

Electrochemistry: Voltaic Cells

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. Voltaic cells have a variety of uses.

In this experiment, you will prepare a variety of semi-microscale voltaic cells in a 24-well test plate. A voltaic cell is constructed by using two metal electrodes and solutions of their respective salts (the electrolyte component of the cell) with known molar concentrations. In Parts I and II of this experiment, you will use a Voltage Probe to measure the potential of a voltaic cell with copper and lead electrodes. You will then test two voltaic cells that have unknown metal electrodes and, through careful measurements of the cell potentials, identify the unknown metals. In Part III of the experiment, you will measure the potential of a special type of voltaic cell called a concentration cell. In the first concentration cell, you will observe how a voltaic cell can maintain a spontaneous redox reaction when it consists of identical metal electrodes (copper or lead), but different electrolyte concentrations. You will then measure the potential of a second concentration cell and use the Nernst equation to calculate the solubility product constant, K_{sp} , for lead iodide, PbI_2 .

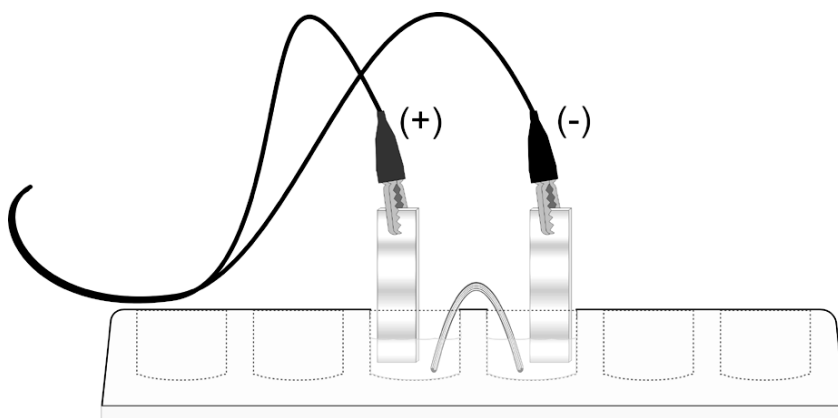


Figure 1

OBJECTIVES

In this experiment, you will

- Prepare a Cu-Pb voltaic cell and measure its potential.
- Test two voltaic cells that use unknown metal electrodes and identify the metals.
- Prepare a copper concentration cell and measure its potential.
- Prepare a lead concentration cell and measure its potential.
- Use the Nernst equation to calculate the K_{sp} of PbI_2 .

MATERIALS

Vernier computer interface	0.10 M copper (II) nitrate, $\text{Cu}(\text{NO}_3)_2$, solution
Computer	0.10 M lead (II) nitrate, $\text{Pb}(\text{NO}_3)_2$, solution
Vernier Voltage Probe	1.0 M copper (II) sulfate, CuSO_4 , solution
Three 10 mL graduated cylinders	0.050 M potassium iodide, KI, solution
24-well test plate	1 M potassium nitrate, KNO_3 , solution
Yarn (salt bridge)	0.10 M X nitrate solution
Cu and Pb electrodes	0.10 M Y nitrate solution
Two unknown electrodes, labeled X and Y	Steel wool
150 mL beaker	Plastic Beral pipets

PRE-LAB EXERCISE

Use the table of standard reduction potentials in your text, or another approved reference, to complete the following table. An example is provided.

Electrodes	Half-reactions	E°	E°_{cell}
Zn Cu	$\text{Zn(s)} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$ $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu(s)}$	+0.76 V +0.34 V	+1.10 V
Cu Pb			
Pb Ag			
Pb Mg			
Pb Zn			

PROCEDURE

1. Connect the LabQuest Mini to your computer using the USB cable. Connect the voltage probe to channel 1 of the LabQuest Mini.
2. Start Logger Pro 3.

NOTE: On the default screen of Logger Pro 3, you will see a meter reading of ~3 V. This reading is not valid and should be considered to be only confirmation that the probe is operating properly.


