Six-Way Galvanic Cell

Voltaic Cells

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Introduction

In an oxidation–reduction reaction, electrons flow from the substance that is oxidized, which loses electrons, to the substance that is reduced, which gains electrons. In a voltaic cell, the flow of electrons accompanying a spontaneous oxidation–reduction reaction occurs via an external pathway, and an electric current is produced. What factors determine the ability of a voltaic cell to produce electricity?

Concepts

- Oxidation–reduction
- Standard reduction potential
- Voltaic cell
- Activity series of metals

Experiment Overview

The purpose of this experiment is to measure cell potentials for a series of micro-voltaic cells. Individual half-cells will be constructed by placing small pieces of unknown metals on a piece of filter paper and adding several drops of their corresponding metal ion solutions. A "salt bridge" between the half-cells will be provided by placing a few drops of aqueous potassium nitrate on the filter paper along the path connecting the half-cells. Voltages will be measured using a multimeter. The identity of the unknown metals will be determined by comparing the data with known standard reduction potentials.

Materials

Copper strips or sheet, Cu, 0.5 cm × 2 cm

Copper(II) sulfate solution, $CuSO_4$, 1 M, 1 mL

Iron strips or sheet, Fe, 0.5 cm × 2 cm

Iron(II) sulfate solution, $FeSO_4$, 1 M, 1 mL

Lead strips or sheet, Pb, 0.5 cm × 2 cm

Lead nitrate solution, $Pb(NO_3)_2$, 1 M, 1 mL

Magnesium ribbon, Mg, 2 cm

Magnesium sulfate solution, $MgSO_4$, 1 M, 1 mL

Potassium nitrate solution, KNO_3, 1 M, 2 mL

Tin strips or sheet, Sn, 0.5 cm × 2 cm

Tin(II) chloride, $SnCl_2$, 1 M, 1 mL

Zinc strips or sheet, Zn, 0.5 cm × 2 cm

Zinc sulfate solution, $ZnSO_4$, 1 M, 1 mL

Filter paper, quantitative, 9-cm

Multimeter

Paper towel

Pencil

Petri dish or acetate transparency

Pipets, Beral-type, or eyedroppers, 7

Sandpaper or steel wool

Scissors

Safety Precautions

Potassium nitrate is a strong oxidant; fire and explosion risk when heated or in contact with organic material; a skin irritant. Lead(II) nitrate solution is moderately toxic by inhalation and ingestion; a strong oxidant; and a body tissue irritant. Tin(II) chloride solution is moderately toxic, a skin irritant and corrosive. Copper(II) sulfate solution is toxic by ingestion. Iron(II) sulfate and zinc sulfate solutions are slightly toxic. Magnesium metal is a flammable solid; avoid contact with flames and heat. Metal pieces may have sharp edges—handle with care. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab. Follow all laboratory safety guidelines. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Obtain one small piece of each unknown metal, A–F.

2. Polish the metal pieces with sandpaper or steel wool, if necessary, to obtain fresh, shiny surfaces. Wipe the metal strips clean with paper towels to remove any bits of steel wool adhering to the metal.

3. Based on appearance, guess which metal each sample is and write the name of the metal next to its corresponding letter on the Six-Way Galvanic Cell Worksheet.

4. Obtain a piece of filter paper. Using a pair of scissors, cut six wedges as shown in Figure 1 and remove the wedges, leaving six "petals." Using a pencil, label each remaining section A–F, respectively.

5. Fold each petal length-wise and cut two small slits in each as shown in Figure 2.

6. Unfold the petals and weave metal strip "A" through the slits in its corresponding petal (see Figure 2). Repeat with each metal strip.
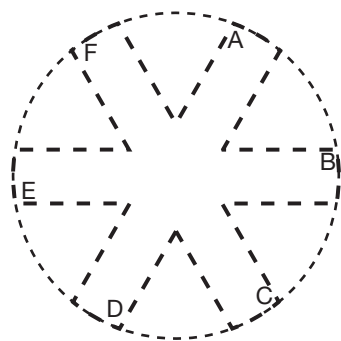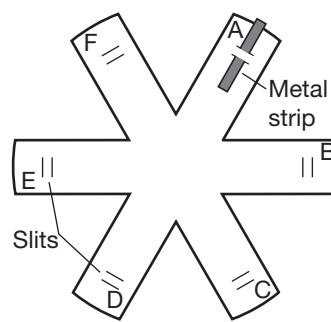

Figure 1.   **Figure 2.**

7. Place the prepared filter paper in a Petri dish or on a sheet of acetate transparency or plastic wrap.

8. Using a clean, Beral-type pipet, add 4–5 drops of potassium nitrate solution in the center of the filter paper. This will serve as the salt bridge.

