Question			Expected Answers	Marks	Additional Guidance
1	a		**F** **B** **G** **E** **D** **FIVE** correct ✓✓✓ **FOUR** correct ✓✓ **THREE** correct ✓	3	**ALLOW** **1450** **736** **G** **76** **–642**
	b		Correct calculation –642 – (+76 + (2 × 150) + 736 + 1450 + (2 × –349)) ✓ –642 – 1864 = – 2506 ✓ (kJ mol^{-1})	2	**ALLOW** for 1 mark: –2705 (2 × 150 and 2 × 349 not used for Cl) –2356 (2 × 150 not used for Cl) –2855 (2 × 349 not used for Cl) +2506 (wrong sign) **DO NOT ALLOW** any other answers
	c		Magnesium ion **OR** Mg^{2+} has greater charge (than sodium ion **OR** Na^{+}) **OR** Mg^{2+} has greater charge density ✓ Magnesium ion **OR** Mg^{2+} is smaller ✓ Mg^{2+} has a stronger attraction (than Na^{+}) to Cl^{-} ion **OR** Greater attraction between oppositely charged ions ✓	3	***ANNOTATIONS MUST BE USED*** **ALLOW** magnesium/Mg is 2+ but sodium/Na is 1+ **DO NOT ALLOW** Mg **atom** is 2+ but Na **atom** is 1+ **ALLOW** 'charge density' here **only** **ALLOW** Mg **OR** magnesium is smaller **DO NOT ALLOW** Mg^{2+} has a smaller **atomic** radius **ALLOW** anion **OR** negative ion for Cl^{-} **DO NOT ALLOW** chlorine ions **DO NOT ALLOW** Mg has greater attraction **ALLOW** 'attracts with more force' for greater attraction but **DO NOT ALLOW** 'greater force (could be repulsion) **ALLOW** reverse argument throughout in terms of Na^{+}
			Total	**8**	

Question			Expected Answers	Marks	Additional Guidance
2	a		BrO_3^- + $5Br^-$ + $6H^+$ $\longrightarrow$ $3Br_2$ + $3H_2O$ ✓	1	**ALLOW** multiples
	b		***graph:*** Straight/diagonal line through origin **OR** 0,0 **AND** 1st order with respect to BrO_3^- ✓	1	***ANNOTATIONS MUST BE USED*** **Both** explanation and 1st order required for mark **DO NOT ALLOW** diagonal line **OR** straight line **OR** constant gradient on its own (no mention of origin **OR** 0,0) **ALLOW** 'As BrO_3^- doubles, rate doubles' **AND** 1st order **ALLOW** rate is proportional to concentration **AND** 1st order
			initial rates data: When $[Br^-]$ is doubled, rate × 2 ✓ 1st order with respect to Br^- ✓ When $[H^+]$ × 2, rate × 4 (2^2) ✓ 2nd order with respect to H^+ ✓	4	Mark order and explanation independently Mark order first, then explanation
			Rate equation rate = k $[BrO_3^-]$ $[Br^-]$ $[H^+]^2$ ✓	1	**ALLOW** ECF from candidate's orders above

