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Acid-Base Demonstration Through Electrolysis of Water Solution Using a Solar Panel

Demostración Ácido-Base a través de electrólisis de solución acuosa usando un panel solar

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Abstract

In this lab demonstration, an integrative physico-chemical phenomenon is demonstrated using an electrolysis cell powered by a solar panel (photovoltaic cell). In these experiments, the students can observe visually the cathode and anode phenomena by using an acid-base indicator in the electrolysis system. Furthermore, it can be demonstrated that reversing the polarity of both electrodes in the electrolysis system results in reversing the electrolysis reaction. This action leads to acid-base neutralization, and therefore, results in changing the color of the indicator presents near both electrodes.

Key Words: Acid-Base reaction, electrolysis, indicator.

Resumen

En este laboratorio se demuestra, un fenómeno físico-químico integral usando una celda de electrolisis potenciada con un panel solar (celda fotovoltaica). En estos experimentos, los estudiantes pueden observar visualmente el fenómeno del cátodo y ánodo usando un indicador ácido-base en el sistema de electrolisis. Además, se puede

demostrar que el cambio de polaridad de ambos electrodos en el sistema invierte la reacción de electrolisis. Esta acción conlleva a la neutralización ácido-base, y por lo tanto, resulta en cambiar el color del indicador presente cerca de ambos electrodos.

Palabras Clave: Reacción, ácido-base, indicadores.

Introduction

Solar energy can be converted into electrical energy by photovoltaic cells. Photovoltaic cells are made of very thin layers of silicon, which absorb the sunlight and convert it directly into electrical energy that can be used for powering different electrical devices. Considering the daily increasing in the number of environmental polluting sources photovoltaic cells are promising means to be used as a non-polluting source of energy (Headley, 1979; Cantrell, 1978; Tomas, 1996; Hugerat and Ilaiyan, 2001; Kedem and Ganiel, 1983; Hodges, 1996)

Starting from the last century, electrolysis of water solutions has been widely demonstrated to students in secondary schools or in a first-year college in order to illustrate oxidation-reduction reactions as well as to demonstrate the usage of an external source of energy for driving non-spontaneous chemical reactions (Zhou, 1996; Heideman, 1986; Hugerat and Basheer, 2001; Kelsh, 1985). To electrolyze water one needs to add an electricity-conducting material that produces free ions once it is dissolved in water. In our experiments, a 1M Na_2SO_4 solution has been electrolyzed using a photovoltaic solar cell (12V) as a source of electric current. Electrode phenomena can be observed when an appropriate indicator is present in the electrolyzed solution. In chemistry, an indicator is a good mean to indicate the presence of a specific chemical or the occurrence of a chemical reaction. Phenolphthalein is an example of an acid-base indicator that turns from colorless in neutral and acidic solutions to violet in basic solutions.

The advantages for using electrolysis systems coupled to photovoltaic cells as opposed to the conventional electrolysis systems:

The authors in this lab demonstration have made a significant modification on the conventional electrolysis systems. Instead of using a Direct Current (DC)-power supply as a source for an electrical current a photovoltaic cell has been coupled to the electrolysis system for supplying an electrical current to carry out an electrolysis process. This approach provides an alternative method for the conventional method where the DC-power supply is the main condition for carrying out any electrolysis activity. This alternative method, in fact, insures laboratory demonstrators to carry out electrolysis reactions outdoors or in any place where a source of a DC-power supply is not available. Also, using photovoltaic cells would avoid the use of batteries that contain toxic ingredients that impose a proper disposal. To the best of our knowledge, this is the first report that describes electrolysis cells coupled to photovoltaic cells. This kind of modification might bring some changes and also encouragement for introductory chemistry students to practice one of the very few unique examples that involves interdisciplinary of scientific phenomena in their laboratory activities. Besides that, using photovoltaic cells as a source of electricity results in increasing the awareness of students to the availability of other friendly sources of energy and therefore increasing their use in our communities to reduce the environmental damage caused by the excessive use of fuel. In many cases, students are very hesitant to use DC-power supplies because of their complexity to regulate the intensity of the flowing current or because of unsafe connections to an electrical source of high electrical current. On the other hand, students are in general familiar with low current photovoltaic cells and therefore they consider them as safer and therefore use them .friendlier in their laboratory activities

