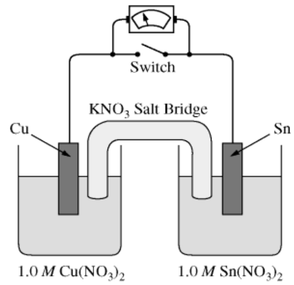
Question 3
(10 points)



A student is given a standard galvanic cell, represented above, that has a Cu electrode and a Sn electrode. As current flows through the cell, the student determines that the Cu electrode increases in mass and the Sn electrode decreases in mass.

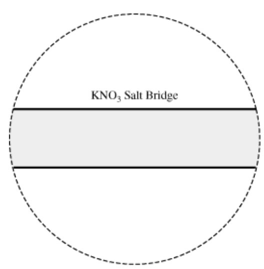
(a) Identify the electrode at which oxidation is occurring. Explain your reasoning based on the student's observations.

Since the Sn electrode is losing mass, Sn atoms must be forming $Sn^{2+}(aq)$. This process is oxidation. OR because the cell operates, $E°$ must be positive and, based on the $E°$ values from the table, it must be Sn that is oxidized.	1 point is earned for the correct answer with justification.

(b) As the mass of the Sn electrode decreases, where does the mass go?

The atoms on the Sn electrode are going into the solution as Sn^{2+} ions.	1 point is earned for the correct answer.

(c) In the expanded view of the center portion of the salt bridge shown in the diagram below, draw and label a particle view of what occurs in the salt bridge as the cell begins to operate. Omit solvent molecules and use arrows to show the movement of particles.



The response should show at least one K^+ ion moving toward the Cu compartment on the left and at least one NO_3^- ion moving in the opposite direction.	1 point is earned for correct representation of both K^+ and NO_3^- ions. (Including free electrons loses this point.) 1 point is earned for correctly indicating the direction of movement of both ions.

Question 3 (continued)

(d) A nonstandard cell is made by replacing the 1.0 *M* solutions of $Cu(NO_3)_2$ and $Sn(NO_3)_2$ in the standard cell with 0.50 *M* solutions of $Cu(NO_3)_2$ and $Sn(NO_3)_2$. The volumes of solutions in the nonstandard cell are identical to those in the standard cell.

(i) Is the cell potential of the nonstandard cell greater than, less than, or equal to the cell potential of the standard cell? Justify your answer.

It is the same. In the cell reaction $Q = \frac{[Sn^{2+}]}{[Cu^{2+}]}$, and the concentrations of Sn^{2+} and Cu^{2+} are equal to each other in both cases.	1 point is earned for the correct answer with justification.

(ii) Both the standard and nonstandard cells can be used to power an electronic device. Would the nonstandard cell power the device for the same time, a longer time, or a shorter time as compared with the standard cell? Justify your answer.

The nonstandard cell would power the device for a shorter time because the supply of Cu^{2+} ions will be exhausted more quickly. OR The nonstandard cell would power the device for a shorter time because the reaction will reach $E = 0$ more quickly.	1 point is earned for the correct answer with justification.

(e) In another experiment, the student places a new Sn electrode into a fresh solution of 1.0 *M* $Cu(NO_3)_2$.

Half-Reaction	$E°$ (V)
$Cu^{+} + e^{-} \rightarrow Cu(s)$	0.52
$Cu^{2+} + 2e^{-} \rightarrow Cu(s)$	0.34
$Sn^{4+} + 2e^{-} \rightarrow Sn^{2+}$	0.15
$Sn^{2+} + 2e^{-} \rightarrow Sn(s)$	–0.14

(i) Using information from the table above, write a net-ionic equation for the reaction between the Sn electrode and the $Cu(NO_3)_2$ solution that would be thermodynamically favorable. Justify that the reaction is thermodynamically favorable.

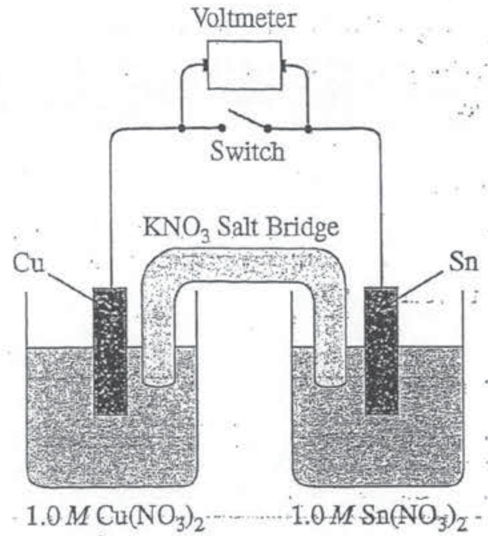
Question 3 (continued)

$Cu^{2+}(aq) + Sn(s) \rightarrow Cu(s) + Sn^{2+}(aq)$ $E°$ is positive (0.34 V + 0.14 V = 0.48 V), therefore the reaction is thermodynamically favorable. OR The cell observations from earlier parts of the question are evidence that the Sn is oxidized and Cu is reduced, therefore $E°$ must be positive.	1 point is earned for the correct net-ionic equation. 1 point is earned for a correct justification (unit not needed in calculation).

