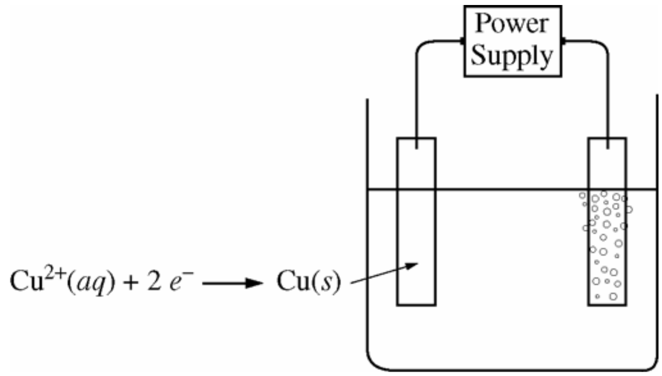
Question 3



An external direct-current power supply is connected to two platinum electrodes immersed in a beaker containing 1.0 M $CuSO_4(aq)$ at 25°C, as shown in the diagram above. As the cell operates, copper metal is deposited onto one electrode and $O_2(g)$ is produced at the other electrode. The two reduction half-reactions for the overall reaction that occurs in the cell are shown in the table below.

Half-Reaction	$E°$(V)
$O_2(g) + 4\,H^+(aq) + 4\,e^- \rightarrow 2\,H_2O(l)$	+1.23
$Cu^{2+}(aq) + 2\,e^- \rightarrow Cu(s)$	+0.34

(a) On the diagram, indicate the direction of electron flow in the wire.

The electron flow in the wire is from the right toward the left (counterclockwise).	One point is earned for the correct direction.

(b) Write a balanced net ionic equation for the electrolysis reaction that occurs in the cell.

$2\,H_2O(l) + 2\,Cu^{2+}(aq) \rightarrow 4\,H^+(aq) + 2\,Cu(s) + O_2(g)$	One point is earned for all three products. One point is earned for balancing the equation.

(c) Predict the algebraic sign of $\Delta G°$ for the reaction. Justify your prediction.

The sign of $\Delta G°$ would be positive because the reaction is NOT spontaneous.	One point is earned for indicating that $\Delta G°$ is greater than zero <u>and</u> supplying a correct explanation.

Question 3 (continued)

(d) Calculate the value of $\Delta G°$ for the reaction.

$E° = -1.23\text{ V} + 0.34\text{ V} = -0.89\text{ V} = -0.89\text{ J C}^{-1}$ $\Delta G° = -n\mathcal{F}E° = -4\,(96{,}500\text{ C mol}^{-1})(-0.89\text{ J C}^{-1})$ $= +340{,}000\text{ J mol}^{-1} = +340\text{ kJ mol}^{-1}$	One point is earned for calculating $E°$. One point is earned for calculating $\Delta G°$ (consistent with the calculated $E°$).

An electric current of 1.50 amps passes through the cell for 40.0 minutes.

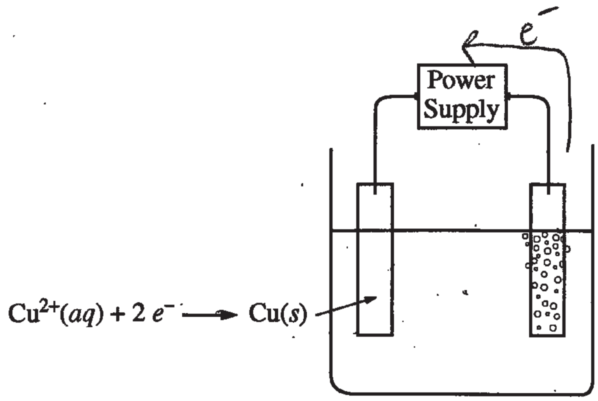
(e) Calculate the mass, in grams, of the $Cu(s)$ that is deposited on the electrode.

