2021

AP CollegeBoard

AP® Chemistry

Sample Student Responses and Scoring Commentary

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Free Response Question 5

- ☑ Scoring Guideline
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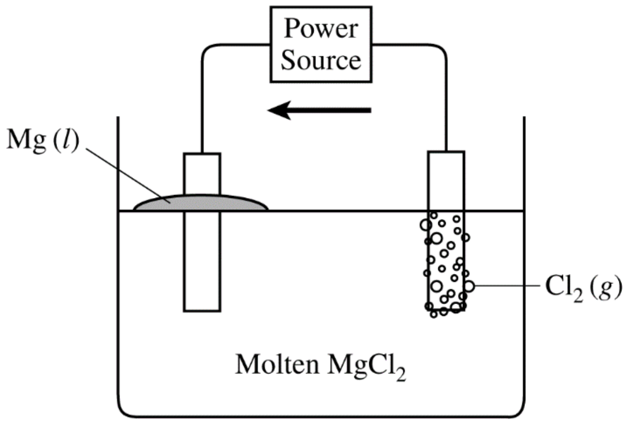
Question 5: Short Answer — 4 points

(a) For the correct answer: **1 point**

Electron flow should be indicated only in a counter-clockwise direction in the external circuit, from the Cl_2 anode to the Mg cathode.



(b) For the correct answer and calculated value: **1 point**

No, because 2.0 V is less than 3.73 V, which is the minimum voltage needed for electrolysis to occur.

$$E^\circ_{cell} = -2.37\text{ V} + (-1.36\text{ V}) = -3.73\text{ V}$$

(c) For the correct calculated value of moles of electrons (may be implicit): **1 point**

$$2.00\text{ g Mg} \times \frac{1\text{ mol Mg}}{24.30\text{ g Mg}} \times \frac{2\text{ mol }e^-}{1\text{ mol Mg}} = 0.165\text{ mol }e^-$$

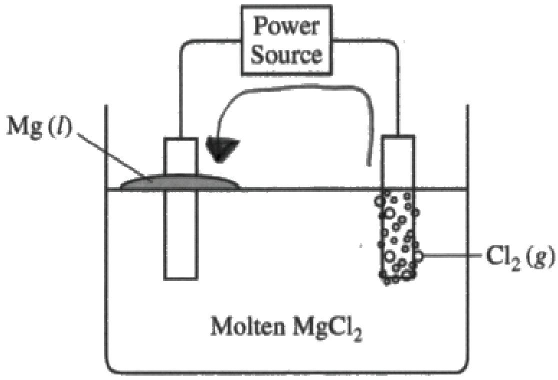
For the correct calculated number of seconds: **1 point**

$$0.165\text{ mol }e^- \times \frac{96{,}485\text{ C}}{1\text{ mol }e^-} \times \frac{1\text{ s}}{5.00\text{ C}} = 3180\text{ s}$$

Total for part (c) **2 points**

Total for question 5 **4 points**

Begin your response to QUESTION 5 on this page.



Half-Reaction	$E°$ (V)
$Mg^{2+} + 2e^- \rightarrow Mg$	−2.37
$Cl_2 + 2e^- \rightarrow 2Cl^-$	+ 1.36

5. Molten $MgCl_2$ can be decomposed into its elements if a sufficient voltage is applied using inert electrodes. The products of the reaction are liquid Mg (at the cathode) and Cl_2 gas (at the anode). A simplified representation of the cell is shown above. The reduction half-reactions related to the overall reaction in the cell are given in the table.

(a) Draw an arrow on the diagram to show the direction of electron flow through the external circuit as the cell operates.

(b) Would an applied voltage of 2.0 V be sufficient for the reaction to occur? Support your claim with a calculation as part of your answer.

$-2.37 - 1.36 = -3.73$ V

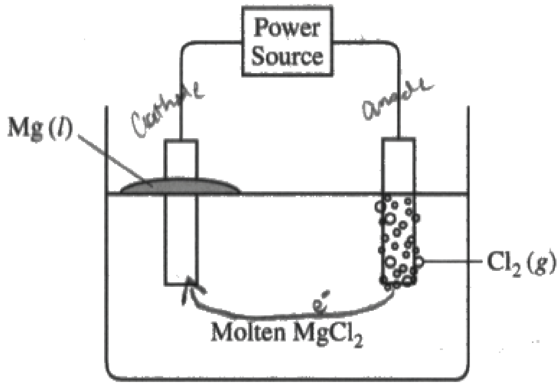
No, 2.0 V would not be sufficient for the reaction to occur, which would need at 3.73 volts.

(c) If the current in the cell is kept at a constant 5.00 amps, how many seconds does it take to produce 2.00 g of Mg(l) at the cathode?

$$2.00 \text{ g Mg} \cdot \frac{1 \text{ mol Mg}}{24.30 \text{ g Mg}} \cdot \frac{2 \text{ mol } e^-}{1 \text{ mol Mg}} \cdot \frac{96485 \text{ coulombs}}{1 \text{ mol } e^-} \cdot \frac{1}{5.00 \text{ amp}}$$

= 3180 seconds

Begin your response to QUESTION 5 on this page.



