



GCE

Chemistry A

Advanced GCE F325

Equilibria, Energetics and Elements

Mark Scheme for June 2010

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Mark Scheme

June 2010

| Question | | Expected Answers | Marks | Additional Guidance |
|--------------|---|---|----------|---|
| 1 | a | <p>F B G E D</p> <p>FIVE correct ✓✓✓ FOUR correct ✓✓ THREE correct ✓</p> | 3 | <p>ALLOW</p> <p>1450 736 G 76 -642</p> |
| | b | <p>Correct calculation $-642 - (+76 + (2 \times 150) + 736 + 1450 + (2 \times -349))$ ✓ $-642 - 1864$ $= -2506$ ✓ (kJ mol⁻¹)</p> | 2 | <p>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</p> |
| | c | <p>Magnesium ion OR Mg²⁺ has greater charge (than sodium ion OR Na⁺) OR Mg²⁺ has greater charge density ✓</p> <p>Magnesium ion OR Mg²⁺ is smaller ✓</p> <p>Mg²⁺ has a stronger attraction (than Na⁺) to Cl⁻ ion OR Greater attraction between oppositely charged ions ✓</p> | 3 | <p>ANNOTATIONS MUST BE USED</p> <p>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</p> <p>ALLOW Mg OR magnesium is smaller DO NOT ALLOW Mg²⁺ has a smaller atomic radius</p> <p>ALLOW anion OR negative ion for Cl⁻ DO NOT ALLOW chlorine ions DO NOT ALLOW Mg has greater attraction</p> <p>ALLOW 'attracts with more force' for greater attraction but DO NOT ALLOW 'greater force' (could be repulsion)</p> <p>ALLOW reverse argument throughout in terms of Na⁺</p> |
| Total | | | 8 | |

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|----------|---|---|---|--|
| 2 | a | $\text{BrO}_3^- + 5\text{Br}^- + 6\text{H}^+ \longrightarrow 3\text{Br}_2 + 3\text{H}_2\text{O}$ ✓ | 1 | ALLOW multiples |
| | b | <p>graph:</p> <p>Straight/diagonal line through origin OR 0,0 AND 1st order with respect to BrO_3^- ✓</p> <p>initial rates data:</p> <p>When $[\text{Br}^-]$ is doubled, rate $\times 2$ ✓ 1st order with respect to Br^- ✓</p> <p>When $[\text{H}^+] \times 2$, rate $\times 4$ (2^2) ✓ 2nd order with respect to H^+ ✓</p> <p>Rate equation rate = $k [\text{BrO}_3^-] [\text{Br}^-] [\text{H}^+]^2$ ✓</p> | 1 4 1 | <p><u>ANNOTATIONS MUST BE USED</u></p> <p>Both explanation and 1st order required for mark</p> <p>DO NOT ALLOW diagonal line OR straight line OR constant gradient on its own (no mention of origin OR 0,0)</p> <p>ALLOW 'As BrO_3^- doubles, rate doubles' AND 1st order ALLOW rate is proportional to concentration AND 1st order</p> <p>Mark order and explanation independently Mark order first, then explanation</p> <p>ALLOW ECF from candidate's orders above</p> |