Question			Expected Answers	Marks	Additional Guidance
			Calculation of rate constant (3 marks) $k = \dfrac{\text{rate}}{[BrO_3^-][Br^-][H^+]^2}$ **OR** $\dfrac{1.19 \times 10^{-5}}{(5.0 \times 10^{-2})(1.5 \times 10^{-1})(3.1 \times 10^{-1})^2}$ ✓ $= 1.7 \times 10^{-2}$ **OR** 1.65×10^{-2} ✓ $dm^9\ mol^{-3}\ s^{-1}$ ✓	3	***ANNOTATIONS MUST BE USED*** **Calculation can be from any of the experimental runs – they all give the same value of *k*** **ALLOW** $mol^{-3}\ dm^9\ s^{-1}$ **ALLOW** 1.6510579×10^{-2} and correct rounding to 1.7×10^{-2} **Correct numerical answer subsumes previous marking point** **DO NOT ALLOW** fraction: $\dfrac{238}{14415}$ -- **ALLOW ECF from incorrect rate equation.** Examples are given below for 1st line of initial rates data. IF other rows have been used, then calculate the rate constant from data chosen. **Example 1:** 1st order with respect to H^+ *rate* = $k\ [BrO_3^-]\ [Br^-]\ [H^+]$ $k = \dfrac{\text{rate}}{[BrO_3^-][Br^-][H^+]}$ **OR** $\dfrac{1.19 \times 10^{-5}}{(5.0 \times 10^{-2})(1.5 \times 10^{-1})(3.1 \times 10^{-1})}$ ✓ $= 5.1 \times 10^{-3}$ **OR** 5.12×10^{-3} ✓ $dm^6\ mol^{-2}\ s^{-1}$ ✓ **ALLOW** $5.11827957 \times 10^{-3}$ and correct rounding to 5.1×10^{-3} -- **Example 2:** Zero order with respect to BrO_3^- *rate* = $k\ [Br^-]\ [H^+]^2$ $k = \dfrac{\text{rate}}{[Br^-][H^+]^2}$ **OR** $\dfrac{1.19 \times 10^{-5}}{(1.5 \times 10^{-1})(3.1 \times 10^{-1})^2}$ ✓ $= 8.3 \times 10^{-4}$ **OR** 8.26×10^{-4} ✓ $dm^6\ mol^{-2}\ s^{-1}$ ✓ **ALLOW** $8.255289629 \times 10^{-4}$ and correct rounding to 8.3×10^{-4}
			Total	**10**	

Question			Expected Answers	Marks	Additional Guidance
3	a		measured pH > 1 **OR** $[H^+] < 0.1$ (mol dm^{-3}) ✓ $[H^+] = 10^{-pH}$ ✓ $K_a = \frac{[H^+][CH_3CH_2COO^-]}{[CH_3CH_2COOH]}$ **OR** $\frac{[H^+]^2}{[CH_3CH_2COOH]}$ ✓ Calculate K_a from $\frac{[H^+]^2}{0.100}$ ✓	4	**ALLOW** C_2H_5 throughout question **ALLOW** $[H^+] < [CH_3CH_2COOH]$ **OR** $[H^+] < [HA]$ **ALLOW** measured pH is higher than expected **ALLOW** measured pH is not as acidic as expected **ALLOW** a quoted pH value or range > 1 and < 7 **OR** between 1 and 7 **ALLOW** $[H^+]$ = antilog –pH **OR** $[H^+]$ = inverse log –pH **ALLOW** $\frac{[H^+][A^-]}{[HA]}$ **OR** $\frac{[H^+]^2}{[HA]}$ **IF** K_a is **NOT** given and $K_a = \frac{[H^+]^2}{0.100}$ is shown, award mark for K_a also (i.e. $K_a = \frac{[H^+]^2}{0.100}$ is automatically awarded the last 2 marks)
	b		**Marks are for correctly calculated values. Working shows how values have been derived.** $[H^+] = 10^{-13.46} = 3.47 \times 10^{-14}$ (mol dm^{-3}) ✓ $[OH^-] = \frac{1.0 \times 10^{-14}}{3.47 \times 10^{-14}} = 0.29$ (mol dm^{-3}) ✓	2	**ALLOW** $3.467368505 \times 10^{-14}$ and correct rounding to 3.5×10^{-14} **ALLOW** 0.28840315 and correct rounding to 0.29, i.e. **ALLOW** 0.288 **ALLOW** alternative approach using pOH: pOH = 14 – 13.46 = 0.54 ✓ $[OH^-] = 10^{-0.54}$ = 0.29 (mol dm^{-3}) ✓ Correct answer gets **BOTH** marks

