24. Electrochemistry

24.2 Standard electrode potentials E

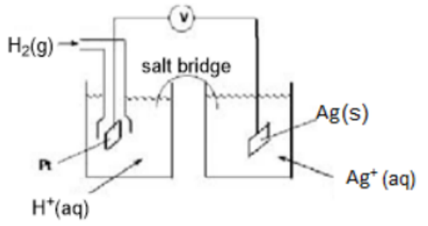
Paper 4

Marking Scheme

Q1.

(g)	**M1** $2C_2O_4^{2-} + O_2(g) + 2H_2O(l) \rightarrow 4CO_2(g) + 4OH^-(aq)$ **M2** $E_{cell} = 0.40 - (-0.59) = 0.99$ V	**2**

Q2.

(a)	**M1** voltage of a half-cell compared to SHE **M2** 1 mol dm^{-3} **AND** 101 kPa **AND** 298 K	**2**
(b)(i)	 **M1** Pt Ag Ag^+ **M2** gas delivery system H_2 H^+ **M3** voltmeter salt bridge wiring Pt to V to Ag	**3**
b(ii)	*E* value would be more negative **AND** shifts $Ag^+ (+ e^-) \leftrightharpoons Ag$ to the left	**1**

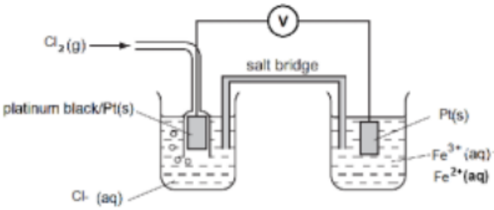
Q3.

(c)(i)	$3MnO_4^{2-} + 4H^+ \rightarrow 2MnO_4^- + MnO_2 + 2H_2O$ **M1** MnO_4^{2-} as a reactant and MnO_4^- + MnO_2 products identified **M2** correct equation	**2**
(c)(ii)	(E_{cell}) decreases / becomes less positive **AND** as [H^+] decreases **AND** equilibrium shifts to the left **OR** in alkali the $E_{cell} = 0.60 - 0.56 = 0.04$ V (working required)	**1**

Q4.

(c)	BiO^+ $3H_2SO_3 + 2BiO^+ + H_2O \rightarrow 3SO_4^{2-} + 8H^+ + 2Bi$ 0.11 V	[1] [1] [1]	**3**

Q5.

(a)	potential difference / voltage between the two half-cells / two electrodes (in a cell) under standard conditions	1
(b)	 salt bridge voltmeter complete circuit [wires/salt bridge in/touching both solutions] Cl_2 Cl^- good delivery system (no arrow required) Pt Pt Fe^{2+} and Fe^{3+} Any three [1], any six [2], all nine [3]	3
(c)	**M1** (ΔG°) = – nFE_{cell}° **OR** –2 × 96500 × 0.59 **M2** ΔG° = –2 × 96500 × 0.59 = –113870 J mol^{-1} ΔG° = –114 kJ mol^{-1} min 3sf ecf	2
(d)(i)	$E = 0.77 + (0.059 / 1) \log (1/0.15)$ use of z = 1 $E = 0.82$ V	1
(d)(ii)	$E_{cell} = 0.59 + 0.77 -$ (answer to (d)(i)) = 0.54 V ecf	1

Q6.

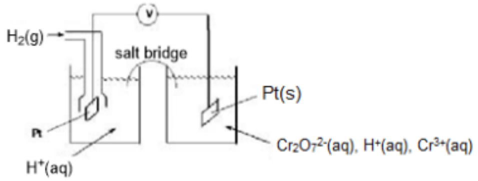
(e)(i)	hydrogen peroxide / H_2O_2 AND +2.18 [1]	1
(e)(ii)	$\Delta G = -nE^\circ_{cell}F$ [1] $\Delta G = (-2 \times 2.18 \times 96500) = -420.7$ (kJ mol–1) [1] ecf	2
(f)(i)	Nernst: (E =) $E^\circ + (0.059 / z)\log[ox] / [red]$ [1] u / c OR (E =) $E^\circ + (RT / zF)\ln[ox] / [red]$ OR (E =) $1.82 + (0.059 / 1)\log(0.02 / 2)$ $E = 1.82 + (0.059 / 1)\log(0.02 / 2) = (+)1.702$ (V) [1] min 2sf OR $E = 1.82 + [(8.314 \times 298 / 1) \times (96\,500)] \ln(0.02 / 2) = (+)1.702$	2
(f)(ii)	$H_2O_2 + 2H+ + 2Co^{2+} \rightarrow 2H_2O + 2Co^{3+}$ [1] ECF for reverse equation from **(f)(i)** if $E > 1.77$ V	1

Q7.

