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Integrated approach of learning: An effective way to teach electrochemistry

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Abstract
Present article focuses on the pedagogical concerns and suggests the ways to make the teaching-learning of electrochemistry effective and interdisciplinary. There are some suggested activities which involve student's participation and certain interesting examples which may motivate students to learn and explore more about this topic and get answers to many misconceptions. This reflects that the approach to deal the topic in coherence with other topics may improve the learning level of students.

Keywords: Electrochemical cell, oxidation-reduction, electric current, photosynthesis, biological photovoltaics

Introduction

Disciplinary approach is predominantly followed in dealing science at higher secondary stage. Physics, Chemistry and Biology; the three branches of science are studied separately at this stage. The concepts of science are compartmentalized into these branches for the sake of systematic study and to touch the depth of the content. However, it ultimately results into considering the concepts with reference to a particular branch, ignoring the connections between them. Interference of one branch into another is generally ignored during pedagogical process. Teachers follow the practice to restrict themselves for the content areas related to their discipline of expertise. Collaboration of one discipline with others finds no space. As a consequence, these disciplines are considered as separate air tight compartments. This unintentional behavior ultimately generates gaps in understanding for the concept as well as lack of interest for the subject. Dealing of chemistry topic without highlighting connections with physics and biology concepts becomes the cause of several alternative concepts or misconceptions. Electrochemical cell is one of the victims of such kind of problem. The topic can provide an opportunity to cross the disciplinary boundaries but a survey conducted with a group of students at higher secondary and graduate level reflects the outcome of dealing the topic with compartmentalization:

A group of students say:

- The cell that we study in chemistry is different from the cell we study in physics.
- In chemistry anode is negatively charged and cathode is positively charged but this is opposite in physics.
- Electricity in chemistry and physics is different because current flows in opposite directions.
- Electricity production in biological cells is absolutely amazing. Is it possible?
- Cell that we study in physics or chemistry has no correlation with the cell that we study in Biology.

Such statements point out the gaps in fundamental understanding about the concept which ultimately promotes rote memorization. It has been quoted that "electrochemistry" is the most difficult topic to teach and understand for teachers, student teachers and students because of its complex structure [1-3]. The difficulties in electrochemistry arise due to the level of abstraction of the topic, lack of inadequate pedagogical practices, representations found in textbooks, interdisciplinary nature of the topic, gap in understanding the relation between the concepts from physics and chemistry. Electrochemistry is the interconnections of several concepts. Content in physics, chemistry and biology help together to deal the problem related to electrochemistry.

Hence, this is very important to have clarity about linkages of topics. The following web represents these interconnections (Figure 1).