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|----------|--|-----------|---|
| | <p>Calculation of rate constant (3 marks)</p> $k = \frac{\text{rate}}{[\text{BrO}_3^-][\text{Br}^-][\text{H}^+]^2}$ <p>OR</p> $\frac{1.19 \times 10^{-5}}{(5.0 \times 10^{-2})(1.5 \times 10^{-1})(3.1 \times 10^{-1})^2} \checkmark$ <p>$= 1.7 \times 10^{-2}$ OR $1.65 \times 10^{-2} \checkmark$ $\text{dm}^9 \text{mol}^{-3} \text{s}^{-1} \checkmark$</p> | 3 | <p>ANNOTATIONS MUST BE USED</p> <p>Calculation can be from any of the experimental runs – they all give the same value of k</p> <p>ALLOW $\text{mol}^{-3} \text{dm}^9 \text{s}^{-1}$</p> <p>ALLOW 1.6510579×10^{-2} and correct rounding to 1.7×10^{-2}</p> <p>Correct numerical answer subsumes previous marking point</p> <p>DO NOT ALLOW fraction: $\frac{238}{14415}$</p> <p>-----</p> <p>ALLOW ECF from incorrect rate equation.</p> <p>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.</p> <p>Example 1: 1st order with respect to H^+</p> $\text{rate} = k [\text{BrO}_3^-] [\text{Br}^-] [\text{H}^+]$ $k = \frac{\text{rate}}{[\text{BrO}_3^-][\text{Br}^-][\text{H}^+]}$ <p>OR</p> $\frac{1.19 \times 10^{-5}}{(5.0 \times 10^{-2})(1.5 \times 10^{-1})(3.1 \times 10^{-1})} \checkmark$ <p>$= 5.1 \times 10^{-3}$ OR $5.12 \times 10^{-3} \checkmark$ $\text{dm}^6 \text{mol}^{-2} \text{s}^{-1} \checkmark$</p> <p>ALLOW $5.11827957 \times 10^{-3}$ and correct rounding to 5.1×10^{-3}</p> <p>-----</p> <p>Example 2: Zero order with respect to BrO_3^-</p> $\text{rate} = k [\text{Br}^-] [\text{H}^+]^2$ $k = \frac{\text{rate}}{[\text{Br}^-][\text{H}^+]^2}$ <p>OR</p> $\frac{1.19 \times 10^{-5}}{(1.5 \times 10^{-1})(3.1 \times 10^{-1})^2} \checkmark$ <p>$= 8.3 \times 10^{-4}$ OR $8.26 \times 10^{-4} \checkmark$ $\text{dm}^6 \text{mol}^{-2} \text{s}^{-1} \checkmark$</p> <p>ALLOW $8.255289629 \times 10^{-4}$ and correct rounding to 8.3×10^{-4}</p> |
| | Total | 10 | |

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|----------|---|--|-------|---|
| 3 | a | <p>measured pH > 1 OR $[H^+] < 0.1$ (mol dm⁻³) ✓</p> <p>$[H^+] = 10^{-pH}$ ✓</p> <p>$K_a = \frac{[H^+][CH_3CH_2COO^-]}{[CH_3CH_2COOH]}$ OR $\frac{[H^+]^2}{[CH_3CH_2COOH]}$ ✓</p> <p>Calculate K_a from $\frac{[H^+]^2}{0.100}$ ✓</p> | 4 | <p>ALLOW C₂H₅ throughout question</p> <p>ALLOW $[H^+] < [CH_3CH_2COOH]$ OR $[H^+] < [HA]$</p> <p>ALLOW measured pH is higher than expected</p> <p>ALLOW measured pH is not as acidic as expected</p> <p>ALLOW a quoted pH value or range > 1 and < 7</p> <p>OR between 1 and 7</p> <p>ALLOW $[H^+] = \text{antilog } -pH$ OR $[H^+] = \text{inverse log } -pH$</p> <p>ALLOW $\frac{[H^+][A^-]}{[HA]}$ OR $\frac{[H^+]^2}{[HA]}$</p> <p>IF K_a is NOT given and $K_a = \frac{[H^+]^2}{0.100}$ is shown, award mark for K_a also</p> <p>(i.e. $K_a = \frac{[H^+]^2}{0.100}$ is automatically awarded the last 2 marks)</p> |
| | b | <p>Marks are for correctly calculated values.</p> <p>Working shows how values have been derived.</p> <p>$[H^+] = 10^{-13.46} = 3.47 \times 10^{-14}$ (mol dm⁻³) ✓</p> <p>$[OH^-] = \frac{1.0 \times 10^{-14}}{3.47 \times 10^{-14}} = 0.29$ (mol dm⁻³) ✓</p> | 2 | <p>ALLOW $3.467368505 \times 10^{-14}$ and correct rounding to 3.5×10^{-14}</p> <p>ALLOW 0.28840315 and correct rounding to 0.29, i.e. ALLOW 0.288</p> <p>ALLOW alternative approach using pOH:</p> <p>pOH = 14 – 13.46 = 0.54 ✓</p> <p>$[OH^-] = 10^{-0.54} = 0.29$ (mol dm⁻³) ✓</p> <p>Correct answer gets BOTH marks</p> |