Question			Expected Answers	Marks	Additional Guidance
	c		Propanoic acid reacts with sodium hydroxide forming propanoate ions/sodium propanoate **OR** $CH_3CH_2COOH + NaOH \rightarrow CH_3CH_2COONa + H_2O$ ✓ Some propanoic acid remains **OR** propanoic acid **AND** propanoate (ions) / sodium propanoate present ✓ equilibrium: $CH_3CH_2COOH \rightleftharpoons H^+ + CH_3CH_2COO^-$ ✓ **Added alkali** CH_3CH_2COOH reacts with added alkali **OR** $CH_3CH_2COOH + OH^- \rightarrow$ **OR** added alkali reacts with H^+ **OR** $H^+ + OH^- \rightarrow$ ✓ $\rightarrow CH_3CH_2COO^-$ **OR** Equilibrium $\rightarrow$ right ✓ **Added acid** $CH_3CH_2COO^-$ reacts with added acid **OR** $[H^+]$ increases ✓ $\rightarrow CH_3CH_2COOH$ **OR** Equilibrium $\rightarrow$ left ✓	7 **5**	***ANNOTATIONS MUST BE USED*** **ALLOW** C_2H_5 throughout question **ALLOW** Adding NaOH forms propanoate ions/sodium propanoate (imples that the NaOH is added to the propanoic acid) **ALLOW**: weak acid **AND** its conjugate base/salt present Throughout, do not penalise comments that imply that pH is constant in presence of buffer **DO NOT ALLOW** HA and A^- in this equilibrium expression For description of action of buffer below, **ALLOW** HA for CH_3CH_2COOH; **ALLOW** A^- for $CH_3CH_2COO^-$ Equilibrium responses must refer back to a written equilibrium. **IF** no equilibrium shown, use the equilibrium as written in expected answers (which is also written on page 6 of the paper) **ALLOW** weak acid reacts with added alkali **ALLOW** conjugate base reacts with added acid **DO NOT ALLOW** salt reacts with added acid

Question			Expected Answers	Marks	Additional Guidance
	d		$HNO_3 + CH_3CH_2COOH \rightleftharpoons CH_3CH_2COOH_2^+ + NO_3^-$ ✓ acid 1 base 2 acid 2 base 1 ✓	2	State symbols **NOT** required **ALLOW** 1 **AND** 2 labels the other way around. **ALLOW** ‘just acid’ and ‘base’ labels throughout if linked by lines so that it is clear what the acid–base pairs are. **IF** proton transfer is wrong way around then **ALLOW** 2nd mark for idea of acid–base pairs, i.e. $HNO_3 + CH_3CH_2COOH \rightleftharpoons CH_3CH_2COO^- + H_2NO_3^+$ ✗ base 2 acid 1 base 1 acid 2 ✓
	e	i	$2CH_3CH_2COOH + Mg \rightarrow (CH_3CH_2COO)_2Mg + H_2$ ✓	1	**IGNORE** state symbols **ALLOW** ionic equation: $2H^+ + Mg \rightarrow Mg^{2+} + H_2$ **IGNORE** any random charges in formula of $(CH_3CH_2COO)_2Mg$ as long as the charges are **correct (charges are treated as working)** i.e. $(CH_3COO^-)_2Mg$ **OR** $(CH_3COO)_2^-Mg$ should **not** be penalised However, Mg^{2+} instead of Mg on the left side of equation is obviously wrong
		ii	$2H^+ + CO_3^{2-} \longrightarrow H_2O + CO_2$ **OR** $2H^+ + CO_3^{2-} \longrightarrow H_2CO_3$ **OR** $H^+ + CO_3^{2-} \longrightarrow HCO_3^-$ ✓	1	State symbols **NOT** required
			Total	**17**	

Question			Expected Answers	Marks	Additional Guidance
4	a	i	Complete circuit (with voltmeter) and salt bridge linking two half-cells ✓ Pt electrode in solution of Fe^{2+}/Fe^{3+} ✓ Ag in solution of Ag^+ ✓	3	**DO NOT ALLOW** 'solution of a silver halide', e.g. AgCl (as these are insoluble) but **DO ALLOW** any solution of any other silver salt (whether insoluble or not) **IF** candidate has used incorrect redox systems, then mark ECF as follows: **(i) each** incorrect system will cost the candidate **one** mark **(ii) ECF** if species have been quoted (see Additional Guidance below) **(iii) ECF** for equation **(iv) ECF** for cell potential ***YOU MAY NEED TO WORK OUT THESE ECF RESPONSES YOURSELF DEPENDING ON THE INCORRECT REDOX SYSTEMS CHOSEN***
		ii	electrons **AND** ions ✓	1	For electrons, **ALLOW** e^- For 'ions', **ALLOW** formula of an ion in one of the half-cells or salt bridge, e.g. Ag^+, Fe^{2+}, Fe^{3+} **ALLOW ECF** as in **(i)**
		iii	$Ag + Fe^{3+} \longrightarrow Ag^+ + Fe^{2+}$ ✓	1	**ALLOW ECF** as in **(i)** **ALLOW** equilibrium sign
		iv	0.43 V ✓	1	**ALLOW ECF** as in **(i)**
	b	i	Cl_2 **OR** O_2 **AND** H^+ ✓	1	**ALLOW** chlor**ine** **ALLOW** O_2 **AND** $4H^+$ **ALLOW** O_2 **AND** acid **DO NOT ALLOW** O_2 alone **DO NOT ALLOW** equation or equilibrium
		ii	I^- ✓	1	**ALLOW** $2I^-$ **OR** iod**ide** **DO NOT ALLOW** equation or equilibrium

