2018

AP® CollegeBoard

AP Chemistry

Sample Student Responses and Scoring Commentary

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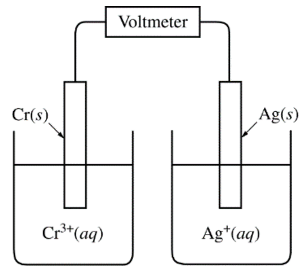
Question 6



A student sets up a galvanic cell at 298 K that has an electrode of Ag(*s*) immersed in a 1.0 *M* solution of Ag^+(*aq*) and an electrode of Cr(*s*) immersed in a 1.0 *M* solution of Cr^{3+}(*aq*), as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

The salt bridge is missing. The salt bridge allows for the migration of ions to maintain charge balance in each half-cell.	1 point is earned for the correct answer <u>and</u> a valid explanation.

Half-Reaction	$E°$(V)
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3e^- \rightarrow Cr(s)$	?

(b) The student adds the missing component to the cell and measures E°_{cell} to be +1.54 V. As the cell operates, Ag^+ ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3e^- \rightarrow Cr(s)$.

$E^\circ_{cell} = E^\circ_{red}(\text{cathode}) - E^\circ_{red}(\text{anode})$ $+1.54\text{ V} = +0.80\text{ V} - x$ $x = +0.80\text{ V} - (+1.54\text{ V}) = -0.74\text{ V}$	1 point is earned for a correct calculation of E°_{red}.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

$3\,Ag^+(aq) + Cr(s) \rightarrow 3\,Ag(s) + Cr^{3+}(aq)$	1 point is earned for the correctly balanced equation.

Question 6 (continued)

(iii) Calculate the value of ΔG° for the overall cell reaction in J/mol_{rxn}.

$\Delta G^\circ = -nFE^\circ = -\left(\frac{3 \text{ mol } e^-}{1 \text{ mol}_{rxn}}\right)\left(96{,}485 \frac{\text{C}}{\text{mol } e^-}\right)\left(1.54 \frac{\text{J}}{\text{C}}\right)$ $= -4.46 \times 10^5 \text{ J/mol}_{rxn}$	1 point is earned for the correct calculation of the value of ΔG°.

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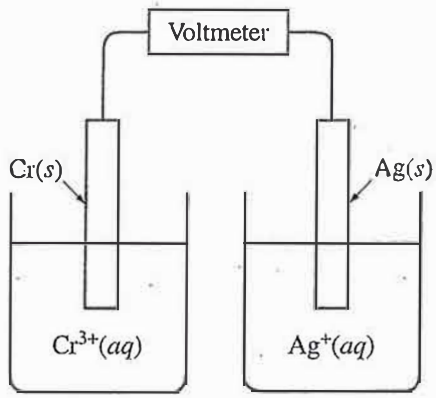

6. A student sets up a galvanic cell at 298 K that has an electrode of Ag(*s*) immersed in a 1.0 *M* solution of $Ag^{+}(aq)$ and an electrode of Cr(*s*) immersed in a 1.0 *M* solution of $Cr^{3+}(aq)$, as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

Half-Reaction	$E°$ (V)
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3e^{-} \rightarrow Cr(s)$	?

(b) The student adds the missing component to the cell and measures $E°_{cell}$ to be +1.54 V. As the cell operates, Ag^{+} ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3e^{-} \rightarrow Cr(s)$.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol_{rxn}.

a. A salt bridge is missing. The salt bridge allows cations to flow to the cathode and anions flow to the anode in order to maintain electric neutrality. Without the salt bridge, this neutrality can not be maintained, so there is no driving force (emf) for the reaction to occur. Thus, the voltage would be 0 without a salt bridge.

b. i. $E°_{cell} = E°_{red}(\text{cathode}) - E°_{red}(\text{anode})$

$1.54V = 0.80V - E°_{red}(Cr^{3+})$

$E°_{red}(Cr^{3+}) = -0.74 V$

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b. ii. $3Ag^+ + \cancel{3e^-} \rightarrow 3Ag(s)$

$Cr(s) \rightarrow Cr^{3+} + \cancel{3e^-}$

$Cr(s) + 3Ag^+(aq) \rightarrow 3Ag(s) + Cr^{3+}(aq)$

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

$\Delta G^o = -(3)(96{,}485\ C/mol)(1.54\ J/C)$

$\Delta G^o = -4.46 \cdot 10^5\ J/mol$

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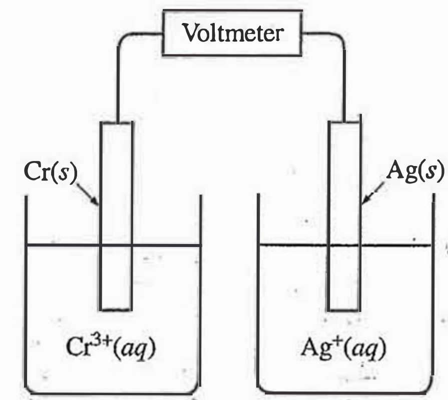

6. A student sets up a galvanic cell at 298 K that has an electrode of Ag(*s*) immersed in a 1.0 *M* solution of $Ag^{+}(aq)$ and an electrode of Cr(*s*) immersed in a 1.0 *M* solution of $Cr^{3+}(aq)$, as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

Half-Reaction	$E°$ (V)
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$	? X

oxidation.

(b) The student adds the missing component to the cell and measures $E°_{cell}$ to be +1.54 V. As the cell operates, Ag^{+} ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol$_{rxn}$.

(a) A salt bridge is missing. The electrons can not be transferred between solutions without a salt bridge, which causes the reading of 0 V.

