| Question | | | er | Marks | Guidance |
|---|---|---|---|---|---|
| 1 | (a) | | **Definition**<br>The e.m.f. (of a half-cell) compared with a (standard) hydrogen half-cell/(standard) hydrogen electrode ✓<br>**Standard conditions**<br>Temperature of 298 K / 25ºC<br>**AND** (solution) concentrations of 1 mol $dm^{-3}$ / 1M<br>**AND** pressure of 101 kPa **OR** 100 kPa ✓ | 2 | **ALLOW** voltage **OR** potential difference **OR** p.d.<br>**OR** electrode potential **OR** reduction potential<br>**OR** redox potential as alternative for e.m.f.<br>**IGNORE** S.H.E. (as abbreviation for standard hydrogen electrode)<br><br>**ALLOW** 1 atmosphere/1 atm **OR** $10^5$ Pa **OR** 1 bar |
| | (b) | | 2.71 V ✓ | 1 | **IGNORE** any sign |
| | (c) | (i) | $Al + 3Fe^{3+} \longrightarrow Al^{3+} + 3Fe^{2+}$ ✓<br>$2Al + 3I_2 \longrightarrow 2Al^{3+} + 6I^-$ ✓<br>$2I^- + 2Fe^{3+} \longrightarrow I_2 + 2Fe^{2+}$ ✓ | 3 | Correct species **AND** balancing needed for each mark<br>**IGNORE** state symbols<br>**ALLOW** equilibrium sign (i.e. assume reaction is to right)<br>**ALLOW** correct multiples<br><br>**IF** there are **more than** three equations<br>• mark a maximum of three equations<br>• mark incorrect equations first |
| | | (ii) | High activation energy **OR** slow rate ✓<br><br>Conditions not standard **OR** concentrations not 1 mol $dm^{-3}$ ✓ | 2 | <br><br>**DO NOT ALLOW** ‘standard conditions’ are different |

| Question | | | er | Marks | Guidance |
| --- | --- | --- | --- | --- | --- |
| | **(d)** | | **ANNOTATE WITH TICKS, CROSSES, etc**<br><br>**General (2 marks – assumed to be acid)**<br>• (*E* of) **7** ($ClO^-/Cl_2$) is more positive/less negative (than **6**) **OR** $E_{cell}$ is (+)0.27 (V) **OR** $E_{cell}$ is positive ✓<br><br>• **6** ($Cl_2/Cl^-$) moves to left **AND 7** ($ClO^-/Cl_2$) to right ✓<br><br>---------------------------------------------------------------------------------<br>**In alkali (3 marking points),**<br>• $H^+$ in **7** ($ClO^-/Cl_2$) is removed by/reacts with $OH^-$/alkali ✓<br><br>• (*E* of) **7** ($ClO^-/Cl_2$) less positive/more negative (than **6**) ✓<br><br>• **6** ($Cl_2/Cl^-$) moves to right **AND 7** ($ClO^-/Cl_2$) to left ✓ | 4 max | **ORA** throughout<br>Minimum identification for system **6** is $Cl^-$<br>Minimum identification for system **7** is $ClO^-$<br>**Note**: $Cl_2$ is unsuitable as an identifier as it features in both system **6** and system **7**<br>**IGNORE** reference to gaining and losing electrons; oxidation and reduction<br>------------------------------------------------------<br>**Note**: identification of systems 6 and 7 could be from use of relevant half equations/overall equation<br>**ALLOW** 'greater' or 'higher' for 'more positive'<br><br>**ALLOW** correct eqn: $Cl^- + ClO^- + 2H^+ \rightarrow Cl_2 + H_2O$<br>**IGNORE** uncancelled electrons<br>**ALLOW** multiples, e.g. $2Cl^- + 2ClO^- + 4H^+ \rightarrow 2Cl_2 + 2H_2O$<br><br>**Note**: **IF** equilibrium shifts are correct, **IGNORE** incorrectly balanced equation but **CON** an equation in wrong direction<br>------------------------------------------------------------------------------<br><br>**ALLOW** correct eqn: $Cl_2 + H_2O \rightarrow Cl^- + ClO^- + 2H^+$<br>**IGNORE** uncancelled electrons<br>**ALLOW** multiples, e.g. $2Cl_2 + 2H_2O \rightarrow 2Cl^- + 2ClO^- + 4H^+$<br><br>**Note**: **IF** equilibrium shifts are correct, **IGNORE** incorrectly balanced equation but **CON** an equation in wrong direction |

