Mark Scheme

Q1.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• calculation of moles of $Cr_2O_7^{2-}$ **(1)** • calculation of moles of Mn^{2+} **(1)** • deduction of whole number mole ratio of $Cr_2O_7^{2-}$: Mn^{2+} **(1)** • deduction of total number of electrons lost by 3 mol of Mn^{2+} **(1)** • deduction of final oxidation state of manganese **(1)**	Example of calculation • moles of $Cr_2O_7^{2-}$ = $\frac{0.100 \times 20.0}{1000}$ = 2(.00) x 10^{-3} (mol) • moles of Mn^{2+} = $\frac{0.200 \times 30.0}{1000}$ = 6(.00) x 10^{-3} (mol) • mole ratio $Cr_2O_7^{2-}$: Mn^{2+} = 1 : 3 • 3 mol Mn^{2+} lose a total of $6e^-$ • each Mn^{2+} loses $2e^-$, so final oxidation state of Mn is (+)4 / IV /Mn^{4+} MP3 and MP4 may be awarded via alternative methods e.g. use of oxidation numbers / moles of electrons correct final oxidation state with no working scores M5 only	**(5)**

Q2.

Question Number	Answer	Additional Guidance	Mark
	• both platinum symbols and salt bridge **(1)** • rest of diagram **(1)**	Pt(s) | $C_2O_4^{2-}(aq)$, $2CO_2(g)$ ⋮ $[MnO_4^-(aq) + 8H^+(aq)]$, $[Mn^{2+}(aq) + 4H_2O(l)]$ | Pt(s) Allow solid lines for salt bridge Allow half cells shown correctly on opposite side Ignore omission of square brackets / state symbols if neither marked scored allow 1 mark for all four 'redox' species in ROOR order, separated by commas or dashed lines, but not solid lines	**(2)**

Q3.

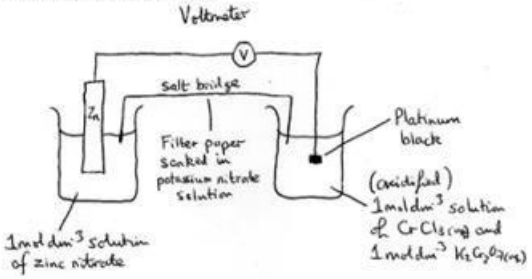
Question Number	Answer	Additional Guidance	Mark
(i)	• correct species **(1)** • balancing **(1)**	Example of equation $Cr_2O_7^{2-} + 14H^+ + 3Zn \rightarrow 2Cr^{3+} + 7H_2O + 3Zn^{2+}$ Allow multiples Allow ⇌ provided equation written in direction shown Ignore state symbols even if incorrect Do not award uncancelled electrons	**(2)**

Question Number	Answer	Additional Guidance	Mark
(ii)	• calculation of $E^{\ominus}_{cell}$	Example of calculation ($E^{\ominus}_{cell}$ = 1.33 – (–0.76)) = (+) 2.09 (V) Allow –2.09 (V) if equation written in reverse in (c) (i) Correct answer with no working scores (1)	**(1)**

Question Number	Answer	Additional Guidance	Mark
(iii)	yes/zinc and acid will reduce chromium(III) ions to chromium(II) ions **and** because $E^{\ominus}_{cell}$ for the reaction between Zn and Cr^{3+} is (+) 0.35 (V) **or** Zn^{2+} / Zn electrode potential / SEP / $E^{\ominus}$ value is more negative / less positive / lower than the Cr^{3+} / Cr^{2+} value **or** Zn/ Zn^{2+} electrode potential / SEP / $E^{\ominus}$ value is less negative / more positive / higher than the Cr^{3+} / Cr^{2+}	Allow positive or >0 if not calculated Allow explanations in terms of the anti-clockwise rule	**(1)**

