# Determination of an Electrochemical Series

In electrochemistry, a voltaic cell is a specially prepared system in which an oxidation-reduction reaction occurs spontaneously. This spontaneous reaction produces an easily measured electrical potential which has a positive value. Voltaic cells have a variety of uses and you commonly refer to them as a “battery”.

Half-cells are normally produced by placing a piece of metal into a solution containing a cation of the metal (e.g., Cu metal in a solution of a soluble salt that releases $Cu^{2+}$ or $Cu^{+}$ into solution). In this micro-version of a voltaic cell, the half cell will be a small piece of metal placed into three drops of a solution on a piece of filter paper. The solution contains a cation of the solid metal. Figure 1 shows the arrangement of the half-cells on the piece of filter paper. The two half-reactions are normally separated by a porous barrier or salt bridge. Here, the salt bridge will be the filter paper soaked in an aqueous solution of potassium or sodium nitrate. Using a voltmeter, the positive terminal (or lead) makes contact with one metal and the negative terminal with another. If a positive voltage is recorded on the meter, the cell you have constructed is spontaneous and you have connected the cell correctly. To construct a spontaneous cell, attach the metal having a higher, more positive, reduction potential to the positive terminal which is the cathode. The metal attached to the negative terminal is the anode and has the lower, more negative, reduction potential.

By comparing the voltage values obtained for several pairs of half-cells, you can establish the reduction potential sequence for the five metals in this lab.

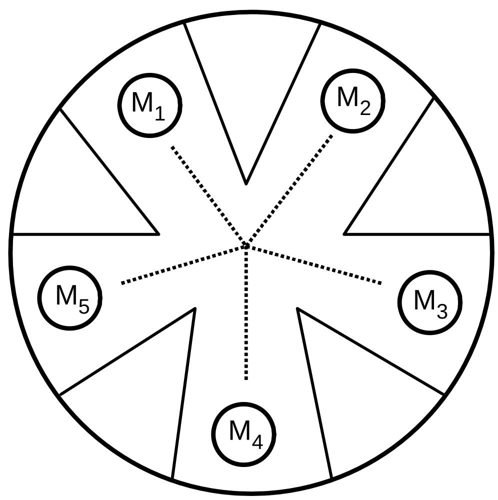



*Figure 1*

## OBJECTIVES

In this experiment, you will

- Prepare micro voltaic cells and measure their potential relative to a standard electrode.
- Use the relative potentials determined to construct numerous spontaneous voltaic cells.
- Calculate the percent error between your calculated and measured voltage values.

*Adapted from Advanced Chemistry with Vernier & Laboratory Experiments for Advanced Placement Chemistry by Sally Ann Vonderbrink, Ph. D.*

## MATERIALS

Data Collection Mechanism computer or handheld

Voltage Probe

Petri dish with filter paper to fit

scissors

sandpaper or steel wool

forceps

set of plastic Beral pipets

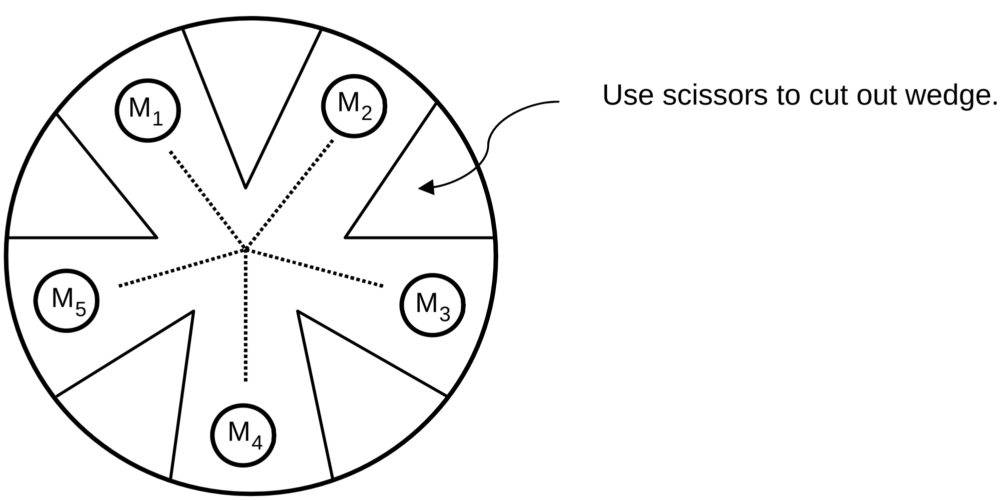
Small samples of each of five metals

1 *M* $KNO_3$ *or* $NaNO_3$ solution

1.0 *M* solutions of each of the five metals labeled $M_1^{2+}$ through $M_5^{2+}$ (pay attention to the charge on the metal, they may not all be 2+ ions)

## PROCEDURE

1. Obtain and wear goggles.
2. Either set up a voltmeter or set up the data collection system that connects an interface to the computer or handheld with the proper interface cable if necessary.
   a. Connect the Voltage Probe to the interface.
   b. Run the data collection program.
   c. You may gather the data with Selected Events, or simply record the readings from the main screen.
3. Obtain a piece of filter paper that fits your Petri dish and draw five small circles with dotted connecting lines, as shown below. Using scissors cut out the pie-shaped wedges between the circles as shown. Label the circles $M_1$, $M_2$, $M_3$, $M_4$, and $M_5$.
4. Obtain the five pieces of metal. Using either sand paper or steel wool, scrub both sides of each piece of metal until shiny. Use the metal that is obviously copper as your reference metal $M_1$.