| Question | | | er | Marks | Guidance |
|---|---|---|---|---|---|
| | **(e)** | **(i)** | $IO_3^-$ has removed/gained electrons from $Sn^{2+}$<br>**OR** $IO_3^-$ has been reduced to $I_2$ / reduced to 0<br>**OR** $IO_3^-$ has oxidised $Sn^{2+}$ ✓ | 1 | **ALLOW** $IO_3^-$ is the oxidising agent as I has been reduced<br>**DO NOT ALLOW** just $IO_3^-$ has been reduced<br>**DO NOT ALLOW** I is the oxidising agent |
| | | **(ii)** | $5Sn^{2+} + 2IO_3^- + 12H^+ \longrightarrow I_2 + 5Sn^{4+} + 6H_2O$<br><br>All chemical species correct with **no extra** chemical species ✓<br>Correct balancing with no electrons shown ✓ | 2 | **ALLOW** correct multiples<br>eg $2\frac{1}{2}\ Sn^{2+} + IO_3^- + 6H^+ \rightarrow \frac{1}{2}\ I_2 + 2\frac{1}{2}\ Sn^{4+} + 3H_2O$<br><br>**IGNORE** $e^-$ for 1st marking point |
| | | | **Total** | **15** | |

| Question | | | Answer | Marks | Guidance |
|---|---|---|---|---|---|
| **2** | **(a)** | **(i)** | complete circuit with **voltmeter** and **salt bridge** linking two half-cells ✓<br><br>Pt electrode in $Fe^{3+}/Fe^{2+}$ half-cell with **same** concentrations ✓<br><br>Cr electrode in 1 mol $dm^{-3}$ $Cr^{3+}$ half-cell ✓ | 3 | Salt bridge **MUST** be labelled<br><br>**ALLOW** $Fe^{2+}$ and $Fe^{3+}$ with concentrations of 1 mol $dm^{-3}$<br>**ALLOW** 1 M but **DO NOT ALLOW** 1 mol |
| | | **(ii)** | $Cr + 3Fe^{3+} \longrightarrow Cr^{3+} + 3Fe^{2+}$ ✓ | 1 | **ALLOW** $\rightleftharpoons$ sign<br><br>**DO NOT ALLOW** if $e^-$ shown uncancelled on both sides, e.g. $Cr + 3Fe^{3+} + 3e^- \longrightarrow Cr^{3+} + 3Fe^{2+} + 3e^-$ |
| | | **(iii)** | 1.51 V ✓ | 1 | **IGNORE** sign |
| | **(b)** | | $Cr_2O_7^{2-}$ **AND** $H^+$ ✓ | 1 | **ALLOW** acidified dichromate |
| | **(c)** | | $Cr_2O_7^{2-}(aq) + 8H^+(aq) + 3HCOOH(aq) \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l) + 3CO_2(l)$ ✓✓<br>State symbols **not** required | 2 | **1st mark for ALL species correct and no extras:**<br>$Cr_2O_7^{2-}$, $H^+$, HCOOH, $Cr^{3+}$, $H_2O$ **AND** $CO_2$<br>**NOTE**: $H^+$ may be shown on both sides<br><br>**ALLOW** $\rightleftharpoons$ sign<br><br>**2nd mark** for correct balancing with $H^+$ cancelled down |
| | **(d)** | **(i)** | $E^{\ominus}$ for chromium (redox system) is more negative/lower/less (than copper redox system) **ORA** ✓<br><br>chromium system shifts to the left / $Cr(s) \longrightarrow Cr^{3+}(aq) + 3e^-$<br>**AND**<br>copper system shifts to the right / $Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$ ✓ | 2 | **ALLOW** $E_{cell}$ is +1.08 V (sign required)<br><br>**ALLOW** Cr loses electrons more readily/more easily oxidised<br>**OR** Cr is a stronger reducing agent<br>**OR** Cu loses electrons less readily<br>**OR** Cu is a weaker reducing agent |

