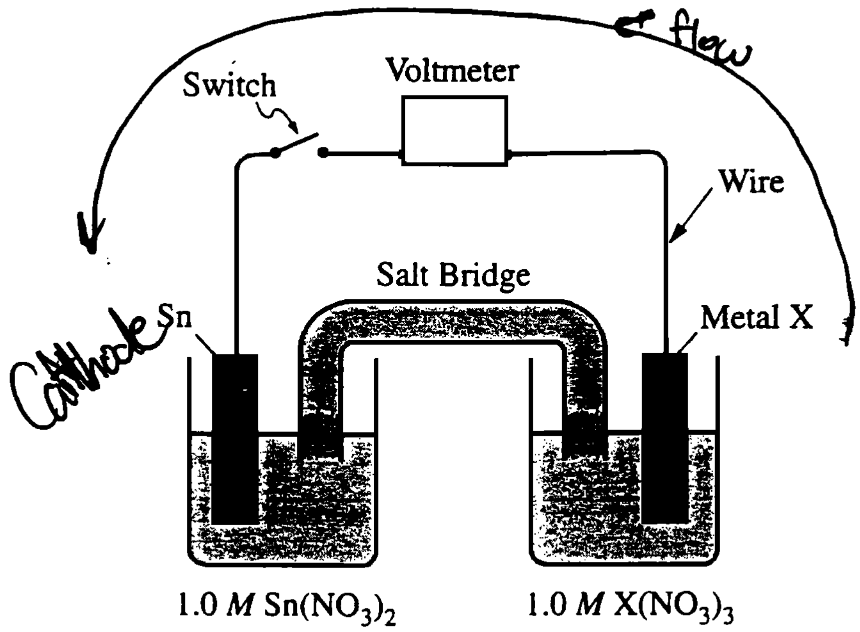
CollegeBoard
Advanced Placement Program

AP® Chemistry (Operational)
2004 Sample Student Responses



6. An electrochemical cell is constructed with an open switch, as shown in the diagram above. A strip of Sn and a strip of an unknown metal, X, are used as electrodes. When the switch is closed, the mass of the Sn electrode increases. The half-reactions are shown below.

$$Sn^{2+}(aq) + 2e^- \rightarrow Sn(s) \qquad E° = -0.14 \text{ V}$$

$$X^{3+}(aq) + 3e^- \rightarrow X(s) \qquad E° = ?$$

(a) In the diagram above, label the electrode that is the cathode. Justify your answer.

(b) In the diagram above, draw an arrow indicating the direction of the electron flow in the external circuit when the switch is closed.

(c) If the standard cell potential, $E°_{cell}$, is +0.60 V, what is the standard reduction potential, in volts, for the X^{3+}/X electrode?

(d) Identify metal X.

(e) Write a balanced net-ionic equation for the overall chemical reaction occurring in the cell.

(f) In the cell, the concentration of Sn^{2+} is changed from 1.0 *M* to 0.50 *M*, and the concentration of X^{3+} is changed from 1.0 *M* to 0.10 *M*.

(i) Substitute all the appropriate values for determining the cell potential, E_{cell}, into the Nernst equation. (Do <u>not</u> do any calculations.)

(ii) On the basis of your response in part (f) (i), will the cell potential, E_{cell}, be greater than, less than, or equal to the original $E°_{cell}$? Justify your answer.

a) The cathode is the site of reduction. Sn^{2+} is being reduced to Sn, thus the increase in mass of the Sn electrode.

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c) The half-reaction containing X must be reversed because X is the site of oxidation.

$0.6V = -0.14V + (^{-}\text{Metal } x)V$

$-0.74V$ = Standard Reduction Potential of X

d) Metal X is Cr

e) $Sn^{2+} + 2e^- \rightarrow Sn(s) \quad \times 3$

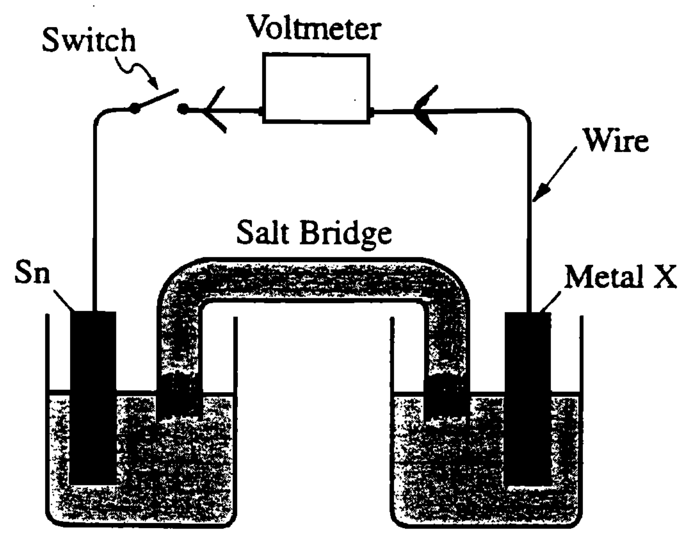
$Cr \rightarrow Cr^{3+} + 3e^- \quad \times 2$

$$3Sn^{2+} + 2Cr \rightarrow 3Sn + 2Cr^{3+}$$

f) i) $\mathcal{E}_{cell} = \mathcal{E}_o\,cell - \frac{RT}{nF}\ln(Q) \longrightarrow Q = \frac{(Cr^{3+})^2}{(Sn^{2+})^3}$

$$\mathcal{E}_{cell} = 0.60\,V - \frac{(8.314\ J/mol\,K)(298\ K)}{(6\ mol\ e^-)(96500\ C/mol)} \ln\left[\frac{(0.1)^2}{(0.5)^3}\right]$$

ii) The fraction in the logarithm will make it negative, making the "$\frac{RT}{nF}\ln Q$" term positive, which adds to $\mathcal{E}^o_{cell}$. Thus, the cell potential will increase.