$q = (1.50\text{ C s}^{-1})(40.0\text{ min}) \times \frac{60\text{ s}}{1\text{ minute}} = 3{,}600\text{ C}$ $\text{mass Cu} = (3{,}600\text{ C}) \times \frac{1\text{ mol } e^-}{96{,}500\text{ C}} \times \frac{1\text{ mol Cu}}{2\text{ mol } e^-} \times \frac{63.55\text{ g Cu}}{1\text{ mol Cu}}$ $= 1.19\text{ g Cu}$	One point is earned for calculating q. One point is earned for calculating the mass of copper deposited. ***OR*** Two points are earned for calculating the mass of copper in one step.

(f) Calculate the dry volume, in liters measured at 25°C and 1.16 atm, of the $O_2(g)$ that is produced.

$n_{O_2} = (1.19\text{ g Cu}) \times \frac{1\text{ mol Cu}}{63.55\text{ g Cu}} \times \frac{1\text{ mol } O_2}{2\text{ mol Cu}} = 0.00936\text{ mol } O_2$ $V = \frac{nRT}{P} = \frac{(0.00936\text{ mol})(0.0821\text{ L atm mol}^{-1}\text{ K}^{-1})(298\text{ K})}{1.16\text{ atm}}$ $= 0.197\text{ L}$	One point is earned for calculating the number of moles of O_2. One point is earned for calculating V (consistent with previous calculations).

3A,



3. An external direct-current power supply is connected to two platinum electrodes immersed in a beaker containing 1.0 M $CuSO_4(aq)$ at 25°C, as shown in the diagram above. As the cell operates, copper metal is deposited onto one electrode and $O_2(g)$ is produced at the other electrode. The two reduction half-reactions for the overall reaction that occurs in the cell are shown in the table below.

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$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$	+1.23
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(a) On the diagram, indicate the direction of electron flow in the wire.

(b) Write a balanced net ionic equation for the electrolysis reaction that occurs in the cell.

(c) Predict the algebraic sign of $\Delta G°$ for the reaction. Justify your prediction.

(d) Calculate the value of $\Delta G°$ for the reaction.

An electric current of 1.50 amps passes through the cell for 40.0 minutes.

(e) Calculate the mass, in grams, of the $Cu(s)$ that is deposited on the electrode.

(f) Calculate the dry volume, in liters measured at 25°C and 1.16 atm, of the $O_2(g)$ that is produced.

3. a) Shown above

b) $2Cu^{2+} + \cancel{4e^-} + 2H_2O \rightarrow 2Cu + O_2 + 4H^+ + \cancel{4e^-}$

$2Cu^{2+} + 2H_2O \rightarrow 2Cu + O_2 + 4H^+$

GO ON TO THE NEXT PAGE.

c) Since $E^\circ < 0$, the reaction is nonspontaneous, and since $\Delta G^\circ = -nFE^\circ$, the sign of ΔG° is positive, which indicates a nonspontaneous reaction.

d) $E^\circ = E^\circ_{cat} - E^\circ_{ano}$

$= +.34 - 1.23$

$= -.89 \text{ V}$

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

$= -4(96500)(-.89)$

$= 340 \text{ kJ}$

e) $q = It = (1.5 A)(40 min)\left(\frac{60 s}{1 min}\right) = 3,600 C$

mass $Cu = (3600 C)\left(\frac{1 mol e^-}{96,500 C}\right)\left(\frac{2 mol Cu}{4 mol e^-}\right)\left(\frac{63.55 g Cu}{1 mol Cu}\right)$

$= 1.19 g$

f) mol $O_2 = (3600 C)\left(\frac{1 mol e^-}{96,500 C}\right)\left(\frac{1 mol O_2}{4 mol e^-}\right)$

