

AP[®] CHEMISTRY
2006 SCORING GUIDELINES (Form B)

Question 2

2. Answer the following questions about voltaic cells.

(a) A voltaic cell is set up using Al/Al³⁺ as one half-cell and Sn/Sn²⁺ as the other half-cell. The half-cells contain equal volumes of solutions and are at standard conditions.

(i) Write the balanced net-ionic equation for the spontaneous cell reaction.

$3 \text{ Sn}^{2+} + 2 \text{ Al} \rightarrow 3 \text{ Sn} + 2 \text{ Al}^{3+}$	One point is earned for the correct direction. One point is earned for the balanced net-ionic equation.
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(ii) Determine the value, in volts, of the standard potential, E° , for the spontaneous cell reaction.

$E^\circ = -0.14 \text{ V} - (-1.66 \text{ V}) = 1.52 \text{ V (or, } 1.52 \text{ J C}^{-1}\text{)}$	One point is earned for the correct answer. (Potential <u>must</u> be positive.)
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(iii) Calculate the value of the standard free-energy change, ΔG° , for the spontaneous cell reaction. Include units with your answer.

$\Delta G^\circ = -nFE^\circ = -\frac{6 \text{ mol } e^-}{1 \text{ mol}} \times \frac{96,500 \text{ C}}{1 \text{ mol } e^-} \times (1.52 \text{ J C}^{-1})$ $= -8.80 \times 10^5 \text{ J mol}^{-1} \text{ (or } -880 \text{ kJ mol}^{-1}\text{)}$	One point is earned for indicating the correct mol e^- to mol reaction ratio. One point is earned for the correct answer with correct units.
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(iv) If the cell operates until [Al³⁺] is 1.08 M in the Al/Al³⁺ half-cell, what is [Sn²⁺] in the Sn/Sn²⁺ half-cell?

$\text{change in } [\text{Sn}^{2+}] = \frac{0.08 \text{ mol Al}^{3+}}{1 \text{ L}} \times \frac{3 \text{ mol Sn}^{2+}}{2 \text{ mol Al}^{3+}} = \frac{0.12 \text{ mol Sn}^{2+}}{1 \text{ L}}$ $[\text{Sn}^{2+}] = 1.00 \text{ mol L}^{-1} - 0.12 \text{ mol L}^{-1} = 0.88 \text{ mol L}^{-1}$	One point is earned for the correct answer.
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(b) In another voltaic cell with Al/Al³⁺ and Sn/Sn²⁺ half-cells, [Sn²⁺] is 0.010 M and [Al³⁺] is 1.00 M. Calculate the value, in volts, of the cell potential, E_{cell} , at 25°C.

$E_{\text{cell}} = 1.52 \text{ V} - \frac{0.0592}{6} \log \frac{(1.00)^2}{(0.010)^3}$ $= 1.52 \text{ V} - 0.0592 \text{ V} = 1.46 \text{ V}$	Answers must be consistent with part (a)(i). One point is earned for the proper exponents. One point is earned for the correct substitution of concentrations. One point is earned for the correct answer.
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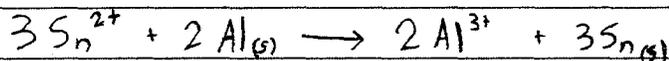
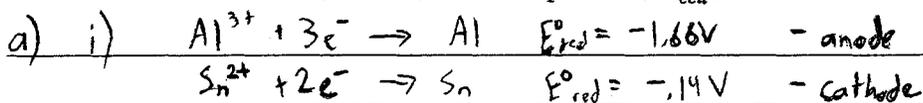
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ii) $E_{cell}^\circ = E_{red}^\circ(\text{cathode}) - E_{red}^\circ(\text{anode}) = (-0.14V) - (-1.66V) \quad E_{cell}^\circ = 1.52V$

iii) $\Delta G^\circ = -nFE^\circ = -(6)(96500 C)(1.52V) \quad \Delta G^\circ = -880 \times 10^3 J = -880 KJ$

iv) $1.08 M \quad Al^{3+} \quad | \quad \begin{matrix} 3 \text{ mol } Sn^{2+} \\ 2 \text{ mol } Al^{3+} \end{matrix} = 1.62 M \quad Sn^{2+}$

b) $Q = \frac{[Al^{3+}]^2}{[Sn^{2+}]^3} \quad E_{cell} = E_{cell}^\circ - \frac{0.0592}{n} \log Q$