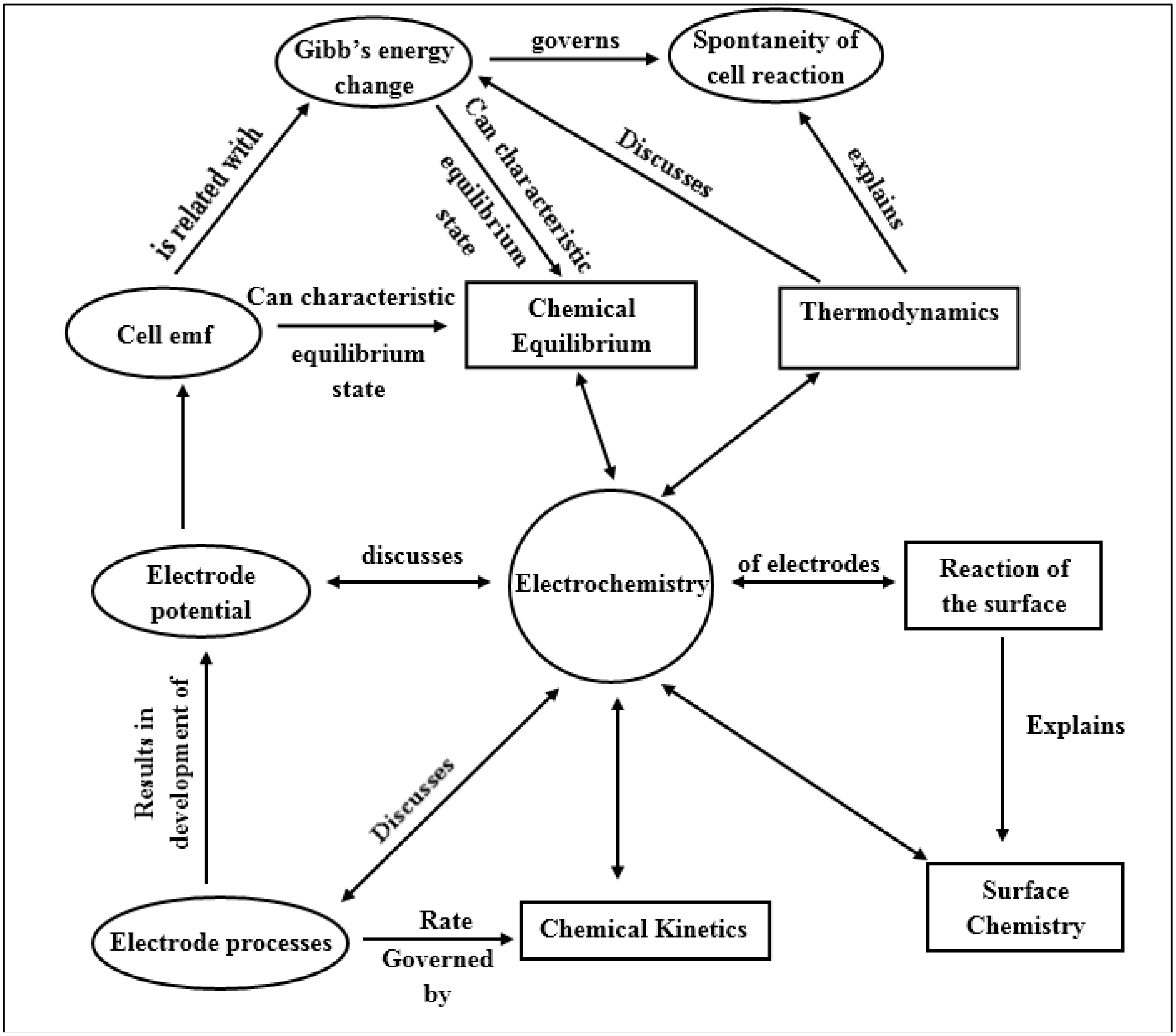

Fig 1: Concept Web of Topics Related to Electrochemistry

Teachers' voice: "We follow the same sequence as given in the textbook". It has been observed that construction of a Daniel cell occupies the first place in the textbooks as well during teaching of electrochemistry. Textbooks generally discusses about batteries at the end of the chapter. Hence, teachers also follow the same sequence as suggested in the textbook. Most of the time it has been found that these topics are generally ignored during transactional process or left for the project work without giving space for discussion. As a result understanding and interest for the topic is lost.

Some studies have suggested ways of remedying misconceptions about electrochemistry in the literature. These studies have used one conceptual change method and/or technique such as computer animations[4-6]or computer-assisted learning [7], conceptual change instruction [8], cooperative learning strategies [9], conceptual change text [10] and jigsaw puzzle techniques.

This paper focuses on some suggestions regarding pedagogical practices that may help in better understanding of the topic. For example, connecting knowledge to real life experiences can be utilized as a tool to generate interest and develop understanding for the subject among learners. Hence, the application part of the concept which is generally discussed at the end of the chapter in textbook can be given space at the beginning during transactional process irrespective of the position of the concept in the book.

The Concept Building

Concept of oxidation and reduction

The concept of oxidation and reduction is linked with the concept of electrochemistry. The fundamental knowledge about redox reactions is necessary to understand the reactions occur in electrochemical cells. Hence, gap in understanding for this concept creates the gap in learning of electrochemistry. The fundamental principles of redox reactions need to be strengthened before initiating the concept of electrochemistry. The example of photosynthesis [11], the phenomenon which is taught to students even at primary levels, a process that occurs in plants and in cyanobacteria and also in purple photosynthetic bacteria, wherein light energy is converted into chemical energy, can be used to explain the concept of oxidation and reduction.. The overall process is described by the chemical equation:

$$CO_2 + H_2O \rightarrow (CH_2O) + O_2 \text{ (requires photons)} \quad (1)$$

Here, "(CH_2O)" represents a carbohydrate. The reduction reaction involves change in oxidation state of the carbon atom from +4 to 0 and oxidation reaction involves change in the oxidation state of oxygen from -2 to 0 (in its natural state of O_2).Thus, the overall reaction of photosynthesis takes place in two steps. In the first step, the oxygen in water is oxidized by the light energy:

$$2H_2O \rightarrow O_2 + 4\,[H^{\cdot}] \quad (2)$$

Here, $[H^{\cdot}]$ represents a reducing agent. In the second step, the $[H^{\cdot}]$ reduces the carbon in CO_2:

$$4[H^{\cdot}] + CO_2 \rightarrow (CH_2O) + H_2O \quad (3)$$

Reaction (2) is known as the "light reaction" and reaction (3) is known as the "dark reaction" but both can take place in the light.

