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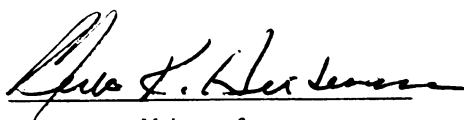
Electrochemistry

presented by

Susan M. Szegedi

has been accepted towards fulfillment
of the requirements for

Masters degree in Science Education



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ELECTROCHEMISTRY

By

Susan Marie Szegedi

A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

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Division of Science and Mathematics Education
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ABSTRACT

ELECTROCHEMISTRY

By

Susan Marie Szegedi

The electrochemistry unit is an important part of the Advanced Placement Chemistry curriculum. By engaging the students in a variety of activities: laboratory investigations, demonstrations and Internet activities, they were able to learn the material and make the best use of a block schedule. The use of technology is also stressed. The findings of this investigation are based upon a pre-test and post-test assessment, laboratory questions, a quiz and a student survey. A significant increase in student achievement suggests that these activities were worthwhile in terms of learning the material for the advanced placement exam and that the students enjoyed performing them.

DEDICATION

This thesis is dedicated to my family without whom this would not have been possible. I would like to thank my husband, Stephen, who encouraged me to do my best and listened to me patiently while I went on and on about what I learned. To my daughters, Stephanie and Samantha, who tried to let their mother do her work, and at the same time maintain some sense of peace in the household. I would also like to dedicate this work to my parents and sisters who "volunteered" to babysit on weekends and during the summer so my daughters would be well taken care of and I could concentrate on my studies.

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RATIONALE FOR STUDY

The rationale for researching and implementing my thesis on electrochemistry was threefold: (1) to provide more hands-on activities to engage student learning; (2) to modify the current delivery of material in a block schedule setting and (3) to incorporate more technology into the curriculum. The class was an advanced placement (AP) chemistry course designed to be the equivalent to the general chemistry course usually taken during the first year of college. The course is team-taught by a veteran teacher, who has over 30 years of experience, and myself. The unit I chose to improve was electrochemistry, which comprises approximately 10% of the AP chemistry curriculum.

In the past, the AP chemistry course was limited to one section or 28 students. Then our central office made "excellence with equity" one of our school district outcomes. To them, this means that all students should be able to achieve in all areas if only given the chance. We could not exclude a student from AP chemistry based upon their prior chemistry course grade. Subsequently, our class typically has 30-50 students or two sections. In addition, before I started teaching, our chemical stockroom shelves were purged of all heavy metal compounds/solutions

due to safety and disposal concerns. Because of these two practices, the electrochemistry unit was severely lacking in laboratory activities. The old labs used lead or nickel compounds and we no longer had enough glassware or lab materials to accommodate the larger class size. Therefore, we did not do **any** labs or demonstrations in this unit.

The impetus for changing this unit was driven both by the students and by the College Board. In 1999, I surveyed the AP chemistry students at the end of the electrochemistry unit, generally asking how it could be improved. The consistent response was more hands on activities or labs. They felt the history that we covered was unimportant, moreover, it is not covered on the AP exam. However, we felt it was important to understand that this knowledge has only been around for a approximately 150 years. The knowledge gained from Faraday, Nernst and Hall helped develop other areas of science as well. According to the College Board AP Program Course Description book for chemistry, which lays out the curriculum for the course, the following electrochemistry labs are recommended:

- 1) Determination of an Electrochemical Series and
- 2) Measurement using Electrochemical Cells and

Electroplating. So, the need to revamp our labs and activities was in order.

