MICROSCALE CHEMISTRY AND SDGS

Kazuko Ogino
Tohoku University
email: oginok@med.tohoku.ac.jp

ABSTRACT

Education is essential for sustainable development. It is important to let pupils understand the key issues such as climate change and energy problems through active and positive learning. We have been engaging in the development and dissemination of microscale chemistry and green chemistry experiments, through which understanding of environmental issues and sustainability can be enhanced. *[African Journal of Chemical Education—AJCE 9(3), November 2019]*

INTRODUCTION

Chemistry has an important role to play in achieving a sustainable human life on earth. However, chemicals are sometimes viewed as the main cause of environmental problems by the general public. It is indispensable to let the general public recognize the positive contribution of chemistry to the improvement of the quality of life, the effort of chemists in developing environmentally friendly chemical products and processes.

The United Nations Decade of Education for Sustainable Development (ESD started from 2005. In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development: "Sustainable Development Goals" (SDGs) consisting of 17 goals in order to eradicate poverty and realize a sustainable world. Many of the goals are related to ESD and chemistry education (Figure 1). The promotion of ESD is essential for many of the goals of SDGs.

Figure 1 Examples of Sustainable Development Goals closely related to chemistry education

ESD allows students to acquire the knowledge, skills, attitude and values necessary to shape a sustainable future (see Figure 1). The knowledge and attitudes are nurtured through deep understanding of environmental issues such as global warming, global energy and resources problems and sustainability. Chemistry Education can contribute to solving many of these problems, such as energy, global warming and greenhouse gases, air pollution, quality of water, etc.

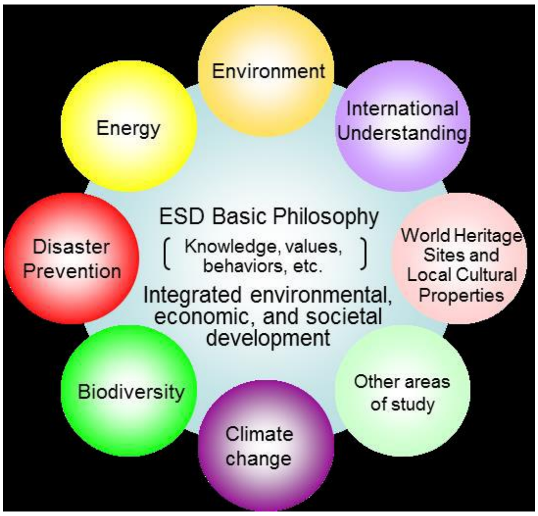

Figure 2 ESD Concept map given by Ministry of Education, Culture, Sports, Science and Technology, Japan http://www.mext.go.jp/en/unesco/title04/detail04/sdetail04/1375695.htm

DEEP UNDERSTANDING THROUGH ACTUAL EXPERIENCES: MICROSCALE CHEMISTRY

Education is critical for promoting sustainable development and improving the capacity of the people to address environment and development issues. Chemistry education can take an important part in the education about environmental issues, especially through laboratory experiments, because deep understanding can be achieved through actual experiences. Microscale laboratory is suited for such purposes because of following reasons:

1. The microscale laboratory is environmentally benign and can make students sensitive to pollution prevention.
2. Many microscale experiments can be done in a very short time. A series of experiments can be done in one workshop. Thus, we can have time to discuss about the experimental observation and relate them to environmental issues and to concepts such as sustainability.

3. Each participant can do experiment by oneself, as the materials do not occupy big area, and are not expensive. Actual experience helps participants to visualize concepts.

We have developed various microscale experiments suitable to the purpose described above. In early times, we used disposable materials, such as 12- and 24-well microplates, hypodermic syringes, three-way stopcocks. Some of the experiments are published in English on wave site [1]. However, in Japan it is difficult for schoolteachers to get these materials.

In 2012, we developed an MC kit with an eight-well plate, with which enormous numbers of microscale experiments can be conducted [2]. The kit consists of various small materials. All the materials are accommodated in a plastic box; the size of the box is 28 cm x 20 cm x 3 cm. The kit is manufactured and distributed by Dai Nippon Printing Co., Ltd (DNP). Since then, we have been running workshops with this Kit on various topics for K4 to K12 students.

In the kit, an 8-well microplate, a lid, stopcocks, several syringes, metal electrodes, pencil lead (carbon electrode), music chip and some other items are accommodated. The lid of the 8-well plate has holes and slits which fit the insertion of metal electrodes, pencil lead, syringes and filter paper.

In many of the workshops we have been practicing following experiments using MC Kits we developed.

