Citrus Battery Contest

Metal Activity and Cell Potentials

Introduction

Design a battery using metal strips and a lemon or an orange.

Concepts

- Electrochemistry
- Metal activity
- Cell potential
- Anode vs. cathode

Materials

Computer or calculator for data collection (optional)

Computer interface system, such as LabQuestTM or CBLTM (optional)

Connector cords with alligator clips, 4

Digital voltmeter (multimeter) or voltage sensor

Lemon, grapefruit or orange

Metal strips (aluminum, copper, iron, magnesium, tin and zinc), 1 cm \times 4 cm, 2 each

Ruler, metric

Sandpaper or steel wool

Scissors, heavy-duty

Safety Precautions

Magnesium metal is a flammable solid. Avoid contact with flames and heat. Any food-grade items that have been brought into the lab are considered laboratory chemicals and are for lab use only. Do not taste or ingest any materials in the laboratory and do not remove any remaining food items after they have been used in the lab. Wear chemical splash goggles, chemical-resistant gloves and chemicalresistant apron. Please review current Safety Data Sheets for additional safety, handling and disposal information.

Procedure

- 1. Cut strips of metal sheet, about 1 cm wide by 4 cm long, using heavy-duty scissors. Place the metal strips on a labeled sheet of paper to keep track of their identity.
- 2. "Prime" the lemon or orange by pushing down slightly and rolling it briskly on a table or benchtop to soften the skin.
- 3. Insert two different metal strips about 1–2 cm apart into the fruit. The metals should penetrate the fruit to a depth of at least 2–3 cm (see Figure 1).
- 4. Attach a voltage lead (or connector cord with alligator clips) from the multimeter or voltage sensor to each metal electrode.
- 5. Measure the voltage. *If a positive voltage reading is obtained*, record the voltage and note which metal is attached to the positive lead and which is attached to the negative lead. *Note:* If a negative voltage reading is obtained, reverse the polarity (switch the positive and negative leads) of the metal electrodes to obtain a positive reading.
- 6. Observe any signs of a chemical reaction in or around each metal electrode.
- 7. Repeat steps 3–6 to measure the voltage for different combinations of metals. Remember to record the identity of the positive and negative electrodes when a positive voltage is obtained.





Citrus Battery Contest continued

8. Set up a friendly competition among different student groups to design a battery that will give the highest voltage. Some questions to consider: (a) What combination of metals gives the highest voltage? (b) Does the voltage depend on the separation between the metals? (c) Can pairs of metals be connected in series to increase the voltage of a citrus battery? (d) Is the battery voltage stable over time? (e) How long will the battery last?

Disposal

It is recommended that you consult your local school board and/or municipal regulations for proper disposal methods that may apply before proceeding.

Tips

- For best results, polish the metal strips with sandpaper or steel wool before use. Rinse well with distilled water and pat dry.
- Have students create data tables to record the results of their experiments.
- See "Observations on Lemon Cells," by Jerry Goodisman, in the *Journal of Chemical Education*, Volume 78, No. 4, pp 516–518 (April 2001), for an explanation of the results obtained with typical electrochemical cells in lemons and orange juice.
- The "Metal Electrode Set" available from Flinn Scientific Canada (Catalogue No. APJ4602) contains six metal electrodes (aluminum, brass, copper, iron, lead and zinc) that are perfect for this activity. The metal pieces do not need to be cut. Magnesium metal ribbon (Catalogue No. MJ0001) and tin strips (Catalogue No. TJ0087) may be purchased separately if desired.

| Positive Electrode (Cathode) | Negative Electrode (Anode) | Voltage |
|------------------------------|----------------------------|---------|
| Cu | Mg | 1.9 V |
| | Zn | 1.0 V |
| | Al | 0.8 V |
| | Fe | 0.5 V |
| | Sn | 0.5 V |
| Sn | Mg | 1.3 V |
| | Zn | 0.5 V |
| | Al | 0.1 V |
| | Fe | 0.0 V |
| Fe | Mg | 1.3 V |
| | Zn | 0.5 V |
| | Al | 0.2 V |
| Al | Mg | 1.2 V |
| | Zn | 0.3 V |
| Zn | Mg | 1.0 V |

Sample Results—Lemon-Cell Batteries

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Discussion

When two metals having different electrical potentials are placed in a solution of an electrolyte (such as a lemon or an orange, with its high concentration of citric acid), a crude electrochemical cell is set up. The cell is a *voltaic cell* resulting from a spontaneous oxidation–reduction reaction. The open-circuit potential difference between the reactions at each electrode is the cell potential, which can be measured with a digital voltmeter or a voltage sensor. The more active metal in a pair is *usually* the negative electrode (the anode). Magnesium, for example, which is the most active metal that was tested, always appears as the anode. (Aluminum is a significant exception to this general trend.) Significant bubbling is observed when magnesium is used as the electrode.

In general, the citrus-cell potential is greater when the two metals are further apart in the electrochemical series. The cell potential does *not* correlate well, however, with the difference in standard reduction potentials between the two metals. The voltage of a citrus cell battery decreases over time, suggesting that the overall reaction in the cell is irreversible.

The highest voltage (+1.9 V) in this demonstration was obtained with a copper-magnesium lemon cell with copper as the positive electrode (the cathode) and magnesium as the negative electrode (the anode). The most likely reactions in this cell are oxidation of magnesium to Mg^{2+} ions at the anode and reduction of H⁺ ions to hydrogen gas at the cathode. (The citric acid content in a lemon or an orange is a rich source of H⁺ ions.) The copper electrode is an inert electrode in this cell.

| Oxidation half-reaction (anode) | $Mg(s) \rightarrow Mg^{2+}(aq) + 2e^{-}$ |
|-----------------------------------|-----------------------------------------------------------------------|
| Reduction half-reaction (cathode) | $2\mathrm{H^{+}(aq)} + 2\mathrm{e^{-}} \rightarrow \mathrm{H_{2}(g)}$ |
| Net reaction | $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$ |

Reference

This activity was adapted from *Electrochemistry*, Vol. 17 in the *Flinn ChemTopic*[™] *Labs* series; Cesa, I., Editor; Flinn Scientific: Batavia IL (2005).

Materials for Citrus Battery Contest are available from Flinn Scientific Canada, Inc.

| Catalogue No. | Description |
|---------------|--------------------------------------------------------------|
| AP6662 | Electrochemistry, Flinn ChemTopic [™] Labs, Vol. 17 |
| APJ4602 | Metal Electrode Set |
| MJ0001 | Magnesium Metal Ribbon, 25 g |
| TJ0087 | Tin, Strips, pkg. 6 |
| AP4639 | Student Multimeter |

Consult www.flinnsci.ca or your Flinn Scientific Canada Catalogue/Reference Manual for current prices.

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