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|--------------|---|---|--|--|--|
| | d | $\text{HNO}_3 + \text{CH}_3\text{CH}_2\text{COOH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COOH}_2^+ + \text{NO}_3^- \checkmark$ <p style="text-align: center;">acid 1 base 2 acid 2 base 1 \checkmark</p> | 2 | <p>State symbols NOT required</p> <p>ALLOW 1 AND 2 labels the other way around.</p> <p>ALLOW 'just acid' and 'base' labels throughout if linked by lines so that it is clear what the acid–base pairs are.</p> <p>IF proton transfer is wrong way around then ALLOW 2nd mark for idea of acid–base pairs, i.e.</p> $\text{HNO}_3 + \text{CH}_3\text{CH}_2\text{COOH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COO}^- + \text{H}_2\text{NO}_3^+ \times$ <p style="text-align: center;">base 2 acid 1 base 1 acid 2 \checkmark</p> | |
| | e | i | $2\text{CH}_3\text{CH}_2\text{COOH} + \text{Mg} \rightarrow (\text{CH}_3\text{CH}_2\text{COO})_2\text{Mg} + \text{H}_2 \checkmark$ | 1 | <p>IGNORE state symbols</p> <p>ALLOW ionic equation: $2\text{H}^+ + \text{Mg} \rightarrow \text{Mg}^{2+} + \text{H}_2$</p> <p>IGNORE any random charges in formula of $(\text{CH}_3\text{CH}_2\text{COO})_2\text{Mg}$ as long as the charges are correct (charges are treated as working) i.e. $(\text{CH}_3\text{COO}^-)_2\text{Mg}$ OR $(\text{CH}_3\text{COO})_2^- \text{Mg}$ should not be penalised</p> <p>However, Mg^{2+} instead of Mg on the left side of equation is obviously wrong</p> |
| | | ii | $2\text{H}^+ + \text{CO}_3^{2-} \longrightarrow \text{H}_2\text{O} + \text{CO}_2$ <p>OR $2\text{H}^+ + \text{CO}_3^{2-} \longrightarrow \text{H}_2\text{CO}_3$</p> <p>OR $\text{H}^+ + \text{CO}_3^{2-} \longrightarrow \text{HCO}_3^- \checkmark$</p> | 1 | State symbols NOT required |
| Total | | | 17 | | |

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|----------|---|-----|---|-------|--|
| 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⁺ → 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 chlorine 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 iodide DO NOT ALLOW equation or equilibrium |

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|----------|--|-----------|---|
| c | <p>A fuel cell converts energy from reaction of a fuel with oxygen into a voltage/electrical energy ✓</p> <p>$2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$ ✓</p> <p>Two from:</p> <ul style="list-style-type: none"> • under pressure OR at low temperature OR as a liquid • adsorbed on solid • absorbed within solid <p style="text-align: right;">✓✓</p> <p>Energy is needed to make the hydrogen OR energy is needed to make fuel cell ✓</p> | 5 | <p>ANNOTATIONS MUST BE USED</p> <p>ALLOW combustion for reaction of fuel with oxygen/reactants</p> <p>ALLOW a fuel cell requires constant supply of fuel</p> <p>OR operates continuously as long as a fuel (and oxygen) are added</p> <p>ALLOW multiples, e.g. $\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$</p> <p>IGNORE state symbols</p> <p>ALLOW 'material' OR metal for solid</p> <p>ALLOW as a metal hydride</p> |
| | Total | 13 | |