(ii) Calculate the value of $\Delta G°$ for the reaction. Include units with your answer.

$\Delta G° = -nFE°$ $\Delta G° = -\dfrac{2 \text{ mol } e^-}{\text{mol}_{rxn}} \times \dfrac{96{,}485 \text{ C}}{\text{mol } e^-} \times \dfrac{0.48 \text{ J}}{\text{C}} = -93{,}000 \text{ J/mol}_{rxn} = -93 \text{ kJ/mol}_{rxn}$	1 point is earned for the correct number of electrons. 1 point is earned for the correct answer with unit.

3A1



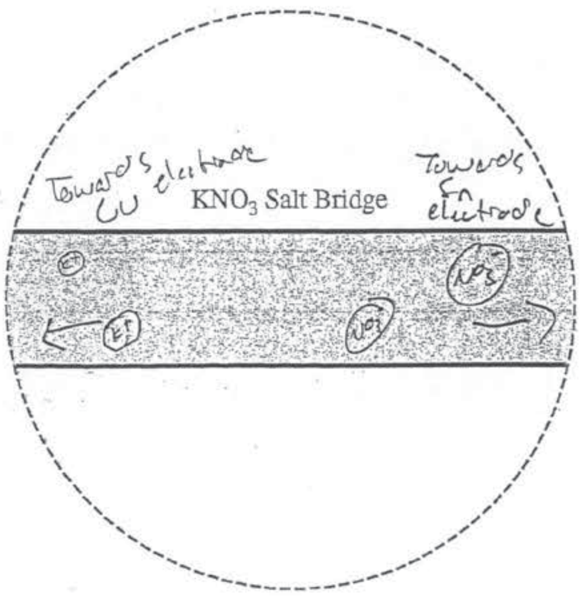
3. A student is given a standard galvanic cell, represented above, that has a Cu electrode and a Sn electrode. As current flows through the cell, the student determines that the Cu electrode increases in mass and the Sn electrode decreases in mass.

(a) Identify the electrode at which oxidation is occurring. Explain your reasoning based on the student's observations.

(b) As the mass of the Sn electrode decreases, where does the mass go?

(c) In the expanded view of the center portion of the salt bridge shown in the diagram below, draw and label a particle view of what occurs in the salt bridge as the cell begins to operate. Omit solvent molecules and use arrows to show the movement of particles.

no H_2O



GO ON TO THE NEXT PAGE.

(d) A nonstandard cell is made by replacing the 1.0 *M* solutions of $Cu(NO_3)_2$ and $Sn(NO_3)_2$ in the standard cell with 0.50 *M* solutions of $Cu(NO_3)_2$ and $Sn(NO_3)_2$. The volumes of solutions in the nonstandard cell are identical to those in the standard cell.

(i) Is the cell potential of the nonstandard cell greater than, less than, or equal to the cell potential of the standard cell? Justify your answer.

(ii) Both the standard and nonstandard cells can be used to power an electronic device. Would the nonstandard cell power the device for the same time, a longer time, or a shorter time as compared with the standard cell? Justify your answer.

(e) In another experiment, the student places a new Sn electrode into a fresh solution of 1.0 *M* $Cu(NO_3)_2$.

Half-Reaction	$E°$ (V)
$Cu^+ + e^- \rightarrow Cu(s)$	0.52
$Cu^{2+} + 2e^- \rightarrow Cu(s)$	0.34
$Sn^{4+} + 2e^- \rightarrow Sn^{2+}$	0.15
$Sn^{2+} + 2e^- \rightarrow Sn(s)$	−0.14

(i) Using information from the table above, write a net-ionic equation for the reaction between the Sn electrode and the $Cu(NO_3)_2$ solution that would be thermodynamically favorable. Justify that the reaction is thermodynamically favorable.

