B8 · Electrolytic cells

Student notes - follow the slides, fill the blanks, work the questions

Goals: Explain how an electrolytic cell uses electrical energy to drive a reaction that is not spontaneous. Identify the anode, cathode, polarity and ion movement, and write half-reactions for molten salts and plating. Compare voltaic and electrolytic cells.

Name: _____ Date: _____

Slide 1 of 8 · Driving a reaction that will not go by itself

E°reaction = E°cathode − E°anode. A _____ value means the reaction goes by itself. A _____ value means it does not.

A power source can force a reaction that is not spontaneous. A cell that uses electrical energy to do this is an _____ cell.

A voltaic cell does the opposite. It turns a spontaneous reaction into _____ energy.

If E°reaction = −1.10 V, the source must supply more than _____ V. Give a minimum voltage as a _____ number.

Example. Given $Cu + Zn^{2+} \rightarrow Cu^{2+} + Zn$, with $E°(Zn^{2+}/Zn) = -0.76$ V and $E°(Cu^{2+}/Cu) = +0.34$ V. Find E°reaction. Does the reaction go by itself? What minimum voltage must a power source exceed to force it?

Work:

Answer: _____

Try it. Given $Cu + Mg^{2+} \rightarrow Cu^{2+} + Mg$, with $E°(Mg^{2+}/Mg) = -2.37$ V and $E°(Cu^{2+}/Cu) = +0.34$ V. Find E°reaction. Does the reaction go by itself? What minimum voltage must a power source exceed to force it?

Work:

Answer: _____

Slide 2 of 8 · Anode, cathode and the power source

Oxidation happens at the _____ and reduction happens at the _____, in every cell, voltaic or electrolytic.

In an electrolytic cell, the power source sets the signs. The negative terminal pushes electrons to the _____, so the cathode is _____.

The electrode joined to the positive terminal hands electrons back to the source. That is oxidation, so it is the _____ and it is _____.

Cations move toward the _____ and anions move toward the _____. Electrons travel only in the _____, and ions carry the charge in the liquid.

Example. A power source is joined by wires to two electrodes in a liquid that has ions. Which electrode is the cathode and which is the anode? Which way do cations and anions move, and where do the electrons travel?

Work:

Answer: _____

Try it. Two inert electrodes dip in molten KBr. Electrode X is joined to the negative terminal of a power source. Name electrode X, name the process at X, and say whether K^+ moves toward or away from X.

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 3 of 8 · A molten salt cell

Molten NaCl has only _____ ions and no water, so each electrode has only one ion that can react.

Na^+ moves to the negative cathode: $Na^+ + e^- \rightarrow$ _____. Cl^- moves to the positive anode: $2Cl^- \rightarrow$ _____ + $2e^-$.

The anode loses _____ electrons and the cathode half gains 1, so double the cathode half. Cell reaction: $2Na^+ + 2Cl^- \rightarrow$ _____.

$E°_{reaction} = -2.71 - (+1.36) =$ _____ V. E° is never multiplied by _____. The source must supply more than 4.07 V.

Example. Molten sodium chloride, NaCl(l), has two inert electrodes joined to a power source. Given $E°(Na^+/Na) = -2.71$ V and $E°(Cl_2/Cl^-) = +1.36$ V. Write both half-reactions and the cell reaction, name the product at each electrode, and find $E°_{reaction}$.

Work:

Answer: _____

Try it. Molten potassium bromide, KBr(l), has two inert electrodes joined to a power source. Given $E°(K^+/K) = -2.93$ V and $E°(Br_2/Br^-) = +1.07$ V. Write the cell reaction, name the product at each electrode, and find $E°_{reaction}$.

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 4 of 8 · Method: how to describe an electrolytic cell

Step 1. List the _____ present. A molten salt has no water.

Step 2. Send _____ to the cathode. Reduction happens at the cathode.

Step 3. Send _____ to the anode. Oxidation happens at the anode.

Step 4. Write the halves and the overall equation. Match the _____ first.

Step 5. Find E°reaction = E°cathode − E°anode. The source must be _____ than its size, and the cathode joins the _____ terminal.

Example. Use the method on molten NaCl with inert electrodes and a power source. What forms at each electrode?

Work:

Answer: _____

Try it. Use the method on molten $MgCl_2$ with inert electrodes. $E°(Mg^{2+}/Mg) = -2.37$ V and $E°(Cl_2/Cl^-) = +1.36$ V. What forms, and what is the minimum voltage?

Work:

Answer: _____

Slide 5 of 8 · Voltaic and electrolytic cells side by side

The same two half-cells can run either way. In the voltaic Zn / Cu cell, the reaction is spontaneous and E°reaction = _____ V.

In the electrolytic cell, a power source forces the reverse reaction, $Cu + Zn^{2+} \rightarrow Cu^{2+} + Zn$. Then E°reaction = _____ V.

Energy changes from chemical to _____ in a voltaic cell, and from electrical to _____ in an electrolytic cell.

In both cells, oxidation happens at the _____. The anode is negative in a _____ cell and positive in an electrolytic cell. In a drawing, a voltmeter means voltaic and a power source means electrolytic.

Example. The Zn^{2+}/Zn (−0.76 V) and Cu^{2+}/Cu (+0.34 V) half-cells run first as a voltaic cell and then as an electrolytic cell. For each, write the overall reaction and E°reaction, and give the sign of the anode.

Work:

Answer: _____

Try it. A cell runs a reaction with E°reaction = −0.46 V. Is it a voltaic or an electrolytic cell? Give the energy change, say whether the reaction is spontaneous, and give the sign of the anode.