PEDAGOGICAL REVIEW

There has been much research on the topic of hands-on or activity based inquiry enhancing student learning. You could go as far back as the ancient Chinese who stated " I hear and I forget. I see and I remember: I do and I understand." Erasmus Darwin stated in 1792 that "A fool... never tried an experiment in his life" (College Board, 2000). Learning by doing is a theme many educators have stressed since John Dewey and Jean Piaget. Recently in the 20th century, there has been a tremendous movement to make science education more active. It can be summarized by DeBoer, "If a single word had to be chosen to describe the goals of science education during the 30 year period that began in the late 1950's, it would have to be INQUIRY" (DeBoer, 1991). The United States Department of Education and the National Science Foundation (1992) together endorsed mathematics and science curricula that "promote active learning, inquiry, problem solving, cooperative learning, and other instructional methods that motivate students" (Rutherford and Alger, 1990). The push toward

more active learning is based upon consistent research. For example, a study by Patricia Stohr-Hunt found that eighth-grade students who experience hands-on activities either every day or once a week, scored significantly higher on a standardized test of science achievement than eighth-grade students who experienced hands-on activities once a month, less than once a month or never (Stohr-Hunt, 1996). In addition, the National Science board summarized that research findings indicate that "students are likely to begin to understand the natural world if they work directly with natural phenomena, using their senses and using instruments to extend the power of their senses" (National Science Board, 1991). In essence all children deserve an education that goes beyond learning isolated facts and skills, to in-depth understanding and complex problem solving that is useful to the students and community outside of the classroom. Lab based inquiry or authentic achievement provides learning that is real and genuine, rather than contrived and artificial. Currently in the 21st century, the technologies emerging from basic science and engineering have given us so many ways to "find out why" that we can hardly enumerate them. Our economy is in the midst of a profound transformation, in which

people's livelihoods are depending less on what they are producing with their hands, and more on what they are producing with their brains (Colwel, 1999). Students who know how to investigate and research a problem will be the most successful in tomorrow's society.

The second objective for changing the current electrochemistry unit was to modify the curriculum in order to best use time in a block schedule. Previously, our high school was on a daily 55 minute period schedule. In the 1999-2000 school year we adopted a seven period, 88 minute/period every-other-day schedule. On Mondays we see all seven periods for 47 minutes, it is considered our "speed day". The other four days are block days. Since the block schedule has been implemented in many parts of the country in the past ten years, we could rely on their successes and failures in order to make our transition go more smoothly. In order for students to get the most out of a block schedule, research indicates that the block should be divided into at least 3 parts: explanation, application and synthesis (Canady and Rettig, 1996). During the explanation portion, teachers do what they have done for years. A mini-lecture is given or student's questions about homework are answered, or a demonstration

is given to focus their attention on the objective for the class period. Following the explanation, the application phase asks students to apply what the teacher has explained. Here is where active learning strategies are incorporated. The authors' stress that providing "hands-on" active learning strategies during the application phase may be the most important determinant of the success or failure of teaching in the block. The science class has a distinct advantage over other disciplines in this phase because laboratory investigations are at the heart of any science class. Lessons end with "synthesis" where the students are to "put it all together". The students reflect and review as the teacher questions or re-teaches.

Another model proposed by Hotchkiss (Hotchkiss, 1995) for designing block time has 5 steps: (1) review homework, (2) present new material, (3) follow with an appropriate activity, (4) offer guided practice, (5) provide closure. In either model, teachers are expected to provide various means of breaking up the block so that students remain engaged and learning. With this in mind, I tried to have at least 2 steps for each block in the electrochemistry unit.

Having class periods almost one and a half the conventional length of time gave me more flexibility in which the pre-lab, lab and post-lab discussion can all be done in one block. In addition to planning how to break up the block, long-term planning is also important. We prepared a weekly assignment sheet for outlining the week's plan for in-class activities and homework. This helped to keep the student's organized and to maintain the time appropriately for each class period. We spent about one hour after school creating the assignment sheet. In conclusion, block scheduling provides the opportunity and the necessity for including a wide range of instructional activities. As science teachers, we beg, borrow or steal every good idea that we see, hear or read about that would add a spark to our regular lesson (Bohince, 1996). I wanted to create a unit that the students not only learned from, but also held their interest for the longer class period. I do not feel I am in the entertainment business, but I do like to keep the students on their toes and actively engaged.