Materials

Photovoltaic solar cell (Siemens, SM10 Module tupe, Rated power P_{max} [W_p]10, Configuration 12V, Rated current I_{MPP} [A] 0.61). This type of solar cell is inexpensive (a few dollars per one unit) and is readily available in electrical devices shops. This type of cell operates outdoors in sunny days and when it is cloudy, a lamp as a source .of light is adequate to start this demonstration

Electrolysis Apparatus (Hoffman Apparatus) see Fig. 1.see below,

.Beakers (250ml)

.Copper wire

Reagents

.Sodium sulfate (Na_2SO_4) solution 1M

.Sulfuric acid (H_2SO_4) solution 1M

.Sodium hydroxide (NaOH) solution 1M

.Phenolphthalein solution

Red cabbage juice: This solution is prepared by boiling red cabbage in water for 15min. After cooling the mixture to room temperature the juice is filtrated to remove .the leaves

Demonstration

A solution of 1M Na_2SO_4 (250 ml) containing a few drops of phenolphthalein is placed in a glass beaker. Fill the electrolysis apparatus with the sodium sulfate solution. Connect the 12V photovoltaic solar cell (Direct Current (DC) power supply) to the electrodes of Hoffman apparatus in order to start the electrolysis. Allow the experiment to run till you observe changes in the color .of the indicator near one of the electrodes

Add 200ml solution of 1M H_2SO_4 and a few drops of phenolphthalein into a 250ml-beaker, to show that the acid form of phenolphthalein indicator is .colorless in acidic solutions

Add 200ml of 1M NaOH and a few drops of phenolphthalein into a 250ml-beaker, to show that the base form of phenolphthalein indicator has a violet .color in alkaline solutions

Observations

Electrolysis of water is a key chemical reaction, which is very often demonstrated for students. When an electrical current (DC) is passed through a water solution, the energy of the electricity breaks the water molecules apart. Oxygen gas and hydrogen ions are produced at the anode while hydrogen gas and hydroxide ions are released at the cathode side (Eqs. 1 and 2) (Hugerat, Basheer, 2001; Ward, Greenbowe, 1987).

Eq. 1: At the anode: $\mathbf{6H_2O_{(l)}}$ ------ $\mathbf{4H_3O^+_{(aq)} + O_{2(g)} + 4e^-}$

Eq. 2: At the cathode: $\mathbf{4H_2O_{(l)} + 4e^-}$ ----- $\mathbf{4OH^-_{(aq)} + 2H_{2(g)}}$

Net cell reaction: $\mathbf{2H_2O_{(l)}}$ ------ $\mathbf{2H_{2(g)} + O_{2(g)}}$

As the electrolysis of water proceeds, the color of the indicator changes in the surrounding of the cathode when phenolphthalein is used as an indicator, while the color in the surrounding of the anode remains colorless. The intensity of the color is dependent on the change in the pH of the solution near the electrode. As a result of electrolysis of water, bubbles of hydrogen gas as well as hydroxide ions accumulate in the cathode side. On the other hand, bubbles of oxygen gas and also hydrogen ions are produced in the anode side. Therefore, after a few minutes from closing the electric circuit it can be clearly observed that the color of the indicator turns into violet near the cathode, while it remains colorless near the anode.

A fascinating phenomenon can be demonstrated when the DC connections between both electrodes is reversed (Hendricks, Williams, 1982). Due to reversing the polarity of both electrodes the initially anode become the cathode and the initially cathode is converted to anode (Fig. 1). As a consequence of this change, an acid - base neutralization occur in the surrounding of each electrode due to the electrolysis of water according to Eqs. 1 and 2. Therefore, the violet color of the surrounding of the new anode gradually disappears and turns to colorless while the colorless surrounding the new cathode turns to violet.