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(a) Draw an arrow on the diagram to show the direction of electron flow through the external circuit as the cell operates.

(b) Would an applied voltage of 2.0 V be sufficient for the reaction to occur? Support your claim with a calculation as part of your answer.

$E°_{cell} = E°_{cathode} - E°_{anode}$

$-3.73V = -2.37 - 1.36$

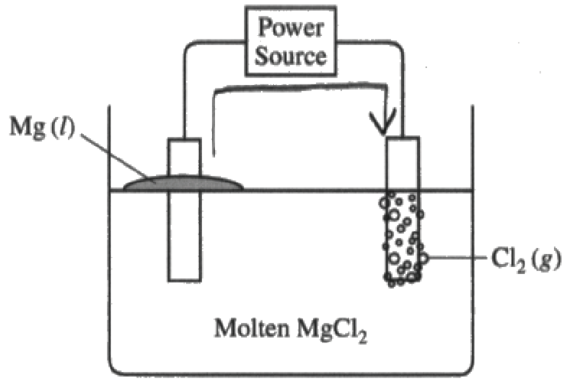
$2.0 \leq -3.73$ – The applied voltage of 2.0 V is sufficient for the reaction to ocure because it is larger than the values of E° for the 2 half reactions.

(c) If the current in the cell is kept at a constant 5.00 amps, how many seconds does it take to produce 2.00 g of Mg(l) at the cathode?

$$2.00g\left(\frac{1\,mol\,Mg}{24.30\,g}\right)\left(\frac{2\,mol\,e^-}{1\,mol\,Mg}\right)\left(\frac{96485\,C}{mol\,e^-}\right)\left(\frac{1\,s}{5\,C}\right) = \boxed{3180\,s}$$

GO ON TO THE NEXT PAGE.

Begin your response to **QUESTION 5** on this page.



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(a) Draw an arrow on the diagram to show the direction of electron flow through the external circuit as the cell operates.

(b) Would an applied voltage of 2.0 V be sufficient for the reaction to occur? Support your claim with a calculation as part of your answer.

An applied voltage of 2.0 V would not be sufficient. The total E° for the reaction is 1.36 V − (−2.37 V) = 3.73 V, which is greater than 2.0 V.

(c) If the current in the cell is kept at a constant 5.00 amps, how many seconds does it take to produce 2.00 g of Mg(l) at the cathode?

$I = \frac{\text{charge}}{\text{time}}$ $\quad 2.00\text{ g Mg} \times \frac{1\text{ mol Mg}}{24.30\text{ g}} \approx 0.0823\text{ mol Mg}$

$0.0823\text{ mol Mg} \times \frac{1\text{ mol}_{rxn}}{1\text{ mol Mg}} = 0.0823\text{ mol}_{rxn}$

$0.0823\text{ mol}_{rxn} \times \frac{2e^-}{1\text{ mol}_{rxn}} \times \frac{96485\text{ C}}{6.022\times10^{23}e^-} \times \frac{1\text{ s}}{5.00\text{ C}} \approx \boxed{5.27\times10^{-21}\text{ s}}$

Question 5

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 5 provides a diagram of an electrolytic cell in which $MgCl_2$ is decomposed into its constituent elements. In part (a), the student must draw an arrow to indicate the direction of electron flow in the cell (ENE-6.A, 3.B). Part (b) asks whether a driving voltage of 2.0 V would be sufficient for the reaction to occur and to provide supporting quantitative evidence (ENE-6.B, 6.D). In part (c), the student calculates the amount of time required for the cell to produce a given mass of elemental magnesium. The question is worth two points: one for identifying the number of moles of electrons involved in the process (SPQ-1.A, 5.F) and one for correctly calculating the number of seconds (ENE-6.D, 5.F).

Sample: 5A
Score: 4

In part (a) the response shows an arrow along the external circuit in a counterclockwise direction, so 1 point was earned. In part (b) the cell potential of the electrolytic cell is calculated and the correct setup is shown. The response also correctly claims "No, 2.0 V would not be sufficient." One point was earned. In part (c) the time required (3180 seconds) is calculated correctly, supported with a correct setup in which the number of moles of electrons is implicit, so 2 points were earned.

Sample: 5B
Score: 2

In part (a) the response shows an arrow from right to left within the molten $MgCl_2$, so 0 points were earned. In part (b) the response incorrectly claims that the voltage "is sufficient for the reaction." Despite the correct calculation of the cell potential, 0 points were earned. In part (c) the time required is calculated correctly, supported with a correct setup in which the number of moles of electrons is implicit, so 2 points were earned.

Sample: 5C
Score: 1

In part (a) the response shows an arrow along the external circuit in a clockwise rather than a counterclockwise direction, so 0 points were earned. In part (b) the cell potential of a voltaic cell (+3.73V) rather than the cell potential of an electrolytic cell is calculated so 0 points were earned. In part (c) the response implicitly shows the calculation of moles of electrons, "0.0823 $mol_{rxn} \times 2\ e^-/1\ mol_{rxn.}$" However, the time is calculated incorrectly, using Avogadro's number. Only 1 point was earned.