(a)(i)	hydrogen, delivery system, H^+, platinum, [1]	**1**
(a)(ii)	iron . . . . . hydrogen . . . . . iron [1]	**1**
(b)(i)	(for specified V^{2+}, V^{3+} or VO^{2+}) E° is more positive than / above –0.44 **AND** more negative than / below 0.77 V [1]	**1**
(b)(ii)	V and VO_2^+ [1]	**1**
(b)(iii)	$V + Fe^{2+} \rightarrow V^{2+} + Fe$ **OR** $VO_2^+ + 2H^+ + Fe^{2+} \rightarrow VO^{2+} + H_2O + Fe^{3+}$ [1]	**1**
(c)(i)	Nernst: E = 0.77 + (0.059 / z)log[ox] / [red] [1] 0.947 [1]	**2**
(c)(ii)	$2Fe^{3+} + Cl^- + 2OH^- \rightarrow 2Fe^{2+} + ClO^- + H_2O$ [1]	**1**
(d)	E°_{cell} = 1.33 V [1] $\Delta G^\circ = -nE^\circ_{cell}F$ [1] –257 [1]	**3**

Q8.

(c)(i)	voltage / EMF / potential difference when a half-cell is connected to a (standard) hydrogen electrode under standard conditions	**1**
(c)(ii)	ions move (from the salt bridge) to maintain charge balance / complete the circuit	**1**

(c)(iii)	 298K, 1 atm, 1 mol dm^{-3} Pt, $H_2(g)$, good delivery system, 298 K, 1 atm Pt, $Cr_2O_7^{2-}(aq)$, $H^+(aq)$ / $Cr^{3+}(aq)$, 1 mol dm^{-3} seen once, voltmeter three for one mark, six for two marks, nine for three marks	**3**
(c)(iv)	SHE labelled negative **AND** arrow in the external circuit moving away from this electrode	**1**
(d)(i)	**M1** $Cr_2O_7^{2-} + 3CH_3CHO + 8H^+ \rightleftharpoons 2Cr^{3+} + 3CH_3COOH + 4H_2O$ **ALLOW** $Cr_2O_7^{2-} + 3CH_3CHO + 5H^+ \rightleftharpoons 2Cr^{3+} + 3CH_3COO^- + 4H_2O$ **M1** E_{cell}° = +2.27 (V)	**2**
(d)(ii)	**M1** $\Delta G^\circ = -nFE_{cell}^\circ$ **M2** $\Delta G^\circ = -4 \times 96\,500 \times 2.01 = -775\,860$ J mol^{-1} ΔG° = –776 kJ mol^{-1} min 3sf	**2**

Q9.

(a)(i)	(Ion (Sn^{2+}/Sn^{4+}) concentration) 1 mol dm^{-3} **AND** 298 K (25 °C)	**1**
(a)(ii)	• **both** half-cells have Pt or C electrode • Sn^{2+} / Sn^{4+} **AND** H^+ solutions • feasible gas delivery system • H_2 label • V/voltmeter **AND** correct circuit **AND** salt bridge touching solution • salt bridge labelled	**3**
(a)(iii)	no (reaction) **AND** both E° values (Sn^{2+} / Sn) –0.14 and (Cl_2 / Cl^-) +1.36 [1] E_{cell} is –1.5 V / E_{cell} is negative **OR** E° of Sn^{4+} / Sn^{2+} is more negative/smaller than E° of Cl_2 / Cl^- [1]	**2**
(a)(iv)	$Sn^{2+} \rightarrow Sn^{4+}$ and $VO^{2+} \rightarrow V^{3+}$ [1] $Sn^{2+} + 2VO^{2+} + 4H^+ \rightarrow Sn^{4+} + 2V^{3+} + 2H_2O$ [1]	**2**