9. Using a separate Beral-type pipet or eyedropper for each solution, place 4-5 drops of metal ion solution onto the center of the slits of the petal that has the corresponding metal strip (solution A on metal strip A, etc.) *Note:* Add more drops of metal ion solution to each petal as needed so the solution migrates and meets the potassium nitrate solution as well as during the course of the experiment if the paper dries.

10. Metal "A" will be used as the "reference electrode." Place the black lead from the multimeter on the piece of metal A and the red lead on the piece of metal "B." Read the live voltage. (When you place the black lead on one metal and the red lead on another, you are assuming the current will run from the black lead metal to the red lead metal, and if it does, the voltage comes out positive. If you see a negative value, that just tells you that the electrons are actually flowing backward (from red to black). So if you place the black lead on metal "X" and the red lead on metal "Y" and the voltmeter reads +0.75 V, that tells you that the electrons are flowing from metal X to metal Y with a driving force of 0.75 V. In other words Y is winning the electron "tug-of-war"—its reduction potential is 0.75 V higher than X's.)

11. In Data Table 1, record the voltage obtained.

12. Repeat steps 10–11 with each of the metals, always keeping the black lead on metal A as the reference electrode. Replenish the metal ion solutions or the salt bridge (potassium nitrate) solution as needed during the course of the experiment if the paper dries out.

13. To rank each metal by reduction potential, metal A has been arbitrarily assigned a reduction potential of 0.0 V (See Data Table 2).

14. Fill in the reduction potential in Data Table 2 for each of the unknown metals relative to metal A's reduction potential of 0.0 V.

15. Write the letter A above the zero point on the number line on the worksheet.

16. Place the rest of the unknown letters in appropriate places above the number line according to their experimental reduction potentials relative to metal A.

17. Complete the worksheet.

Disposal

Consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Iron(II) sulfate solution is air and light sensitive—prepare the solution fresh for each lab. Excess iron(II) sulfate solution may be disposed of by rinsing it down the drain with plenty of excess water according to Flinn Suggested Disposal Method #26b. Save the other metal ion solutions in properly labeled bottles for future use. With the exception of magnesium, the metal pieces may be reused from lab to lab and from year to year. Rinse the metal pieces with distilled water, dry them thoroughly on paper towels, and store them in properly labeled zipper-lock plastic bags for future use. Magnesium metal ribbon should be freshly cut each year; dispose of used magnesium pieces in the solid trash according to Flinn Suggested Disposal Method #26a.

Tips

- Other metal ion solutions may be substituted for the metal sulfate solutions—try copper(II) nitrate, copper(II) chloride, iron(II) ammonium sulfate, magnesium nitrate, zinc nitrate, etc. Assuming the concentration of metal ions in each microcell is equal, the actual concentration (e.g., 0.1, 0.5 or 1 M) should not affect the measured cell potentials. We have found, however, that the most consistent results were obtained using 1 M solutions of the metal sulfates, as described in the Materials section.

- Either potassium nitrate or sodium nitrate may be used as the "salt bridge" electrolyte in this experiment. Do not use sodium or potassium chloride as the electrolyte if silver is one of the metals being tested.

- Other metals may also be used in this experiment. If time permits, consider adding nickel, silver or aluminum to the list of metals to be tested. Students may set up two filter paper cutouts using a total of nine different metals (iron must be repeated as the reference electrode on each filter paper). Use nickel sulfate, silver nitrate and aluminum sulfate solutions as the source of metal ions for their respective half-cells. Silver usually gives very good results. Aluminum tends to give poor results, due to its "self-protecting" oxide coating.