| Question | | | Answer | Marks | Guidance |
|---|---|---|---|---|---|
| | **(d)** | **(ii)** | Cr reacts with $H^+$ ions/acid to form $H_2$ gas ✓ | 1 | **ALLOW** equation:<br>$2Cr + 6H^+ \longrightarrow 2Cr^{3+} + 3H_2$ (**ALLOW** multiples)<br>**DO NOT ALLOW** just 'hydrogen forms',<br>i.e. Cr, $H^+$/acid **AND** $H_2$ must **all** be included for the mark |
| | **(e)** | **(i)** | 1.45 V ✓ | 1 | **IGNORE** sign |
| | | **(ii)** | **2 marks**, ✓ ✓, for **two** points from the following list:<br><br>**1.** Methanoic acid is a liquid **AND** easier to store/transport<br>**OR** hydrogen is a gas **AND** harder to store/transport<br>**OR** hydrogen as a liquid is stored under pressure<br><br>**2.** Hydrogen is explosive/more flammable<br><br>**3.** HCOOH gives a greater cell potential/voltage<br><br>**4**. HCOOH has more public/political acceptance than hydrogen as a fuel | 2 | **ASSUME** 'it' refers to HCOOH<br><br>**DO NOT ALLOW** 'produces no $CO_2$'<br><br>**IGNORE** comments about biomass and renewable<br>*HCOOH and $H_2$ are **both** manufactured from natural gas* |
| | | | **Total** | **14** | |

| Question | | | er | Mark | Guidance |
|---|---|---|---|---|---|
| 3 | (a) | | **Definition**<br>The e.m.f. (of a half-cell) compared with a standard hydrogen half-cell/standard hydrogen electrode ✓<br>**Standard conditions**<br>Temperature of 298 K / 25ºC<br>**AND** (solution) concentrations of 1 mol $dm^{-3}$<br>**AND** pressure of 101 kPa **OR** 100 kPa ✓ | 2 | **ALLOW** voltage **OR** potential difference **OR** p.d. **OR** electrode potential **OR** reduction potential **OR** redox potential as alternative for e.m.f.<br>**IGNORE** S.H.E. (as abbreviation for standard hydrogen electrode)<br><br>**ALLOW** 1 atmosphere/1 atm **OR** $10^5$ Pa **OR** 1 bar |
| | (b) | | 1.25 (V) ✓ | 1 | **IGNORE** any sign |
| | (c) | (i) | $Cd + 2NiO(OH) + 2H_2O \longrightarrow Cd(OH)_2 + 2Ni(OH)_2$<br>LHS: correct species and correctly balanced ✓<br>RHS: correct species and correctly balanced ✓ | 2 | **2 marks for correct equation**<br>**ALLOW** NiOOH OR $NiO_2H$<br><br>**ALLOW** $\rightleftharpoons$ sign for equation<br>(*ie* assume reaction goes from left to right)<br>**ALLOW** 1 mark for correctly balanced equation with $e^-$ and/or $OH^-$ shown<br>e.g.: $Cd + 2NiO(OH) + 2H_2O + 2OH^- + 2e^- \longrightarrow$<br>$Cd(OH)_2 + 2Ni(OH)_2 + 2OH^- + 2e^-$<br><br>**ALLOW** 1 mark for balanced correct reverse equation with $OH^-$ **AND** $e^-$ cancelled:<br>$Cd(OH)_2 + 2Ni(OH)_2 \longrightarrow Cd + 2NiO(OH) + 2H_2O$ |
| | | (ii) | oxidation: Cd from 0 to +2 ✓ '+' sign **not** required<br><br>reduction: Ni from +3 to +2 ✓'+' sign **not** required | 2 | **ALLOW** $Cd^0 \rightarrow Cd^{2+}$ (shows 0 and 2+)<br><br>**ALLOW** $Ni^{3+} \rightarrow Ni^{2+}$ (shows 3+ and 2+)<br>**ALLOW ECF** from **(c)(i)** equation written 'wrong way around'. |
| | (d) | (i) | reverse reactions to charging<br>**OR**<br>$Cd(OH)_2 + 2e^- \longrightarrow Cd + 2OH^-$<br>$Ni(OH)_2 + OH^- \longrightarrow NiO(OH) + H_2O + e^-$<br>**OR**<br>reaction that is reverse to reaction given in **c(i):**<br>$Cd(OH)_2 + 2Ni(OH)_2 \longrightarrow Cd + 2NiO(OH) + 2H_2O$ ✓ | 1 | If half-equations are given, then **BOTH** equations required<br><br>**ALLOW** $\rightleftharpoons$ sign for equation<br>(*ie* assume reaction goes from left to right) |