Work:

Answer: _____

Slide 6 of 8 · Your turn: molten zinc bromide

Write the ion movement first. Molten $ZnBr_2$ has Zn^{2+} and Br^- ions. Positive ions go to the negative electrode, the _____. Br^- goes to the _____.

Cathode: Zn^{2+} + _____e^- → Zn. Anode: _____ → Br_2 + $2e^-$.

Both halves move 2 electrons, so they cancel when added. Cell reaction: Zn^{2+} + $2Br^-$ → _____.

E°reaction = −0.76 − 1.07 = _____ V. Swapping the electrodes would wrongly give _____ V, as if the cell ran by itself.

Example. Molten zinc bromide, $ZnBr_2(l)$, has two inert electrodes joined to a power source. Given $E°(Zn^{2+}/Zn)$ = −0.76 V and $E°(Br_2/Br^-)$ = +1.07 V. Decide the product at each electrode, write the cell reaction and find the minimum voltage.

Work:

Answer: _____

Try it. Molten copper(II) bromide, $CuBr_2(l)$, has two inert electrodes joined to a power source. Given $E°(Cu^{2+}/Cu)$ = +0.34 V and $E°(Br_2/Br^-)$ = +1.07 V. Decide the product at each electrode, write the cell reaction and find the minimum voltage.

Work:

Answer: _____

Slide 7 of 8 · Electroplating and refining

To plate an object, make it the _____. It is joined to the _____ terminal, metal ions gain electrons there, and the object gains mass.

In silver plating, the cathode half-reaction is $Ag^+ + e^- \rightarrow$ _____. A silver bar as the anode dissolves: Ag → _____ + e^-, so the Ag^+ concentration stays nearly constant.

In copper refining, impure copper is the _____ and a sheet of pure copper is the _____. Cu is oxidized at one and Cu^{2+} is reduced at the other.

Impurities with a more _____ E° than Cu^{2+}/Cu, such as silver and gold, stay solid. Impurities with a more negative E°, such as zinc, _____.

Example. A steel spoon and a bar of silver are placed in silver nitrate solution, $AgNO_3(aq)$, and joined to a power source. How can a thin layer of silver be placed on the spoon? Name the cathode and anode, write both half-reactions and state each mass change.

Work:

Answer: _____

Try it. A metal key is to be plated with nickel. The cell has a nickel bar and nickel(II) sulfate solution, $NiSO_4(aq)$, joined to a power source. Name the cathode, write both half-reactions and state each mass change.

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 8 of 8 · The same method with two silver electrodes

The same rule works for any metal. At the cathode, $Ag^+ + e^- \rightarrow$ _____, so the cathode gains mass. At the anode, Ag → _____ + e^-, so the anode loses mass.

Silver moves from one electrode to the other, so the Ag^+ concentration stays about the _____.

Both electrodes use the same half-cell, so E°reaction = +0.80 − (+0.80) = _____ V.

Real cells need a _____ voltage above 0.00 V to beat resistance. That is why plating and refining use little energy.

Example. Two silver electrodes dip in $AgNO_3(aq)$. Electrode 1 is joined to the negative terminal of a power source and electrode 2 to the positive terminal. Given E°(Ag^+/Ag) = +0.80 V. Name each electrode, give its half-reaction and mass change, and find E°reaction.

Work:

Answer: _____

Try it. Two copper electrodes dip in $CuSO_4(aq)$ and are joined to a power source. Given E°(Cu^{2+}/Cu) = +0.34 V. Write the half-reaction at the cathode and at the anode, and find E°reaction.

Work:

Answer: _____

B8 · Practice

Electrolytic cells | Questions 1-2 of 7

1. Given the Data Booklet table values Mg^{2+}/Mg at -2.37 V and Zn^{2+}/Zn at -0.76 V. A student wants to drive $Zn^{2+} + Mg \rightarrow Zn + Mg^{2+}$ backwards in an electrolytic cell, so $Mg^{2+} + Zn \rightarrow Mg + Zn^{2+}$. Find $E°_{reaction}$ for the reaction in the cell and the smallest voltage that must be exceeded.

Work:

Final answer (with unit): _____

2. In an electrolytic cell with inert electrodes, which electrode is joined to the positive terminal of the power source? Name the process that happens there and the direction in which anions move.

Work:

Final answer (with unit): _____

B8 · Practice

Electrolytic cells | Questions 3-4 of 7

3. Write the half-reactions and the cell reaction for molten NaCl and name the product at each electrode.

Work:

Final answer (with unit): _____

4. Given molten $ZnBr_2(l)$ with inert electrodes (Data Booklet table values: $E°(Zn^{2+}/Zn) = -0.76$ V; $E°(Br_2/Br^-) = +1.07$ V). Write the half-reaction at each electrode and calculate E°reaction.

Work:

Final answer (with unit): _____

B8 · Practice

Electrolytic cells | Questions 5-6 of 7

5. A copper bar and a metal key are placed in copper(II) sulfate solution to plate the key with copper. Say which one is the cathode, write its half-reaction and predict the mass change of each.

Work:

Final answer (with unit): _____

6. Compare a voltaic cell and an electrolytic cell for the Zn / Cu pair. Give the sign of E°reaction, the energy change and the sign of the anode in each.

Work:

Final answer (with unit): _____

B8 · Practice

Electrolytic cells | Questions 7-7 of 7

7. Challenge: Given molten $CaCl_2(l)$ with inert electrodes (Data Booklet table values: $E°(Ca^{2+}/Ca) = -2.87$ V; $E°(Cl_2/Cl^-) = +1.36$ V). Write the half-reaction at each electrode, name each product, and find $E°_{reaction}$ in volts. Then state the least voltage the power source must supply.

Work:

Final answer (with unit): _____