

Experiment 8

Establishing a Table of Reduction Potentials

The main objective of this experiment is to establish the reduction potentials of four metals relative to an arbitrarily chosen metal, and then arrange them into a table that has the form of a table of standard reduction potentials. This will be done by measuring the voltage difference between various pairs of half-cells made from the metals and suitable ionic solutions. Note: The words “voltage” and “potential” mean the same thing—historical usage determines when one or the other word is used.

A voltaic cell utilizes a spontaneous oxidation-reduction reaction to produce an electrical current and a voltage. (Note: The term “voltaic cell” means the same thing as the word “battery.”) Half-cells are normally produced by placing a piece of metal into a solution containing the cation of the metal (e.g., Cu metal in a solution of CuSO_4 which ionizes to give Cu^{2+}). In this version of a voltaic cell, the half cell will be a small piece of metal placed onto 3 drops of solution which is on a piece of filter paper. The solution contains the cation of the solid metal. Figure 1 shows the arrangement of half-cells on a piece of filter paper. The two half-reactions are normally separated by a porous barrier or a salt bridge. Here, the salt bridge will be several drops of aqueous NaNO_3 solution placed on the filter paper between the two half cells. Using the computer as a voltmeter, the red lead makes contact with one metal and the black lead makes contact with another metal.

By comparing the voltages obtained for four pairs of half-cells, and by recording which metal was the (+) or (–) electrode, you can establish a table of reduction potentials for the five metals in this lab.

Materials

Windows PC		one piece of filter paper, 11.0 cm diameter
Vernier interface	LabPro	1 cm×1 cm sheets of metals Cu, Zn, Pb, Ag, Fe
LoggerPro		1 M NaNO_3
Vernier Voltage Probe		1 M solutions of Cu^{2+} , Zn^{2+} , Pb^{2+} , Ag^+ , Fe^{2+}
one Petri dish		steel wool
forceps		

Procedure

1. Obtain and wear eye protection. You will work in groups as assigned by your instructor.
2. Prepare the computer for data collection by opening the Experiment 28 folder from *Chemistry with Computers*. Then open the experiment file called “Exp 28 LabPro Voltage.” The sensor that will be automatically set is called “Voltage (–10 to +10).” The calibration is “Volts_10V.” The computer is now set to monitor voltage, in volts.

You can read the voltage in the Meter window when the voltage probe leads are connected to a cell. When the leads are not in contact with a cell (or each other), a meaningless default voltage may be displayed. If you touch the two leads together, the voltage will drop to 0.00 V.

- Obtain a piece of filter paper and draw five small circles in pencil and connect them with dots, as shown in Figure 1. Be sure the dots are not touching—if a solid pencil line connects two metal pieces, it will short out the circuit and no voltage reading will be obtained. Label the circles Cu, Zn, Pb, Ag, Fe. Place the filter paper in the Petri dish (either the bottom part or the cover).

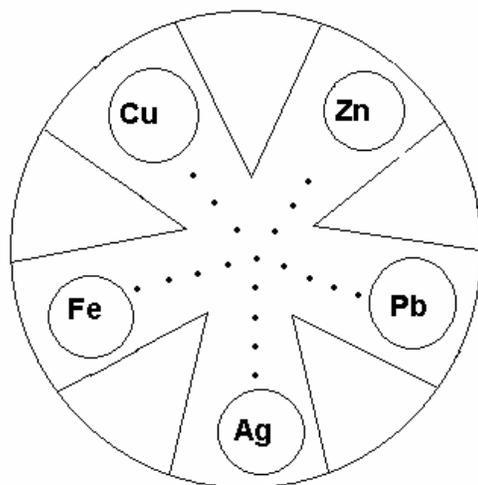


Figure 1

- Wash your hands with soap and water to remove excess grease which can contaminate the metal pieces. Wipe your hands with paper towels, not Kimwipes. Obtain 5 pieces of metal: Cu, Zn, Pb, Ag, Fe. Use steel wool to clean both surfaces of each piece of metal and the metal contacts of the red and black leads. Wipe off each metal and the leads with a Kimwipe and now only hold it with clean forceps. The object is to not get grease or dirt from your fingers on the metal. Place each metal on a clean paper towel which is labeled with the names of the metals. **It is very important that you don't mix up the metals.**
- Place 3 drops of each solution containing the cation of the metal on its circle (Cu^{2+} on Cu, etc.). Then place the piece of metal on the wet spot of its respective cation. The top side of the metal should be kept dry. Then add several drops of 1 M NaNO_3 to the line drawn between each circle and the center of the filter paper. Be sure there is a continuous trail of NaNO_3 between each circle and the center. You may have to periodically dampen the filter paper with NaNO_3 during the experiment. **CAUTION:** Handle these solutions with care. Some are poisonous, especially Pb^{2+} , and some cause hard-to-remove stains, especially Ag^+ . If a spill occurs, ask your instructor how to clean it up safely.

