Building a Voltaic Pile

Summary

An Italian anatomy professor, Luigi Galvani, noticed that the legs of dead frogs jumped when touched with a metal, concluding that animals generate electricity to yield motion. Alessandro Volta, a physics professor, thought the electricity was externally generated by metallic contact. As proof, Volta built a "pile" consisting of layers of two different metals, zinc and silver, in contact and separated by brine-soaked cloth.[1] He demonstrated this first battery in 1799 and published an account of it in 1800.[2] This simple apparatus was the beginning of our modern world, a world unthinkable without electricity always at our fingertips.

Main idea

To construct a series of voltaic cells powerful enough to do visible work. Volta used zinc and silver; we will use zinc and more easily available copper.

Materials

1. A strip of aluminum foil
2. About five or six pieces of 1-inch square cardboard or card stock saturated with sodium chloride solution
3. About five or six pennies (copper shell)
4. About five or six ¼ inch zinc washers, and if possible, one 5/8 inch zinc washer
5. A digital multimeter
6. Some LEDs (obtainable from hobby shops, or www.evilmadscientist.com, where they can be purchased in bulk)

Safety Suggestions

Safety Goggles Required
Protective clothing suggested
Do not eat or drink any of the materials used in this activity
Thoroughly wash hands after this activity

Procedure

Prep work: Soak as many 1-inch square pieces of cardboard (e.g., from the back of a yellow pad) or card stock as needed in a saturated solution of NaCl; drain on absorbent paper immediately prior to use

Procedure for each working group:

Step A. Fold a piece of aluminum foil (about 15 X 4 cm) lengthwise until it forms a strip that can lie flat on your workspace. This will act as your conducting lead for the battery you are about to construct.
Step B. Turn on the multimeter and set it to 9V DC
Step C. Connect the black (negative) lead of the multimeter to one end of the aluminum strip
Step D. Place the 5/8 inch (or ¼ inch) zinc washer on the other end of the strip, a moist card stock piece on top of the washer and place a penny on top of it. This is your first voltaic cell.
Step E. Hold the red (positive) lead of the multimeter firmly on the penny.
Step F. Observe and record the voltage shown on the multimeter face in your table.*
Step G. Place a ¼ inch zinc washer, a moist piece of card stock, and a penny on top of what you have already built. With the red lead of the digital multimeter held firmly on the top penny, observe and record the voltage. This is cell number two.
Step H. Repeat steps F and G two more times. Figure 1 is a diagrammatic cross-section of the arrangements of your voltaic pile.
Step J. Connect a black (negative) lead to one end of the strip at the bottom of the pile and the other end of the lead to the cathode of a common LED (short pin) and link the anode (long pin) of the LED directly to the top of the pile (the penny).

Your pile should pack enough of a voltage at this point (four cells) to light the LED. Most common LEDs require a little more than 1.5 volts. (See Figure 2)
Step K. On simple graph paper, plot the data from your table: “Number of Cell” on the ordinate (y-axis) and “Volts” on the abscissa (x-axis). What do you observe?
*Make a 2-column table. Label column one “Number of Cell” and column two “Volts”

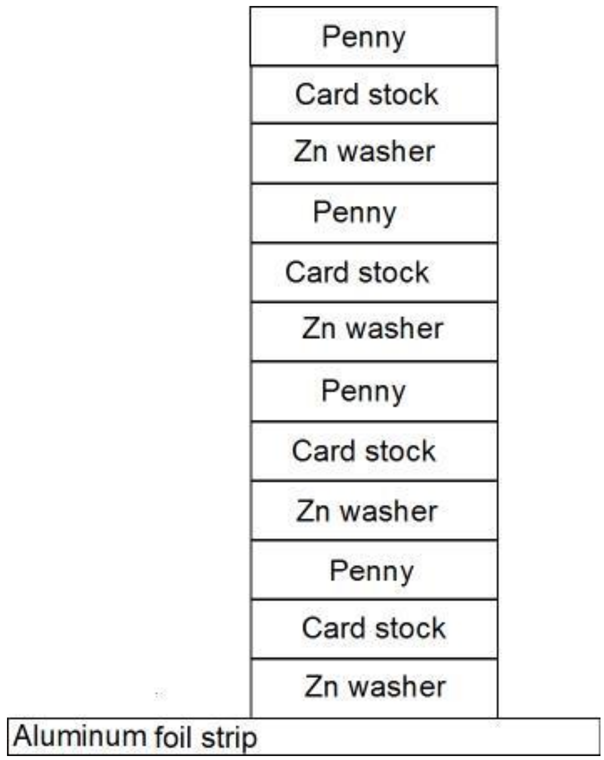

Figure 1 Cross-sectional schematic diagram of the voltaic pile

Where’s the chemistry?
In 1799, atoms, ions, and electrons were unknown, so Volta could not possibly have come up with a chemical explanation of this observed phenomenon. However, we now know that the basis of electricity is electron transfer, called affinity in Volta’s day. He realized that different metals had different electrical effects and even arranged some common metals in a series according to these effects. Today we call this arrangement an electromotive series. Volta’s series, going from greatest effect to least was: zinc, tinfoil, common tinplate, lead, iron, brass or bronze, copper, platinum, gold, silver, mercury. The metals farthest apart from one another are those which, when placed in contact, produced the greatest effect.[3]
The effect is actually electron transfer. In the case of the two metals that we used, the zinc loses electrons according to the following half-equation:

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ (oxidation half-equation – loss of electrons)