1. Measurement of the volumes of gases evolved by the electrolysis of water: Smallest Hoffman Voltammeter in the world
2. Electrolysis of some aqueous solutions: Copper(II) chloride solution, Sodium sulfate solution
3. Principle of fuel cells
4. Electroplating
5. Daniel cell
6. Voltaic cells consist of two different metals
7. Lead-acid battery

8. Conductivity of solutions
9. Acidic, neutral and basic solutions
10. Indicators, neutralization, acid-base reactions
11. Indicators from plants
12. Qualitative analyses of ions.

TYPICAL WORKSHOPS

In this paper two typical workshops are described. One is on the electrolysis of water and voltaic cells, and the other is on oxygen. They can be carried out in two hours. The workshops consist of several microscale experiments.

1. Workshop on Electrolysis of Water and Voltaic Cells: Workshops to Study Various Forms of Energy

   In this workshop 5 microscale experiments are included: a. Electrolysis of water in a pipette, b. Microscale Hoffman electrolytic cell, c. Electrolysis of water to form acidic and alkaline solutions, d. Principle of fuel cells, e. Construction of Voltaic cells. The details are described in ref.1, in which materials available commercially in most countries are used.

a. Electrolysis in a pipette

Materials: Plate, lid, pipette, small pins, red and black lead with clips, 9-V battery, soap solution, 3 M sodium carbonate solution

Procedure:

A plastic 1-mL-pipette is filled with sodium carbonate solution and two small pins are pierced into the bulb of the pipette as shown in Figure 3. These pins serve as electrodes. The pipette is placed in a well of the microplate. Soap solution is poured into another well. The open end of the pipet is immersed into the soap solution. The electrodes are connected to a 9 V battery.

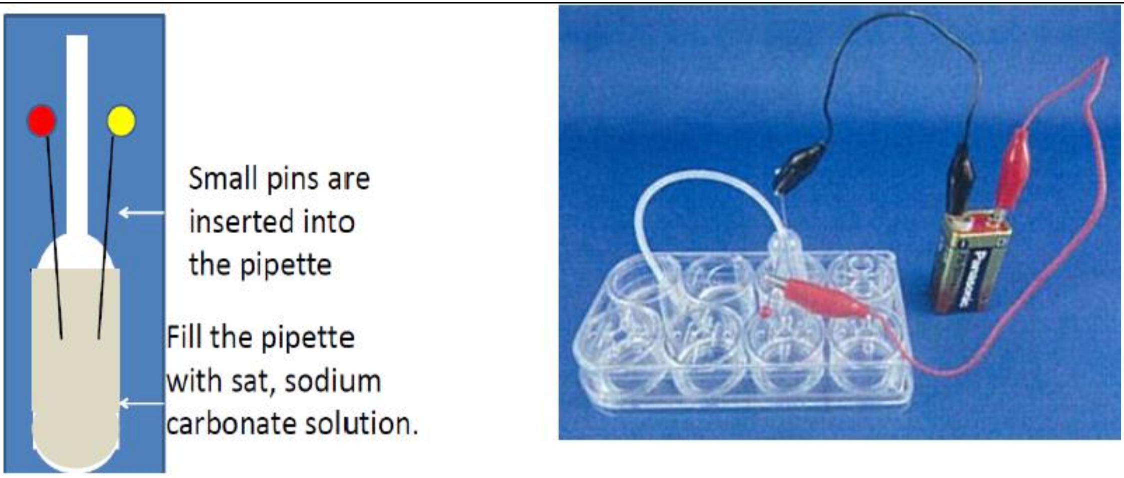

Figure 3 A 1mL-pipette is used as an electrolytic cell. The tip of the pipette is bent so that it is in a soap. This is a modification of the experiment by N. H. Zhou [3].

Generation of gas is observed at each electrode (Figure 3). The evolved gas (oxyhydrogen gas) forms bubbles at the surface of the soap solution. Ignite the bubbles. You will observe the detonation with an astonishing loud sound.

Then battery is removed from the pipette, and a hand generator is connected to the two pins inserted in the pipette. When students turn the generator, gas is evolved from the pipette. Students are always concentrated in turning the generator to let bubbles form rapidly (Figure 4). The foam on the surface of the well explodes when the flame is brought nearby.

Figure 4 Primary school (left) and middle school (right) pupils are turning hand generators to decompose water into its elements.