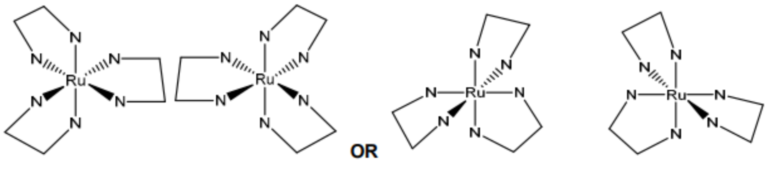
Q10.

(a)(i)	the voltage produced by a half-cell compared with a standard hydrogen electrode [1] 1 mol dm^{-3}, 298 K, 1 atm [1]	**2**
(a)(ii)	Mg wire and Pt wire [1] voltmeter, salt bridge, complete circuit [1] solutes Mg^{2+} and MnO_4^-, Mn^{2+}, H^+ [1]	**3**
(a)(iii)	Mg is minus, Pt is plus arrow points towards MnO_4^- / Mn^{2+} half-cell	**1**
(a)(iv)	3.90 V	**1**
(a)(v)	$5Mg + 2MnO_4^- + 16H^+ \rightarrow 5Mg^{2+} + 2Mn^{2+} + 8H_2O$	**1**
(a)(vi)	no change **and** dilution will make Mg^{2+} / Mg potential even more negative	**1**

Q11.

(e)(i)	$4Cr^{2+} + O_2 + 4H^+ \rightarrow 4Cr^{3+} + 2H_2O$ **OR** $2Cr^{2+} + O_2 + 2H^+ \rightarrow 2Cr^{3+} + H_2O_2$ **M1:** correct species **M2:** balancing	**2**
(e)(ii)	E°_{cell} = 1.23 – (–0.41) = (+)1.64 V **OR** E°_{cell} = 0.68 – (–0.41) = (+)1.09 V value linked to **(e)(i)**	**1**

Q12.

<table>
<tr><td>(a)(i)</td><td>M1: voltage of an electrode / a half-cell compared to / connected to (standard) hydrogen electrode / half-cell
M2: (at concentration of) 1 mol / dm^3 AND (pressure of) 1 atm / 101 kPa (or in Pa) AND 298 K / 25°C</td><td>2</td></tr>
<tr><td>(a)(ii)</td><td><table><tr><th>$E^\ominus$</th><th>redox system</th></tr><tr><td>Most negative</td><td>B</td></tr><tr><td>↑</td><td>C</td></tr><tr><td>Least negative</td><td>A</td></tr></table></td><td>1</td></tr>
<tr><td>(a)(iii)</td><td>

M1 / M2: two 3D isomers of $[Ru(en)_3]^{3+}$
M3: optical / enantiomerism</td><td>3</td></tr>
<tr><td>(b)(i)</td><td>$E^\ominus_{cell}$ = 1.07 – 0.80 = (+)0.27 V
AND direction of electron flow = Ag^+ / Ag to Br_2 / Br^-</td><td>1</td></tr>
<tr><td>(b)(ii)</td><td>M1: $E^\ominus_{cell}$ 3rd box ticked
M2:
[Ag^+] decreases AND so (Ag^+ / Ag) equilibrium shifts to the left
OR
[Ag^+] decreases AND <i>E</i> for (Ag^+ / Ag) becomes less positive / more negative</td><td>2</td></tr>
</table>

Q13.

(a)	$2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$ **OR** $2CuSO_4 + 4NaI \rightarrow 2CuI + I_2 + 2Na_2SO_4$ [1]	1

(c)	M1: (Cu^{2+} / Cu^+) $E^\ominus$ = (+)0.15 V **AND** (I_2 / I^-) $E^\ominus$ = (+)0.54 V [1] M2: <u>No</u>, since ($E^\ominus_{cell}$) negative / –0.39 V **OR** <u>No</u>, since (I_2 / I^-) is more positive than (Cu^{2+} / Cu^+) **OR** <u>No</u>, I_2 is more easily reduced **OR** No, I_2 stronger oxidant ORA [1]	2
(d)	M1: Cu^{2+} / Cu^+ *E* becomes more positive as equilibrium shifts to the right [1] M2: The **new** E for Cu^{2+} / Cu^+ is more positive **than 0.54** / $E^\ominus$ (I_2 / I^-) [1]	2

Q14.