The third objective for change in this unit was to incorporate more computer technology into the electrochemistry lessons. The computer was to be used as a

tool for data collection, data analysis and research on the world wide web. This could be done with our ten mobile computers with universal lab interfaces and the static computer lab. Twenty years ago I managed to graduate from college without knowing anything about computers, but today's college graduates are required to use them, probably on a daily basis. It is only natural to teach students how to use this valuable tool since they will need these skills for the rest of their lives. Even though it is the year 2000, some of my students have not adapted computers into their everyday life. Although this adaptation is not my intention, I would like them to be exposed to their use in the science lab so that it will be easier for them in college. The Internet has allowed access to a vast amount of information for both teachers and students. With the Internet and a good teacher, students can locate information and communicate with others, allowing them to connect with relevant real-world resources (Serium and Koch, 1996). In utilizing the Internet, I can bring current information into my lessons, such as descriptions of fuel cells and state of the art batteries that I could not find in standard college textbooks.

Along with the three pedagogical objectives for this unit, I would also like to address some of the misconceptions students have in the topic of electrochemistry. There has been considerable research on difficulties or misconceptions students have in studying electrochemistry. One of the basic ones is confusion about the nature of electric current both in metallic conduction and in electrolytic conduction. They can state "in order to conduct electricity, you need charged particles free to move," but they really do not understand the difference between metallic conduction versus electrolytic conduction. Garnett and Treagustin (1992), based on interviews of students in Australia, identified nine misconceptions about electric current. My study focused on the first four.

- Protons flow in metallic conductors.
- The movement of ions in solution does not constitute an electric current.
- Protons flow in electrolytes.
- Electrons flow in electrolytes.
- Conventional current is the flow of positive charges (usually protons).

- Protons and electrons flow in opposite directions in an electrolyte.
- Electricity in chemistry and physics is different because the current flows in opposite directions.
- Electrons move through the solution by being attracted from one ion to another.
- When an electrolyte conducts a current, electrons move onto an ion at the cathode and are carried by that ion to the anode.

Sanger and Greenbowe (1997), replicated the research done by Garnett and Treagust. In brief, their findings were similar.

In general, the misconceptions can be summed up by saying many students cling to the notion that electrons flow from the anode to the cathode along the wire, are released into the electrolyte at the cathode, travel through the salt bridge and the electrolyte and emerge from the solution at the anode (Sanger and Greenbowe, 1997).

In summary, my rationale for revising the electrochemistry unit was three-fold: (1) to provide a

more hands-on approach, (2) modify my teacher methods to accommodate the longer block schedule and (3) to incorporate more technology into the unit. In addition, I wanted to specifically address one misconception about current flow in galvanic cells. The time frame for the unit was three weeks. Since AP chemistry is a lab based course, the district agreed with us that more than one block was needed in order to meet the minimum amount of minutes per week recommended by the College Board. Therefore, for the first semester the AP chemistry class met everyday for hours three and four of the seven period schedule. In terms of total minutes of instruction, this was 404 minutes per week. The College Board recommends 290 minutes per week. For the second semester, the AP chemistry class is a single block or 228 minutes per week for an average of 316 minutes per week for the year.

Besides these three points, my hypothesis is: If students are actively engaged in a variety of activities (experiments, demonstrations, computer based activities) then their understanding of electrochemistry will increase compared to the knowledge they bring with them.

OVERVIEW OF THE SCIENCE

In order for students to be successful in the electrochemistry unit, they must have previous knowledge of balancing oxidation-reduction reactions or redox equations. We covered this topic in 15 school days. The topics covered included:

- Faraday's Laws of Electrolysis
- The production of iron from iron ore and aluminum from aluminum ore
- The electrolysis of several solutions
- Metal reactivities
- Galvanic cells or batteries
- The Nernst Equation
- Gibb's free energy
- Fuel cells