5. Place 1-2 drops of each solution on its circle (e.g., $M_1^{2+}$ on circle labeled $M_1$). Then place the piece of $M_1$ metal (copper) on the wet spot with its respective cation ($Cu^{2+}$). The top side of the metal should be kept dry. Then add several drops of 1.0 *M* sodium or potassium nitrate to the dotted line drawn between each circle and the center of the filter paper. Be sure that there is a continuous trail of sodium or potassium nitrate between each circle and the center. You may have to periodically dampen the filter paper with sodium or potassium nitrate during the experiment. **CAUTION**: *Handle these solutions with care. Some are poisonous and some cause hard to remove stains. If a spill occurs, tell your instructor.*

6. Measure the potential of the first cell by connecting $M_1$ to $M_2$. This is done by bringing the positive terminal or lead of the voltmeter into contact with $M_1$ (copper) and the negative terminal in contact with the other metal $M_2$. If the voltage displayed in the meter is negative, then reverse the terminals. Recall that the + terminal is the cathode and that reduction takes place there, thus you are measuring *oxidation potentials* and will need to change their sign to report them as *reduction potentials* in Data Table 2.

7. With a positive voltage displayed, wait about five seconds to take a voltage reading and record the value in **DATA TABLE 1**. Be sure to press down on the metal piece in order to make good contact. Also record which metal is the positive terminal and which is negative. Use the same procedure to measure the potential of the other three cells , $M_1$ to $M_3$, $M_1$ to $M_4$, and $M_1$ to $M_5$, continuing to use $M_1$ (copper) as the reference electrode, thus it remains connected to the positive terminal of the voltmeter and negative voltage readings are possible.

8. Analyze your data thus far and arrange the five metals from the highest (most positive) reduction potential to the lowest (most negative) reduction potential. Metal $M_1$ (copper) will be assigned an arbitrary value of 0.00 V since it is used as a reference electrode.

9. Using the voltmeter, *measure* the potential of the remaining possible *spontaneous* cell combinations. If the sodium or potassium nitrate solution has dried (or if any of the other solutions have dried), you may have to re-moisten it. Record each *measured spontaneous cell potential* in Data Table 3 and identify which metal was the cathode and the anode for the *spontaneous* cell.

10. *Calculate* the predicted potentials for the remaining possible *spontaneous* cell combinations and record each *calculated potential* in DATA TABLE 3. Show your calculations within the data table.

11. When you have finished collecting data, use forceps to remove each of the pieces of metal from the filter paper. Rinse each piece of metal with tap water. Dry it and return it to the correct container. Remove the filter paper from the Petri dish using forceps and discard it in the trash. Rinse the Petri dish with tap water, making sure that you do not touch the chemicals.

## DATA TABLE 1

| Voltaic Cell (metals used) | Measured Oxidation Potential, $E^\circ_{ox}$ (V) |
|---|---|
| $M_1$ / $M_2$ | |
| $M_1$ / $M_3$ | |
| $M_1$ / $M_4$ | |
| $M_1$ / $M_5$ | |

## DATA TABLE 2

| Metal ($M_x$) | Measured $E^\circ_{red}$, arranged from most positive to most negative (V) |
|---|---|
| | |
| | |
| | |
| | |
| | |

## DATA TABLE 3

| Metal Combinations Tested | Measured Potential for Spontaneous Cell (V) | Calculated Potential for Spontaneous Voltaic Cell (V) | Percent Error (%) |
|---|---|---|---|
| $M_2$ & $M_3$ | | | |
| $M_2$ & $M_4$ | | | |
| $M_2$ & $M_5$ | | | |
| $M_3$ & $M_4$ | | | |
| $M_3$ & $M_5$ | | | |
| $M_4$ & $M_5$ | | | |

## PRE-LAB QUESTIONS

1. A student has successfully set up their Petri dish and is ready to collect data. The student notices the voltmeter is reading a negative voltage. What should the student do to correct the problem?

2. A student is given the task of establishing a table of reduction potentials for four metals. The experimentally determined reduction potentials appear in the table below.

| **Half -reaction** | **Reduction Potential (V)** |
|---|---|
| $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ | 0.62 |
| $Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$ | 0.00 |
| $Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$ | −0.15 |
| $Al^{3+}(aq) + 3e^- \rightarrow Al(s)$ | −1.38 |

(a) Which electrode served as the standard electrode for the experiment? Justify your answer.

(b) Which ion is most easily reduced? Justify your answer.

(c) Which metal is most easily oxidized? Justify your answer.

(d) The copper and aluminum electrodes are connected to form a battery which is a *spontaneous* cell with a positive voltage.

(i) Which is oxidized? Justify your answer.

(ii) Which is the anode? Justify your answer.

(iii) Write the balanced net ionic equation for the reaction that takes place.

(iv) Calculate $E°$ for the battery.

## POST- LAB QUESTIONS AND DATA ANALYSIS

1. Calculate the percent error between your calculated and measured potentials for Step 10 of the procedure and place your values in DATA TABLE 3.

2. Examine a published reduction potential table that uses the standard hydrogen electrode as its reference electrode. Locate the published reduction potential of $M_1$ (copper) and use it to determine the likely identity of each of the metals using your data from DATA TABLE 2.

3. What is the purpose of polishing the metals? How would your measured potentials be affected if you failed to polish the metals?

4. What is the function of the sodium or potassium nitrate?

5. Did the ranking of your measured potentials agree with the theoretical published reduction potential table of $E^{o}_{red}$ values?