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|----------|---|----|--|-------|--|
| 5 | a | i | $(K_c =) \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} \checkmark$ | 1 | Must be square brackets |
| | | ii | $\text{dm}^6 \text{ mol}^{-2} \checkmark$ | 1 | ALLOW $\text{mol}^{-2} \text{ dm}^6$ ALLOW ECF from incorrect K_c expression |
| | b | | <p>Unless otherwise stated, marks are for correctly calculated values. Working shows how values have been derived.</p> <p>$[\text{N}_2] = \frac{7.2}{6.0}$ OR $1.2 \text{ (mol dm}^{-3}\text{)}$</p> <p>AND $[\text{H}_2] = \frac{12}{6.0}$ OR $2.0 \text{ (mol dm}^{-3}\text{)}$ \checkmark</p> <p>$[\text{NH}_3] = \sqrt{(K_c \times [\text{N}_2] \times [\text{H}_2]^3)}$</p> <p>OR $\sqrt{(8.00 \times 10^{-2} \times 1.2 \times 2.0^3)}$ \checkmark</p> <p>$= 0.876$ OR $0.88 \text{ (mol dm}^{-3}\text{)}$ \checkmark</p> <p>amount $\text{NH}_3 = 0.876 \times 6 = 5.26$ OR 5.3 (mol) \checkmark</p> | 4 | <p>ANNOTATIONS MUST BE USED</p> <p>For all parts, ALLOW numerical answers from 2 significant figures up to the calculator value</p> <p>1st mark is for realising that concentrations need to be calculated.</p> <p>Correct numerical answer with no working would score all previous calculation marks</p> <p>ALLOW calculator value: 0.876356092 down to 0.88, correctly rounded</p> <p>ALLOW calculator value down to 5.3, correctly rounded</p> |

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|----------|---|-------|--|
| b | <p>EXAMPLES OF INCORRECT RESPONSES IN (b) THAT MAY BE WORTHY OF CREDIT</p> | | <p>-----</p> <p>ALLOW ECF from incorrect concentrations (3 marks) For example, If concentrations not calculated at start, then</p> $[\text{NH}_3] = \sqrt{(8.00 \times 10^{-2} \times 7.2 \times 12.0^3)} \checkmark$ $= 31.5 \text{ mol dm}^{-3} \checkmark$ <p>Equilibrium amount of $\text{NH}_3 = 31.5 \times 6 = 189.6 \text{ (mol)} \checkmark$</p> <p>-----</p> <p>IF candidate has K_c expression upside down, then all 4 marks are available in (b) by ECF</p> <p>Correct $[\text{N}_2]$ AND $[\text{H}_2] \checkmark$</p> $[\text{NH}_3] = \sqrt{\frac{[\text{N}_2][\text{H}_2]^3}{K_c}} = \sqrt{\frac{1.2 \times 2^3}{8.00 \times 10^{-2}}} \checkmark$ $= 11.0 \text{ mol dm}^{-3} \checkmark$ <p>Equilibrium amount of $\text{NH}_3 = 11.0 \times 6 = 66.0 \text{ (mol)} \checkmark$</p> <p>-----</p> <p>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))</p> <p>Correct $[\text{N}_2]$ AND $[\text{H}_2] \checkmark$</p> <p>$[\text{NH}_3]$ expression ✗</p> <p>ECF: Calculated $[\text{NH}_3] \checkmark$</p> <p>ECF: Equilibrium amount of $\text{NH}_3 \checkmark$</p> |

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|----------|-----|---|-------|---|
| | 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 $\frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3}$ no longer equal to K_c |
| | d i | $\text{CH}_4 + \text{H}_2\text{O} \longrightarrow 3\text{H}_2 + \text{CO}$ ✓ | 1 | State symbols NOT required ALLOW: $\text{CH}_4 + \text{H}_2\text{O} \longrightarrow \text{CH}_3\text{OH} + \text{H}_2$ $\text{CH}_4 + 2\text{H}_2\text{O} \longrightarrow 4\text{H}_2 + \text{CO}_2$ $\text{CH}_4 + \text{H}_2\text{O} \longrightarrow 2\text{H}_2 + \text{HCHO}$ $\text{CH}_4 + 2\text{H}_2\text{O} \longrightarrow 3\text{H}_2 + \text{HCOOH}$ |
| | ii | Electrolysis of water OR $\text{H}_2\text{O} \longrightarrow \text{H}_2 + \frac{1}{2}\text{O}_2$ ✓ | 1 | ALLOW electrolysis of brine DO NOT ALLOW reforming DO NOT ALLOW cracking DO NOT ALLOW reaction of metal with acid |