Question			Expected Answers	Marks	Additional Guidance
	c		A fuel cell converts energy from reaction of a fuel with oxygen into a voltage/electrical energy ✓ $2H_2 + O_2 \rightarrow 2H_2O$ ✓ Two from: • under pressure **OR** at low temperature **OR** as a liquid • adsorbed on solid • absorbed within solid ✓✓ Energy is needed to make the hydrogen **OR** energy is needed to make fuel cell ✓	5	***ANNOTATIONS MUST BE USED*** **ALLOW** combustion for reaction of fuel with oxygen/reactants **ALLOW** a fuel cell requires constant supply of fuel **OR** operates continuously as long as a fuel (and oxygen) are added **ALLOW** multiples, e.g. $H_2 + ½O_2 \rightarrow H_2O$ **IGNORE** state symbols **ALLOW** 'material' **OR** metal for solid **ALLOW** as a metal hydride
			Total	**13**	

Question			Expected Answers	Marks	Additional Guidance
5	a	i	(K_c =) $\dfrac{[NH_3]^2}{[N_2]\ [H_2]^3}$ ✓	1	Must be square brackets
		ii	$dm^6\ mol^{-2}$ ✓	1	**ALLOW** $mol^{-2}\ dm^6$ **ALLOW ECF** from incorrect K_c expression
	b		**Unless otherwise stated, marks are for correctly calculated values. Working shows how values have been derived.** $[N_2] = \dfrac{7.2}{6.0}$ **OR** 1.2 ($mol\ dm^{-3}$) **AND** $[H_2] = \dfrac{12}{6.0}$ **OR** 2.0 ($mol\ dm^{-3}$) ✓ $[NH_3] = \sqrt{(K_c \times [N_2] \times [H_2]^3)}$ **OR** $\sqrt{(8.00 \times 10^{-2} \times 1.2 \times 2.0^3)}$ ✓ = 0.876 **OR** 0.88 ($mol\ dm^{-3}$) ✓ amount NH_3 = 0.876 × 6 = 5.26 **OR** 5.3 (mol) ✓	4	***ANNOTATIONS MUST BE USED*** For **all** parts, **ALLOW** numerical answers from 2 significant figures up to the calculator value 1st mark is for realising that concentrations need to be calculated. **Correct numerical answer with no working would score all previous calculation marks** **ALLOW** calculator value: 0.876356092 down to 0.88, correctly rounded **ALLOW** calculator value down to 5.3, correctly rounded