From this experiment, students understand that water is stable and energy is required to decompose water to hydrogen and oxygen. Through this experiment, we can let students recognize how energy is converted.

b. Measurement of the volumes of gases evolved by the electrolysis:

Figure 5 shows the world's smallest Hoffman-type electrolytic cell, which is constructed with 0.8-mL-syringes, disposable stopcocks and a microplate. Big pins pierced on the 0.8-mL-syringes serve as electrodes. The syringes can be filled with sodium carbonate solution by the aid of a hypodermic syringe connected to the side arm of the 3-way stopcock. After the two 0.8-mL-syringes are filled, electrodes are connected to a 9 V battery and electrolysis start. Observe the bubbles at the electrodes and measure the volumes of gases by reading the graduation. In a few minutes, the formation of bubbles stops. As the pin (electrode) is inserted at the graduation of 0.8 mL, the electric continuity does not exist when the gas formation reached to the 0.8 mL graduation.

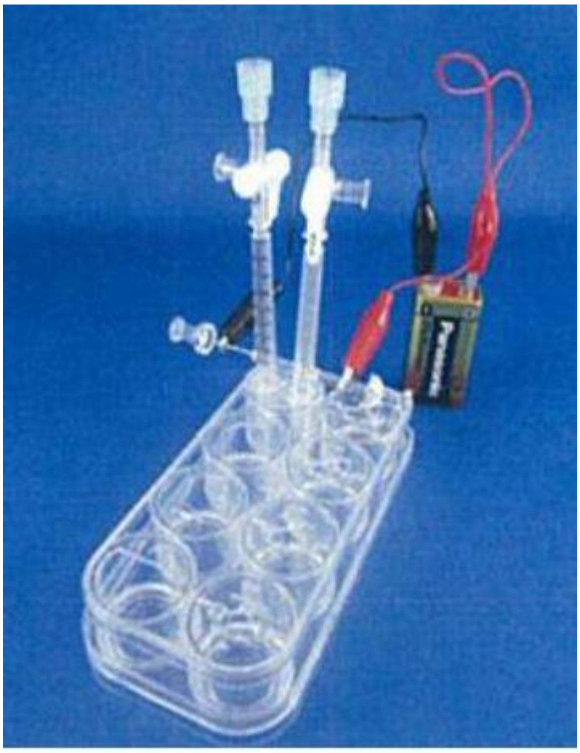

Figure 5 Small Hoffman electrolytic cell. The electrolysis comes to an end in 3 minutes, and shows the H_2:O_2 ratio is 2;1 in volume.

Then it is observed the volume of gas formed at cathode is 0.8 mL and that at anode is 0.4 mL. It is shown clearly that twice as much hydrogen is formed as that of oxygen as indicated by the equation:

At cathode:

$$2\ H_2O + 2e^- \rightarrow 2\ OH^- + H_2 \quad (1)$$

or

$$4\ H_2O + 4e^- \rightarrow 4\ OH^- + 2\ H_2 \quad (1')$$

At the anode:

$$2\ H_2O \rightarrow 4H^+ + O_2 + 4\ e^- \quad (2)$$

Overall cell reaction: $2\ H_2O \rightarrow O_2 + 2\ H_2$ (3)

From the results, students understand that water can be decomposed to form molecular hydrogen and oxygen in 2:1 ratio

The following two experiments (3 and 4) can be carried out successively in 20 seconds.

c. Electrolysis of sodium sulfate solution:

Add ca. 2 mL of sodium sulfate solution and 3 drops of BTB into a well. The solution should be green. Separate the well into two parts (the anode and the cathode compartments) with a piece of filter paper. Insert one carbon rod (electrode) in one side, and another carbon electrode in the other side. Clip electrical leads to electrodes and 3 V direct current electric source. Observe carefully the electrode surface for the evolution of gas and changes in color of the solution around each electrode: blue around cathode and yellow around the anode. These phenomena can be understood by Eq.1 and Eq.2.

The solution in the anodic compartment becomes acidic changing the color from green to yellow, and the solution in the cathodic compartment becomes alkaline changing the color from green to blue.