Linkage between cell in biology and cell in chemistry or physics

Galvani's compatriot, Alessandro Volta, was one of the first to appreciate that, while biological organisms generate and are influenced by electricity, electric phenomena are not exclusive to life and can be generated by an apparatus as simple as two disks of different metal in contact with each other and with an ionic solution [12]. These simple electrochemical cells possess a characteristic potential. Under standard conditions, the electrochemical potential is an unvarying property of a specific pair of metals or other chemical substances, one of which is oxidized and one reduced, and it is proportional to the standard free energy of the redox (reduction > oxidation) reaction. There is in fact an identity between the electrical work done by an electrochemical cell and the free energy. The Nernst equation is the second link between thermodynamics and electricity, and relates the concentrations of chemical compounds at equilibrium and their electrochemical potential under nonstandard conditions. This link underpins the generation of bioelectrical potentials; cells pump ions across cell membranes, leading to electrical potentials, which are in turn sustained by equilibria with ion concentration gradients across these membranes. Biological organisms do not merely do chemistry; they also do electrochemistry.

The large voltages electric eels and catfish produce are generated by stacking literally thousands of cell membranes, each of which individually creates a potential of the order of 100 mV. Similarly, all cells carry membrane potentials. These potentials are the foundation of nerve transmission and also drive the transport of most chemical compounds across biological membranes. A number of different kinds of ion pumps, of which the most important is the sodium> potassium ATPase, actively transport ions across cell membranes, using the chemical energy provided by ATP hydrolysis to overcome unfavorable electrical and chemical potential gradients. The negative potential across the cell membrane allows positive ions such as Ca^{2+} and $Mg^{\cdot}$. The electrical potential itself is exquisitely sensitive to the movement of small numbers of ions, and can under the right circumstance change rapidly, allowing the phenomenon of nerve conduction.

Convention for direction of current

In a conductive material, the moving charged particles which constitute the electric current are called charge carriers. In metals, which make up the wires and other conductors in most electrical circuits, the positively charged atomic nuclei are held in a fixed position and the negatively charged electrons are free to move, carrying their charge from one place to another. In other materials, notably the semiconductors, the charge carriers can be positive *or* negative, depending on the dopant used. Positive and negative charge carriers may even be present at the same time, as happens in an electrochemical cell.

A flow of positive charges gives the same electric current and has the same effect in a circuit as an equal flow of negative charges in the opposite direction. Since current can be the flow of either positive or negative charges, or both, a convention is needed for the direction of current that is independent of the type of charge carriers. The direction of conventional current is arbitrarily defined as the same direction as positive charges flow.

Experimental Activity

At this point, involvement of learner in opening of dry cell will facilitate them to learn about structure of dry cell. Hands on experiences with the construction of improvised dry cell and Daniel cell help the learner to make connections between production of electricity and reactions taking place in cell.

Activity 1: Dissection/opening of a used dry cell

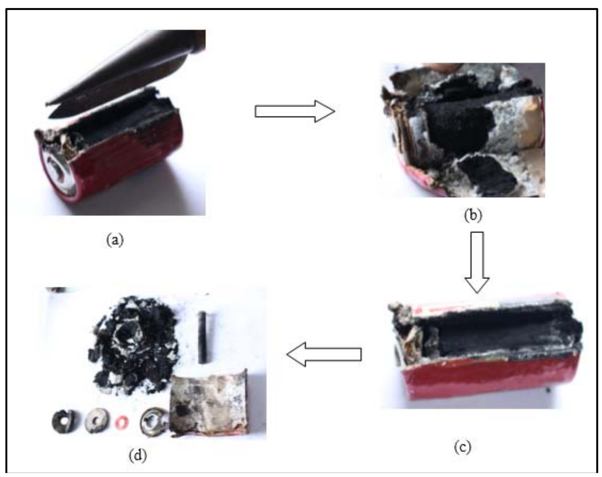

Fig 2: Pictorial representation of the steps in opening of the used dry cell.