Question Number	Answer	Additional Guidance	Mark
(iv)	An explanation that makes reference to the following points: • the energy difference between the two sets of d orbitals is different in the two ions / Cr^{3+} and Cr^{2+} **or** there is different splitting of the d orbital**s** / d subshell **(1)** • electrons undergo different d-d transitions/ are promoted to a higher d-orbital absorbing/requiring a different amount of energy **or** a different amount of energy is absorbed the frequency / wavelength/colour of (visible) light absorbed is different **(1)**	Allow the d orbital energies are different Allow different charges / oxidation numbers alter the d orbital energies differently Do not award reference to a single d orbital splitting/ d orbital splitting Ignore references to charges/charge density/oxidation numbers/electron configurations of the ions Do not award references to electrons being excited and falling back to the ground state (or words to that effect) Allow the frequency / wavelength of (visible) light transmitted / reflected is different Do not award emitted instead of absorbed Ignore reference to different ligands	**(2)**

Q4.

Question Number	Answer	Additional Guidance	Mark
	A diagram that includes • **(M1)** (high resistance) voltmeter/V **(1)** • **(M2)** salt bridge to complete circuit **(1)** • **(M3)** filter paper soaked in (saturated) potassium nitrate/KNO_3 solution **(1)** **(M4)** zinc electrode of zinc metal and suitable zinc salt **(1)** • **(M5)** platinum (black) electrode **(1)** • **(M6)** suitable chromium salts **(1)** • **(M7)** all solutions to be 1 mol dm^{-3} (wrt ions) **(1)**	Example of diagram  Salt bridge must dip into the solutions Allow sodium chloride/potassium chloride for potassium nitrate e.g. $ZnSO_4$ e.g. $CrCl_3$ / $K_2Cr_2O_7$ if $Cr_2(SO_4)_3$ is used then M7 can only be awarded if its concentration is 0.5 mol dm^{-3} Allow electrodes drawn the other way round Ignore temperature is 298 K Penalise use of just names once only	**(7)**

Q5.

Question Number	Answer	Additional Guidance	Mark
(i)	• four correct species **(1)** • balancing and the correct number of electrons **(1)**	An example of equation $[Cr(OH)_6]^{3-} + 2OH^- \rightarrow CrO_4^{2-} + 4H_2O + 3e^-$ Accept multiples	**(2)**

Question Number	Answer	Additional Guidance	Mark
(ii)	• equation	An example of equation $2CrO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + H_2O$ Accept $\rightleftharpoons$ / multiples	**(1)**

Question Number	Answer	Additional Guidance	Mark
(iii)	• oxidation half equation **(1)** • reduction half equation **(1)** • overall equation **(1)**	$H_2O_2 \rightarrow 2H^+ + O_2 + 2e^-$ $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$ $Cr_2O_7^{2-} + 8H^+ + 3H_2O_2 \rightarrow 2Cr^{3+} + 7H_2O + 3O_2$ for M3 do not award if H^+/ e^- left on both sides Accept multiples Allow $\rightleftharpoons$ Ignore state symbols even if incorrect Oxidation and reduction half equations scores (2) if not identified but in correct order Award (1) only for M1 and M2 if half equations are not in correct order No TE on incorrect half equations	**(3)**

Q6.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• substitution of correct values into expression **(1)** • calculation of $\ln[Ag^+(aq)]$ **(1)** • calculation of $[Ag^+(aq)]$ **(1)**	Example of calculation $0.72 = 0.80 + \frac{8.31 \times 293}{96500} \times \ln[Ag^+(aq)]$ $\ln[Ag^+(aq)] = (0.72 - 0.80) \times \frac{96500}{8.31 \times 293}$ $= -3.1707$ $[Ag^+(aq)] = e^{\ln[Ag^+(aq)]}$ $= 0.041976 / 4.1976 \times 10^{-2}$ (mol dm^{-3}) TE on $\ln[Ag^+(aq)]$ Ignore SF except 1 SF Correct answer with no working scores full marks Expression can be rearranged before substitution of values	**(3)**