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|----------|--|-------------------|---|
| e i | <p>Unless otherwise stated, marks are for correctly calculated values. Working shows how values have been derived.</p> $\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants}) /$ $= (2 \times 192) - (191 + 3 \times 131) \checkmark$ $= -200 \text{ (J K}^{-1} \text{ mol}^{-1}) \text{ OR } -0.200 \text{ (kJ K}^{-1} \text{ mol}^{-1}) \checkmark$ <p>Use of 298 K (could be within ΔG expression below) \checkmark</p> $\Delta G = \Delta H - T\Delta S$ <p>OR</p> $\Delta G = -92 - (298 \times -0.200)$ <p>OR</p> $\Delta G = -92000 - (298 \times -200) \checkmark$ $= -32.4 \text{ kJ mol}^{-1} \text{ OR } -32400 \text{ J mol}^{-1} \checkmark$ <p>(Units must be shown)</p> <p>For feasibility, $\Delta G < 0$ OR ΔG is negative \checkmark</p> | <p>5</p> <p>1</p> | <p>ANNOTATIONS MUST BE USED</p> <p>See Appendix 1 for extra guidance for marking 5e(i) and 5e(ii)</p> <p>NO UNITS required at this stage IGNORE units</p> <p>ALLOW -32.4 kJ OR -32400 J (Units must be shown) Award all 5 marks above for correct answer with no working</p> <p>IF $25 \text{ }^{\circ}\text{C}$ has been used instead of 298 K, correctly calculated ΔG values are = -87 kJ mol^{-1} OR $-87000 \text{ J mol}^{-1}$ 4 marks are still available up to this point and maximum possible from (e)(i) is 5 marks</p> |
| | <p>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 \checkmark</p> <p>Eventually $\Delta H - T\Delta S$ becomes positive \checkmark</p> | <p>2</p> | <p>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</p> <p>ALLOW ΔG becomes positive OR $\Delta G > 0$</p> |

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|----------|-----|--|-----------|---|
| | 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 | |

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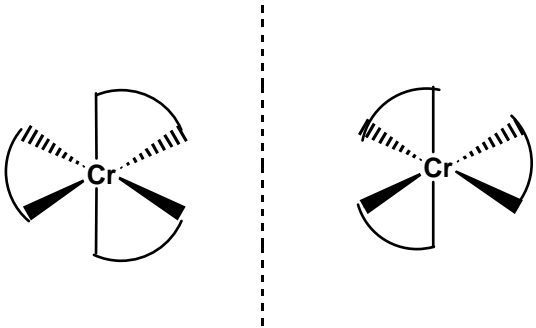
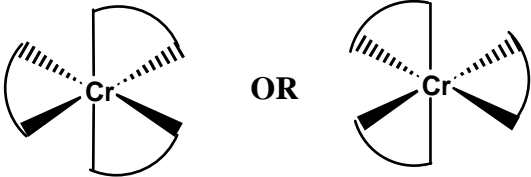
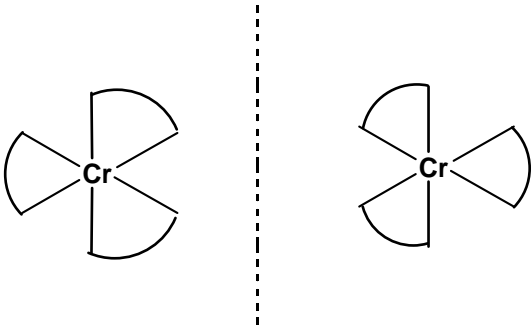
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|----------|---|----|---|-------|---|
| 6 | a | i | $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$ ✓ | 1 | ALLOW $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$ (i.e. 4s before 3d) ALLOW $[\text{Ar}]4s^1 3d^5$ OR $[\text{Ar}]3d^5 4s^1$ |
| | | ii | $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3$ ✓ | 1 | ALLOW $[\text{Ar}]3d^3$ ALLOW $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^0$ OR $[\text{Ar}]3d^3 4s^0$ |
| | b | | $\text{Zn} \longrightarrow \text{Zn}^{2+} + 2\text{e}^-$ ✓ $\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 8\text{e}^- \longrightarrow 2\text{Cr}^{2+} + 7\text{H}_2\text{O}$ ✓ $4\text{Zn} + \text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ \longrightarrow 4\text{Zn}^{2+} + 2\text{Cr}^{2+} + 7\text{H}_2\text{O}$ ✓ | 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 | $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 6\text{NH}_3 \longrightarrow [\text{Cr}(\text{NH}_3)_6]^{3+} + 6\text{H}_2\text{O}$ ✓ ✓ | 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 : $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 4\text{NH}_3 \longrightarrow [\text{Cr}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{3+} + 4\text{H}_2\text{O}$ |
| | 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) |