In the process of electrolysis, electrical energy is used to produce a chemical change that would otherwise not occur spontaneously. The students used the method of

factor-label or dimensional analysis and the relationship that an **ampere = coulomb/s** to solve several types of problems. An example of this is: "how many minutes must a current of 5.00 amps be applied to a solution of Ag^{+1} to produce 10.5 grams of silver metal?" The balanced chemical equation is:

$\text{Ag}^{+1} + \text{e}^{-} \rightarrow \text{Ag}^{\circ}$ since you are looking for

time $s = C/A$

$s = 10.5\text{g}/5.00\text{A} \times 1 \text{ mole Ag}/107.87 \text{ g} \times \text{A/C/s}$

$\times 1\text{min}/60 \text{ s} \times 1 \text{ mole e}^{-}/1 \text{ mole Ag} \times 96,485 \text{ C}/1 \text{ mole e}^{-}$
 $= 31.3 \text{ minutes}$

Electrolysis is the application of a voltage to a solution and observing the products and writing the two half reactions for each cell. For instance, when a solution of CuCl_2 is used, effervescence of chlorine gas at one electrode and the plating of copper metal at the other electrode occurs.



Aluminum production is an application of electrolysis. In 1886 Charles Martin Hall and Paul Heroult, independently, found they could produce aluminum by passing

a current through a molten $\text{Al}_2\text{O}_3/\text{Na}_3\text{AlF}_6$ mixture (Zumdahl, 1997). The molten cryolite (Na_3AlF_6) acted as the solvent for the Al_2O_3 ore. In contrast, the production of iron from iron ore is **not** an electrolytic one, but rather the chemical reduction of iron ore into pure iron. The iron and steel industry are of major economic importance and a chemistry student should have some knowledge of this industrial process.

To understand how batteries or galvanic cells work, we need to recognize that different metals have different reactivities. For example, when you are given two metals to make a battery, Cu and Zn, we can predict that the zinc will be oxidized more readily than the copper since it is chemically more active.

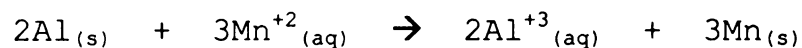
Galvanic cells or batteries consist of an oxidizing agent in one compartment of a cell that pulls electrons through a wire from a reducing agent in the other compartment of a cell. The "pull" or driving force on the electron is called the cell potential or electromotive force. This pull is due to the different reactivities of the two species involved. Given a galvanic cell with a zinc electrode in zinc sulfate solution and a copper electrode in copper sulfate solution, the voltage is

determined using the standard reduction potential tables. One species must get oxidized (Zn) and the other species must get reduced (Cu). Unlike an electrolytic process, a galvanic cell runs spontaneously in the direction that gives a positive value for the voltage or E_{cell} .

While the standard reduction potential is determined at 25°C and all solutions at 1.00 M, the Nernst equation is used to determine a cell potential at non-standard conditions. The Nernst equation was developed by Walther Hermann Nernst who won the Nobel Prize in chemistry in 1920. It is stated:

$$E = E^{\circ} - 0.0952/n \times \log (Q)$$

where E° is the standard potential, E is the cell potential, n is the number of electrons gained or lost and Q is the reaction quotient (products raised to the power of their coefficient of the reaction divided by the reactants raised to the power of their coefficient in the balanced chemical reaction). For instance, in the following reaction:



Calculate E when $[\text{Mn}^{+2}] = 0.50 \text{ M}$ and $[\text{Al}^{+3}] = 1.50 \text{ M}$

$$E^{\circ} = 0.48 \text{ volts}$$

$$E_{\text{cell}} = 0.48 \text{ volts} - 0.0592/6 \log [\text{Al}^{+3}]^2/[\text{Mn}^{+2}]^3$$

$$E_{\text{cell}} = 0.48 \text{ volts} - 0.0592/6 \log [1.50]^2/[0.50]^3 = 0.47\text{v}$$

The Nernst equation is useful for determining the voltage of a battery as it is running because the concentration of the solutions change as the reaction proceeds.

