

AP[®] CHEMISTRY
2013 SCORING GUIDELINES

Question 2

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



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*).

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

$\text{charge} = \text{moles } e^- \times \text{Faraday's constant}$ $= 26.1 \text{ mol } e^- \times \frac{9.65 \times 10^4 \text{ C}}{1 \text{ mol } e^-} = 2.52 \times 10^6 \text{ C}$ $I = \frac{q}{t}$ $t = \frac{q}{I} = \frac{2.52 \times 10^6 \text{ C}}{152 \text{ C/s}} = 1.66 \times 10^4 \text{ s}$	<p>1 point is earned for the correct amount of charge transferred.</p> <p>1 point is earned for the correct time.</p>
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(c) Calculate the volume of CO₂(*g*), measured at 301 K and 0.952 atm, that is produced in the process.

$\text{mol CO}_2 = 8.71 \text{ mol Al} \times \frac{3 \text{ mol CO}_2}{4 \text{ mol Al}} = 6.53 \text{ mol CO}_2$ $PV = nRT$ $V = \frac{nRT}{P} = \frac{(6.53 \text{ mol}) \left(0.0821 \frac{\text{L atm}}{\text{mol K}} \right) (301 \text{ K})}{0.952 \text{ atm}} = 1.70 \times 10^2 \text{ L CO}_2$	<p>1 point is earned for the number of moles of CO₂.</p> <p>1 point is earned for the volume of CO₂.</p>
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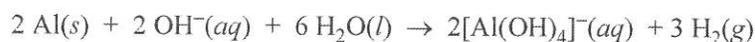
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Question 2 (continued)

- (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.
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When $\text{Al}(s)$ is placed in a concentrated solution of KOH at 25°C , the reaction represented below occurs.



Half-reaction	E° (V)
$[\text{Al}(\text{OH})_4]^-(aq) + 3 e^- \rightarrow \text{Al}(s) + 4 \text{OH}^-(aq)$	-2.35
$2 \text{H}_2\text{O}(l) + 2 e^- \rightarrow \text{H}_2(g) + 2 \text{OH}^-(aq)$	-0.83

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

(i) E° , in volts, for the formation of $[\text{Al}(\text{OH})_4]^-(aq)$ and $\text{H}_2(g)$ at 25°C

$E^\circ = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = -0.83 \text{ V} - (-2.35 \text{ V}) = 1.52 \text{ V}$	1 point is earned for the correct value of E° .
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(ii) ΔG° , in $\text{kJ/mol}_{\text{rxn}}$, for the formation of $[\text{Al}(\text{OH})_4]^-(aq)$ and $\text{H}_2(g)$ at 25°C

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