Take a used commercial dry cell, a file, a cutter and a piece of cloth (Figure 2). While dissecting the cell wear safety glasses and gloves. Take care while handling file and cutter during dissecting the outer metallic covering of the cell.

- Make group of students as per the convenience. Provide each group a used commercial dry cell. It would be better to make available different brands of cells to different groups. Engage students to open dry cells under supervision (If necessary, a teacher may

demonstrate it first) and photographs of different stages of dissection may be taken (Figure 2).
- Ask students to explore the parts of cells and make a list and initiate group discussion for sharing of observations and to reach at conclusion regarding different parts of a cell of different brands (Figure 2).

Activity 2: **Construction of an improvised Dry cell (Group activity) [13]**

You need 100 mL of saturated ammonium chloride(NH_4Cl), 4.0 g powdered manganese dioxide(MnO_2), 1 torch bulb (1.5V), 2 wire leads with alligator clips on both ends,1 cotton/ felt pad about 12cm x 5cm x 5mm thick, 1 zinc foil/plate, 1carbon rod (8.0 mm in diameter obtained after dissection of dry cell), string,1voltmeter with probes, 1spatula

Moisten the cotton/felt pad by immersing it in the saturated NH_4Cl solution and squeezing it. Sprinkle 4 g of MnO_2 with a spatula in a layer onto the pad.

- Wrap the pad around the carbon rod with the MnO_2 between the carbon and the pad. Put it on zinc foil/plate and make sure that zinc does not touch the carbon rod (Figure3). Tie the assembly together with a string.
- Press one of the probes of the voltmeter against the zinc and the other probe against the carbon rod. Attach the lead from the positive terminal of the torch bulb to the carbon rod and clip the other lead to the zinc foil/plate. The torch will glow.

Understanding through worksheet

If necessary, help of worksheets may be taken to revise the concepts. One such worksheet is suggested here for redox reaction.

Worksheet 1: Redox Reactions

Fig 3: Pictorial representation of rusted article

- Addition of oxygen to any atom is called ……………………
- Addition of hydrogen to any other atom is called ……………………
- Removal of oxygen from a given species/compound is ……………………
- Removal of Hydrogen from a given species/compound is ……………………
- Addition of electron to any atom is ……………………
- Removal of electron from any atom is ……………………
- $Zn(s) \longrightarrow Zn^{2+} + 2e^-$
  This is …………………… process (oxidation/Reduction)
- $Cu^{2+} + 2e^- \longrightarrow Cu(s)$
  This is …………………… process (oxidation/Reduction)
- Oxidation process occurs in any chemical reaction with simultaneous reduction Process. (T/F)
- Oxidation and reduction reactions occur in isolation. (T/F)
- Oxidation is followed by reduction. (T/F)
- The phenomenon of decay of any object is…………(corrosion/rusting)
- This phenomenon involves simultaneous ……..and …………

Activities Relating Knowledge with Real Life

Glucometer

The teacher may talk about Glucometer which are used commonly nowadays by diabetic patients to monitor their blood glucose levels with a minimal amount of sample blood. Glucometers utilize disposable electrochemical cells and involves two steps

Step 1: Oxidation of glucose by enzyme, glucose oxidase (GOD) [14] is an enzyme that directly oxidizes glucose.

Step 2: Reduction of enzyme by mediator. Mediator transports electrons to working electrode.

When blood is added, glucose is oxidized by enzyme coated on the working electrode. Voltage is applied between working and reference electrode. The current is measured between working and reference electrode

Biological Photovoltaics (BPV)

It is an energy-generating technology which uses oxygenic photoautotrophic organisms, or fractions thereof, to harvest light energy and produce electrical power[15]. Biological photovoltaic[16-17] devices are a type of biological electrochemical system, or microbial fuel cell, and are sometimes also called photo-microbial fuel cells or "living solar cells. In a biological photovoltaic system, electrons generated by photolysis of water are transferred to an anode. A relatively high-potential reaction takes place at the cathode, and the resulting potential difference drives current through an external circuit to do useful work. It is hoped that using a living organism (which is capable of self-assembly and self-repair) as the light harvesting material, will make biological photovoltaics a cost-effective alternative to synthetic light energy-transduction technologies such as silicon-based photovoltaics

Conclusion

The above activities will certainly generate more curiosity among the students to understand and explore the concepts of electrochemistry. Now the teacher may introduce the intricacies of the topic by introducing electrode potential, different types of electrochemical cells, difference between cell and battery, applications of electrochemical cells and relevance of this topic in context with other branches of chemistry.

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