(b) $E°_{cell} = E°_{Ag} - E°_{Cr}$

(i) $1.54V = 0.80V - E°_{Cr}$

$E° = -0.74V$

The reduction potential for $Cr^{3+} + 3e^{-} \rightarrow Cr$ is $-0.74V$

(ii) $3Ag^{+}(aq) + Cr(s) \rightarrow Cr^{3+}(aq) + 3Ag(s)$

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(iii) $\Delta G = -n \cdot F \cdot E°$

$= -3 \text{ mol } e^- \cdot \frac{96485 \text{ C}}{1 \text{ mol } e^-} \cdot 1.54 \text{ J/C}$

$= -446000 \text{ J/mol rxn.}$

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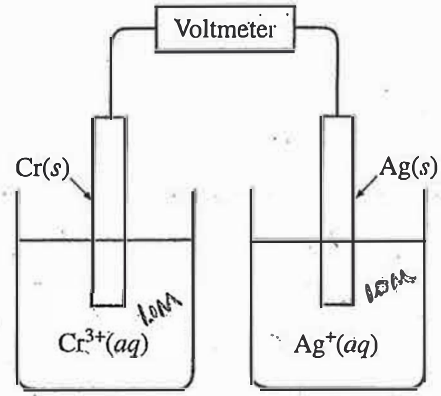

6. A student sets up a galvanic cell at 298 K that has an electrode of Ag(*s*) immersed in a 1.0 *M* solution of $Ag^{+}(aq)$ and an electrode of Cr(*s*) immersed in a 1.0 *M* solution of $Cr^{3+}(aq)$, as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

Half-Reaction	$E°$ (V)
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$	?

anode - cathode = V

(b) The student adds the missing component to the cell and measures $E°_{cell}$ to be +1.54 V. As the cell operates, Ag^{+} ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol$_{rxn}$.

a. The missing component of the cell is the salt bridge, and it is necessary in order to obtain a nonzero voltage because it allows the exchange and flow of electrons.

b. i. $0.80\text{ V} - (x) = +1.54\text{ V}$ $x = -.74$

$E° = -0.74\text{ V}$

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ii. $Cr^{3+}_{(aq)} + Ag_{(s)} \rightleftharpoons Ag^{+}_{(aq)} + Cr_{(s)}$

iii. $\Delta G^\circ = -nFE^\circ = -2\,\text{mol } e^-(96{,}485\ C/\text{mol } e^-)(1.54\ V) = -297173.8$

$\Delta G^\circ = -297000\ J/mol_{rxn} = -2.97 \times 10^5\ J/mol_{rxn}$

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Question 6

Overview

This question required students to identify that the salt bridge was missing and to articulate its role in a standard galvanic cell. They then needed to calculate the standard reduction potential of the anode, given the cathode potential and the overall cell potential. Students were asked to write the balanced net-ionic equation for the overall reaction and then to calculate the standard Gibbs free energy change for the overall cell reaction.

In part (a) a schematic drawing of an electrochemical cell was provided, with the salt bridge omitted. The question asked students to identify the missing component of the cell and to explain its importance for obtaining a nonzero voltage (LO 3.12; SP 2.2, 2.3, 6.4). A correct response to this question required identification of the missing salt bridge and a discussion of its role in allowing for the migration of ions between half-cell compartments. This component is necessary to maintain charge balance during the operation of the cell.
In part (b)(i) students were asked to calculate the value of $E°$ for the standard reduction of Cr^{3+} (LO 3.13; SP 5.1). The question indicated that Ag^+ ions are reduced, so students needed to deduce that chromium is oxidized in the overall cell reaction. In part (b)(ii) the question required the chromium and silver half-reactions from the data table to be combined into a balanced chemical equation appropriate for a galvanic cell (LO 3.2; SP 1.5, 7.1). Finally, in part (b)(iii), the students were asked to calculate the standard Gibbs free energy change for the overall cell reaction (LO 5.14; SP 2.2).

Sample: 6A
Score: 4

In part (a) the student states that the salt bridge "allows cations to flow to the cathode and anions flow to the anode" and discusses how this maintains "electric neutrality." These statements cover the basic elements of "migration of ions" and maintaining "charge balance" expressed in the rubric; thus, 1 point was earned. In part (b)(i) the student correctly calculates the value of $E°_{red}$ for the chromium half-cell reaction and earned 1 point. In part (b)(ii) the student correctly balances the equation, and 1 point was earned. In part (b)(iii) the student correctly calculates the value of $\Delta G°$ and earned 1 point.

Sample: 6B
Score: 2

In part (a) the student does not address the migration of ions in the salt bridge, only the transfer of electrons between solutions. Because the question pertains to the salt bridge, and electrons do not migrate through the salt bridge, no point was earned. In part (b)(i) the student correctly calculates the value of $E°_{red}$ for the chromium half-cell reaction and earned 1 point. In part (b)(ii) the student correctly balances the equation and earned 1 point. In part (b)(iii) the student's calculation of $\Delta G°$ is off by a factor of 10; thus, no point was earned.

Sample: 6C
Score: 1

In part (a) the student erroneously states that the salt bridge "allows the exchange and flow of electrons," rather than ions, and does not address the migration of ions in the salt bridge, so no point was earned. In part (b)(i) the student correctly calculates the value of $E°_{red}$ for the chromium half-cell reaction, and 1 point was earned. In part (b)(ii) the student misidentifies the oxidation and reduction half-reactions and also does not correctly balance the species in the equation, so the point was not earned. In part (b)(iii) the student incorrectly identifies the number of moles of electrons transferred in the reaction as $n = 2$, so no point was earned.