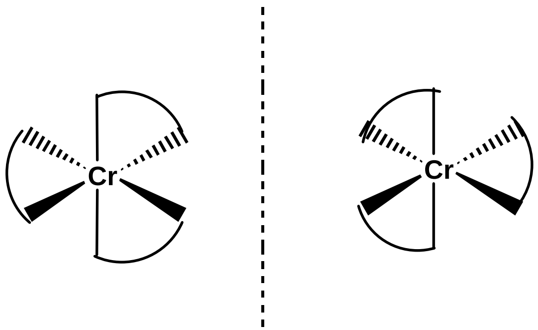
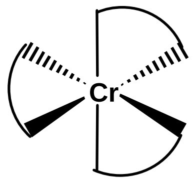
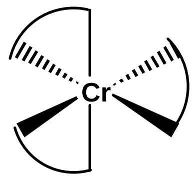
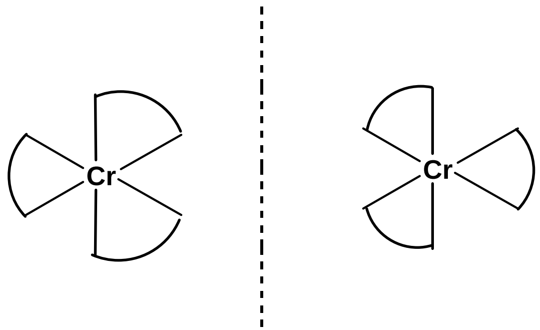
Question			Expected Answers	Marks	Additional Guidance
	b		**EXAMPLES OF INCORRECT RESPONSES IN (b) THAT MAY BE WORTHY OF CREDIT**		-- **ALLOW ECF from incorrect concentrations (3 marks)** For example, If concentrations **not** calculated at start, then $[NH_3] = \sqrt{(8.00 \times 10^{-2} \times 7.2 \times 12.0^3)}$ ✓ = 31.5 mol dm^{-3} ✓ Equilibrium amount of NH_3 = 31.5 × 6 = 189.6 (mol) ✓ -- **IF** candidate has K_c expression upside down, then all **4 marks** are available in **(b)** by **ECF** Correct $[N_2]$ AND $[H_2]$ ✓ $[NH_3] = \sqrt{\frac{[N_2]\,[H_2]^3}{K_c}} = = \sqrt{\frac{1.2 \times 2^3}{8.00 \times 10^{-2}}}$ ✓ = 11.0 mol dm^{-3} ✓ Equilibrium amount of NH_3 = 11.0 × 6 = 66.0 (mol) ✓ -- **IF** candidate has used K_c value of 8.00 × 10^{-2} **AND** values for N_2 **AND** H_2 with powers wrong, mark by **ECF** from calculated as below (**3 max in (b)**) Correct $[N_2]$ AND $[H_2]$ ✓ $[NH_3]$ expression ✗ **ECF**: Calculated $[NH_3]$ ✓ **ECF**: Equilibrium amount of NH_3 ✓

Question			Expected Answers	Marks	Additional Guidance
	c	i	Equilibrium shifts to right **OR** Equilibrium towards ammonia ✓ Right hand side has fewer number of (gaseous) moles ✓	2	**ALLOW** 'moves right' **OR** 'goes right' **OR** 'favours right' **OR** 'goes forwards' **ALLOW** 'ammonia side' has fewer moles **ALLOW** 'there are more (gaseous) moles on left'
		ii	K_c does not change ✓ Increased pressure increases concentration terms on bottom of K_c expression more than the top **OR** system is now no longer in equilibrium ✓ top of K_c expression increases and bottom decreases until K_c is reached ✓	3	***ANNOTATIONS MUST BE USED*** Any response in terms of K_c changing scores **ZERO** for Part **(ii)** **ALLOW** K_c is temperature dependent only **OR** K_c does not change with pressure **ALLOW** $\frac{[NH_3]^2}{[N_2]\,[H_2]^3}$ no longer equal to K_c
	d	i	$CH_4 + H_2O \longrightarrow 3H_2 + CO$ ✓	1	State symbols **NOT** required **ALLOW**: $CH_4 + H_2O \longrightarrow CH_3OH + H_2$ $CH_4 + 2H_2O \longrightarrow 4H_2 + CO_2$ $CH_4 + H_2O \longrightarrow 2H_2 + HCHO$ $CH_4 + 2H_2O \longrightarrow 3H_2 + HCOOH$
		ii	Electrolysis of water **OR** $H_2O \longrightarrow H_2 + ½O_2$ ✓	1	**ALLOW** electrolysis of brine **DO NOT ALLOW** reforming **DO NOT ALLOW** cracking **DO NOT ALLOW** reaction of metal with acid