Q7.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• (high resistance) voltmeter **(1)** • platinum /Pt (electrode) **(1)** • manganese(II) **and** manganese(III) ions / Mn^{2+} **and** Mn^{3+} **(1)**	Allow potentiometer / Wheatstone bridge / just 'V' Ignore high voltage Do not award voltameter Ignore just 'inert metal' Do not award manganese / Mn Allow any named manganese(II) salt **and** manganese(III) salt Ignore concentration and units	**(3)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b) (i)	• potassium nitrate / KNO_3	If name and formula are given, both must be correct If more than one substance given, all must be correct Allow potassium chloride / KCl sodium nitrate / $NaNO_3$ sodium chloride / NaCl ammonium nitrate / NH_4NO_3 ammonium chloride / NH_4Cl Ignore concentration	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(b) (ii)	• wire does not allow the flow of ions **or** wire (only) allows flow of electrons **or** salt bridge allows flow of ions **or** salt bridge does not allow the flow of electrons **or** a flow of ions is needed to complete the circuit **or** ions (need to) flow between the half-cells / between the solutions	Allow any indication of movement for flow in all points Allow the salt bridge donates / removes ions (to balance the charges in the solution and the wire does not do this) Ignore just 'the circuit is not complete' Ignore references to changes in potential difference / $E^{\ominus}$ / $E^{\ominus}_{cell}$	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(c) (i)	• correct equation	Example of equation $2Mn^{3+} + Cu \rightarrow 2Mn^{2+} + Cu^{2+}$ Allow multiples Allow ⇌ provided equation is written in the direction shown Ignore state symbols, even if incorrect Ignore cancelled electrons e.g. $2Mn^{3+} + Cu \rightarrow 2Mn^{2+} + Cu^{2+} + 2e$ Do not award equation with uncancelled electrons	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)(ii)	• $E^{\ominus}$ = 1.15 – (–0.34) = (+)1.49 (V)	Stand alone mark Correct answer with no working scores the mark	(1)

Q8.

Question Number	Answer	Additional Guidance	Mark
(i)	• identification of oxidising agent	Either acidified (potassium) manganate(VII) / MnO_4^- and H^+ Or acidified hydrogen peroxide / H_2O_2 and H^+ Allow H^+ shown in equation in (i) or (ii) If the acid is specified it must be sulfuric acid	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	• value of $E^{\ominus}_{cell}$	Either $E^{\ominus}_{cell}$ = (+)0.15 (V) for acidified (potassium) manganate(VII) Or $E^{\ominus}_{cell}$ = (+)0.41 (V) for acidified hydrogen peroxide No TE on any other reagent in (i)	(1)

Q9.

Question Number	Answer	Additional Guidance	Mark
	• substitution of values into the equation (1) • calculation of K_c (1)	Example of calculation $\ln K_c = \frac{5 \times 0.15 \times 96\,500}{8.31 \times 298}$ ($\ln K_c$ = 29.226) $K_c = 4.9289 \times 10^{12}$ $= 4.9 \times 10^{12} / 4.93 \times 10^{12}$ TE on their value for $\ln K_c$ Ignore SF except 1SF Correct answer with no working scores (2)	(2)

Q10.

Question Number	Answer	Additional Guidance	Mark
	• one half-equation **(1)** • other half-equation **(1)** • state symbols **(1)**	<u>Examples of half-equations</u> $Pb(s) + SO_4^{2-}(aq) \rightleftharpoons PbSO_4(s) + 2e^-$ Allow $Pb(s) + H_2SO_4(aq) \rightleftharpoons PbSO_4(s) + 2H^+(aq) + 2e^-$ $PbO_2(s) + 4H^+(aq) + SO_4^{2-}(aq) + 2e^- \rightleftharpoons PbSO_4(s) + 2H_2O(l)$ Allow $PbO_2(s) + 2H^+(aq) + H_2SO_4(aq) + 2e^- \rightleftharpoons PbSO_4(s) + 2H_2O(l)$ Allow multiples Allow single headed arrows in the forward direction Ignore missing charge on electrons Conditional on correct species in one equation that has scored either M1or M2	**(3)**

Q11.

