Experiment 32: Electrochemistry and the Voltaic Cell

Purpose The purpose of this experiment is for students to use oxidation reduction reactions to become more familiar with electrochemistry and voltaic cells.

Background
This experiment consists of four parts.
1) Part 1: Three different voltaic cells will be constructed using a metal electrode in its respective metal ion solution as one half of the voltaic cell. The other half of the voltaic cell will be a graphite electrode in a hydrochloric acid solution.
2) Part 2: Three different voltaic cells will be constructed using a metal electrode in its respective metal ion solution as one half of the voltaic cell. The other half of the voltaic cell will be another metal in its respective metal ion solution.
3) Part 3: One of the voltaic cells from part 1 will be used to study the effect of dilution with respect to voltage. The results will be explained with the Nernst equation.
4) Part 4: One of the voltaic cells from part 2 will be used to turn on an LED diode.

Oxidation reduction reactions are referred to as redox reactions. These reactions involve the transfer of electrons. The overall reaction can be divided into its two half reactions; one half reaction involves the oxidation and the other half reaction involves the reduction. Both half reactions exist at the same time; there cannot be one without the other.

Voltaic cells are constructed with separated half reactions. By physically separating the two half reactions, while still connecting them, the electrons are forced to travel through an external wire. The voltage of the cell is observed with a voltmeter, put into the electron path. There are many reasons why the voltage of the cell in lab will yield a voltage lower than expected. Two reasons are:
1) the salt bridge might be giving resistance, so try more salt bridges in the cell
2) the electrodes might be corroded, so clean the electrodes

Placing a device, such as a lightbulb, in the external wire path forces the electrons to do electrical work for us. If the voltaic cell does not produce enough voltage for the lightbulb to turn on, then the voltage needs to be higher. However, a particular redox reaction produces only so much voltage. Therefore, sometimes two voltaic cells connected in series must be used to turn on the lightbulb. You have done this with any flashlight that needed more than one battery. Voltages will add together when constructed in series.

The voltage of a voltaic cell in standard state conditions (1 M, 25 °C) can be calculated with the following equation:

$$E°_{cell} = E°_{red}\text{ (cathode)} – E°_{red}\text{ (anode)}$$

When the cell is not in standard state conditions, the voltage of the cell can be calculated with the Nernst equation:

$$E_{cell} = E^{0}_{cell} - \left(\frac{RT}{nF}\right)(\ln Q)$$

R = 8.314 J/(K ▪ mol)
T = temp., Kelvin
n = number of moles e-
F = 96,500 J/(V ▪ mol)

$$Q = \frac{[M^{+}_{prod}]^{coeff.}}{[M^{+}_{react}]^{coeff.}}$$

$$M_{(s)} + M^{+}_{react} \dashrightarrow M^{+}_{prod} + M_{(s)}$$

Version 1 of the Nernst equation

$$E_{cell} = E^{0}_{cell} - \left(\frac{RT}{nF}\right)\left(\ln \frac{[M^{+}_{prod}]^{coeff.}}{[M^{+}_{react}]^{coeff.}}\right)$$

Chemicals

Electrodes: Magnesium, Copper, Graphite, Zinc

Electrolyte Solutions: (all 0.1 M) $Mg(NO_3)_2$ $CuSO_4$ $Zn(NO_3)_2$ HCl

Saturated solution of NaCl

Equipment

Beakers (150 mL) (approx. 6)

Electrical wires (2) with alligator clips

Graduated cylinder

Voltmeter (1)

LED diode lightbulb (1)

Tubing and cotton balls as the salt bridge

Experimental Procedure

Part 1: Construction of Voltaic Cells

Save the electrolyte solutions and electrodes for use in the other parts of this experiment.

1) Obtain four beakers (150 mL), two wires, one voltmeter, three pieces of tubing, cotton balls, one Mg electrode, one Cu electrode, one graphite electrode, and one Zn electrode. Obtain approximately 100 mL each of the electrolyte solutions: $Mg(NO_3)_2$, $CuSO_4$, $Zn(NO_3)_2$, HCl.

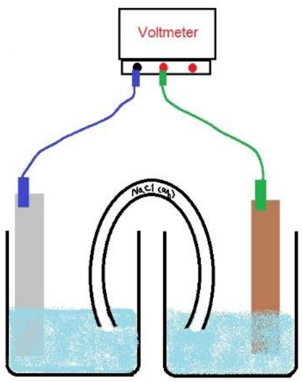
2) Build the following voltaic cells, one at a time, by following the setup shown below:

   Mg electrode in the $Mg(NO_3)_{2(aq)}$ and the graphite electrode in the $HCl_{(aq)}$

   Cu electrode in the $CuSO_{4(aq)}$ and the graphite electrode in the $HCl_{(aq)}$

   Zn electrode in the $Zn(NO_3)_{2(aq)}$ and the graphite electrode in the $HCl_{(aq)}$

   For each of these cells, measure the voltage. Calculate the expected voltage of the cells using standard state reduction voltages. One of these combinations will be a "no reaction". If your measured voltages are lower than your calculated voltages, try adding an additional salt bridge. If a third salt bridge fits, try adding that as well. You can also try to clean your electrodes to increase the voltage. Record your observations and measured voltages as you do this.