(d)(i)	$E^\ominus_{cell}$ = + 0.30 [1]	**1**
(d)(ii)	$4[Co(NH_3)_6]^{2+} + O_2 + 2H_2O \rightleftharpoons 4[Co(NH_3)_6]^{3+} + 4OH^-$ [1]	**1**
(d)(iii)	M1 No, because 1.82 V **and** 1.23 V [1] M2 $E^\ominus_{cell}$ = –0.59 / 1.23 lower than 1.82 / 1.82 greater than 1.2 [1]	**2**

Q15.

(a)(i)	$6CO_2 + 24H^+ + 24e^- \rightarrow C_6H_{12}O_6 + 6H_2O$ **ALLOW** $6CO_2 + 12H^+ + 12e^- \rightarrow C_6H_{12}O_6 + 3O_2$ for both marks **ALLOW** one mark for an unbalanced equation showing the correct species of either equation	**2**

(a)(ii)	salt bridge (indicated) voltmeter / V labelled O_2 good delivery system H_2 good delivery system Pt electrode H^+ / HCl / H_2SO_4 solution labelled (at least once) 1 atm 1 mol dm^{-3} quoted Every two correct responses = 1 mark	**4**
(a)(iii)	$E^\ominus_{cell}$ = (+) 1.23 V **AND** positive electrode = O_2 half-cell identified	**1**

Q16.

(a)	**M1** data seen H_2O_2/H_2O +1.77V and MnO_2/Mn^{2+} +1.23 V and O_2/H_2O_2 +0.68 V **OR** E_{cell}= 0.55 V (first step) **and** 0.54 V (second step) **M2** $MnO_2 + H_2O_2 + 2H^+ \rightarrow Mn^{2+} + O_2 + 2H_2O$ **M3** $Mn^{2+} + H_2O_2 \rightarrow MnO_2 + 2H^+$	**3**

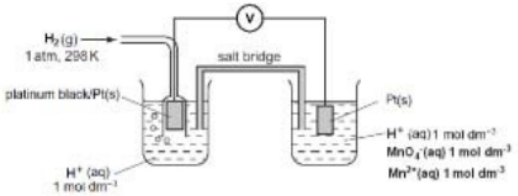
Q17.

(f)	It is feasible as the E_{cell} will be positive/+0.12 V	**1**

Q18.

(a)(i)	**M1** potential difference between two half-cells/two electrodes in a cell **M2** under conditions of 1 atm., 298 K, (all) solutions being 1 mol dm^{-3}	**2**
(a)(ii)	**both** platinum	**1**
(a)(iii)	$E^{\ominus}_{cell}$ = 1.82 – 1.36 = **(+)0.46 V**	**1**
(a)(iv)	$2Co^{3+} + 2Cl^- \rightarrow Cl_2 + 2Co^{2+}$	**1**
(b)	**M1** Q= 2.5 x 30 x 60 C = 4500 C **AND** 96500 **OR** 579000 seen moles of CO_2= 4500/579000 = 7.8 x10^{-3} or 7.77 x 10^{-3} **M2** volume of CO_2 = 7.77 x 10^{-3} x 24000 = **187 cm^3**	**2**

Q19.