Question			Expected Answers	Marks	Additional Guidance
	e	i	**Unless otherwise stated, marks are for correctly calculated values.** **Working shows how values have been derived.** $\Delta S = \Sigma S$(products) – ΣS(reactants) / = (2 × 192) – (191 + 3 × 131) ✓ = –200 (J K^{-1} mol^{-1}) **OR** –0.200 (kJ K^{-1} mol^{-1}) ✓ Use of 298 K (could be within ΔG expression below) ✓ $\Delta G = \Delta H - T\Delta S$ **OR** ΔG = –92 – (298 × –0.200) **OR** ΔG = –92000 – (298 × –200) ✓ = –32.4 kJ mol^{-1} **OR** –32400 J mol^{-1} ✓ **(Units must be shown)** For feasibility, $\Delta G < 0$ **OR** ΔG is negative ✓	5 1	***ANNOTATIONS MUST BE USED*** See **Appendix 1** for extra guidance for marking **5e(i)** and **5e(ii)** **NO UNITS** required at this stage **IGNORE** units **ALLOW** –32.4 kJ **OR** –32400 J **(Units must be shown)** Award all 5 marks **above** for correct answer with no working **IF** 25 ºC has been used instead of 298 K, correctly calculated ΔG values are = –87 kJ mol^{-1} **OR** –87000 J mol^{-1} **4 marks** are still available up to this point and maximum possible from **(e)(i)** is 5 marks
		ii	As the temperature increases, $T\Delta S$ becomes more negative **OR** $T\Delta S$ becomes more negative than ΔH **OR** $T\Delta S$ becomes more significant ✓ Eventually $\Delta H - T\Delta S$ becomes positive ✓	2	**ALLOW** $T\Delta S > \Delta H$ (i.e. assume no sign at this stage) **ALLOW** 'entropy term' as alternative for $T\Delta S$ **ALLOW** **–**$T\Delta S$ becomes more positive **ALLOW** **–**$T\Delta S$ decreases **ALLOW** ΔG becomes positive **OR** $\Delta G > 0$

Question			Expected Answers	Marks	Additional Guidance
		iii	Activation energy is too high **OR** reaction too slow ✓	1	**ALLOW** increases the rate **OR** more molecules exceed activation energy **OR** more successful collisions **ALLOW** rate constant increases **IGNORE** comments on yield
			Total	**22**	

Question			Expected Answers	Marks	Additional Guidance
6	a	i	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$ ✓	1	**ALLOW** $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$ (i.e. 4s before 3d) **ALLOW** $[Ar]4s^1 3d^5$ **OR** $[Ar]3d^5 4s^1$
		ii	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^3$ ✓	1	**ALLOW** $[Ar]3d^3$ **ALLOW** $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^0$ **OR** $[Ar]3d^3 4s^0$
	b		$Zn \longrightarrow Zn^{2+} + 2e^-$ ✓ $Cr_2O_7^{2-} + 14H^+ + 8e^- \longrightarrow 2Cr^{2+} + 7H_2O$ ✓ $4Zn + Cr_2O_7^{2-} + 14H^+ \longrightarrow 4Zn^{2+} + 2Cr^{2+} + 7H_2O$ ✓	3	**ALLOW** multiples **WATCH** for balancing of the equations printed on paper **IF** printed equations and answer lines have different balancing numbers **OR** electrons, **IGNORE** numbers on printed equations (i.e. treat these as working) and mark responses on answer lines **only** **NO ECF** for overall equation i.e. the expected answer is the **ONLY** acceptable answer
	c	i	Ligand substitution ✓	1	**ALLOW** ligand exchange
		ii	$[Cr(H_2O)_6]^{3+}$ ✓ + $6NH_3 \longrightarrow$ $[Cr(NH_3)_6]^{3+}$ ✓ + $6H_2O$	2	1 mark is awarded for each side of equation **ALLOW** equilibrium sign **ALLOW** 1 mark for 2+ shown instead of 3+ on both sides of equation **ALLOW** 1 mark for substitution of 4 NH_3: $[Cr(H_2O)_6]^{3+} + 4NH_3 \longrightarrow [Cr(NH_3)_4(H_2O)_2]^{3+} + 4H_2O$
	d	i	Donates an electron pair to a metal ion **OR** forms a coordinate bond to a metal ion ✓	1	**ALLOW** donates an electron pair to a metal **ALLOW** dative (covalent) bond for coordinate bond
		ii	Donates **two** electron pairs **OR** forms **two** coordinate bonds ✓ Lone pairs on two O atoms ✓	2	First mark is for the idea of two coordinate bonds **ALLOW** lone pair on O and N **DO NOT ALLOW** lone pairs on COO^- (could involve C) Second mark is for the atoms that donate the electron pairs Look for the atoms with lone pairs also on response to **(d)(iii)** and credit here if not described in **(d)(ii)**

