Question 2

Answer the following questions involving the stoichiometry and thermodynamics of reactions containing aluminum species.

$$2\ Al_2O_3(l) + 3\ C(s) \rightarrow 4\ Al(l) + 3\ CO_2(g)$$

An electrolytic cell produces 235 g of Al(*l*) according to the equation above.

(a) Calculate the number of moles of electrons that must be transferred in the cell to produce the 235 g of Al(*l*).

$235\text{ g Al} \times \dfrac{1\text{ mol Al}}{26.98\text{ g Al}} = 8.71\text{ mol Al}$	1 point is earned for the number of moles of Al.
$Al^{3+} + 3\,e^- \rightarrow Al$, therefore, 3 mol e^- transferred per mol Al $8.71\text{ mol Al} \times \dfrac{3\text{ mol }e^-}{1\text{ mol Al}} = 26.1\text{ mol }e^-$	1 point is earned for correct stoichiometry and the number of moles of electrons.

(b) A steady current of 152 amp was used during the process. Determine the amount of time, in seconds, that was needed to produce the Al(*l*).

charge = moles e^- × Faraday's constant $= 26.1\text{ mol }e^- \times \dfrac{9.65 \times 10^4\text{ C}}{1\text{ mol }e^-} = 2.52 \times 10^6\text{ C}$	1 point is earned for the correct amount of charge transferred.
$I = \dfrac{q}{t}$ $t = \dfrac{q}{I} = \dfrac{2.52 \times 10^6\text{ C}}{152\text{ C/s}} = 1.66 \times 10^4\text{ s}$	1 point is earned for the correct time.

(c) Calculate the volume of $CO_2(g)$, measured at 301 K and 0.952 atm, that is produced in the process.

$\text{mol } CO_2 = 8.71\text{ mol Al} \times \dfrac{3\text{ mol } CO_2}{4\text{ mol Al}} = 6.53\text{ mol } CO_2$	1 point is earned for the number of moles of CO_2.
$PV = nRT$ $V = \dfrac{nRT}{P} = \dfrac{(6.53\text{ mol})\left(0.0821\dfrac{\text{L atm}}{\text{mol K}}\right)(301\text{ K})}{0.952\text{ atm}} = 1.70 \times 10^2\text{ L } CO_2$	1 point is earned for the volume of CO_2.

Question 2 (continued)

(d) For the electrolytic cell to operate, the Al_2O_3 must be in the liquid state rather than in the solid state. Explain.

Al_2O_3 is an ionic compound; in the solid state it will not conduct electricity. In order for the cell to operate, Al_2O_3 must be in the liquid state so that the ions are mobile and able to move to the electrodes to react (and/or complete the circuit).	1 point is earned for a correct explanation.

When Al(*s*) is placed in a concentrated solution of KOH at 25°C, the reaction represented below occurs.

$$2\ Al(s) + 2\ OH^-(aq) + 6\ H_2O(l) \rightarrow 2[Al(OH)_4]^-(aq) + 3\ H_2(g)$$

Half-reaction	$E°$ (V)
$[Al(OH)_4]^-(aq) + 3\ e^- \rightarrow Al(s) + 4\ OH^-(aq)$	−2.35
$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq)$	−0.83

(e) Using the table of standard reduction potentials shown above, calculate the following.

(i) $E°$, in volts, for the formation of $[Al(OH)_4]^-(aq)$ and $H_2(g)$ at 25°C

$E° = E°_{cathode} - E°_{anode} = -0.83\text{ V} - (-2.35\text{ V}) = 1.52\text{ V}$	1 point is earned for the correct value of $E°$.

(ii) $\Delta G°$, in kJ/mol$_{rxn}$, for the formation of $[Al(OH)_4]^-(aq)$ and $H_2(g)$ at 25°C

$\Delta G° = -nFE° = -(6)(9.65 \times 10^4\text{ C})(1.52\text{ V})$ $= -8.80 \times 10^5\text{ J/mol}_{rxn} = -8.80 \times 10^2\text{ kJ/mol}_{rxn}$ (or $-880.\text{ kJ/mol}_{rxn}$)	1 point is earned for $n = 6$. 1 point is earned for the correct value of $\Delta G°$.