(ii) Calculate the value of $\Delta G°$ for the reaction. Include units with your answer.

a) Oxidation is occurring at the Sn electrode. Since the Sn electrode is decreasing in size, this means Sn^{2+} is being released into the Solution. Therefore, Sn's electrons are lost, making it oxidized.

b.) Into the Solution as Sn^{2+} Ions.

c)

d) i) They will be the same. ~~the~~ ~~[illegible]~~ Since both molarities of solution are equal, no change will be made ~~to~~ Q. This means that there will be no effect on the Electrical potential.

ii) A shorter time. There are less moles in solution, therefore less Cu^{2+}, ~~[illegible]~~ therefore the cell will be able to power the device for shorter time.

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

e) i) $Sn_{(s)} + Cu^{2+}_{(aq)} \rightarrow Sn^{2+}_{(aq)} + Cu_{(s)}$

This is thermodynamically favored because the Electrical Potential, .34-(-.14) is positive, which makes ΔG negative, making the reaction Spontaneous and Thermodynamically favored ~~And Because God Said so~~

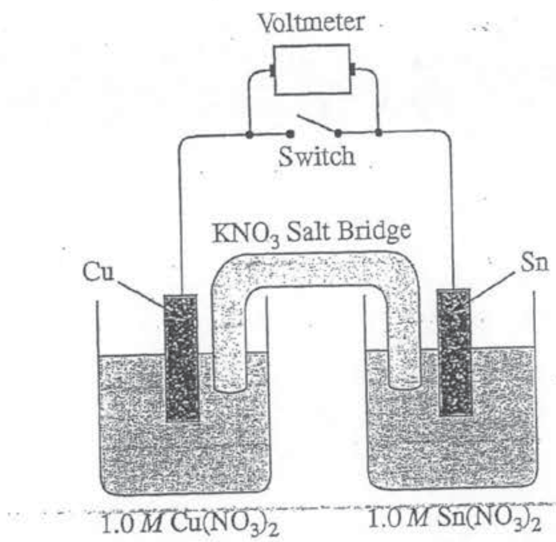
ii) $\Delta G^\circ = -nFE^\circ_{cell}$

$\Delta G = -2(96500)(.48) = -92600\ J\left(\frac{1kJ}{1000J}\right)$

$\boxed{-93.\ kJ/mol}$

GO ON TO THE NEXT PAGE.

3B₁

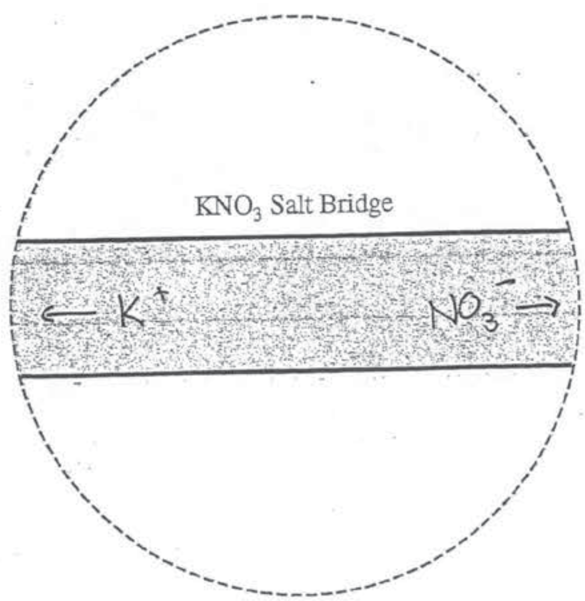


3. A student is given a standard galvanic cell, represented above, that has a Cu electrode and a Sn electrode. As current flows through the cell, the student determines that the Cu electrode increases in mass and the Sn electrode decreases in mass.

(a) Identify the electrode at which oxidation is occurring. Explain your reasoning based on the student's observations.

(b) As the mass of the Sn electrode decreases, where does the mass go?

(c) In the expanded view of the center portion of the salt bridge shown in the diagram below, draw and label a particle view of what occurs in the salt bridge as the cell begins to operate. Omit solvent molecules and use arrows to show the movement of particles.



GO ON TO THE NEXT PAGE.

(d) A nonstandard cell is made by replacing the 1.0 *M* solutions of $Cu(NO_3)_2$ and $Sn(NO_3)_2$ in the standard cell with 0.50 *M* solutions of $Cu(NO_3)_2$ and $Sn(NO_3)_2$. The volumes of solutions in the nonstandard cell are identical to those in the standard cell.

(i) Is the cell potential of the nonstandard cell greater than, less than, or equal to the cell potential of the standard cell? Justify your answer.

(ii) Both the standard and nonstandard cells can be used to power an electronic device. Would the nonstandard cell power the device for the same time, a longer time, or a shorter time as compared with the standard cell? Justify your answer.

(e) In another experiment, the student places a new Sn electrode into a fresh solution of 1.0 *M* $Cu(NO_3)_2$.