Discussion

The basic design of a galvanic or voltaic cell is shown in Figure 3 for the net reaction of zinc and hydrochloric acid. The substances involved in each half-reaction are separated into two compartments connected by an external wire and a salt bridge.

$$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^- \quad 2H^+(aq) + 2e^- \rightarrow H_2(g)$$
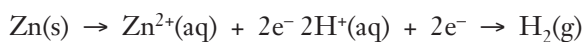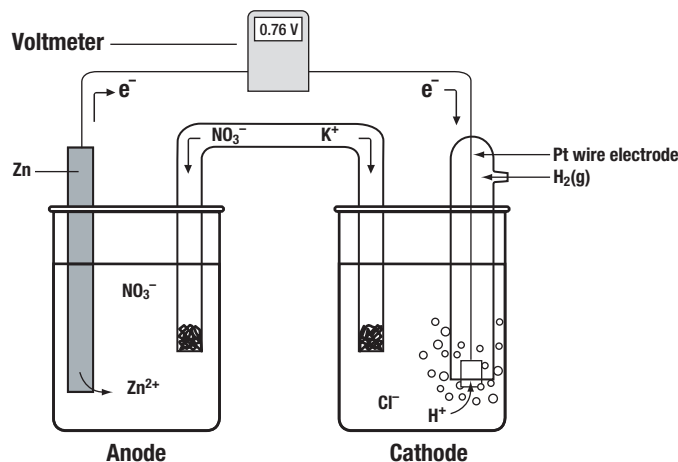
Figure 3. Components of an Electrochemical Cell.
Net Reaction: $Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$

Each half-reaction takes place at the surface of a metal plate or wire called an electrode. The electrode at which oxidation occurs is called the anode, while the electrode at which reduction occurs is called the cathode. Electrons flow spontaneously from the anode (the negative electrode) to the cathode (the positive electrode). Charge buildup at the electrodes is neutralized

by connecting the half-cells internally by means of a *salt bridge,* a porous barrier containing potassium nitrate or another electrolyte. Dissolved ions flow through the salt bridge to either electrode, thus completing the electrical circuit.

The ability of a voltaic cell to produce an electric current is called the cell potential and is measured in volts. If the cell potential is large, there is a large "electromotive force" pushing or pulling electrons through the circuit from the anode to the cathode. The cell potential for a spontaneous chemical reaction in a voltaic cell is always positive. The standard cell potential (E°_{cell}) is defined as the maximum potential difference between the electrodes of an electrochemical cell under standard conditions—25 °C, 1 M concentrations of ions, and 1 atm pressure (for gases).

It is impossible to directly measure the potential for a single electrode. The overall cell potential for an electrochemical cell may be expressed, however, as the difference between the standard reduction potentials (E°_{red}) for the reactions at the cathode and at the anode (Equation 1).

$$E^\circ_{cell} = E^\circ_{red} \text{ (cathode)} - E^\circ_{red} \text{ (anode)} \qquad \textit{Equation 1}$$

The standard reduction potential is defined as the voltage that a reduction half-cell will develop under standard conditions when it is combined with the standard hydrogen electrode (SHE), which is arbitrarily assigned a potential of zero volts (Equation 2).

$$2H^+(aq, 1\ M) + 2e^- \rightarrow H_2(g, 1\ atm) \qquad \textit{Equation 2}$$

$$E^\circ_{red} \text{ (SHE)} = 0$$
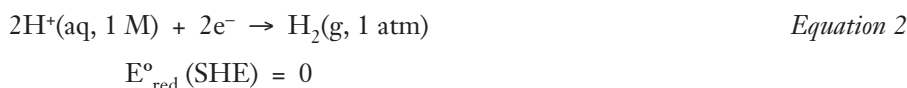
For the zinc/hydrochloric acid voltaic cell shown in Figure 3, the measured cell potential is equal to 0.76 V. Substituting this value and the zero potential for the SHE into Equation 1 gives a value of –0.76 V for the standard reduction potential of the Zn^{2+}/Zn half-cell.

$$E^\circ_{red} \text{ (cathode)} - E^\circ_{red} \text{ (anode)} = E^\circ_{cell}$$

$$E^\circ_{red} \text{ (SHE)} - E^\circ_{red} (Zn^{2+}/Zn) = 0.76\ V$$

$$0 - E^\circ_{red} (Zn^{2+}/Zn) = 0.76\ V$$

$$E^\circ_{red} (Zn^{2+}/Zn) = -0.76\ V$$

When two half-cells are combined in a voltaic cell, the reaction that has a more positive standard reduction potential will occur as a reduction, while the reaction that has a less positive (or negative) standard reduction potential will be reversed and will take place as an oxidation. In this experiment, electrochemical cells consisting of different metal ion/metal half-cells, e.g., copper(II) sulfate/copper metal versus iron(II) sulfate/iron metal, will be tested.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standard E: Science and Technology
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, interactions of energy and matter
Content Standard E: Science and Technology