The lead/acid battery is a practical application of a galvanic cell. Even though there is much current research for replacements, the lead/acid battery, supplying 6 or 12 volts, is still the work horse of the car battery industry.

The Gibb's free energy or the maximum amount of energy available to do work in a reaction, can be calculated from cell potentials. The relationship is $\Delta G^\circ = -nFE^\circ$ where ΔG° is the standard Gibb's free energy, n is the number of electrons lost or gained and F is Faraday's constant which is equal to 96,485 C/mole e^- and E° is the standard cell potential. It should be stressed that a spontaneous reaction, such that occurs in a battery has a **+ E°** value and a **- ΔG°** value.

A fuel cell is a galvanic cell for which the reactants are continuously supplied (Zumdahl, 1997). In a fuel cell the energy released in the reaction is used to produce an

electric current. The electrons flow from a reducing agent to the oxidizing agent through a conductor. Many consider fuel cells to be the power source for the future. Car companies are considering hybrid cars with fuel cells and standard hydrocarbon burning engines.

In conclusion, the students will gain an understanding of electrochemistry from Faraday's laws of electrolysis developed in the early 1800's, through Nernst in the early 1900's to fuel cells in the early 2000's.

DEMOGRAPHICS

The eleventh and twelfth grade high school students participating in this study are from a suburban school in Oakland County, which is 25 miles north of Detroit, Michigan. There are approximately 1250 students enrolled in the school. The class meets for two semesters, meeting on a seven period block schedule. The entire school curriculum is college preparatory, as demonstrated by ninety-eight percent of the 1998-1999 graduating seniors were planning to attend a two or four year degree program. The community is considered professional and educated and this is reflected in the high educational goals it sets for its children. The high school is accredited by the North

Central Association of Colleges and Secondary Schools through the University of Michigan. The curriculum of the entire school is considered college preparatory. During the 1998-99 school year, 273 students took advanced placement exams and 229 or 84% scored a 3 or better. The SAT average for 1998-99 was 1199 and the ACT composite score was 24.3. The high school is one of the top three feeder schools in the state for the University of Michigan.

The student body has a spectrum of nationalities including: Caucasian, Arabic, Asian, African-American, Albanian and Jewish. According to the bilingual teacher, 20% of the students speak a second language at home. The community is considered middle to upper middle class in terms of socioeconomic status. Two sections or 30 students from the AP chemistry class participated in this study. There are no criteria for enrolling in the class: all who have successfully completed the first year chemistry class are permitted to enroll. Generally though, the students have obtained an A or B grade in the previous chemistry course and like the content area and/or the teacher.

In conclusion, my research at Michigan State during the summer of 1999, focused on revising the AP chemistry electrochemistry unit with the three goals of providing

more hands on activities, making the best use of the block schedule and utilizing more computer technology.

IMPLEMENTATION

As stated in the introduction, I had three goals for the unit: (1) diversify lessons to make the block effective; (2) include more labs and demonstrations for hands on activities; and (3) to incorporate more computer-based technology. The class is team taught and we took 15 days to cover all of the material. The students took a pre-test (Appendix A-I) on electrochemistry after they completed their prior unit quiz on balancing redox equations. My colleague commented after looking at the pre-test scores (23%), "It looks like fertile teaching territory, Susan." Even though taking physics is a prerequisite for taking AP chemistry, the physics department does not cover the topic of electricity, so very few students knew how a battery worked or how current flows.

The basic outline of the topics covered with approximate time spent for each idea is shown in Table 1. Appendix A contains copies of the pre-test/post-test (it was the identical test). Appendix B is a compilation of labs or demos used in the unit.