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| iii | <p>Forms two optical isomers OR two enantiomers OR two non-superimposable mirror images ✓</p>  <p>✓✓ For each structure</p> | 3 | <p>IGNORE any charges shown</p> <p>ALLOW any attempt to show bidentate ligand. Bottom line is the diagram on the left.</p> <p>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:</p>  <p>2nd mark for reflected diagram of SECOND stereoisomer. The diagram below would score the 2nd mark but not the first</p>  |

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| Question | Expected Answers | Marks | Additional Guidance |
|--------------|---|-----------|---|
| e | <p style="text-align: center;">N : H : Cr : O 11.1/14 : 3.17/1 : 41.27/52 : 44.45/16</p> <p>OR 0.793 : 3.17 : 0.794 : 2.78 ✓</p> <p>A: $\text{N}_2\text{H}_8\text{Cr}_2\text{O}_7$ ✓</p> <p>Ions: NH_4^+ ✓ $\text{Cr}_2\text{O}_7^{2-}$ ✓</p> <p>B: Cr_2O_3 ✓</p> <p>Correctly calculates molar mass of C $= 1.17 \times 24.0 = 28.08 \text{ (g mol}^{-1}\text{)}$ ✓</p> <p>C: N_2 ✓</p> <p>Equation: $(\text{NH}_4)_2\text{Cr}_2\text{O}_7 \longrightarrow \text{Cr}_2\text{O}_3 + 4\text{H}_2\text{O} + \text{N}_2$ ✓</p> | 8 | <p>ANNOTATIONS MUST BE USED</p> <p>ALLOW A: $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$</p> <p>IF candidate has obtained NH_4CrO_4 for A, ALLOW NH_4^+ DO NOT ALLOW CrO_4^-</p> <p>ALLOW: (relative) molecular mass ALLOW: 28 ALLOW: 'C is 28'</p> <p>ALLOW $\text{N}_2\text{H}_8\text{Cr}_2\text{O}_7$ in equation.</p> |
| Total | | 22 | |