Part 2: Construction of more Voltaic Cells

1) Use the electrolyte solutions and equipment from Part 1 for Part 2.
2) Build the following voltaic cells, one at a time, by following the setup shown in your prelab discussion:

   Mg electrode in the $Mg(NO_3)_{2(aq)}$ and the Cu electrode in the $CuSO_{4(aq)}$

   Zn electrode in the $Zn(NO_3)_{2(aq)}$ and the Cu electrode in the $CuSO_{4(aq)}$

   Zn electrode in the $Zn(NO_3)_{2(aq)}$ and the Mg electrode in the $Mg(NO_3)_{2(aq)}$

   For each of these cells, measure the voltage. Calculate the expected voltage of the cells using standard state reduction voltages. If your measured voltages are lower than your calculated voltages, try adding an additional salt bridge. If a third salt bridge fits, try adding that as well. You can also try to clean your electrodes to increase the voltage. Record your observations and measured voltages as you do this.

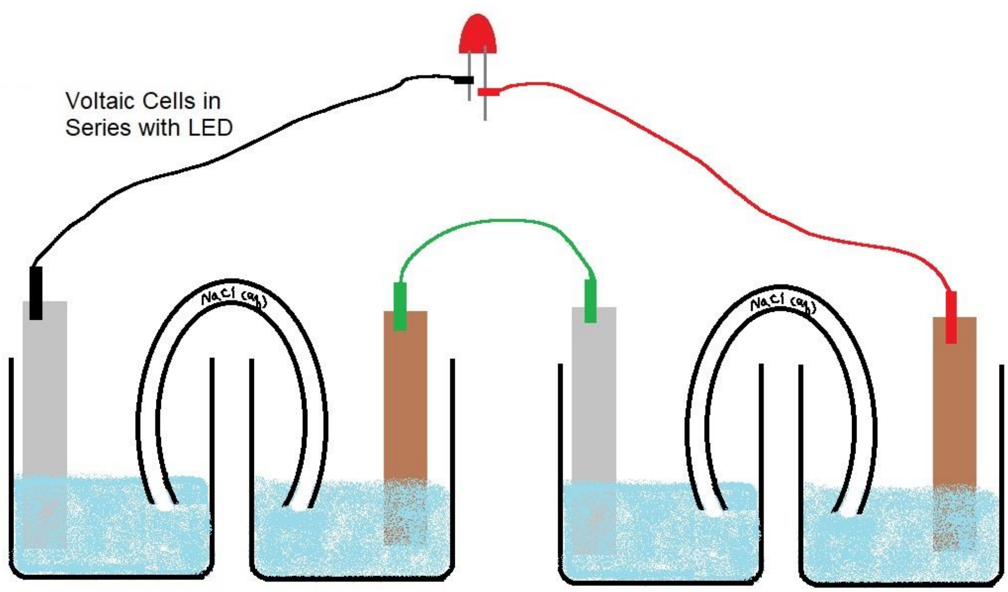
Part 3: Dilutions, Voltages and the Nernst Equation

1) Do a 1:100 dilution of the hydrochloric acid solution. Record the details of how you did the dilution in your notebook.
2) Construct the Mg / HCl cell, using the diluted HCl solution and the same number of salt bridges as in Part 1. Record the voltage. Did the voltage change from Part 1? Use the Nernst equation to calculate the expected Ecell, using your measured voltage from Part 1 as E°cell.

Part 4: A Voltaic Cell and a Light Bulb

(Use one of your higher-voltage voltaic cells from Part 2.)

1) Reconstruct your choice of a voltaic cell used previously. The goal is to create enough voltage to turn on the LED diode lightbulb. The specifications for this light bulb state a minimum of 2.2 V is needed to turn the lightbulb on.
2) Instead of using a voltmeter in the path of the electrons, you will put the LED diode there. The shorter wire on the flat side of the plastic head is where the anode wire should be connected. The longer wire is where the cathode should be connected.
3) If your voltaic cell does not turn the LED diode on, then you will have to connect two or three voltaic cells in series (in series adds the voltages together). To connect in series, you will need additional wires with alligator clips and an additional voltaic cell setup. Use the same electrodes and electrolyte solutions as the voltaic cell from Part 4, step 1. Connect the cathode from one voltaic cell to the anode of the other voltaic cell. Connect each side of the LED to the unused electrodes in each voltaic cell; the anode from one cell to the short LED wire and the cathode from the other cell to the longer LED wire.
   If the LED does not turn on, you will need a third voltaic cell added in series. Do not connect more than 3 cells in series.



Notebook:

As part of your Experimental Procedure section, draw each voltaic cell you constructed.
As part of your Data section, make a table with all of the voltages you measured.
As part of your Calculation/Results section, write the balanced overall reaction and two half-reactions for each cell you constructed. Show the calculations for all expected voltages. Use the Nernst equation to calculate the change in voltage due to the dilution.
As part of your Conclusion section, comment on your results. Did you get the expected voltages? Were there any difficulties encountered? Did more salt bridges help?