Question			Expected Answers	Marks	Additional Guidance
		iii	Forms two optical isomers **OR** two enantiomers **OR** two non-superimposable mirror images ✓  ✓✓ For each structure	3	**IGNORE** any charges shown **ALLOW** any attempt to show bidentate ligand. Bottom line is the diagram on the left. 1 mark for 3D diagram with ligands attached for ONE stereoisomer. Must contain 2 out wedges, 2 in wedges and 2 lines in plane of paper:  **OR**  2nd mark for reflected diagram of SECOND stereoisomer. The diagram below would score the 2nd mark but not the first 

Question			Expected Answers	Marks	Additional Guidance
	e		N : H : Cr : O 11.1/14 : 3.17/1 : 41.27/52 : 44.45/16 **OR** 0.793 : 3.17 : 0.794 : 2.78 ✓ **A**: $N_2H_8Cr_2O_7$ ✓ Ions: NH_4^+ ✓ $Cr_2O_7^{2-}$ ✓ **B**: Cr_2O_3 ✓ Correctly calculates molar mass of **C** = 1.17 × 24.0 = 28.08 (g mol^{-1}) ✓ **C**: N_2 ✓ Equation: $(NH_4)_2Cr_2O_7 \longrightarrow Cr_2O_3 + 4H_2O + N_2$ ✓	8	***ANNOTATIONS MUST BE USED*** **ALLOW A**: $(NH_4)_2Cr_2O_7$ **IF** candidate has obtained NH_4CrO_4 for A, **ALLOW** NH_4^+ **DO NOT ALLOW** CrO_4^- **ALLOW**: (relative) molecular mass **ALLOW**: 28 **ALLOW**: '**C** is 28' **ALLOW** $N_2H_8Cr_2O_7$ in equation.
			Total	**22**	

Question			Expected Answers	Marks	Additional Guidance
7	a	i	$H_2O_2 \longrightarrow O_2 + 2H^+ + 2e^-$ ✓✓	2	All other multiples score 1 mark e.g. $½\ H_2O_2 \longrightarrow ½\ O_2 + H^+ + e^-$ $5H_2O_2 \longrightarrow 5O_2 + 10H^+ + 10e^-$
	b		**Marks are for correctly calculated values.** **Working shows how values have been derived.** $n(KMnO_4) = \dfrac{0.0200 \times 23.45}{1000} = 4.69 \times 10^{-4}$ (mol) ✓ $n(H_2O_2) = 5/2 \times 4.69 \times 10^{-4} = 1.1725 \times 10^{-3}$ (mol) ✓ $n(H_2O_2)$ in 250 cm^3 solution $= 10 \times 1.1725 \times 10^{-3} = 1.1725 \times 10^{-2}$ (mol) ✓ concentration in g dm^{-3} of original H_2O_2 $= 40 \times 1.1725 \times 10^{-2} \times 34 = 15.9$ (g dm^{-3}) ✓	4	***ANNOTATIONS MUST BE USED*** **DO NOT ALLOW** 4.7×10^{-4} **ALLOW** 1.173×10^{-3} OR 1.17×10^{-3} (i.e. 3 significant figures upwards) **ALLOW** by **ECF**: 5/2 × ans above **ALLOW** by **ECF** 10 × ans above **ALLOW** concentration $H_2O_2 = 0.0469$ mol dm^{-3} **ALLOW** by **ECF** $40 \times n(H_2O_2) \times 34$ **ALLOW** $0.0469 \times 10 \times 34 = 15.9$ g dm^{-3} ✓ **ALLOW** two significant figures, 16 (g dm^{-3}) up to calculator value of 15.946 g dm^{-3}
			$n(O_2) = 5/2 \times 4.69 \times 10^{-4} = 1.1725 \times 10^{-3}$ (mol) ✓ volume $O_2 = 24.0 \times 1.1725 \times 10^{-3} = 0.0281\ dm^3$ ✓	2	**ALLOW** 0.028 dm^3 **OR** 0.02814 dm^3 **ALLOW** 28 cm^3 **OR** 28.14 cm^3 Value **AND** units required **DO NOT ALLOW** 0.03 dm^3 **ALLOW** by **ECF**: 24.0 × calculated moles of O_2 (2 significant figures up to calculator value)
			Total	**8**	