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(a) In the diagram above, label the electrode that is the cathode. Justify your answer.
reduction → decrease in oxidation #/gain electrons

(b) In the diagram above, draw an arrow indicating the direction of the electron flow in the external circuit when the switch is closed.

(c) If the standard cell potential, $E°_{cell}$, is +0.60 V, what is the standard reduction potential, in volts, for the X^{3+}/X electrode?

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(ii) On the basis of your response in part (f) (i), will the cell potential, E_{cell}, be greater than, less than, or equal to the original $E°_{cell}$? Justify your answer.

a) When the circuit is complete so electrons can flow, the mass of the Sn electrode increases, indicating that electrons are flowing into the Sn electrode. The cathode is where reduction takes place. Reduction is a decrease in oxidation number, which is a gain of electrons. Since

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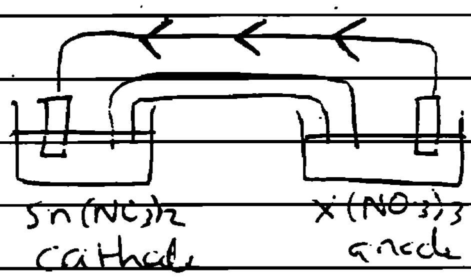
the Sn electron gains electrons, it is reduced, therefore (the Sn electrode is the cathode)

b)



c) $3(Sn^{2+} + 2e^- \rightarrow Sn(s))$ $E° = -.14V$

$2(X(s) \leftarrow X^{3+}(aq) + 3e^-)$ $E° = -x$ ($E°$ for X^{3+}/X electrode $= x$)

total $E° = .60$ V

total $E° = .60V = -x - .14V \rightarrow -x = .74V$

$\therefore E°$ for X^{3+}/X = ($-.74V$)

d) X must be metal that can have oxidation state 3+ and be solid as element X

($\therefore$ element X is aluminum)

e) $3(Sn^{2+} + 2e^- \rightarrow Sn(s))$

$2(Al(s) \leftarrow Al^{3+}(aq) + 3e^-)$

($3Sn^{2+}(aq) + 2Al(s) \rightarrow 3Sn(s) + 2Al^{3+}(aq)$)

f) i) $E = E° - \frac{RT}{nF}\ln Q$

$E = .60V - \frac{.08206 \cdot 298}{6 \cdot 96,485} \cdot \ln\left(\frac{1M}{1M}\right)$

ii) since the $\ln(1) = 0$, $E = .60V - \frac{.08206 \cdot 298}{6 \cdot 96,485} \cdot 0$, therefore $E = .60V$

($\therefore$ E cell will equal E° cell)

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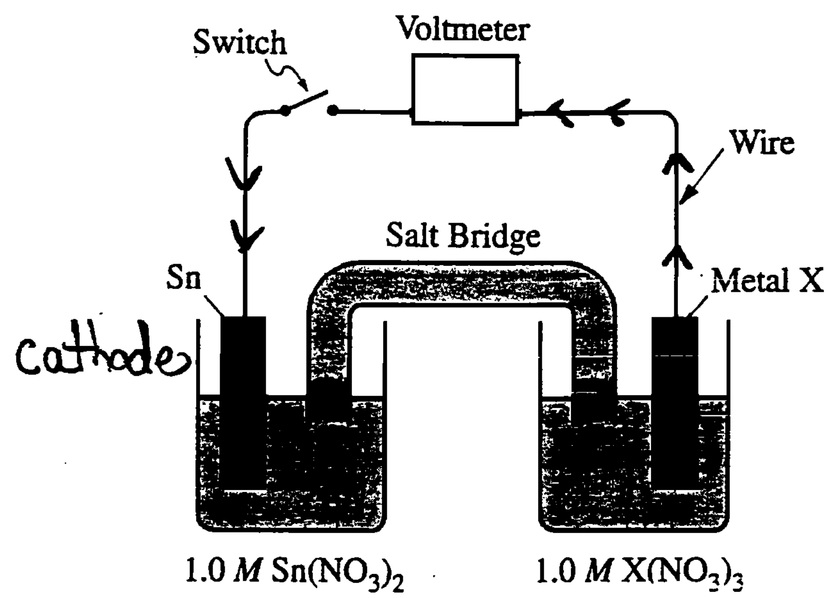

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(ii) On the basis of your response in part (f) (i), will the cell potential, E_{cell}, be greater than, less than, or equal to the original $E°_{cell}$? Justify your answer.

6) a) The side with Sn is the cathode due to Sn^{2+} being reduced causing the formation of Sn(s). Reduction occurs at the cathode.

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c) $E^{o}_{cell} = E_{Sn^{2+}} + E_{x}$

$.60V = -.14V + E_x$

$.60V$
$+.14V$

$\boxed{.74V} = E_x$

d) Cr(s)

e) $(Sn^{2+} + 2e^- \rightarrow Sn)3 \quad (Cr \rightarrow Cr^{3+} + 3e^-)2$

$\boxed{3Sn^{2+} + 2Cr \rightarrow 2Cr^{3+} + 3Sn}$

f) i) $E_{cell} = E^{o}_{cell} - \frac{.0592}{n} \log Q$

$E_{cell} = .74V - \frac{.0592}{6mol} \log\left(\frac{.10M}{.50M}\right)$

ii) The Ecell will be greater than E°cell due to the log of a number smaller than one coming out negative which charges the sign so that there is addition to the E°cell.