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Journal of Applied Research in Science and Humanities

Design of galvanic cells using simple, low-cost paper

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Abstract

This article's stated goal is to give teachers a low-cost model for a lab exercise and to demonstrate galvanic cells using a paper-based device. As electrodes, metal ions, and electrolyte, respectively, metal strips, metal solutions, and KCl solution are used. In addition to supporting reactions, a paper-based device functions as an electrolyte salt bridge. This article obvious the key points of the paper-based galvanic cell activity, highlighting its cost-effectiveness, simplicity, and versatility for use across various educational levels in the field of chemistry. It also emphasizes the practicality and potential applications of the activity in both classroom demonstrations and student experiments. Moreover, teachers can adapt and customize the paper-based device to suit their specific teaching needs in chemistry and related fields, for broad application and enhanced student learning experiences.

Key Words:

Electrodes – Electrolyte – potential – Salt bridge – Galvanic cell

1. Introduction:

An electrochemical cell is a device that generates electrical energy from chemical reactions. Electrochemical cells which generate an electric current are called voltaic or galvanic cells. An Electrical energy can be applied to the cells to cause non-spontaneous chemical reactions, via electrolysis for example, these cells are called electrolytic cells.

A galvanic cell (sometimes called voltaic) is a device that produces an electric current by

means of redox reaction (Brosmer, et al. 2012, 763) (Grønneberg, et al.2006 ,1201)

The total cell potential of a galvanic cell is determined by adding the two half–cell reduction potentials, which can also be computed using the equation that follows:

$E°_{cell} = E°_{cathode} - E°_{anode}$ (1)

Mini the total cell potential, expressed in volts (V), is the $E°_{cell}$. The standard reduction potentials for the reactions at the cathode and anode are represented by the values of $E°_{cathode}$ and $E°_{anode}$, respectively.

The Daniell cell or a zinc–copper cell is a model of a basic galvanic cell that is frequently used. Because of its less expensive and easily adaptable varieties for both qualitative and quantitative analysis, this cell has been featured frequently in several introductory chemistry textbooks

(Cracolice, et al.2011 ,582) (Elis Nelson Ortiz, Etal.2012,643) (Supasorn Suwajanakorn, etal.2015,393) In this cell, zinc and copper are used as electrodes. Each of the metals is immersed into a solution of its ions. The two solutions are connected through a salt bridge or a porous pot. The functions of a salt bridge or a porous pot are to prevent the two electrodes from mixing and to allow the movement of the ions in order to complete the circuit. The salt bridge can also be a U–shaped tube that contains a saturated solution Such as (KCl, KNO_3 OR Na_2SO_4) which doesn't react with the two electrolytes.

The form of the Danielle cell:

$Zn_{(s)} | Zn^{2+}_{(aq)} || Cu^{2+}_{(aq)} | Cu_{(s)}$.

The lemon battery is another easily type of this cell that is frequently used for science projects in schools since it shows the essential parts of a battery (Worley,et al.1988,65) metal strips, known as electrodes, are placed inside a lemon; these are usually copper and zinc. The electrolyte in this case is lemon juice.

A paper–based device has several benefits in analytical chemistry, including low cost and quick and simple fabrication (Yetisen, et al. 2013, 2210) (Liu, et al.2014 ,1214) Although some reports showed different devices for construction of galvanic cells (Brosmer, etal.2012,763) (Grønneberg, etal.2006,1201). However, cells using a paper device are still not widely published. As a result, the purpose of this article is to show how to create paper–based galvanic cells, which are inexpensive, readily available, disposable, and flexible. Students can quickly create the paper–based galvanic cells with small pieces of metal strips, and filter paper. To build each half–cell, metal strip electrodes are placed on paper–based galvanic cells. To connect all of the Activity half–cells, an electrolyte solution is added to the device's centre. A paper–based apparatus serves as an electrolyte salt bridge in addition to a support for reactions. The paper tool created here is ideal for teaching electrochemistry in a laboratory experiment, classroom activity, or demonstration in a short time period.

galvanic cell: is an electrochemical cell which converts the free energy of a chemical process into electrical energy.

The anode: is the electrode where oxidation (loss of electrons) takes place.

The cathode: is the electrode where reduction (gain of electrons) takes place.

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A Salt bridge: is used to maintain electrical neutrality inside the circuit of a galvanic cell.
Redox reactions: are reactions that involve the transfer of electrons from one species to another.
Electrolyte: substance that conducts electric current as a result of a dissociation into positively and negatively charged particles called ions

Figure (1): Equipment and materials needed for the fabrication of galvanic cells.