(c)(i)	 • MnO_4^-, H^+, Mn^{2+} in same beaker **AND** H^+ in other beaker • both electrodes Pt(s) (**ALLOW** graphite) • one solute clearly identified as 1M / 1 mol dm^{-3} • 298 K **OR** 1 atm • voltmeter / potentiometer labelled (or circled V) • salt bridge labelled (must touch the solution) • a good delivery system for H_2(g) • H_2(g) mark as two correct points = 1 mark [4]	**4**

(c)(ii)	F_2 **OR** $S_2O_8^{2-}$ **OR** H_2O_2 **OR** HOCl **OR** Co^{3+} **OR** Pb^{4+} [1] $2Mn^{2+} + 8H_2O + 5F_2 \rightarrow 2MnO_4^- + 16H^+ + 10F^-$[1] **OR** $2Mn^{2+} + 5S_2O_8^{2-} + 8H_2O \rightarrow 2MnO_4^- + 16H^+ + 10SO_4^{2-}$ **OR** $Mn^{2+} + 4H_2O + 5Co^{3+} \rightarrow MnO_4^- + 8H^+ + 5Co^{2+}$ **OR** $2Mn^{2+} + 8H_2O + 5Pb^{4+} \rightarrow 2MnO_4^- + 16H^+ + 5Pb^{2+}$ **OR** $2Mn^{2+} + 5H_2O_2 \rightarrow 2MnO_4^- + 6H^+ + 2H_2O$ **OR** $2Mn^{2+} + 10HOCl \rightarrow 2MnO_4^- + 6H^+ + 5Cl_2 + 2H_2O$	**2**

Q20.

(c)(i)	1.36 1.07 0.54 [1]	**1**
(c)(ii)	all of them [1] (all $E^\ominus$ values) greater than 0.15 / $E^\ominus_{cell}$ greater than zero [1] e.g. $Sn^{2+} + X_2 \rightarrow Sn^{4+} + 2X$ [1]	**3**
(c)(iii)	MnO_2 [1]	**1**
(d)(i)	1.24 V [1]	**1**
(d)(ii)	platinum, platinum [1]	**1**
(d)(iii)	increase [Fe^{2+}] or decrease [Fe^{3+}] increase [$S_2O_8^{2-}$] or decrease [SO_4^{2-}] [1]	**1**

Q21.

(c)(i)	**M1** $Li \rightarrow Li^+ + e^-$ **and** $I_2 + 2e^- \rightarrow 2I^-$ **M2** $2Li + I_2 \rightarrow 2Li^+ + 2I^-$	**2**
(c)(ii)	$E^\ominus_{cell}$ = 0.54 –(–3.04) = +**3.58 V** [1]	**1**
(c)(iii)	**M1** amount of Li = 0.10 / 6.9 = 1.45 × 10^{-2} mol [1] **M2** Q needed = 96500 × 1.45 × 10^{-2} = **1399** (1398.55) C [1] ecf **M3** t = 1399 / (2.5 × 10^{-5}) = **5.6** × **10^7** s [1] ecf 2sf min	**3**

Q22.

(d)	The potential difference when a half-cell is connected to a (standard) hydrogen electrode under standard conditions [1] **OR** the potential difference / voltage / EMF between a hydrogen electrode and another half-cell under standard conditions [1]	**1**
(e)(i)	salt bridge • voltmeter / V • Ag • Ag^+ (or soluble silver salt) • Pt • H_2 (and delivery correct) + H^+ (or named strong acid) • 1 atm. (pressure) • 1 mol dm^{-3} (and 298 K) • mark as • ✓ • ✓ • ✓ • ✓ [4]	**4**
(e)(ii)	Ag electrode labelled **and** arrow (in the external circuit moving towards this electrode) [1]	**1**

Q23.

(a)	Platinum **and** platinum	**1**
(b)(i)	**M1:** Nernst quoted correctly $E = E^{\circ} + 0.0590 / z\log [ox] / [red]$ or $E = 1.49 + 0.0590\log 5$ **M2:** (+)1.53 V minimum 2 sig. fig. Correct answer scores 2 marks	**2**
(b)(ii)	+ / – 0.46 minimum 2 sig. fig.	**1**
(b)(iii)	**M1:** $Mn^{3+} + 2Br^{-} \rightarrow Mn^{2+} + Br_2$ **M2:** $2Mn^{3+} + 2Br^{-} \rightarrow Mn^{2+} + Br_2$	**2**

Q24.

(d)	**M1:** E° values 1.36 and 0.77 quoted **M2:** $2FeSO_4 + Cl_2 \rightarrow Fe_2(SO_4)_2Cl_2$ or $2Fe^{2+} + Cl_2 \rightarrow 2Fe^{3+} + 2Cl^{-}$	**2**