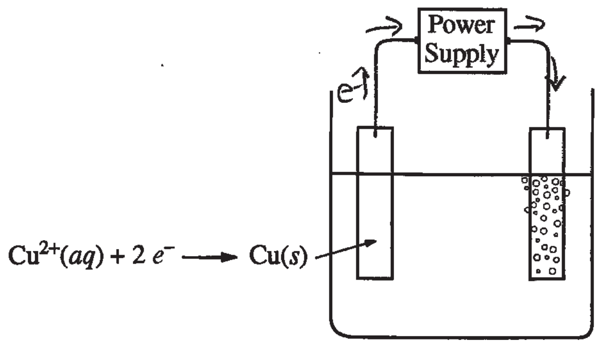
$= .00932 \text{ mol } O_2$

$PV = nRT$

$V = \frac{nRT}{P} = \frac{(.00932)(.0821)(298)}{1.16}$

$V = 0.197 L$

3B, 1



3. An external direct-current power supply is connected to two platinum electrodes immersed in a beaker containing 1.0 *M* $CuSO_4(aq)$ at 25°C, as shown in the diagram above. As the cell operates, copper metal is deposited onto one electrode and $O_2(g)$ is produced at the other electrode. The two reduction half-reactions for the overall reaction that occurs in the cell are shown in the table below.

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red - cathode
flip - ox - anode

(a) On the diagram, indicate the direction of electron flow in the wire.

(b) Write a balanced net ionic equation for the electrolysis reaction that occurs in the cell.

(c) Predict the algebraic sign of $\Delta G°$ for the reaction. Justify your prediction.

(d) Calculate the value of $\Delta G°$ for the reaction.

An electric current of 1.50 amps passes through the cell for 40.0 minutes.

(e) Calculate the mass, in grams, of the $Cu(s)$ that is deposited on the electrode.

(f) Calculate the dry volume, in liters measured at 25°C and 1.16 atm, of the $O_2(g)$ that is produced.

b) $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

$(Cu \rightarrow Cu^{2+} + 2e^-)2$

$O_2 + 4H^+ + 2Cu \rightarrow Cu^{2+} + 2H_2O$

$\boxed{O_2(g) + 4H^+(aq) + 2Cu(s) \rightarrow Cu^{2+}(aq) + 2H_2O(l)}$

c) $\Delta G°$ will be negative because it is a galvanic cell reaction, therefore the reaction is spontaneous.

3B$_2$

d) $\Delta G° = -n\mathcal{F}E°$

$E° = 1.23V + {}^{-}0.34V = 0.89V$

$\Delta G° = -(4 \text{mol } e^-)(96500 \text{ C/mol } e^-)(0.89V)$

$= -344000 J \times \frac{1 kJ}{1000 J} = \boxed{-344 \text{ kJ}}$

e) $\frac{1.50 A}{} \times \frac{1 C/s}{1 A} \times \frac{60 sec}{1 min} \times \frac{40.0 min}{} \times \frac{1 mol e^-}{96500 C} \times \frac{2 mol Cu}{4 mol e^-} \times \frac{63.55 g}{1 mol Cu}$

$= \boxed{1.19 \text{ g Cu}}$

f) $\frac{1.19 \text{ g Cu}}{} \times \frac{1 mol Cu}{63.55 g} \times \frac{1 mol O_2}{2 mol Cu} = 0.00936 \text{ mol } O_2$

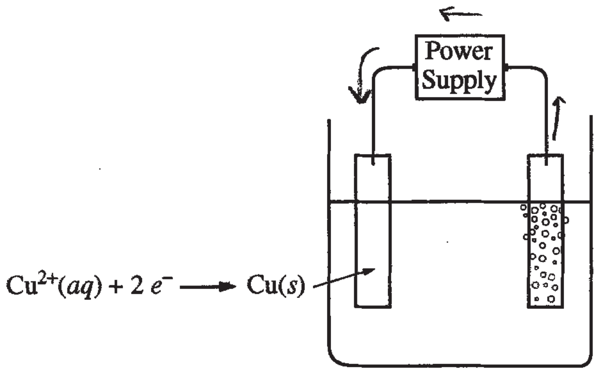
$PV = nRT$

$V = \frac{nRT}{P}$

$V = \frac{(0.00936 mol)(0.0821 \frac{L\,atm}{mol\,K})(298 K)}{1.16 atm}$

$= 0.197 L \times \frac{1000 mL}{1 L} = \boxed{197 \text{ mL}}$

3C1



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(a) On the diagram, indicate the direction of electron flow in the wire.