2.The Theoretical Framework:

The purpose of this article is to show how to create paper-based galvanic cells, which are inexpensive, readily available, disposable, and flexible. Students can quickly create the paper-based galvanic cells with small pieces of metal strips, wax, and filter paper. To build each half-cell, metal strip electrodes are placed on paper-based galvanic cells. To connect all of the Activity half-cells, an electrolyte solution is added to the device's centre. A paper-based apparatus serves as an electrolyte salt bridge in addition to a support for reactions. The paper tool created here is ideal for teaching electrochemistry in a laboratory experiment, classroom activity, or demonstration in a short time period.

3.Methods of Research and the tools used:

the tools and solutions used for the fabrication of paperbased galvanic cells are listed in Figure 1.

According to Kay and colleagues (Zedeng Chen, Etal.2012,90), the creation of a paper-based device using filter paper has been accepted. In our activity the five distribution channels of the filter paper are drawn using scissors. Clean the five strips (Zn, Cu, Al, Pb and Fe) from any oxides or rust using a piece of emery paper before using to obtain good results. Each stripe was put on its channel of the filter paper. The schematic illustration for fabricating paper-based galvanic cells is shown in Figure 2.

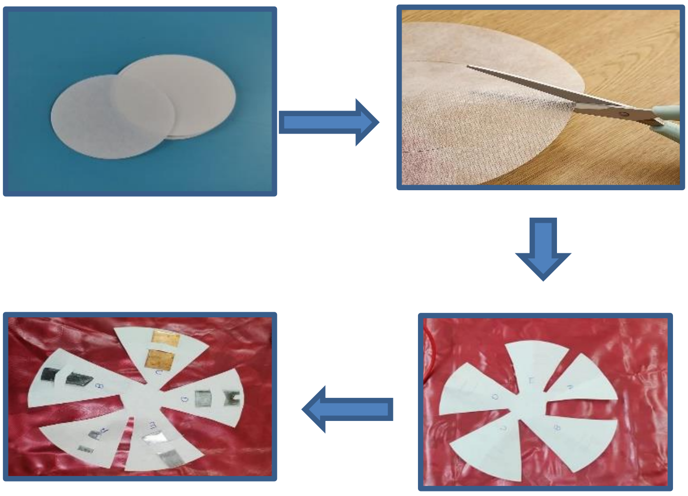

Figure (2): Schematic illustration for fabricating paper-based galvanic cells.

Equipments:

- **Metal strips (Copper, Aluminium, Lead, Iron, Zinc)**
- **Emery paper**
- **Voltmeter**
- **Filter paper (for salt bridge)**
- **Dropper or pipette**
- **Container for metal ion solutions**
- **Stirring rod**

Materials:

– Metal ion solutions (e.g., $CuSO_4$, $Al2(SO_4)_3$, $(CH3COO)_2Pb$, $FeSO_4$, $ZnSO_4$)

– KCl solution (for salt bridge)

–Distilled water

–Paper–based template with 5 distribution channels use slats (e.g., $CuSO_4$, $Al_2(SO_4)_3$, $(CH3COO)_2Pb$) were papered by using distilled water in concentration of 1.0 M The metal ion solution is added to its corresponding metal strip in each of the five distribution channels (e.g., $ZnSO_4$ solution on the zinc strip, etc.). Subsequently, 1.0 M KCl solution is placed in the centre of the paper–based galvanic cells to act as an electrolyte, also known as a salt bridge, between the half–cells on a filter paper. Lastly, a voltmeter is used to measure the cell potentials (see Figure 3).

The steps for creating a simple galvanic cell using a filter paper with 5 electrodes.

- **Cut the filter paper correspondingly**
- **Clean the electrodes using a piece of emery paper to remove any corrosion layer(rust). shown in Figure 2.**
- **Obtain Zn plate, Cu plate, Al plate, Pb plate, and Fe plate.**
- **Prepare solutions of KCL, ZnSO4, FeSO4, $(CH3COO)_2Pb$, $CuSO_4$, $Al_2(SO_4)_3$ [1M]**
- **Place the electrodes in KCl solution so that there is an electrical reaction between two electrodes.**
- **Connect the electrodes and use them to generate electric current.**
- **Measure the cell potentials using a voltmeter!**
- **You can use this galvanic cell to power small devices.**
- **Make sure to follow safety precautions while experimenting with creating a galvanic cell and avoid exposure to harmful chemicals.**

4. Results

The standard potential of a cell, or E0cell, for spontaneously occurring chemical reactions is always positive in nature. For instance, the overall cell reaction in the Daniell cell,