$E_{cell} = 1.52V - \frac{0.0592}{6} \log \left(\frac{(1.00)^2}{(0.010)^3} \right) \quad E_{cell} = 1.46V$

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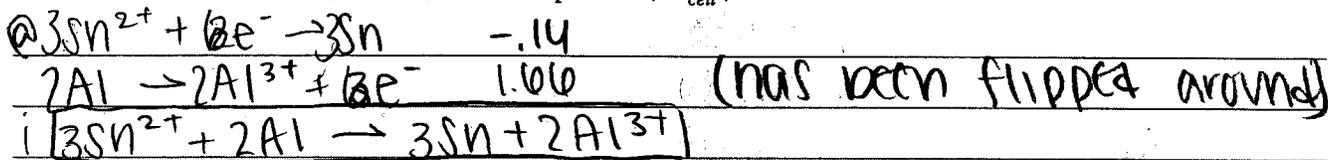
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ii flip the lower equation. (on the volt chart, Al is lower than Sn)

$$-0.14 + 1.66 = 1.52 \text{ V}$$

iii. $\Delta G = -nFE^\circ$

$$= -6 \cdot 96500 \cdot 1.52 \text{ V}$$

$$= -880080 \text{ J/kmol}$$

iv. $1.52 = 1.52 - \frac{RT}{nF} \ln \frac{[\text{Al}]}{[\text{Sn}]}$

$$\frac{RT}{nF} \ln \frac{[\text{Al}]}{[\text{Sn}]} = 0 \quad \therefore [\text{Al}] = [\text{Sn}] = 1.08 \text{ M}$$

$$E_{\text{cell}} = E^\circ_{\text{cell}} - \frac{RT}{nF} \ln \frac{[\text{Al}]}{[\text{Sn}]}$$

$$1.52 - \frac{(8.31)(298)}{6 \cdot 96500} \ln \frac{1}{0.010}$$

$$= 1.5 \text{ V}$$

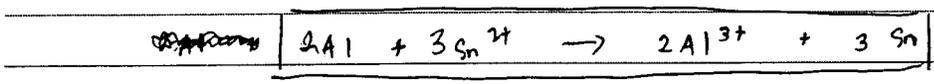
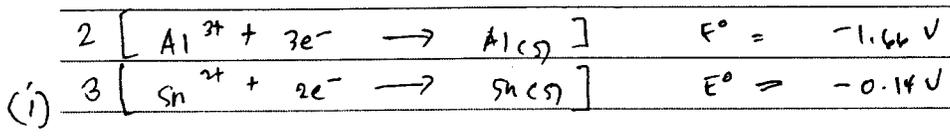
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2C

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- (b) In another voltaic cell with Al/Al^{3+} and Sn/Sn^{2+} half-cells, $[\text{Sn}^{2+}]$ is 0.010 M and $[\text{Al}^{3+}]$ is 1.00 M . Calculate the value, in volts, of the cell potential, E_{cell} , at 25°C .



ii)
$$-0.14\text{ V} - (-1.66\text{ V}) = \boxed{1.65\text{ V}}$$

iii)
$$\Delta G^\circ = -nFE^\circ$$

$$= -4(96500)(1.65\text{ V})$$

$$= \frac{-955,350\text{ J}}{\text{mol}} = \boxed{-9.55 \times 10^5\text{ J/mol}}$$

iv)
$$\Delta G^\circ = -2.303 RT \log K$$

$$\frac{-9.55 \times 10^5\text{ J}}{\text{mol}}$$

b)

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AP[®] CHEMISTRY
2006 SCORING COMMENTARY (Form B)

Question 2

Sample: 2A

Score: 8

This excellent response earned 8 out of 9 possible points: 2 points for part (a)(i), 1 point for part (a)(ii), 2 points for part (a)(iii), and 3 points for part (b). The point was not earned for part (a)(iv).

Sample: 2B

Score: 6

In this good response, 1 point was earned in part (a)(iii) for the correct number of moles of electrons, but the second point was not earned because the units are incorrect and the number of significant figures in the answer is different by more than one from the proper number. The point was not earned in part (a)(iv) because the concentrations of Al^{3+} and Sn^{2+} are not equal. In part (b) one point was earned for substitution of the correct concentrations, but the point for correct exponents was not earned. The calculation with incorrect exponents is done correctly, so a second point was earned in part (b).

Sample: 2C

Score: 4

The point was not earned in part (a)(ii) because of a math error in the calculation. This incorrect value was used correctly in part (a)(iii), so part (a)(iii) earned full credit. The point was not earned in part (a)(iv). Part (b) is not attempted.