(b) Write a balanced net ionic equation for the electrolysis reaction that occurs in the cell.

(c) Predict the algebraic sign of $\Delta G°$ for the reaction. Justify your prediction.

(d) Calculate the value of $\Delta G°$ for the reaction.

An electric current of 1.50 amps passes through the cell for 40.0 minutes.

(e) Calculate the mass, in grams, of the $Cu(s)$ that is deposited on the electrode.

(f) Calculate the dry volume, in liters measured at 25°C and 1.16 atm, of the $O_2(g)$ that is produced.

b) $Cu^{+2}_{(aq)} + O_{2(g)} + 4H^+_{(aq)} \rightarrow Cu_{(s)} + 2H_2O_{(l)}$

c) $\Delta G°$ will be positive. $\Delta G°$ would be negative if the reaction was spontaneous, but in this case it is not. The reaction is not spontaneous because a power supply is running the reaction.

3C2

d) $\Delta G^{\circ} = -nFE^{\circ}$

$= -1\left(96500 \frac{\text{coulombs}}{\text{mole}}\right)(0.34\text{ v})$

$\Delta G^{\circ} = -3.3 \times 10^{4}$

E) (1.50 amps)(40.0 min) = 60 coulombs

$60 \text{ coulombs} \times \frac{1 \text{ mol}}{96,500 \text{ coulombs}} \times \frac{1 \text{ mol Cu}}{2 \text{ mole}^-} \times \frac{63.5 \text{ g Cu}}{1 \text{ mol Cu}} = 0.0197 \text{ g Cu}$

F) $V = \frac{nRT}{P}$

$V = \frac{(1 \text{ mol})(.0821 \text{ L-atm})(298\text{K})}{(\text{K-mol})(1.16 \text{ atm})}$

$V = 21.1 \text{ atm } O_2$

Question 3

Overview

This question analyzed an electrolysis experiment. It evaluated students' skills in a number of areas, including electrochemistry, stoichiometry, thermodynamics, and gas laws.

Sample: 3A
Score: 10

This response earned all 10 points: 1 for part (a), 2 for part (b), 1 for part (c), 2 for part (d), 2 for part (e), and 2 for part (f). Acceptable units for $\Delta G°$ in part (d) include kJ, kJ mol^{-1}, J, J mol^{-1}, CV, and CV mol^{-1}.

Sample: 3B
Score: 6

The point was not earned in part (a) because the direction of electron flow is incorrect. In part (b) the equation for the electrolysis reaction is reversed and also is not balanced, so no points were earned. Both points were earned in part (d) because the calculations are consistent with the reversed net-ionic equation obtained in part (b). The point was not earned in part (c) because the response is inconsistent with the calculated $E°$. (Generally, part (c) was scored after part (d) so that consistency with the $E°$ calculated could be checked. Credit could be earned for stating that $\Delta G°$ was negative only if this answer was justified based on a positive $E°$.) All points were earned in parts (e) and (f).

Sample: 3C
Score: 3

The point was earned in part (a). The points were not earned in part (b) because the stoichiometry of the equation is incorrect, and the equation is reversed. The point was earned in part (c): the correct sign of $\Delta G°$ is given and justified based on the observation that the reaction is not spontaneous. The points were not earned in part (d) because $E°$ is calculated incorrectly, and the value used for n is incorrect. In part (e) the calculation of q omits one of the conversion factors (60 s/1 min), so the first point was not earned; however, the calculation of the mass of Cu using this incorrect number of coulombs is done correctly, so the second point was earned. The points were not earned in part (f) because the volume of O_2 calculated is that for 1 mol O_2, not for the amount of O_2 that would be produced under the conditions given.