Educational experiment to demonstrate Faraday's Law of electrolysis using Zinc–Air batteries

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Abstract

We developed a new educational experiment to demonstrate Faraday's Law of electrolysis using button-type zinc-air batteries (PR44) and a resistor to discharge it. Although the output current from a PR44 is small, by connecting four PR44 in series, a clear result was obtained just as in an experiment using larger batteries such as the PR2330. In addition, the apparatus was not only inexpensive but also easy to build and handle for high school students.

1. Introduction

Faraday's law of electrolysis, stating that the number of moles of substance produced at an electrode during electrolysis is directly proportional to the number of moles of electrons transferred at that electrode, is learned by students studying senior high school chemistry in Japan. In most cases, electrolysis of a $CuSO_4$ solution with a copper plate is used to demonstrate it (1, 2); however, this kind of experiment needs not only a certain quantity of chemicals but also several elaborate devices such as an analytical balance, a DC power supply, and a DC ammeter. In addition, it takes a long time for students to obtain quantitative data.

From such a viewpoint, we reported a new educational experiment using a zinc-air battery (PR2330) with a resistor or current regulative diodes to discharge it (3). These experiments did not need any chemicals, and therefore, no waste treatment was required. In addition, the quantitative measurement can be accomplished within a short time. However, production of PR2330 batteries has ended because they were produced originally for pocket pagers which are not used today. An alternative experiment cannot be created by just changing the type of battery because the output current of the PR2330 was exceptionally large and there is no zinc-air battery commercially available which is equivalent to the PR2330. Therefore, we developed a new experiment using an apparatus with a different structure which uses four smaller batteries (PR44) instead of the PR2330. The apparatus is not only inexpensive but also easy to build and handle. In addition, the obtained data is educationally quantitative enough, just like the experiment using the PR2330.

2. Experimental

Apparatus

The structure of the PR44 (Fig.1) is the same as the PR2330 which we used in our early studies.

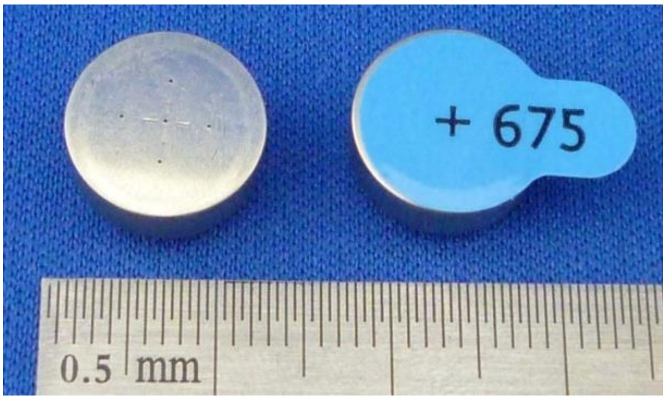


Fig.1 Zinc-air battery (PR44)
(left: Tab removed, right: before Tab was removed)

The anode material is powder of zinc metal and it is stored inside the battery, but no cathode material, such as MnO_2, is stored inside it. Instead, it uses the oxygen in the air that comes into the battery through several holes on the cathode side. As potassium hydro-oxide is used as the electrolyte, the electrode reactions at the anode and the cathode are expressed as;

$$\text{anode} : Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^- \quad (1)$$

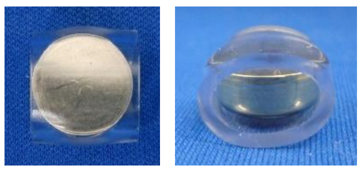
$$\text{cathode} : O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (2)$$

and the total reaction is expressed as;

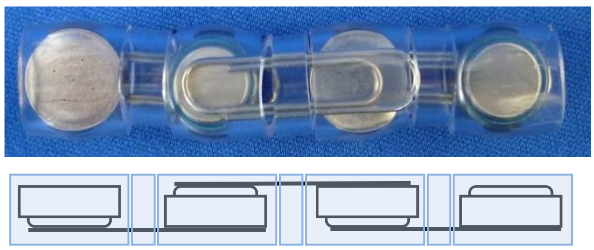
$$2Zn + O_2 \rightarrow 2ZnO \quad (3)$$

The PR44 battery is produced by several companies. The PR44 used in this study was the product of VARTA Microbattery GmbH (Germany). A tab is put on the cathode side of the battery to seal the air holes, and you must remove the tab before using the battery. Immediately after the tab is removed, the PR44 absorbs a certain amount of oxygen even if it is not electrically connected to a circuit. Therefore, at least one hour before the experiment, the tabs should be removed without being connected to anything so that the cathode is in equilibrium with oxygen in the air.

While the diameter of the PR2330 is 23mm, the diameter of the PR44 is 11.6mm, which means the electric current coming from the PR44 is much smaller than that from the PR2330. In order to compensate for this difference, four PR44s are connected in series in this study. Each PR44 is squeezed into a short flexible PVC tube (OD=12mm, ID=10mm, L=14mm) as shown in Fig.2 (a). After four tubed PR44s are prepared, they are connected as shown in Fig.2(b) using paperclips and PVC tube spacers (OD=12mm, ID=10mm, L=5mm). The spacers are needed to avoid connecting three batteries with one paperclip which would create a short circuit.



(a)PR44 squeezed into a tube



(b) Tubed PR44s connected with paperclips

Fig. 2 Four PR44s connected in series

Then, as shown in Fig.3, the four connected batteries are put in a test tube (ID=18mm, L=90mm) and sealed with a silicone rubber plug through which two electric leads and a scaled part cut out from a 1mL plastic pipette (cf. Fig.4) are fixed. The two leads are connected to both ends of the four batteries respectively using the same paperclips. The pipette is used to find out the volume of gas (oxygen) absorbed in the batteries during discharge.