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6. Use the metal that is obviously copper as the reference metal. Copper is chosen as the reference metal simply because it is so easy to identify. Determine the voltage of the four cells by connecting Cu to Zn, Cu to Pb, Cu to Ag, and Cu to Fe. This is done by bringing the red lead in contact with one metal and the black lead in contact with the other. You must expose the metal contacts on the probes and touch them to the metal squares to take voltage readings. Start by placing the red lead on the Cu and the black lead on the zinc. The voltage should be positive. Here is the way the system is designed: If the red lead is connected to the (+) terminal and the black lead is connected to the (–) terminal, the voltage reading will be positive. (Just to see what will happen, reverse the leads. Notice that the voltage is now negative.)
 7. With the positive voltage between copper and zinc displayed, wait at least 5 seconds to take a voltage reading, and record the value in the Data Table in the column Measured Voltage #1. Be sure to wait until the voltage reading has stabilized. Also record which metal is the (+) terminal and which is the (–) terminal.
 8. If the voltage reading is positive, the metal that is connected to the red lead is considered the (+) terminal. The other metal is considered the (–) terminal. If the voltage reading is negative, the metal connected to the red lead is considered the (–) terminal and the other metal is considered the (+) terminal. By convention, the red lead is the one that determines the sign of the voltage.
 9. Use the same procedure to measure the voltage of the other three cells going around the circle clock-wise. Pick up only the black (–) lead when you touch the other metals. Continue to use **Cu** as the reference electrode with the red electrode touching the copper. Repeat your four measurements two more times by going around the circle twice, and record the voltages in the columns labeled #2 and #3.
 10. When you have finished, 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. **Don't mix up the metals.** Remove the filter paper from the Petri dish using the forceps, and discard it as directed by your instructor. Rinse the Petri dish with tap water, making sure that your hands do not come in contact with any solutions remaining on the plastic.

Your Report

1. Complete the Data Table and Results Tables 1 & 2. Use the footnotes in Results Table 1 to help you fill in the table.
2. In addition to handing in all the tables, on a separate piece of paper write the four sets of ionic half reactions and the net ionic reactions.
3. Discuss possible errors in the experiment. It is likely that these are substantial and that the percent errors listed in Results Table 2 will be fairly large. This is to be expected with the crude apparatus we used in this experiment.

Data Table

Voltaic Cell (metals used)	Measured Voltage (V)			Metal at the (+) Terminal	Metal at the (-) Terminal	Half reaction that goes as a reduction (this is for the metal at the (+) terminal)*	Half reaction that goes as an oxidation (this is for the metal at the (-) terminal)*
	#1	#2	#3				
Cu – Zn							
Cu – Pb							
Cu – Ag							
Cu – Fe							

TO HELP YOU DECIDE THE CHARGE OF EACH TERMINAL OF A HALF CELL.

An oxidation gives up electrons. Electrons are negative. So the half cell where an oxidation is taking place is going to be the negative terminal because the negative electrons are *coming out of* this half cell.

A reduction takes electrons. Taking of electrons is essentially making the half cell positive because the negative electrons are *going into* the half cell. So the half cell that goes as a reduction is going to be the positive electrode.

Results table 1

Voltaic Cell (metals used)	Average Measured Voltage from the Data Table (V)	Metal at the (+) Terminal	Metal at the (-) Terminal	Reduction potential of metal reacting with Cu (assumes that Cu has a reduction voltage of 0.00 V) ¹	Adjusted reduction potential of metal reacting with Cu (assumes that Cu has a reduction voltage of 0.34 V) ²
Cu – Zn					
Cu – Pb					
Cu – Ag					
Cu – Fe					

Footnote #1: If Cu is the (+) terminal and the other metal (M) is the (-) terminal, the Cu is going as a reduction and M is going as an oxidation. By definition, the reduction potential of M is (-). If Cu is (-) and M is (+), then Cu is going as an oxidation and other metal is going as a reduction. By definition, the reduction potential of M is (+). Essentially, this means that the sign of each voltage in the first column is to be reversed when entered in this column.

Footnote #2: In the previous column, Cu was arbitrarily assigned a voltage of 0.00 V. However, the actual standard reduction potential of Cu is 0.34 V. Thus, to convert the reduction potential in the previous column to actual reduction potentials, add 0.34 V to each entry.

Results Table 2

Reduction potential in descending order from most (+) to most (-) reordered from the last column in Results Table 1. (Don't forget to insert Cu at the +0.34 V position in this table)	Metal	Actual reduction potential of each metal from the textbook (Zumdahl, 6 th ed, p 833)*	Percent error between your measured reduction voltage (column #1) and the actual reduction voltage (column #3). (Cu will, of course, have a 0% error)**

* Be careful to chose the proper half reactions. These involve the metal and the ions listed in the materials section on page L-1.

**Students in the past have found that iron gives the largest percent error. It turns out that the "iron" we are using is really mild steel and is alloyed with other metals, so a large error is to be expected. We have not found a source of pure iron at this time.

Is the order of the metals in Results Table 2 the same as that in the table of Standard Reduction Potentials on p 833 in Zumdahl's text?

Yes No (circle one)

If you circled No, check all your calculations. The order should come out the same as in the standard table.

The formula for percent error:

$$\% \text{ error} = \left| \frac{\text{your value} - \text{book value}}{\text{book value}} \right| \times 100\%$$

The vertical lines stand for absolute value, meaning that the sign of the number between the vertical lines is always positive.