3. Clip the red and black leads of the voltage probe together. The meter reading will drop to a value below ~0.1 V, which is normal behavior.
4. Open the Experiment menu and choose Zero. After the sensor has been zeroed, the meter reading will be 0.00 V (or very close to 0.00 V).






You are now ready to measure cell potentials.

TWO IMPORTANT POINTS:







- A) If you exit Logger Pro 3 and re-start it for a new experiment with the voltage probe, you must re-zero the probe.
- B) Do NOT zero the probe if the red and black leads are not connected. If you do, you will be effectively subtracting ~3 V from all subsequent measurements, which will mean that all of the readings will be negative values.

Part I Determine the E° for a Cu-Pb Voltaic Cell

1. Obtain and wear goggles.
2. Use a 24-well test plate to construct your voltaic cell. Use Beral pipets to transfer small amounts of 0.10 M $\text{Cu}(\text{NO}_3)_2$ and 0.10 M $\text{Pb}(\text{NO}_3)_2$ solutions to two neighboring wells in the test plate. **CAUTION:** *Handle these solutions with care. Clean up spills as directed.*
3. Obtain one Cu and one Pb metal strip to act as electrodes. Polish each strip with steel wool. Place the Cu strip in the well of $\text{Cu}(\text{NO}_3)_2$ solution and place the Pb strip in the well of $\text{Pb}(\text{NO}_3)_2$ solution. These are the half-cells of your Cu-Pb voltaic cell.
4. Make a salt bridge by soaking a short length of yarn in a beaker than contains a small amount of 1 M KNO_3 solution. Connect the Cu and Pb half-cells by draping the wet yarn between the two wells, ensuring that the two ends of the yarn are immersed in the two electrolytes.
5. Connect a Voltage Probe to Channel 1 of the Vernier computer interface. Connect the interface to the computer with the proper cable.
6. Start the Logger *Pro* program on your computer. Open the file “20 Electrochemistry” from the *Advanced Chemistry with Vernier* folder.
7. Measure the potential of the Cu-Pb voltaic cell. Complete the steps quickly to get the best data.
 - a. Click  Collect to start data collection. **Note:** When the voltage measurement 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 about 0.00 V.

- b. Connect the leads from the Voltage Probe to the Cu and Pb electrodes to get a positive potential reading. Click  immediately after making the connection with the Voltage Probe.
- c. Remove both electrodes from the solutions. Clean and polish each electrode.
- d. Put the Cu and Pb electrodes back in place to set up the voltaic cell for a second measurement. Connect the Voltage Probe to the electrodes, as before. Click  immediately after making the connection with the Voltage Probe.
- e. Remove the electrodes. Clean and polish each electrode again.
- f. Set up the voltaic cell a third, and final, time. Click  immediately after making the connection with the Voltage Probe. Click  to end the data collection.
- g. Click the Statistics button, . Record the mean in your data table as the average potential. Close the statistics box on the graph screen by clicking the X in the corner of the box.

Part II Determine the E° for Two Voltaic Cells Using Pb and Unknown Metals

8. Obtain a small amount of the unknown electrolyte solution labeled “0.10 M X” and the corresponding metal strip, X.
9. Use a Beral pipet to transfer a small amount of 0.10 M X solution to a well adjacent to the 0.10 M $\text{Pb}(\text{NO}_3)_2$ solution in the test plate.
10. Make a new salt bridge by soaking a short length of yarn in the beaker of 1 M KNO_3 solution. Connect the X and Pb half cells with the yarn.
11. Measure the potential of the X-Pb voltaic cell. Complete this step quickly.
 - a. Click  to start data collection.
 - b. Connect the leads from the Voltage Probe to the X and Pb electrodes to get a positive potential reading. Click  immediately after making the connection with the Voltage Probe.
 - c. Remove both electrodes from the solutions. Clean and re-polish each electrode.
 - d. Set up the voltaic cell again. Connect the Voltage Probe, as before. Click  immediately after making the connection with the Voltage Probe.
 - e. Remove the electrodes. Clean and polish each electrode again.
 - f. Test the voltaic cell a third time. Click  immediately after making the connection with the Voltage Probe.
 - g. Click  to end data collection.
 - h. Click the Statistics button, . Record the mean in your data table as the average potential and then close the statistics box on the graph screen by clicking the X in the corner of the box.
12. Repeat Steps 8 to 11 using the second unknown and its corresponding electrolyte solution, labeled “Y”.

