces it to the right) so increases the value of *E* / *E* > 1.33 (V) **(1)** (concentrated hydrochloric acid) • increases the concentration of chloride ions in the second equilibrium (and displaces it to the left) so decreases the value of *E* / *E* < 1.36 (V) **(1)** • the difference between 1.33 and 1.36 is (very) small **and** so using concentrated hydrochloric acid, E_{cell} will be positive (so the reaction occurs) **(1)**	Ignore any references to E_a/energy Allow just 'when [H^+] increases the first equilibrium shifts to the right' Allow because the coefficient for H^+ is 14, the position of equilibrium is very sensitive to the concentration of H^+ Allow just 'when [Cl^-] increases the second equilibrium shifts to the left' There must be some indication of the equilibrium referred to but can simply be Cl_2:2 Cl^- Allow answer in terms of first $E^\ominus$ increasing (above 1.36 (V)) **or** second $E^\ominus$ decreasing (below 1.33(V)) so E_{cell} will be positive for M3 Allow chlorine escapes and displaces second equilibrium to the left and decreases $E^\ominus$ decreasing below 1.33 (V) so E_{cell} will be positive Ignore references to anode/cathode	**(3)**

Question Number	Answer	Additional Guidance	Mark
18(b)(ii)	**(1)** • left hand side of cell diagram • central vertical lines and right hand side of cell diagram **(1)**	Example of cell diagram: $Pt(s) \mid 2Cl^-(aq) \mid Cl_2(g) \parallel [Cr_2O_7^{2-}(aq) + 14H^+(aq)], [2Cr^{3+}(aq)+7H_2O(l)] \mid Pt(s)$ Allow comma between Cl^- and Cl_2 Do not award missing molar ratio but penalise once only Allow dotted / dashed vertical lines in the cell junction of the cell diagram Allow comma between dichromate ion and proton Allow vertical line between protons and chromium(III) ions Ignore missing / incorrect state symbols Ignore omission of water Ignore missing brackets/use of rounded brackets Penalise inclusion of electrons once only	**(2)**