Question number	Answer	Mark
	The only correct answer is A ($4H^+(aq) + O_2(g) + 4e^- \rightarrow 2H_2O(l)$) ***B*** *is incorrect because methanol does not react with hydrogen* ***C*** *is incorrect because this reaction shows an oxidation* ***D*** *is incorrect because this reaction shows an oxidation*	**(1)**

Q12.

Question Number	Answer	Additional Guidance	Mark
(i)	An explanation that makes reference to the following points: • balanced equation **(1)** • calculation of $E^{\ominus}_{cell}$ value **(1)** • $E^{\ominus}_{cell}$ / answer is negative / <0 **and** the reaction is not (thermodynamically) feasible **(1)**	<u>Example of equation</u> $Br_2(aq) + H_2O(l) \rightarrow HOBr(aq) + HBr(aq)$ Allow multiples Allow $H^+(aq) + Br^-(aq)$ for HBr(aq) Allow reversible arrows Ignore state symbols even if incorrect $E^{\ominus}_{cell} = 1.09 - 1.57 = -0.48$ (V) Allow correct answer without calculation Allow 3 marks for reverse argument $HOBr(aq) + HBr(aq) \rightarrow Br_2(aq) + H_2O(aq)$ (1) $E^{\ominus}_{cell} = 1.57 - 1.09 = (+) 0.48$ (V) (1) $E^{\ominus}_{cell}$ is positive / >0 so the reverse of disproportionation is (thermodynamically) feasible (1)	(3)

Question Number	Answer	Additional Guidance	Mark
(ii)	An answer that makes reference to the following point: • disproportionation is an equilibrium system (and although K is very small, there is still a small concentration of disproportionation products) **or** excess water is used **or** concentration is not 1 mol dm^{-3} **or** HOBr undergoes further disproportionation	Ignore just 'non-standard conditions' Ignore references to activation energy / collision theory Ignore H^+ / ions from the water	(1)

Q13.

Question Number	Acceptable Answers	Additional Guidance	Mark
	A description that makes reference to the following points: **M1 and M2 –colours** Yellow → blue → green → violet / lavender / purple / mauve 2 or 3 colours linked to correct species / oxidation states / reactions **(1)** 4 colours linked to correct species / oxidation states / reactions **(1)** **M3 - statement** Statement that sequence is from +5 to +4 to +3 to +2 **or** (step-wise) reduction / zinc is a reducing agent **(1)** **M4, M5 and M6 - equations** These three equations, **with** appropriate $E^{\ominus}$ values $Zn + 2VO_3^- + 8H^+ \rightarrow Zn^{2+} + 2VO^{2+} + 4H_2O$ **and** $E^{\ominus}$ = (+)1.76 (V) **(1)** $Zn + 2VO^{2+} + 4H^+ \rightarrow Zn^{2+} + 2V^{3+} + 2H_2O$ **and** $E^{\ominus}$ = (+)1.1(0) (V) **(1)**	M3 can be implied from species in explanation or equations Allow multiples Ignore state symbols even if incorrect 3 correct equations with incorrect $E^{\ominus}$ scores 2 2 correct equations with incorrect $E^{\ominus}$ scores 1 3 correct $E^{\ominus}$ with incorrect equations scores 1	**(7)**
	$Zn + 2V^{3+} \rightarrow Zn^{2+} + 2V^{2+}$ **and** $E^{\ominus}$ = (+)0.5(0) (V) **(1)** **M7 – stops at V^{2+}** No (further) reduction (feasible) to V metal / V(0) **or** $Zn + V^{2+} \rightarrow Zn^{2+} + V$ not feasible **or** $E^{\ominus}$ = −0.42 (V) **(1)**		