Appendix 1

Extra guidance for marking atypical responses to **5e(i)** and **5e(ii)**

Question			Expected Answer	Mark	Additional Guidance
5	e	i	**TOTAL ENTROPY APPROACH:** **ALL MARKS AVAILABLE** **Unless otherwise stated, marks are for correctly calculated values.** **Working shows how values have been derived.** $\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$ / $= (2 \times 192) - (191 + 3 \times 131)$ ✓ $= -200$ (J K^{-1} mol^{-1}) **OR** -0.200 (kJ K^{-1} mol^{-1}) ✓ Use of 298 K (could be within expression below) ✓ $\Delta S_{total} = \Delta S_{system} + \Delta S_{surroundings}$ $\Delta S_{surroundings} = -\dfrac{\Delta H}{T}$ **OR** $\Delta S_{total} = \Delta S_{system} - \dfrac{\Delta H}{T}$ **OR** $\Delta S_{total} = -0.200 - \dfrac{-92}{298}$ **OR** $\Delta S_{total} = -200 - \dfrac{-92000}{298}$ ✓ $= 0.109$ kJ (K^{-1} mol^{-1}) **OR** 109 J (K^{-1} mol^{-1}) ✓ Feasible when $\Delta S_{total} > 0$ ✓	5 1	***ANNOTATIONS MUST BE USED*** **NO UNITS** required at this stage **IGNORE** units **ALLOW** 0.109 kJ **OR** 109 J **IF** 25ºC has been used instead of 298 K, correctly calculated ΔS_{total} values are = 3.48 kJ K^{-1} mol^{-1} **OR** 3,480 J K^{-1} mol^{-1}

Question			Expected Answer	Mark	Additional Guidance
5	e	i	**MAX/MIN TEMPERATURE APPROACH:** **5 MARKS MAX AVAILABLE** **Unless otherwise stated, marks are for correctly calculated values.** **Working shows how values have been derived.** $\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$ / $= (2 \times 192) - (191 + 3 \times 131)$ ✓ $= -200$ ($J\ K^{-1}\ mol^{-1}$) **OR** -0.200 ($kJ\ K^{-1}\ mol^{-1}$) ✓ Use of 298 K (could be within ΔG expression below) ✓ $\Delta G = \Delta H - T\Delta S$ **OR** When $\Delta G = 0$, $0 = \Delta H - T\Delta S$; **OR** $T = \dfrac{\Delta H}{\Delta S} = \dfrac{-92}{-0.200}$ **OR** $T = \dfrac{\Delta H}{\Delta S} = \dfrac{-92000}{-200}$ ✓ = 460 K ✓ = 187 °C (use of 298) ✓ The condition $\Delta G = 0$ because temperature at which $\Delta G = 0$ is the maximum temperature for feasibility **AND** justification for the being the maximum ✓		***ANNOTATIONS MUST BE USED*** **This candidate has not answered the question but many marks are still available.** **NO UNITS** required at this stage **IGNORE** units By this approach, the calculated temperature is the switchover between feasibility and non-feasibility but it cannot be assumed that this is the maximum temperature

Question			Expected Answer	Mark	Additional Guidance
5	**e**	**ii**	As the temperature increases, $\Delta H/T$ becomes **less** negative **OR** $\Delta H/T$ becomes **more** negative than ΔS(system) **OR** $\Delta H/T$ becomes **less** significant **OR** ΔS(surroundings) becomes **less** significant **OR** ΔS(system) > $\Delta H/T$ **OR** ΔS(system) > ΔS(surroundings) ✓ Eventually ΔS(total) becomes **negative** ✓	2	**ALLOW** $\Delta H/T > \Delta S_{system}$ (i.e. assume no sign at this stage) **ALLOW** **–**$\Delta H/T$ becomes more positive **ALLOW** **–**$\Delta H/T$ increases