While $Zn^{2+}(aq)$ is entering the NaCl-soaked cardboard, two positively charged hydrogen ions (H^+) from the brine (Note: Brine is a highly concentrated salt solution.) accept the two electrons lost by the Zn(s) at the copper surface, become reduced, and form an uncharged hydrogen molecule:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$ (reduction half-equation – gain of electrons at the cathode)

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

The overall electrochemical reaction does not involve the copper which acts as a chemically inert metallic conductor to transport electrons in the circuit.[4]

Instead of the more benign NaCl that we used as the conductive salt bridge, Volta used sulfuric acid. Reaction between the acid and the copper surface can generate aqueous copper(II) sulfate, which could act as another possible conducting solution with the following reduction half-equation:

$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$ (reduction half-equation – gain of electrons)

producing the following overall chemical reaction.

$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$ (overall reaction)

However, if one uses a solution of copper(II) sulfate as the electrolyte, the reduction half-reaction would be the same as above, but the use of sulfuric acid could be avoided.

This method, recommended by *ChemCom,* 6th edition,[5] is more straightforward and more understandable for students than the use of the NaCl salt bridge. The measured cell potential is greater here due to the additional copper half-reaction contribution.

Electricity is produced when the electrons transferred are forced to travel through an external circuit and, in the process, they can do work such as activate a measuring instrument such as a digital multimeter or light up an LED if the voltage is high enough. The metals at the top of the series tend to be oxidized relative to the metals toward the bottom, which have a greater relative tendency to be reduced. The reduction-oxidation (or redox) pair is called a “cell.” A group of cells placed in a pile have a measurable additive electrical effect. In honor of Volta, the cell is called a voltaic cell and the pile a voltaic pile. The unit of measure for the potential electrical effect of the cell or the pile, the electromotive force, is called the “volt.” This type of cell generates electricity via chemical reactions.

What did you see?
A 4-cell voltaic pile can light up an LED See photograph below (Fig. 2).

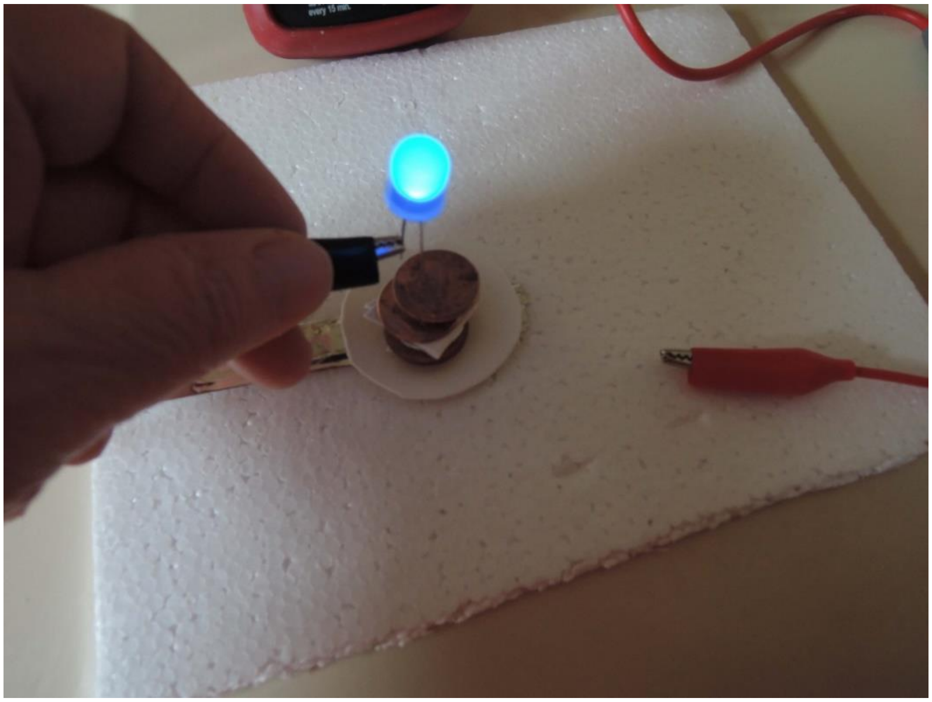

Figure 2 A functioning voltaic pile lights up an LED

References:

[1] Stock, J. T.; Orna, M. V. *Electrochemistry Past and Present*. American Chemical Society Symposium Series Volume 390; American Chemical Society: Washington, DC, 1989.

[2] Volta, A. On the Electricity excited by the mere Contact of conducting Substances of different kinds. *Phil. Trans*. **1800**, *90*, 403-431.

[3] Bowden, M. E. *Chemistry Is Electric*! Chemical Heritage Foundation: Philadelphia, PA, 1997; p. 9.

[4] Goodisman, J. Observations on Lemon Cells. *J. Chem. Educ*. **2001**, *78*, 516-518.

[5] American Chemical Society. *Chemistry in the Community (ChemCom), 6th ed*. W. H. Freeman: San Francisco, CA, 2012; pp. 562-564.

Drawing for Figure 1 and Photograph for Figure 2 by Mary Virginia Orna

Acknowledgment: The idea for this activity came from a post by Joe Schwarcz of the McGill Office for Science and Society, Nov. 8, 2018: Why do some people experience pain when they chew on aluminum? https://www.mcgill.ca/oss/article/you-asked/why-do-i-get-jolt-pain-every-time-i-chew-piece-aluminum-foil (accessed Feb. 23, 2019)

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