$Zn_{(s)} | Zn^{2+}_{(aq)} || Cu^{2+}_{(aq)} | Cu_{(s)}$, is

$Zn_{(s)} + Cu^{2+}_{(aq)} \rightarrow Zn^{2+}_{(aq)} + Cu_{(s)}$

The observed cell potentials, $E°_{cell}$ (obs), were 1.08 V, whereas the theoretical cell potentials, $E°_{cell}$ (theo), for the galvanic cell $Zn_{(s)} | Zn^{2+}_{(aq)} || Cu^{2+}_{(aq)} | Cu_{(s)}$, were 1.10 V based on the values for the standard reduction potentials (see Electromotive series). As indicated by Table 1, the $E°_{cell}$ (obs) and the $E°_{cell}$ (theo) values differ slightly in general.

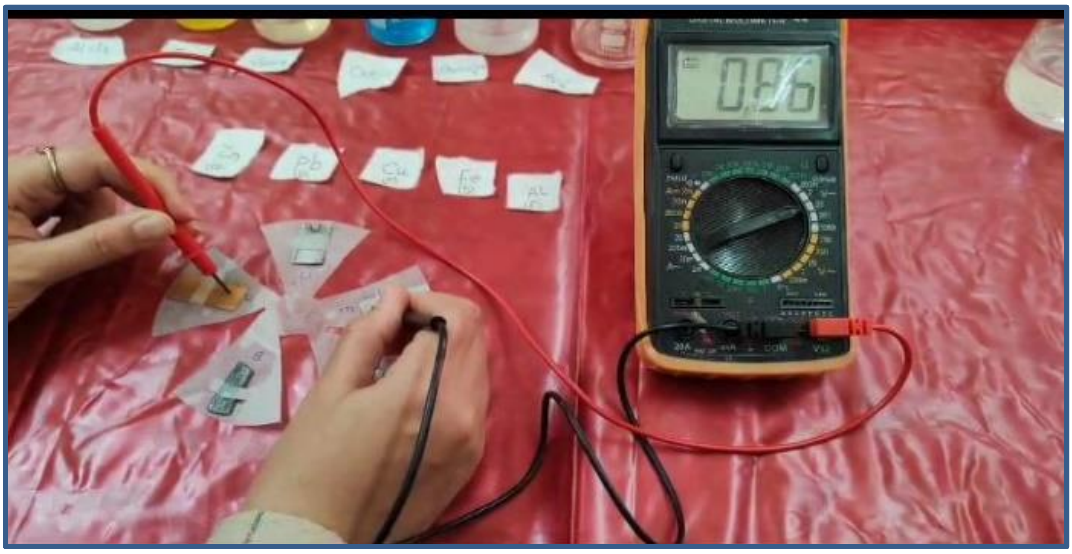

Figure (3): Measuring the overall cell potentials by a multi-meter.

Table 1. Comparison between $E°_{cell}$ (Obs) and $E°_{cell}$ (Theo)

Cell	Practical $E°_{cell} = E°_c - E°_a$		Theoretical $E°cell = E°_c - E°_a$		
	E^0_c	$E°_{cell}$	$E°_{cell}$	$E°_a$	$E°_c$
Zn|Cu	**0.32**	**1.08**	**1.1v**	$E°_{Zn}$ **-0.76v**	$E°_{Cu}$ **0.32v**
Zn|Pb	**-0.13**	**0.58**	**0.63v**	$E°_{Zn}$ **-0.76v**	E^0_{pb} **-0.13v**
Zn|Fe	**-0.42**	**0.34**	**0.32v**	$E°_{Zn}$ **-0.76v**	$E°_{Fe}$ **-0.44v**
Fe|Pb	**-0.13**	**0.31**	**0.31v**	$E°_{Fe}$ **-0.44v**	$E°_{Pb}$ **-0.13v**
Fe|Cu	**0.31**	**0.75**	**0.78v**	$E°_{Fe}$ **-0.44v**	$E°_{Cu}$ **0.32v**
Pb|Cu	**0.35**	**0.48**	**0.47v**	$E°_{Pb}$ **-0.13v**	$E°_{Cu}$ **0.32v**
Al|Zn	**-0.77**	**0.89**	**0.9v**	$E°_{Al}$**-1.66v**	$E°_{Cu}$ **-0.76v**
Al|Pb	**-0.12**	**1.8**	**1.5v**	$E°_{Al}$ **-1.66v**	$E°_{pb}$ **-0.13v**
Al|Fe	**-0.42**	**1.24**	**1.22v**	$E°_{Al}$ **-1.66v**	$E°_{Fe}$ **-0.44v**
Al|Cu	**0.32**	**1.97**	**1,98v**	$E°_{Al}$ **-1.66V**	$E°_{Cu}$ **0.32v**
E°cell (obs) is measured at 25 °C (298 K) and 1M concentration					