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| Question | | | Expected Answers | Marks | Additional Guidance |
|----------|---|---|---|----------|--|
| 7 | a | i | $\text{H}_2\text{O}_2 \longrightarrow \text{O}_2 + 2\text{H}^+ + 2\text{e}^- \checkmark\checkmark$ | 2 | All other multiples score 1 mark e.g. $\frac{1}{2} \text{H}_2\text{O}_2 \longrightarrow \frac{1}{2} \text{O}_2 + \text{H}^+ + \text{e}^-$ $5\text{H}_2\text{O}_2 \longrightarrow 5\text{O}_2 + 10\text{H}^+ + 10\text{e}^-$ |
| | b | | <p>Marks are for correctly calculated values. Working shows how values have been derived.</p> $n(\text{KMnO}_4) = \frac{0.0200 \times 23.45}{1000} = 4.69 \times 10^{-4} \text{ (mol) } \checkmark$ $n(\text{H}_2\text{O}_2) = 5/2 \times 4.69 \times 10^{-4} = 1.1725 \times 10^{-3} \text{ (mol) } \checkmark$ $n(\text{H}_2\text{O}_2) \text{ in } 250 \text{ cm}^3 \text{ solution}$ $= 10 \times 1.1725 \times 10^{-3} = 1.1725 \times 10^{-2} \text{ (mol) } \checkmark$ $\text{concentration in } \text{g dm}^{-3} \text{ of original } \text{H}_2\text{O}_2$ $= 40 \times 1.1725 \times 10^{-2} \times 34 = 15.9 \text{ (g dm}^{-3}) \checkmark$ $n(\text{O}_2) = 5/2 \times 4.69 \times 10^{-4} = 1.1725 \times 10^{-3} \text{ (mol) } \checkmark$ $\text{volume } \text{O}_2 = 24.0 \times 1.1725 \times 10^{-3} = 0.0281 \text{ dm}^3 \checkmark$ | 4 | <p>ANNOTATIONS MUST BE USED</p> <p>DO NOT ALLOW 4.7×10^{-4}</p> <p>ALLOW 1.173×10^{-3} OR 1.17×10^{-3} (i.e. 3 significant figures upwards) ALLOW by ECF: $5/2 \times$ ans above</p> <p>ALLOW by ECF $10 \times$ ans above ALLOW concentration $\text{H}_2\text{O}_2 = 0.0469 \text{ mol dm}^{-3}$</p> <p>ALLOW by ECF $40 \times n(\text{H}_2\text{O}_2) \times 34$ ALLOW $0.0469 \times 10 \times 34 = 15.9 \text{ g dm}^{-3} \checkmark$</p> <p>ALLOW two significant figures, 16 (g dm⁻³) up to calculator value of 15.946 g dm⁻³</p> <p>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</p> <p>ALLOW by ECF: $24.0 \times$ calculated moles of O_2 (2 significant figures up to calculator value)</p> |
| | | | Total | 8 | |

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Appendix 1

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

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

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| Question | Expected Answer | Mark | Additional Guidance |
|----------|---|------|--|
| 5 e i | <p>MAX/MIN TEMPERATURE APPROACH: 5 MARKS MAX AVAILABLE</p> <p>Unless otherwise stated, marks are for correctly calculated values. Working shows how values have been derived.</p> $\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants}) /$ $= (2 \times 192) - (191 + 3 \times 131) \checkmark$ $= -200 \text{ (J K}^{-1} \text{ mol}^{-1}) \text{ OR } -0.200 \text{ (kJ K}^{-1} \text{ mol}^{-1}) \checkmark$ <p>Use of 298 K (could be within ΔG expression below) \checkmark</p> $\Delta G = \Delta H - T\Delta S$ <p>OR When $\Delta G = 0$, $0 = \Delta H - T\Delta S$;</p> <p>OR $T = \frac{\Delta H}{\Delta S} = \frac{-92}{-0.200}$</p> <p>OR $T = \frac{\Delta H}{\Delta S} = \frac{-92000}{-200} \checkmark$</p> <p>= 460 K \checkmark</p> <p>= 187 °C (use of 298) \checkmark</p> <p>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 \checkmark</p> | | <p>ANNOTATIONS MUST BE USED</p> <p>This candidate has not answered the question but many marks are still available.</p> <p>NO UNITS required at this stage IGNORE units</p> <p>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</p> |

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| 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 $\Delta S(\text{system})$ OR $\Delta H/T$ becomes less significant OR $\Delta S(\text{surroundings})$ becomes less significant OR $\Delta S(\text{system}) > \Delta H/T$ OR $\Delta S(\text{system}) > \Delta S(\text{surroundings})$ ✓ Eventually $\Delta S(\text{total})$ becomes negative ✓ | 2 | ALLOW $\Delta H/T > \Delta S_{\text{system}}$ (i.e. assume no sign at this stage) ALLOW $-\Delta H/T$ becomes more positive ALLOW $-\Delta H/T$ increases |

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