Q14.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• calculation of moles of Cr **(1)** **MP2, 3 & 4 are only available for answers using a 3:2 mole ratio** • deduction of mole ratio of **X** to Cr^{3+} **(1)** • calculation of moles of **X** **(1)** • calculation of molar mass / A_r of **X** **and** identification of **X** accordingly **(1)**	Example of calculation Moles Cr = $\frac{1.456}{52(.0)}$ = 0.028(0) **3** mol **X** : **2** mol Cr^{3+} / Cr Allow $2Cr^{3+} + 3X \rightarrow 3X^{2+} + 2Cr$ Moles **X** = 0.028(0) x 1.5 = 0.042(0) Correctly multiplying by 1.5 for MP3 implies MP2 $M_r = \frac{1.021}{0.042(0)}$ = 24.3 (g mol^{-1}) **and** (so) **X** is magnesium/Mg COMMENT: If transpose 3:2 ratio, **X** has M_r = 54.7 (g mol^{-1}) and **X** = Mn so scores M1, then M3 and M4 by TE (i.e. **(3)** marks overall)	**(4)**

Q15.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• Na / sodium	Do not award Na^+	**(1)**

Q16.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	• MnO_2, MnO_4^-, OH^- and MnO_4^{2-} species correct in a single equation **(1)** • H_2O on right **and** balancing **(1)**	Example of equation $MnO_2 + 2MnO_4^- + 4OH^- \rightarrow 3MnO_4^{2-} + 2H_2O$ Ignore state symbols, even if incorrect Do not award M1 if H^+ is on the left Allow cancelled electrons Allow multiples	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	An answer that makes reference to: • 2 different species are oxidised and reduced (to form the same species) **or** there is not 1 species that is being oxidised and reduced **or** 2 different oxidation states are not produced from one oxidation state **or** only 1 oxidation state / +6 is formed as a product **or** Mn changes from +4 and +7 to +6 (only)	This mark can be awarded even if (i) is incorrect Allow manganate(VI) / MnO_4^{2-} is oxidised and reduced in the reverse reaction Allow Mn in the same species is not being oxidised and reduced Ignore just 'Mn is not simultaneously oxidised and reduced' Ignore this is reverse disproportionation / comproportionation Do not award O / H is oxidised / reduced Do not award molecules / compounds for species	**(1)**

Q17.

Question Number	Answer	Mark
(i)	**The only correct answer is A** ***B*** *is not correct because* Cl^- *is not an oxidising agent* ***C*** *is not correct because* I_2 *is not a powerful enough oxidising agent* ***D*** *is not correct because* Mn^{2+} is not an oxidising agent	**(1)**

Question Number	Answer	Additional Guidance	Mark
(ii)	• all species on correct sides of equation **and** no electrons / electrons cancelled **(1)** • balancing correct species **(1)** • $E^{\ominus}_{cell}$ value **(1)**	Example of ionic equation $2MnO_4^- + 16H^+ + 10Br^- \rightarrow 2Mn^{2+} + 8H_2O + 5Br_2$ Allow ⇌ Allow correct species if shown in working with half-equations but slip made in final equation e.g. charge missing Ignore state symbols Allow multiples Allow M2 for almost correct species $E^{\ominus}_{cell}$ (= 1.51 – 1.09) = (+)0.42 (V) No TE on incorrect equation	(3)

Q18.

Question Number	Answer	Additional Guidance	Mark
	• reduction half-equation	Example of half equation $½O_2 + H_2O + 2e^- \rightarrow 2OH^-$ Allow multiples Ignore state symbols even if incorrect	(1)

Q19.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	• correct temperature **and** pressure	Examples of values Temperature: 298 K / 25°C Pressure: 1 atm / 1 bar 100 kPa/ 1 x 10^5 Pa / 101 kPa / 1.01 x 10^5 Pa / 1 x 10^5 Nm^{-2} / 1.01 x 10^5 Nm^{-2} Values **and** units are needed Ignore reference to concentration even if incorrect	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	• ammeter / symbol for ammeter **and** replace with (high resistance) voltmeter / symbol for voltmeter **(1)**	The mistakes can be in any order Ignore any other errors Ignore reasons for replacements Allow replace with potentiometer / Wheatstone bridge Do not award voltameter	(3)
	• ethanoic acid **and** replace with solution that is 1.0 mol dm^{-3} with respect to $H^+(aq)$ **(1)**	Allow replace with (1.0 / 1.16-1.18 mol dm^{-3}) hydrochloric acid / HCl / nitric acid / HNO_3 **or** Allow 0.5 mol dm^{-3} sulfuric acid / H_2SO_4 Ignore just 'replace with a strong acid'	
	• potassium chloride / chemical in salt bridge **and** replace with potassium nitrate / KNO_3 / sodium nitrate / $NaNO_3$ **(1)**	Allow replace chloride with a nitrate anion Ignore replace with a different anion that will not react with Ag^+	