Sample Data *(Student data will vary.)*

Metal sample	Hypothesis	Actual
A		*Iron*
B		*Magnesium*
C		*Tin*
D		*Lead*
E		*Zinc*
F		*Copper*

Data Table 1

Black Lead	Red Lead	Voltage (V)
A	B	*−1.12*
A	C	*0.11*
A	D	*0.18*
A	E	*−0.42*
A	F	*0.57*

Data Table 2

Metal Sample	Relative Reduction Potential (V)
A	*0.0*
B	*−1.12*
C	*0.11*
D	*0.18*
E	*−0.42*
F	*0.57*

```
        B                    E         A C D          F
|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|
                                      |
                                      0
      Mg                   Zn       Fe Sn Pb       Cu
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Post-Lab Questions

1. The table of standard reduction potentials in not based on metal A being 0.0 V. Research a more complete table. What element is designated as 0.0 V?

   Hydrogen

2. Rank the six metals tested from most positive to most negative standard reduction potential. Write a general statement describing the relationship between the standard reduction potential of a metal and metal activity.

   Cu > Pb > Sn > Fe > Zn > Mg

   Metals with more negative standard reduction potentials are more active (more easily oxidized) than metals with more positive standard reduction potentials. Magnesium was the most active metal tested, and it had the most negative standard reduction potential.

Reference

Flinn ChemTopic™ Labs, Vol. 17, *Electrochemistry;* Cesa, I., Editor; Flinn Scientific, Inc; Batavia, IL (2006).

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Six-Way Galvanic Cell* activity, presented by Bob Becker, is available in *Voltaic Cells*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Six-Way Galvanic Cell* are available from Flinn Scientific, Inc.

Catalog No.	Description
C0182	Copper Strips
C0246	Copper(II) Sulfate Solution, 1 M
I0058	Iron Strips
F0016	Iron(II) Sulfate
L0065	Lead Strips
L0014	Lead(II) Nitrate
M0139	Magnesium Ribbon
M0016	Magnesium Sulfate Heptahydrate
P0070	Potassium Nitrate
S0165	Sandpaper
T0087	Tin Strips
S0354	Tin(II) Chloride Solution, 1 M
Z0024	Zinc Strips
Z0031	Zinc Sulfate Solution, 1 M
AP3102	Filter Paper, 9 cm
AP4639	Multimeter
AP1721	Pipets, Beral-Type
AP5394	Scissors, Student

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Six-Way Galvanic Cell Worksheet

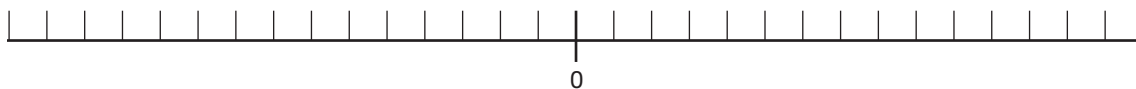Write what you think each metal sample is next to its corresponding letter.

Metal sample	Hypothesis	Actual
A		
B		
C		
D		
E		
F		

Data Table 1

Black Lead	Red Lead	Voltage (V)
A	B	
A	C	
A	D	
A	E	
A	F	

Data Table 2

Metal Sample	Relative Reduction Potential (V)
A	
B	
C	
D	
E	
F	

0

Using the actual reduction potentials for Cu, Zn, Pb, Sn, Mg and Fe listed in the chart below, place these symbols beneath the number line in their appropriate places.

Next to each hypothesis above, list the actual identity of each metal sample.

Standard Reduction Potentials Reduction Half Reaction e° (v)	
$Cu^{2+} + 2e^- \rightarrow Cu$	0.34
$Pb^{2+} + 2e^- \rightarrow Pb$	–0.13
$Sn^{2+} + 2e^- \rightarrow Sn$	–0.14
$Fe^{2+} + 2e^- \rightarrow Fe$	–0.44
$Zn^{2+} + 2e^- \rightarrow Zn$	–0.76
$Mg^{2+} + 2e^- \rightarrow Mg$	–2.37

Post-Lab Questions

1. The table of standard reduction potentials in not based on metal A being 0.0 V. Research a more complete table. What element is designated as 0.0 V?

2. Rank the six metals tested from most positive to most negative standard reduction potential. Write a general statement describing the relationship between the standard reduction potential of a metal and metal activity.