| Question | | | er | Mark | Guidance |
|---|---|---|---|---|---|
| | (d) | (ii) | $4OH^- \longrightarrow O_2 + 2H_2O + 4e^-$ ✓<br>$2H_2O + 2e^- \longrightarrow H_2 + 2OH^-$ ✓ | **2** | **ALLOW** multiples; **ALLOW** ⇌ sign for each equation<br>**Note**: These are the **only** correct responses |
| | | | **Total** | **10** | |

| Question | | | Expected Answers | Marks | Additional Guidance |
|---|---|---|---|---|---|
| **4** | **a** | | Complete circuit (with voltmeter) and salt bridge linking two half-cells ✓<br>Pt electrode in solution of $Fe^{2+}/Fe^{3+}$ ✓<br>Ag in solution of $Ag^+$ ✓ | 3 | **DO NOT ALLOW** 'solution of a silver halide', e.g. AgCl (as these are insoluble) but<br>**DO ALLOW** any solution of any other silver salt<br>(whether insoluble or not)<br><br>**IF** candidate has used incorrect redox systems, then mark ECF as follows:<br>**(i) each** incorrect system will cost the candidate **one** mark<br>**(ii)** if species have been quoted (see Additional Guidance below)<br>**(iii)** for equation<br>**(iv)** for cell potential<br>***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** $e^-$<br>For 'ions', **ALLOW** formula of an ion in one of the half-cells or salt bridge, e.g. $Ag^+$, $Fe^{2+}$, $Fe^{3+}$<br>**ALLOW ECF** as in **(i)** |
| | | **iii** | $Ag + Fe^{3+} \longrightarrow Ag^+ + Fe^{2+}$ ✓ | 1 | **ALLOW ECF** as in **(i)**<br>**ALLOW** equilibrium sign |
| | | **iv** | 0.43 V ✓ | 1 | **ALLOW ECF** as in **(i)** |
| | **b** | **i** | $Cl_2$<br>**OR** $O_2$ **AND** $H^+$ ✓ | 1 | **ALLOW** chlor**ine**<br>**ALLOW** $O_2$ **AND** $4H^+$<br>**ALLOW** $O_2$ **AND** acid<br>**DO NOT ALLOW** $O_2$ alone<br>**DO NOT ALLOW** equation or equilibrium |
| | | **ii** | $I^-$ ✓ | 1 | **ALLOW** $2I^-$ **OR** iod**ide**<br>**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 ✓<br><br>$2H_2 + O_2 \rightarrow 2H_2O$ ✓<br><br>Two from:<br>• under pressure **OR** at low temperature **OR** as a liquid<br>• adsorbed on solid<br>• absorbed within solid<br>✓✓<br><br>Energy is needed to make the hydrogen<br>**OR** energy is needed to make fuel cell ✓ | 5 | ***ANNOTATIONS MUST BE USED***<br>**ALLOW** combustion for reaction of fuel with oxygen/reactants<br>**ALLOW** a fuel cell requires constant supply of fuel<br>**OR** operates continuously as long as a fuel (and oxygen) are added<br>**ALLOW** multiples, e.g. $H_2 + ½O_2 \rightarrow H_2O$<br>**IGNORE** state symbols<br><br>**ALLOW** 'material' **OR** metal for solid<br>**ALLOW** as a metal hydride |
| | | | **Total** | **13** | |

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