Table 1. Basic Outline for Electrochemistry Unit

Day	Topics Covered	Time Frame (minutes)
1	Quiz on balancing redox reactions w/ ion electron method, Electrochemistry pre-test*	60 quiz, 28 pre-test
2	Introduction to Electricity/Coulomb's law, Faraday's 1 st law of electrolysis, Lab Colors and Oxidation Numbers*	44 lecture, 44 lab
3	Faraday's 2 nd law of electrolysis, C=A/s problems	88
4	Video-Aluminum*, video-Iron Production* Discuss homework	30 for each video/discuss, 28 hwk
5	Quiz-Electrochemistry, Demo Electrolytic Refining of Cu*, NaCl and H ₂ SO ₄ Electrolysis	35 quiz, 30 demo, 23 electrolysis
6	Lab-Electrolysis*/Lecture Standard Reduction Potential and Standard Hydrogen Electrode	44 lab, 44 lecture
7	Demo-Electrolysis and Environmental Remediation*, start lecture galvanic cells	15 demo, 73 lecture
8	Lab-Metal Reactivity Series*, problems from textbook	60 lab, 28 problems
9	Quiz Batteries, Introduce Nernst equation	48 quiz, 48 lecture
10	Lecture lead/acid battery, Demo-Citrus Battery and Potato Battery*	68 lecture, 20 demo
11	Lab-Batteries*, Introduction to Gibb's Free Energy	44 lab, 44

12	Internet -Fuel Cells and History of Batteries*	64 Internet, 24 test review
13	Review for test	88
14	Unit Test	96
15	Post-test*, start new material	30 test, 58 new material

*denotes new activities/labs

Although many teachers teach this AP chemistry unit in the spring, we chose to teach it in the fall because it is one of the more difficult units; the information is completely new to the students and we knew from experience that seniors become less motivated to learn as the school year ends. As far as where this unit fits into the curriculum, it could be anywhere in the two semesters, although the students must understand the factor-label method for problem solving and they need to balance redox equations. We also chose to start with electrolysis and then move to galvanic cells. We started with a discussion of Coulomb and Faraday in order to give a more historical approach to the unit. Perhaps the order we did things could be improved upon, but it was difficult going from no labs or activities the previous year, to four labs, three demos, two videos and two Internet activities, while trying

to incorporate them at the appropriate time in the daily schedule. In addition, we also had to juggle 30 students in this study among two teachers. Usually on lab days, we split them into two groups, the alphas and betas, so half of each student's time was spent in lab and the other half in lecture.

Topics that we covered prior to this unit included: Introduction to Equilibrium, Chemical Formula Writing, Chemical Equations, Reaction Stoichiometry, Balancing Redox Reactions. The study lasted from October 27 until November 16, 1999.

*Description of Each Newly Developed Demonstration,
Experiment, Video or Internet Activity and Their Evaluation
(Appendix Reference is in parentheses)*

1) Colors and Oxidation Numbers (B-IV)

The purpose of this lab was for students to gain more practice in balancing redox equations. They also needed to identify the oxidizing and reducing agents in each reaction. The phenomenon of one species acting as a reducing agent and an oxidizing agent or disproportionation

was observed. In addition, the students made a generalization that as the oxidation number increases, the wavelength of light or color you see in a solution decreases that is, a shift toward the blue end of the spectrum. The lab works well with small test tubes and dropping bottles for all the solutions. The students must be told the products for each reaction in order for them to balance the equations correctly. It must be noted that assigning oxidation numbers to species is only a tool in balancing the charges and chemical equations. It is useful for keeping track of electrons in redox reactions, but they are not realistic estimates of the actual charges on individual atoms in a molecule.

2) Videos (Aluminum Chemistry in Action; Iron and Steel

Chemistry in Action)

The purpose of these videos was for students to take a field trip within the classroom. We "traveled" to England to see how aluminum is obtained electrolytically from Al_2O_3 or alumina. The video lasted 20 minutes and was interesting and informative. My students, as high school seniors, were very adept in answering the questions as the video was playing, but we stopped it when someone needed

clarification. It was stressed that electricity must be used to separate the aluminum from the oxygen since aluminum is so reactive and its affinity for oxygen is so strong. Since this process uses so much electricity, it has become very economical to recycle aluminum cans today.