5. Interpretation of Results:

In the present study, individual half-cell reactions occur at the surface of electrodes (metal strips). The anode is the electrode at which oxidation takes place, and the cathode is the electrode at which reduction takes place. Electrons can flow spontaneously through the external wire from the anode (the negative electrode of the galvanic cell) to the cathode (the positive electrode of the cell), and the current continues its path in the circuit through the movement of ions across the salt bridge. To clarify chemical concepts, such as redox reactions, students must deal with three level of representation: macroscopic, submicroscopic, symbolic (Treagast,et al.2008, 237) (Cullen, et al.2011,1562) (Ortiz Nieves, et al. 2012, 643).

Considering $Zn_{(s)}|Zn^{2+}_{(aq)}||Cu^{2+}_{(aq)}|Cu_{(s)}$, the oxidized Zn metal, is the reducing agent. During the process, the reducing agent gets oxidized because it loses electrons. On the other hand, the oxidising agent is the Cu^{2+} ion, which is reduced by taking up electrons that have been transferred from Zn metal (see Figure 4).

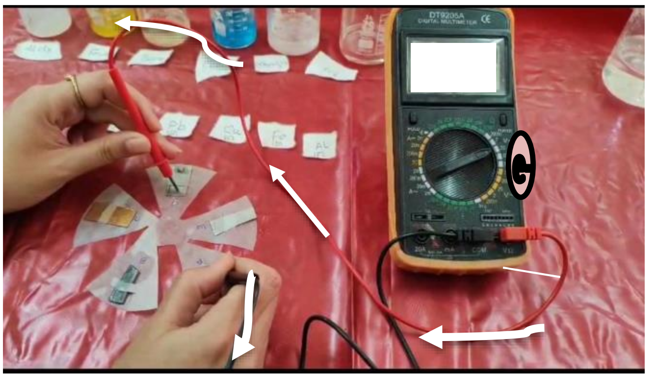

Figure (4): Illustration of the overall cell

Students may find it easier to relate what is happening at a submicroscopic level between the Zn metal and Cu^{2+} ion during a hands-on activity if chemistry concepts are explained using three levels of representation (i.e., change in colour of Cu^{2+} solution). After that, they can use a symbolic level (chemical equation) to depict the change. These aids students gain a deep understanding of electrochemistry concepts (Supasorn, et al.2015, 393).

Furthermore, it is possible that Difficulties faced by students in understanding the connections between the three levels of representation are due to their lack of exposure to symbolic, submicroscopic, or macroscopic types of information. In this study the less active metal cation can be reduced by the more active metal. Based on the data from this study, the reducing ability of metals is listed as follows: Al, Zn, Fe and Pb. In spite of multiple microscale and simplified techniques for building galvanic cells have been reported in prior literature, this work is a very simple and economical novel idea for fabricating galvanic cells. Either a laboratory class or an active learning "lecture" or "discussion" setting would be appropriate for this exercise. It is possible for teachers to create a paper-based tool for use in chemistry classes as well as related subjects like environmental, forensic, and biochemistry.

6. Conclusion:

We've shown how to make a galvanic cell with a paper-based device in an easy activity. This simple–to–assemble and operate device is suitable for use as a model to teach high school students about electrochemistry in the laboratory. In first–year, general, and upper–division graduate courses in analytical chemistry, this kind of activity can be employed as an active learning method. Teachers in a variety of fields, including environmental chemistry, forensic chemistry, and biochemistry, can also build and modify a paper device to teach their labs.

7.Acknowledgment:

No words can ever express our sincere gratitude to ALLAH who guided and aided us to bring this thesis to light. All work to fail to express our thanks and sincere gratitude to Dr. Nobl Fouad Elboraei, Assistant Professor of Electro Chemistry, Faculty of Education, Ain Shams University for suggesting the point, for her continuous supervision, guidance, constructive criticisms, beneficial discussion and indispensable help to write down this work in its final form. We would like to thank MS: Hanan, Chemistry Laboratory Preparation of Education, Ain Shams University for her help, encouragement and her interest. We would like to thank Prof. Dr. Mohamed Abbas, Head of Chemistry Department, Faculty of Education, Ain Shams University for his help, encouragement and his interest. Gratitude is also extended to staff of chemistry department, faculty of Education, Ain Shams University, for providing the necessary facilities to bring this work.

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