Half-Reaction	$E°$ (V)	
$Cu^+ + e^- \rightarrow Cu(s)$	0.52	
$Cu^{2+} + 2e^- \rightarrow Cu(s)$	0.34	✓
$Sn^{4+} + 2e^- \rightarrow Sn^{2+}$	0.15	
$Sn^{2+} + 2e^- \rightarrow Sn(s)$	−0.14	↻

(i) Using information from the table above, write a net-ionic equation for the reaction between the Sn electrode and the $Cu(NO_3)_2$ solution that would be thermodynamically favorable. Justify that the reaction is thermodynamically favorable.

(ii) Calculate the value of $\Delta G°$ for the reaction. Include units with your answer.

a. $Cu^{+2} + 2e^- \rightarrow Cu$ Reduction oxidation is occuring at the Sn electrode. For the mass of Cu
$Sn \rightarrow Sn^{+2} + 2e^-$ Oxidation to increase, the Cu^{+2} ion would have to be reduced to Cu.
That means that oxidation must occur in the Sn electrode.

b. The mass goes to the $Sn(NO_3)_2$ solution. The oxidation of Sn forms Sn^{+2}.

c. The NO_3^- will go to the Sn side to even out the loss of electrons.

d. i. The cell potential remains the same because cell potential does not depend on the molar concentrations or molar quantities of the reactants.

ii. Because the nonstandard cell has less molar concentrations / quantities of reactants, it will run for a shorter time than the standard cell. The reaction will end much sooner.

e. i. $Cu^{+2} + Sn \rightarrow Cu + Sn^{+2}$ $E° = 0.48$ V

The reaction is thermodynamically favored because it has a positive $E°$, so $\Delta G° = -$. No energy or electricity is needed to start the reaction.

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

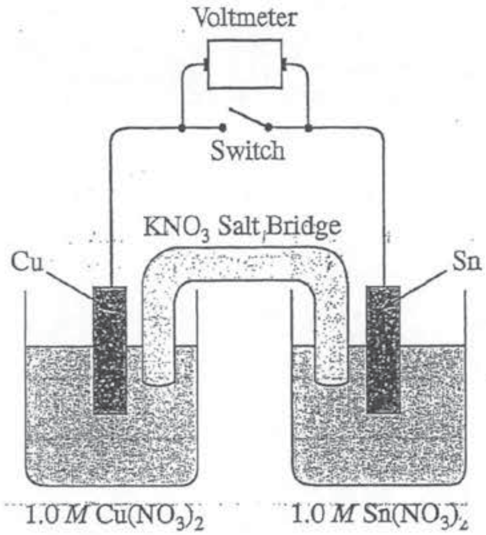
ii. $\Delta G° = -nFE°$

$\Delta G° = -(4)(96,485)(0.48)$ $\quad (mol)(\frac{C}{mol})(V)$

$\Delta G° = -1.9 \times 10^5$ C·V

GO ON TO THE NEXT PAGE

3C1



3. A student is given a standard galvanic cell, represented above, that has a Cu electrode and a Sn electrode. As current flows through the cell, the student determines that the Cu electrode increases in mass and the Sn electrode decreases in mass.

   (a) Identify the electrode at which oxidation is occurring. Explain your reasoning based on the student's observations.

   (b) As the mass of the Sn electrode decreases, where does the mass go?

   (c) In the expanded view of the center portion of the salt bridge shown in the diagram below, draw and label a particle view of what occurs in the salt bridge as the cell begins to operate. Omit solvent molecules and use arrows to show the movement of particles.

GO ON TO THE NEXT PAGE.

(d) A nonstandard cell is made by replacing the 1.0 *M* solutions of $Cu(NO_3)_2$ and $Sn(NO_3)_2$ in the standard cell with 0.50 *M* solutions of $Cu(NO_3)_2$ and $Sn(NO_3)_2$. The volumes of solutions in the nonstandard cell are identical to those in the standard cell.

(i) Is the cell potential of the nonstandard cell greater than, less than, or equal to the cell potential of the standard cell? Justify your answer.

(ii) Both the standard and nonstandard cells can be used to power an electronic device. Would the nonstandard cell power the device for the same time, a longer time, or a shorter time as compared with the standard cell? Justify your answer.

(e) In another experiment, the student places a new Sn electrode into a fresh solution of 1.0 *M* $Cu(NO_3)_2$.