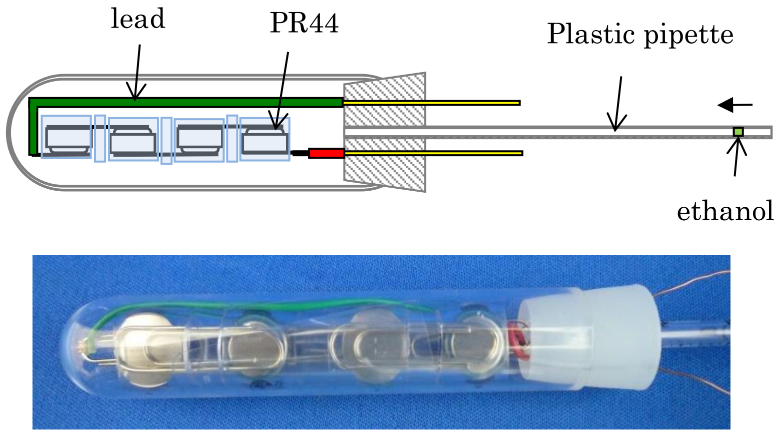


Fig. 3 Experimental apparatus

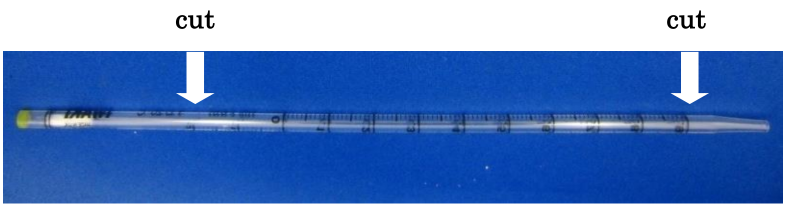


Fig. 4 How to cut out a scaled part from a pipette

How to use

To demonstrate Faraday's Law, we connect a resister (500Ω) between the ends of the two leads coming out of the plug. After putting a small quantity of methanol into the pipette, we place the apparatus horizontally so that the methanol can move smoothly inside the pipette without being affected by gravity. The pressure inside the test tube decreases as the air-zinc batteries discharge (absorb oxygen in the test tube), which makes the methanol drop in the pipette move toward the battery. Thus, we can measure the time required for the methanol to pass the 0.05mL scale lines of the pipette. In this way, the relation between the volume of reacted oxygen and the time of discharge can be obtained.

On the other hand, Faraday's Law can be expressed as;

$$\text{amount of reacted oxygen in one battery} = It/4F \qquad (4)$$

where, I, t, and F are the discharging current, time of discharging, and Faraday constant, respectively. Assuming that one mole of oxygen gas occupies 24.8L at room temperature, the volume of reacted oxygen in the four batteries V(mL) can be expressed as eq.(2) ;

$$\frac{V(\mathrm{mL})/1000(\mathrm{mL/L})}{24.8(\mathrm{L/mol})} = 4 \cdot \frac{I(\mathrm{A}) \cdot t(\mathrm{s})}{4F(\mathrm{C/mol})} \qquad (5)$$

Although the nominal voltage of a zinc-air battery is 1.4V, the terminal voltage of four PR44s in series is 5V when they are connected to a 500 Ω resistor. Therefore, the current coming from a PR44 can be calculated as I = 5V/500Ω = 0.01A, and therefore, equation(2) can be simplified as;

$$\begin{aligned} V(\mathrm{mL}) &= 4 \times \{0.01t / (4 \times 96500)\} \times 24.8 \times 1000 \\ &= 0.00257t \end{aligned} \qquad (6)$$

Equation(6) can be compared with the experimental results on graph.

3. Results and Discussion

A typical example of the result is presented in Fig.5, where the relation between the time required for the ethanol to pass the 0.05mL scale lines and the volume of oxygen absorbed is plotted with the theoretical line derived from eq.(6). Although the experiment was finished in several minutes, including preparation for measuring, the obtained data was coincident with the calculated data within a few percent. It is noted here that a CRD（Current Regulative Diode）can be used instead of a resistor to obtain more quantitative data.

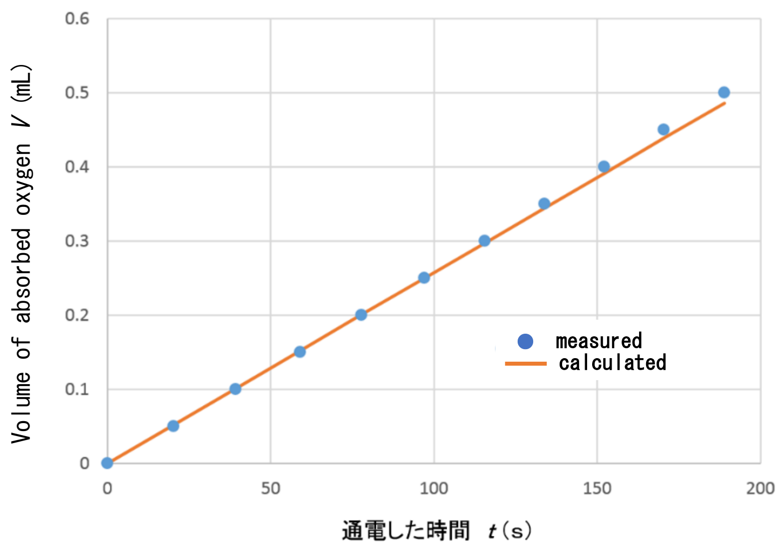


Fig.5　Typical example of experimental

Time of discharge t (s)

Reference

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