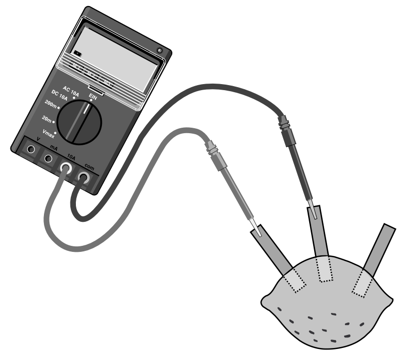
Citrus Battery Contest

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

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 × 4 cm, 2 each
Ruler, metric
Sandpaper or steel wool
Scissors, heavy-duty
Computer interface system, such as LabQuest™ or CBL™ (optional)
Computer or calculator for data collection (optional)

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 chemical-resistant 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.
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.

Publication No. 10830
100419

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

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. Inert metals such as copper or tin may be cleaned and saved for future use. Metals that show signs of chemical reaction may be disposed of in the solid trash according to Flinn Suggested Disposal Method #26a.

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 (Catalog No. AP4602) 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 ribbon (Catalog No. M0139) and tin strips (Catalog No. T0087) may be purchased separately if desired.

Sample Results — Lemon-Cell Batteries

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

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) $2H^+(aq) + 2e^- \rightarrow H_2(g)$

Net reaction $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
- MS-PS3 Energy
  - PS3.A: Definitions of Energy
  - PS3.B: Conservation of Energy and Energy Transfer

Disciplinary Core Ideas: High School
- HS-PS1 Matter and its Interactions
  - PS1.A: Structures and Properties of Matter
  - PS1.B:Chemical Reactions
- HS-PS3 Energy
  - PS3.D: Energy in Chemical Processes

Science and Engineering Practices
- Planning and carrying out investigations
- Constructing explanations and designing solutions

Crosscutting Concepts
- Scale, proportion, and quanitity
- Energy and matter

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, Inc.

Catalog No.	Description
AP6662	Electrochemistry, Flinn ChemTopic™ Labs, Vol. 17
TC1559	LabQuest™ Mini
TC1561	LabQuest™ 2 Interface
TC1506	Voltage Probe
AP4602	Metal Electrode Set
M0139	Magnesium, Ribbon, 12.5 g
T0087	Tin, Strips, pkg. 6
AP4639	Student Multimeter

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