Half-Reaction	$E°$ (V)
$Cu^{+} + e^{-} \rightarrow Cu(s)$	0.52
$Cu^{2+} + 2e^{-} \rightarrow Cu(s)$	0.34
$Sn^{4+} + 2e^{-} \rightarrow Sn^{2+}$	0.15
$Sn^{2+} + 2e^{-} \rightarrow Sn(s)$	−0.14

(i) Using information from the table above, write a net-ionic equation for the reaction between the Sn electrode and the $Cu(NO_3)_2$ solution that would be thermodynamically favorable. Justify that the reaction is thermodynamically favorable.

(ii) Calculate the value of $\Delta G°$ for the reaction. Include units with your answer.

a) $Cu^{+2} + 2e^{-} \rightarrow Cu$, Cu is being oxidized because based off of the students observations, Cu electrode is gaining mass which also means it's gaining electrons.

b) The mass goes to the Cu electrode because the electrons are being given to Cu and therefore the Sn electrode is losing mass.

c) In diagram

d) i) Less than because not as much energy can be created due to the concentrations of $Cu(NO_3)_2$ and $Sn(NO_3)_2$ being reduced

ii) Same amount of time because a decrease in concentration doesn't affect the voltage of a cell allowing the nonstandard cell be able to power a device as long as the standard cell.

e) i) $Cu^{+2} + 2e^{-} \rightarrow Cu(s)$ $E° = .34$

$Sn^{+2} \rightarrow Sn^{+4} + 2e^{-}$ $E° = -.15$

$Cu^{+2} + Sn^{+2} \rightarrow Sn^{+4} + Cu$ $E_{net} = .19V$ A positive voltage makes this reaction

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

thermodynamically favorable.

ii) $\Delta G^0 = -nFE^0$

$\Delta G^0 = -2(9.6485 \times 10^4)(.19V)$

$\Delta G^0 = -36664.3$ J/mol$_{rxn}$ $\times \frac{1 kJ}{1000 J} =$ $\boxed{-36.7 \text{ kJ/mol} = \Delta G^0}$

GO ON TO THE NEXT PAGE.

Question 3

Overview

This question covered a variety of concepts relating to electrochemistry. Students were given a labeled diagram and a description of a standard galvanic Sn/Cu cell, and told about the changes in the masses of the electrodes as the cell operated. In parts (a) and (b), students were asked to identify, based on observations, the electrode at which oxidation occurred, and to explain the observed change in mass at the Sn electrode. In part (c) students were asked to show (on a provided diagram) the particle-level flow of ions in the salt bridge. In part (d), students were asked how the concentrations of the ions in the cell related to the potential and total energy provided by the cell. In part (e), students were asked to give the net ionic equation, E°_{cell} , and ΔG° for the same reaction under different conditions, and to relate these values to the thermodynamic favorability of the process.

Sample: 3A
Score: 10

This response earned all 10 points: 1 point in part (a), 1 point in part (b), 2 points in part (c), 1 point in part (d)(i), 1 point in part (d)(ii), 2 points in part (e)(i), and 2 points in part (e)(ii). In part (a) there was no penalty for referring to the "size" rather than the mass of the electrode. In part (e)(i) the reference to ΔG° is correct but not required; linking thermodynamic favorability to the sign of E° was enough to earn the point.

Sample: 3B
Score: 8

All possible points were earned in parts (a), (b), and (c). In part (d)(i), while the student begins by predicting that the cell potential remains the same, no point was earned for the general (incorrect) statement that cell potential does not depend on the concentrations of the reactants. This response does not cite the significance of the solution concentrations being equal. The response to part (d)(ii) earned the point for correctly linking the shortened run time to the smaller quantity of reactant (note that linking it to reduced concentration alone would not earn the point). In this case there was no penalty for referring to "quantities of reactants" in the plural, even though the change in quantity of only one of the reactants was relevant. Both points were earned in part (e)(i) for a clear and complete response. In part (e)(ii) the incorrect value of n loses the first point, but the rest of the calculation is correct and the second point was earned (The unit C·V is equivalent to J.)

Sample: 3C
Score: 5

In part (a) the response correctly identifies the reaction that takes place in the copper half-cell, but incorrectly labels it as an oxidation process, thus no point was earned. In part (b) attributing the loss of mass to the loss of electrons (a common error) earned no point. Both points were earned in part (c). No points were earned in part (d). In part (e)(i) the net-ionic equation is incorrect and the first point was not earned; the student chooses the Sn^{2+} to Sn^{4+} oxidation (even though Sn^{2+} is not present at the start of the experiment). However, the thermodynamic favorability is correctly based on the positive value of E°, earning the second point. In part (e)(ii) both points were earned; the number of electrons (n) and the value of E° from part (e)(i) are used appropriately in the calculation of ΔG°, and the signs and units are carried through appropriately.