In order to show different color-change for the acid-base indicator, red cabbage juice (or any other known acid-base indicator available in the chemicals storeroom) can be used instead of phenolphthalein (Skinner, 1981). The plant pigments present in red cabbage, authocyanins, turn to red in acidic solutions, purple in neutral solutions, and green to yellow in basic solutions. It can be clearly observed after a few minutes of electrolysis that the color of the indicator turns as the following:

Anode: purple $\longrightarrow$ red

Cathode: purple $\longrightarrow$ green

The same phenomena can be observed when exchanging their connections to the DC reverses the polarity of both electrodes. In this case, reversing the polarity of both electrodes changes the initially red color to green near the new cathode and from green to red near the new anode.

In this lab demonstration, students can observe an integrative physico-chemical phenomena related to an acid-base neutralization. Here, the neutralization has been carried out as a result of electrolysis of water powered by photovoltaic cells that converts sunlight into a non-polluting source of electrical energy. Currently, the development of a quantitative acid-base titration *via* electrolysis of water using a solar .panel is under a further study in our laboratory

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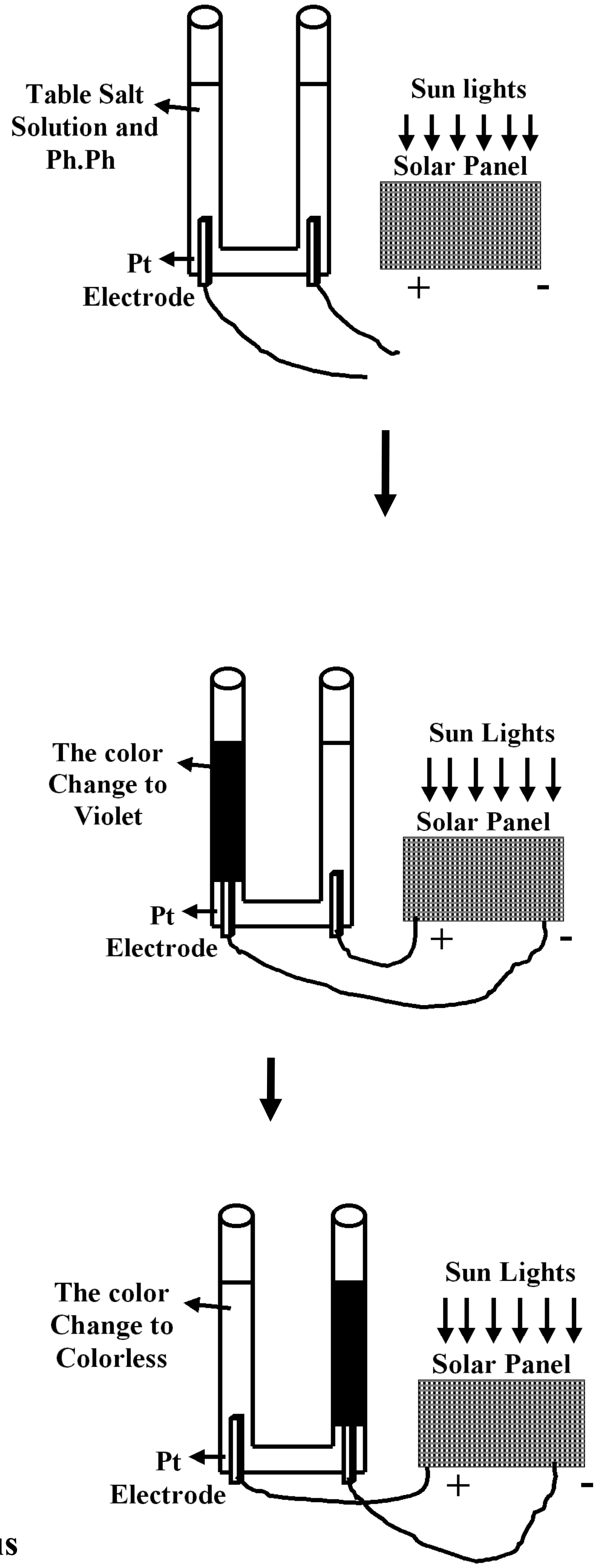

A

B

FIG. 1: Electrolysis Apparatus