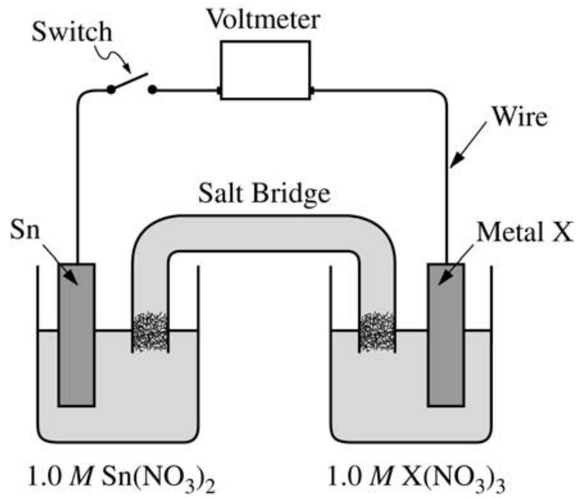



6. An electrochemical cell is constructed with an open switch, as shown in the diagram above. A strip of Sn and a strip of an unknown metal, X, are used as electrodes. When the switch is closed, the mass of the Sn electrode increases. The half-reactions are shown below.

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

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

(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, $E^\circ_{cell}$, is +0.60 V, what is the standard reduction potential, in volts, for the $X^{3+}/X$ electrode?

(d) Identify metal X.

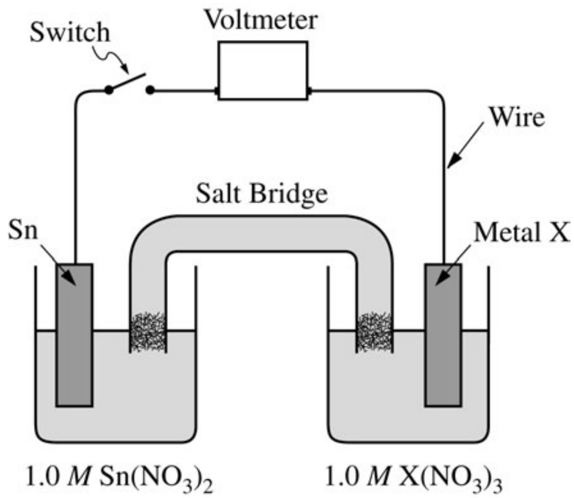
(e) Write a balanced net-ionic equation for the overall chemical reaction occurring in the cell.

(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 not 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 $E^\circ_{cell}$? Justify your answer.

## Question 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.

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

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

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

| | |
|---|---|
| The Sn (tin) electrode is the cathode. | 1 point for identifying Sn as the cathode |
| The increase in mass indicates that reduction occurs at the Sn electrode: $Sn^{2+}(aq) + 2\,e^- \rightarrow Sn(s)$ Reduction occurs at the cathode. | 1 point for reasoning based on increase in mass |

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

| | |
|---|---|
| Diagram should have arrow showing electrons flowing from the anode towards the cathode. | 1 point for correct direction of electron flow |

**Question 6 (cont')**

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

| | |
|---|---|
| $E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode}$<br>$+0.60\text{ V} = -0.14\text{ V} - E^\circ_{anode}$<br>$E^\circ_{anode} = -0.74\text{ V}$ | 1 point for correct potential with correct sign |

(d) Identify metal X.

| | |
|---|---|
| Cr | 1 point for correct metal |

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

| | |
|---|---|
| $3\ Sn^{2+} + 2\ Cr \rightarrow 3\ Sn + 2\ Cr^{3+}$ | 1 point for correctly balanced net-ionic equation |

(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*.

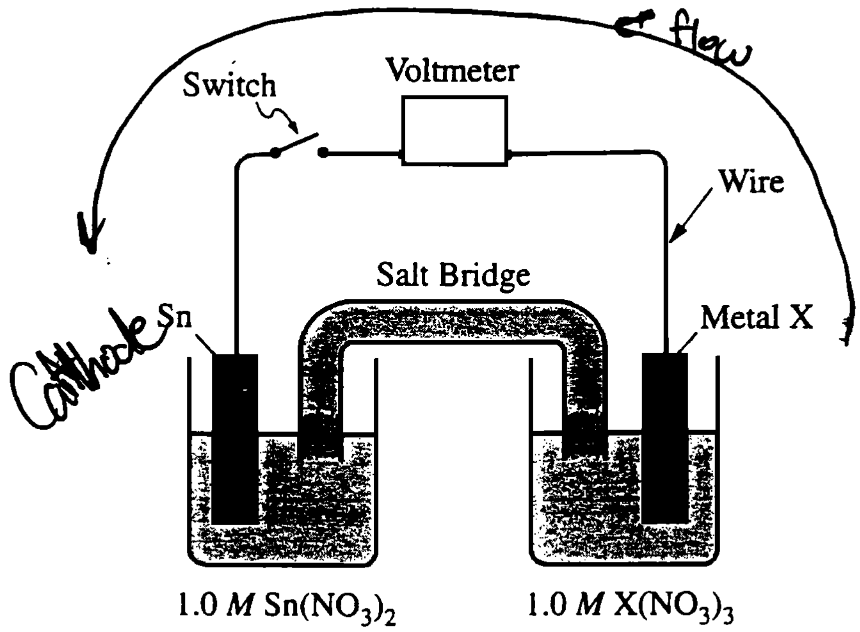
(i) Substitute all the appropriate values for determining the cell potential, $E_{cell}$, into the Nernst equation. (Do not do any calculations.)

| | |
|---|---|
| $E_{cell} = E^\circ_{cell} - \dfrac{0.0592}{n}\log\dfrac{[Cr^{3+}]^2}{[Sn^{2+}]^3}$<br>$E_{cell} = +0.60\text{ V} - \dfrac{0.0592}{6}\log\dfrac{[0.10]^2}{[0.50]^3}$ | 1 point for using $E^\circ_{cell} = +0.60$ V<br>1 point for using $n = 6$<br>1 point for substituting correctly into the $Q$ expression based on the equation in part (e) |

(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 $E^\circ_{cell}$? Justify your answer.

| | |
|---|---|
| $E_{cell}$ will be greater (more positive). Since the $Q$ ratio is a number less than 1, the log of the ratio will be negative. A negative times a negative is positive.<br>Thus, $-\dfrac{0.0592}{6}\log\dfrac{[0.10]^2}{[0.50]^3}$ increases $E_{cell}$ | 1 point for the correct prediction with an explanation based on $Q$ |

 6A 1




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.