Q20.

Question Number	Answer	Additional Guidance	Mark
(i)	• titres calculated and both ticks correct **(1)** • mean calculated **(1)**	<table><tr><td>Run</td><td>Trial</td><td>One</td><td>Two</td><td>Three</td></tr><tr><td>Final volume / cm^3</td><td>17.50</td><td>34.10</td><td>17.20</td><td>34.10</td></tr><tr><td>Initial volume / cm^3</td><td>0.00</td><td>17.30</td><td>0.00</td><td>17.20</td></tr><tr><td>Titre / cm^3</td><td>17.50</td><td>16.80</td><td>17.20</td><td>16.90</td></tr><tr><td>Concordant titres (✓)</td><td></td><td>✓</td><td></td><td>✓</td></tr><tr><td>Mean titre / cm^3</td><td colspan="4">**16.85**</td></tr></table>Both titres to 2 dp mean = (16.90+16.80)÷2 = 16.85 (cm^3) allow TE for M2 for mean of One, Two and Three = 16.97 (cm^3)	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	• calculation of moles of $Na_2C_2O_4$(aq) **(1)** • calculation of moles of $KMnO_4$ in titre **(1)** • calculation of moles of $KMnO_4$ in 100 cm^3 **(1)** • calculation of M_r for $KMnO_4$ **(1)** • calculation of mass of 1 tablet in mg to 2 or 3SF **(1)**	Example of calculation (25.0÷1000) x 0.200 = 0.005 / 5.00 x 10^{-3} (mol) 5.00 x 10^{-3} x 2÷5 = 0.002 / 2.00 x 10^{-3} (mol) 2.00 x 10^{-3} x (100÷16.85) = 0.011869 (mol) 158 0.011869 x 158 = 1.8754 g (1.8754÷5) x 1000 = 375.07 mg = 380 / 375 (mg) Correct answer with or without working scores 5 marks 0.38 g scores 4 marks (M5 not awarded) TE at each stage and on mean titre 379 mg from 0.012 scores (5)	**(5)**

Question Number	Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to the following points • (reaction is slow initially) as MnO_4^- and $C_2O_4^{2-}$ are (both) negative (ions) so will repel (each other) **(1)** • when (sufficient) Mn^{2+} ions form they (auto) catalyse the reaction **(1)** • Mn^{2+} ions will reduce MnO_4^- ions (as $E^\ominus$ is more negative) forming Mn^{3+} ions OR $MnO_4^- + 8H^+ + 4Mn^{2+} \rightarrow 5Mn^{3+} + 4H_2O$ ($E^\ominus = +0.02V$) **(1)** • Mn^{3+} ions then oxidise $C_2O_4^{2-}$ ions (reforming Mn^{2+}) (as $E^\ominus$ is more positive) OR $C_2O_4^{2-} + 2Mn^{3+} \rightarrow 2Mn^{2+} + 2CO_2$ ($E^\ominus = +0.85V$) **(1)**	Allow 'heat is required to overcome high activation energy when catalyst is absent' Allow Mn^{2+} ions will react with MnO_4^- ions as $E^\ominus$ is more negative Allow Mn^{3+} ions then react with $C_2O_4^{2-}$ ions (reforming Mn^{2+}) as $E^\ominus$ is more positive May be shown in equations and / or by calculating $E^\ominus$	**(4)**