Part III Prepare and Test Two Concentration Cells

13. Set up and test a copper concentration cell.
 - a. Prepare 20 mL of 0.050 M CuSO_4 solution by mixing 1 mL of 1.0 M CuSO_4 solution with 19 mL of distilled water.
 - b. Set up a concentration cell in two adjacent wells of the 24-well test plate by adding 5 mL of 0.050 M CuSO_4 solution to one well and 5 mL of 1.0 M CuSO_4 solution to an adjacent

- well. Use a polished Cu metal electrode in each well. Use a KNO_3 -soaked yarn as the salt bridge, as in Parts I and II.
- Click **Collect** to start data collection.
 - Test and record the potential of the concentration cell in the same manner that you tested the voltaic cells in Parts I and II.
14. Set up a concentration cell to determine the solubility product constant, K_{sp} , of PbI_2 .
- Prepare 10 mL of 0.050 M $\text{Pb}(\text{NO}_3)_2$ solution by mixing 5 mL of 0.10 M $\text{Pb}(\text{NO}_3)_2$ solution with 5 mL of distilled water.
 - Mix 9 mL of 0.050 M KI solution with 3 mL of 0.050 M $\text{Pb}(\text{NO}_3)_2$ solution in a small beaker. In this reaction, most of the Pb^{2+} and I^- ions will form the precipitate PbI_2 , but a small amount of the ions will remain dissolved, based on the value of the K_{sp} of PbI_2 .
 - Set up the half-cells in adjacent wells of the 24-well test plate. Place 5 mL of 0.050 M $\text{Pb}(\text{NO}_3)_2$ solution in one half cell, and 5 mL of the PbI_2 mixture, from the small beaker, into an adjacent half cell. Use polished Pb electrodes in each half-cell. Use a KNO_3 -soaked length of yarn as the salt bridge.
 - Test and record the potential of the cell in the same manner that you tested the voltaic cells and the copper concentration cell in Parts I, II, and III above.
15. Discard the electrodes and the electrolyte solutions as directed. Rinse and clean the 24-well plate. **CAUTION:** *Handle these solutions with care. If a spill occurs, ask your instructor how to clean up safely.*

DATA TABLE

Results of Parts I and II	Cu/Pb	X/Pb	Y/Pb
Average cell potential (V)			

Results of Part III	Cu concentration	Pb/ PbI_2
Average cell potential (V)		

DATA ANALYSIS

1. (Part I) Compare the average cell potential that you measured for your Cu/Pb cell, with the E_{cell} that you calculated in the pre-lab exercise. Explain why your cell potential is different from the text value.
2. (Part II) The unknown metals X and Y were either magnesium, silver, or zinc. Use the text value for the reduction potential of Pb and your measured cell potentials for the unknowns to identify X and Y.
3. (Part III) Use the Nernst equation to calculate the theoretical value of E of the copper-concentration cell and compare this value with the cell potential that you measured.
4. (Part III) Use the Nernst equation and the information that you collected about the Pb/PbI₂ cell to complete the following calculations.
 - a. Use the cell potential for the Pb-PbI₂ cell and the known [Pb²⁺] to calculate the [Pb²⁺] in equilibrium with PbI₂.
 - b. Use the original diluted [Pb²⁺] and [I⁻] to calculate the [I⁻] in solution.
 - c. Use your data to calculate the K_{sp} of PbI₂

The value of the K_{sp} of PbI₂ has been reported by various authors to be in the range 8.4×10^{-9} to 1.4×10^{-8} . How does your experimental K_{sp} of PbI₂ compare with this range of accepted values?