Lemon Cells Revisited—The Lemon-Powered Calculator

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In the course of doing chemical demonstrations at several grade schools and demonstrations in freshman chemistry lecture, we have found that students relate most to experiments that involve common everyday items found in the home. It really drives home the point that chemistry is an integral part of their daily lives. While teaching electrochemistry to our freshman classes we wanted to demonstrate the principles of a voltaic cell using items that students could easily obtain. Being able to repeat the demonstration themselves would reinforce the concepts they learned in lecture.

We knew that by placing a penny and a galvanized nail into a lemon, we could produce a potential of about 1 volt, but we wished to be able to use the current produced to power easily obtainable items for use as demonstrations in the classroom. The use of dissimilar metal strips and a lemon to create a voltaic cell is even portrayed in a current freshman chemistry text (*1*). We were unable to reproduce a previously published version of the lemon battery (*2*). We thus decided to search for items that could be used in a small-to-medium-sized classroom that fit two requirements: each item had to be easily obtainable, and each item that worked had to work repeatably.

The items found to work reproducibly are found in Tables 1 and 2. Table 1 shows the minimum number of cells wired in series needed, using copper and zinc electrodes; Table 2 shows the minimum number of cells wired in series needed, using copper and magnesium electrodes. Zinc and copper electrodes were prepared by cutting copper and zinc sheets 1 mm thick into strips 1 cm × 5 cm; magnesium electrodes were made by bending 10-cm strips of magnesium ribbon in half. Because magnesium is more active than zinc, the potential produced is higher and thus fewer cells are needed. The light-emitting diodes are best seen in a dimly lit room, and the piezo buzzers are best heard in a small-to-medium-sized classroom. Wires were wrapped around the battery terminals of the clocks and calculator for attachment to the electrodes placed in the lemons. The desktop clock has a transparent LCD panel with numbers 2 inches high, making it visible to all students in our large lecture hall. The LCD travel alarm clock displays numbers 1 inch high and the alarm is easily audible in the lecture hall. The lemon-powered calculator (Fig. 1) is especially intriguing to students; in fact, several students have used it to take quizzes and exams.

The lemon cell is peculiar in that, unlike a Daniell cell, both oxidation and reduction take place at the same electrode. The anode metals become oxidized (Zn to Zn^{2+}, Mg to Mg^{2+}) and the hydrogen ions in the lemon are reduced to hydrogen gas, in part, at the zinc and magnesium electrodes. In fact, hydrogen gas can be seen vigorously bubbling out from around the magnesium electrode. The copper electrode is simply an auxiliary electrode; it acts as an electron shunt, where reduction of hydrogen ions to hydrogen gas also takes place. This can be verified by replacing the copper electrode with carbon electrodes made by snapping off the eraser end of a no. 2 pencil and sharpening both ends to a point. The voltage readings are comparable (Zn/Cu: 0.979 V, Zn/C: 0.989 V) but the current readings are different (Zn/Cu: 240 µA, Zn/C: 50 µA), which is not surprising because carbon (graphite) is much less conductive than copper. Similar results were obtained when using Mg/Cu and Mg/C. There has been some speculation as to

Table 1. Zinc/Copper—Lemon Cells Wired in Series

Item	Radio Shack Cat. No.	Minimum in Series (No.)[a]	Best Results (No.)[a]
Red wide-angle LED	276-203	3	4
PC board mount piezo buzzer	273-074	2	2
Red blinking LED	276-036C	2	3
Green blinking LED	276-030	2	3
Red jumbo LED	276-214	2	4
Low-current red LED	276-044	3	4
Piezo buzzer, 3.5 kHz	273-060	2	2
Pulsing piezo buzzer, 2.8 kHz	273-066	2	4
PC board mount piezo buzzer, 2.8 kHz	273-065	2	2
Piezo buzzer, 2.7 kHz	273-059	2	2
Stick-on LCD clock/calendar/timer	63-840A	2	2
LCD travel alarm clock	63-723	2	2
LCD desktop clock	63-729	2	2
Texas Instruments TI-30X calculator	—	3	4

Note: Zinc and copper electrodes are placed 2.0 cm apart. For each lemon cell: 0.96–0.98 V, 240 µA current.
[a]Data represent number of lemons.

Table 2. Magnesium/Copper—Lemon Cells Wired in Series

Item	Radio Shack Cat. No.	Minimum in Series (No.)[a]	Best Results (No.)[a]
Red wide-angle LED	276-203	1	3
PC board mount piezo buzzer, 3.2 kHz	273-074	1	2
Red blinking LED	276-036C	2	3
Green blinking LED	276-030	2	3
Red jumbo LED	276-214	2	3
Low-current red LED	276-044	1	3
Piezo buzzer, 3.5 kHz	273-060	1	2
Pulsing piezo buzzer, 2.8 kHz	273-066	2	2
PC board mount piezo buzzer, 2.8 kHz	273-065	1	2
Piezo buzzer, 2.7 kHz	273-059	1	2
Stick-on LCD clock/calendar/timer	63-840A	1	1
LCD travel alarm clock	63-723	1	1
LCD desktop clock	63-729	1	1
Texas Instruments TI-30X calculator	—	2	3

Note: Magnesium and copper electrodes are placed 2.0 cm apart. For each lemon cell: 1.5–1.6 V, 400 µA current.
[a]Data represent number of lemons.

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Figure 1. Lemon pi! The TI-30 calculator powered by three lemon cells.

what compounds are responsible for the potentials produced from the lemon cells (*3*). In addition to various salts and organic compounds, lemons contain citric acid (pK_{a_1} = 3.13), ascorbic acid (pK_{a_1} = 4.17) and NADP (pK_{a_1} = 3.9). Since lemon juice contains 5–8% citric acid, it must be the major species undergoing reaction. A 5% solution of citric acid was prepared (pH 2.02) and compared to freshly squeezed lemon juice (pH 2.36). The results were again comparable: Zn/Cu, 0.993 V (1200 μA) in 5% citric acid, 0.986 V (850 μA) in lemon juice; Mg/Cu, 1.614 V (1970 μA) in 5% citric acid, 1.670 V (1600 μA) in lemon juice. Replacing the copper electrode with carbon and immersing both electrodes in lemon juice gave voltage readings similar to readings for the lemon cells but there was a substantial drop in current, as was expected (Zn/C: 0.881 V, 154 μA; Mg/C: 1.71 V, 730 μA). That the current readings for lemon juice are substantially higher than those for the lemon cell shows that the membranes in the lemon are acting as a barrier to ion migration and thus limiting the amount of current.

Students of all ages find it fascinating that electrical energy can be obtained by constructing a device made from ordinary household items, and the use of easily obtainable items make this a worthwhile demonstration for elementary, secondary, and college-level teachers of science and chemistry.

Literature Cited

1. Hill, J. W.; Petrucci, R. H. *General Chemistry*; Prentice-Hall: Upper Saddle River, NJ, 1996.
2. Worley, J. D.; Fournier, J. *J. Chem. Educ.* **1988,** *65*, 158.
3. Shakhashiri, B. *Chemical Demonstrations: A Sourcebook for Teachers of Chemistry*, Vol. 4; University of Wisconsin Press: Madison, WI, 1992; p 110.

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