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

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

(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, $E^\circ_{cell}$, 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 not 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 $E^\circ_{cell}$? Justify your answer.

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

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 6.

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

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

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

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

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.

## Question 6

**Sample: 6A**
**Score: 10**

This response earns a perfect score of 10 points: 2 points for part (a), 1 point for part (b), 1 point for part (c), 1 point for part (d), 1 point for part (e), 3 points for part (f)(i), and 1 point for part (f)(ii). In part (f)(ii), the explanation of the change in voltage is clear and logical.

**Sample: 6B**
**Score: 8**

The point is not earned in part (d) for the identification of aluminum as metal X. Note that full credit is earned in part (e) even though aluminum is used in the equation instead of iron, because this response is consistent with the incorrect answer given in part (c), and the stoichiometry is correct. Only 2 out of 3 points are earned in part (f)(i) because the *Q* term is incorrect. Full credit is earned in part (f)(ii) because the answer is consistent with the incorrect answer given in part (f)(ii).

**Sample: 6C**
**Score: 7**

This response contains three common errors. The point is not earned in part (c) because the standard reduction potential should be negative. Only 1 out of 3 points is earned in part (f)(i) because 0.74 V is used in the Nernst equation instead of 0.60 V, and the exponents are not included in the *Q* term.

## Question 6

***What was the intent of this question?***

The required essay was designed to assess students' knowledge of electrochemistry and to integrate a variety of chemical principles. Students were expected to identify the cathode in a galvanic cell, to calculate a reduction potential, and to use the Nernst equation to determine the effects of changes in concentration.

***How well did students perform on this question?***

It was apparent that many students were familiar with the material. The mean score for this question was 4.1 out of a possible 10 points. There were many perfect scores. The parts of the question most frequently answered correctly were the identification of the cathode, the electron flow, and the identification of the metal. The least frequently earned points were calculating the reduction potential and interpreting the voltage after concentration changes.

***What were common student errors or omissions?***

Part (a): Most students earned points for identification of the cathode. The most common errors included the following:

- Students mislabeled the anode and cathode.
- Students confused standard line notation with position of the half cells (anode-left and cathode-right).
- Students identified the electrode as the solution or the container rather than the metal.
- Students failed to recognize that the mass gain was due to $Sn^{2+}$ plating out as Sn metal and incorrectly reasoned that it was due to the movement of electrons into the cathode.

Part (b): Most students earned the point for properly showing the electron flow. The most common error was representing the electron flow through the salt bridge or traveling in some type of complete circuit using the salt bridge.

Part (c): The most common error occurred when students gave an oxidation potential of +0.74 V for Cr metal instead of a reduction potential for $Cr^{3+}$. Another common error was to combine the data improperly as $E^{\circ}_{cell} = 0.60\text{ V} - 0.14\text{ V} = 0.46\text{ V}$.

Part (d): Most students were able to identify Cr as metal X regardless of the answer obtained in Part (c). Those not identifying Cr most often chose Fe or some other metal known to possess a 3+ oxidation state. Many students incorrectly identified $Cr^{3+}$ as the metal.

Part (e): The most common mistake was failure to balance mass and charge. Some students failed to remove spectator ions, and some failed to remove free electrons.

Part (f)(i): Many students did not include exponents from the balanced equation when substituting for $Q$. Some were unable to select the Nernst equation and often chose $\Delta G = -RT\ln K$ or $\Delta G = -nFE$. Students often substituted the total of the solution molarities rather than the number of electrons transferred; some substituted in the reduction potential value from Part (c) instead of the cell potential.

Part (f)(ii): Many students incorrectly reasoned that anything subtracted would reduce the voltage, without recognition that ln $Q$ was a negative value. Many incorrectly simplified that when the concentration decreases, the voltage decreases.

Parts (f)(i) and (f)(ii) were frequently omitted, even when students had earned all points in Parts (a) through (e).

***Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?***

- Be sure to include a thorough unit on electrochemistry.
- Have students draw, label, calculate, and make observations for galvanic cells and electrolytic cells.
- Have students properly identify anode and cathode and write half-cell reactions for each.
- Make sure that students have the opportunity to describe the flow of electrons and what is actually taking place in each type of cell. Many students had the misconception that electrons were being "pushed" and "pulled" from one cell to another or that protons and electrons were exchanging places, thus accounting for the mass change.
- Students should have the opportunity to perform an electrochemical cell lab and measure voltages.
- Encourage students to read and answer all parts of each question.
- Encourage mathematical reasoning, sign, and magnitude, when dealing with questions involving formulas. Substantial partial credit is earned on this type of question for reasoning based on an equation or an answer obtained in the previous part(s) of the question.
- Make use of the Nernst equation to calculate the $E$ for a galvanic cell.
- Encourage students to fully establish equations before making substitutions.
- Ensure that students understand what each quantity in an equation represents. For example, it is not enough to understand that $n$ is the number of moles if there is no comprehension of what this value actually represents.