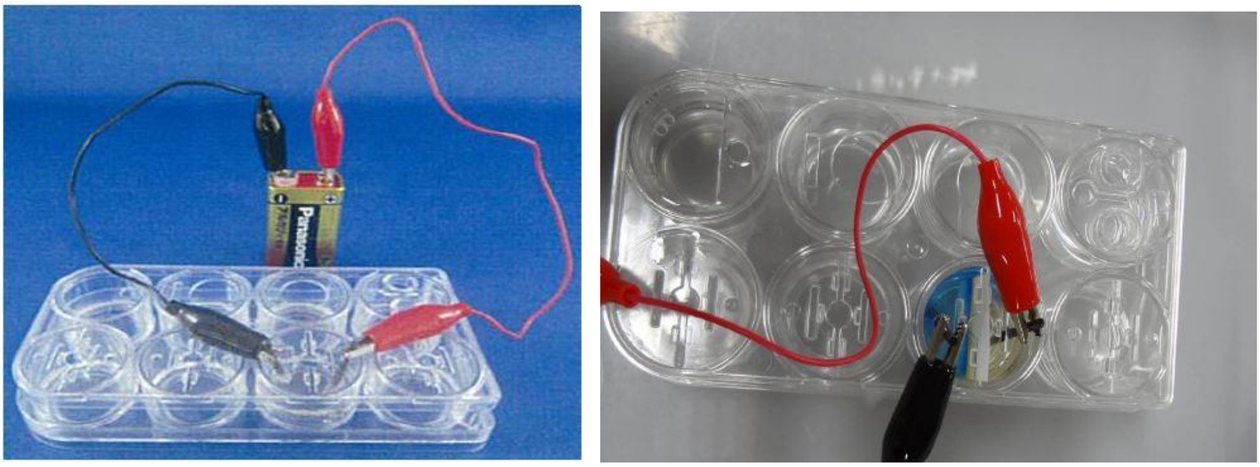

Figure 6 Electrolysis of water in sodium sulfate solution containing BTB (bromothymol blue). The well was green before electrolysis. It turns to blue in the cathodic compartment and yellow in the anodic compartment 5 seconds after electrolysis.

d. Principle of fuel cell

Disconnect the clips from the dry cells as soon as the changes have been observed. Connect the clips to a music chip. Then music can be heard (Figure 7). Now the electrolytic cell has become a battery.

The molecular hydrogen and oxygen formed at the cathode and the anode respectively now constitute a Voltaic cell:

Cathode: $O_2 + 4H^+ + 4\,e^- \rightarrow 2H_2O$ (4)

Anode: $2\,H_2 \rightarrow 4H^+ + 4\,e^-$ (5)

Overall: $2\,H_2 + O_2 \rightarrow 2H_2O$

These reactions are the same as those taking place in a hydrogen fuel cell. Here, we can explain the principle of actual fuel cell, though fuel cells are *not* batteries because they are not self-contained systems—the fuel must be continuously supplied to generate electricity.

Figure 7 After the electrolysis shown in Figure 6, disconnect the battery and connect a music chip to the electrodes. Then you can hear music

They understand hydrogen is a kind of fuel. We can let participants discuss why fuel cells are environmentally friendly, and how it is used now in society.

e. Construction of Voltaic cells:

In our microscale kit, strips of copper, zinc, iron and lead are accommodated. Therefore, various voltaic cells, model of lead acid battery can be constructed easily. Some of them can be included in the 2-hour-workshop. In most workshops, the most popular cell is one constructed with a cherry tomato, copper and zinc strips.

2. Workshops on Oxygen

Recently, we found the Oxygen sensor invented by Mistuo Takahashi [4] is very useful in workshops of primary school pupils. It uses zinc–air batteries and oxygen concentration in the range 10 – 50 % can be measured easily. Monitoring oxygen consumption in respiration and photosynthesis is possible. The following experiments were included in our workshops.

a. Oxygen concentration in expiratory air:

   Breathing of participants, plants, etc.

b. Oxygen concentration of the air in a bag containing some plants under sunshine: Photosynthesis

c. Some microscale experiments on gases: Different behaviours of CO_2, O_2, and H_2 can be recognized by experiments though all these gases are colourless, tasteless and odourless.

Through these experiments, students are interested in the difference of oxygen concentration of the inhaled air and the expired air. We can let students think about the following questions:

- Which atmospheric gases support our life?
- Why oxygen concentration remains almost constant in the air?
- Why atmospheric carbon dioxide has increased in the last 100 years?

RESULTS AND DISCUSSION

In our workshops, we provide one Kit to every student. For most students, it is a first experience to do experiments by her/himself. At first many students seem to hesitate to start an experiment. However, once they started, they become concentrated and worked very actively. It maybe because our experiments are accompanied by dramatic changes which are perceptible by eyes, ears and nose.

As microscale experiments can be carried out in a short time, students can experience a systematically arranged series of experiments on some topics in one workshop. They could have deepened their understanding of various concepts such as energy and transformation of energy (e.g. from chemical to electrical, from mechanical to electrical, *etc*.), electrolysis, electrochemical cells, merits of fuel cells. In some cases, physics, biology and earth science are integrated. Students enjoyed such meaningful experiments. Students seem to feel that chemistry is related to various aspects of daily life, and sustainable society.

The workshops could have stimulated students' interest toward science. Students' interest and understanding on energy and environmental issues can be enhanced. Our microscale experiments are useful in ESD and understanding of SDGs.

ACKNOWLEDGMENT

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