Although the refining of iron ore into iron is a chemical process, as opposed to an electrolytic process, I included a 20 minute video on iron production and steel making as it is an important industrial application of a redox reaction. I asked questions about each step of the process going from Fe_2O_3 to Fe in a blast furnace. Again, the students could watch the video and take notes at the same time but had trouble discerning the big ideas. After the video, I asked, "So what is the basic process happening in a blast furnace?" Very few students could say the reduction of iron ore into pure iron ($\text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 2\text{Fe} + 3\text{CO}$). It was important to have a 10 minute discussion after the video in order to reinforce the basic ideas presented. The video also showed how iron is made into steel at a steel factory. Again, as in the aluminum industry, a significant amount of scrap steel is added to the new steel to recycle and reduce costs. This was the first time I incorporated videos into my curriculum and it worked beautifully. I would highly

recommend both videos for this unit. It also was a terrific way to break up the block of 88 minutes.

3) Demonstration Electrolytic Refining of Copper (B-V)

This demonstration was modified from a lab given to me by Paul Hunter in the chemistry department at Michigan State University. It was called *Measuring the Charge of an Electron by Electrolysis*. Due to time considerations, I modified the lab into a demonstration of the electrolytic refining of copper. A six-volt commercial lantern battery is used as the source of electricity and two copper electrodes are used with a solution of 1.0 M copper(II) sulfate as the electrolyte. If a voltage is applied for a about 1 hour, the students observe the anode getting "eaten away" or smaller in size and the plating out of copper at the cathode. This process is used industrially to produce ultrapure copper which is needed for electrical wiring to obtain low resistance so the wires do not over heat.

4) Electrolysis Lab (B-II)

The purpose of this lab was for students to observe electrolysis. A current from a 9-volt battery was used on three separate solutions: KI; CuCl₂ and NaCl. Starch solution and phenolphthalein were used as indicators. This lab was done when I took NSC 861 (1997) at Michigan State

University. It only takes about five minutes of reaction time for the students to see visible signs of a reaction at each electrode. For the KI solution, effervescence occurs at the cathode as H_2 gas is produced. At the anode, iodide ion is oxidized to iodine and turns the starch solution blue/black. For the CuCl_2 solution, effervescence occurs at the anode as the chloride ion is oxidized to chlorine gas and the copper is reduced and plates out at the cathode. For the NaCl solution, since sodium is too active to be reduced, hydrogen is produced at the cathode and the phenolphthalein turns pink in the presence of OH^{-1} . ($\text{HOH} \rightarrow 2\text{H}^{+1} + \text{OH}^{-1}$, $2\text{e}^{-} + \text{H}^{+1} \rightarrow \text{H}_2$) At the anode the chloride ion is oxidized to chlorine gas. After discussing electrolysis in lecture/video, the students really enjoyed performing this lab (smiles and comments such as "this is cool"), they enjoyed observing the chemical reactions they had been writing about.

5) Demonstration-Electrochemical Remediation of the Environment (B-VII)

As an application of electrolysis in the everyday world, I included this demonstration based on the microscale lab by Singh, Pike and Szafran from the Journal of Chemical Education, May 1998. The remediation of

contaminated subsurfaces (ground water and soil) can be done electrolytically. Suitable anodes and cathodes are inserted in the ground and a voltage applied. In a process called electroosmotic transport, the soil particles in contact with aqueous solutions are frequently negatively charged due to chemical and physical adsorption. The cations from the liquid tend to neutralize this charge, producing an outer layer of liquid. The voltage creates a movement of this layer where the pollutants can be collected and removed. The pollutants for this demonstration were CuSO_4 and KMnO_4 solutions. The voltage is not sufficient to chemically reduce the permanganate or copper, so no new pollutants are produced. The demonstration uses a 9-volt battery and although it showed the migration of the ions and many of my students are concerned about environmental pollution, the demo was really too small and unimpressive. In the future, I would probably use a lantern battery and a larger set-up. Most demos are better if they are bigger and this one could be modified to meet that criterion.

6) Lab-Metal Reactivity Series (B-III)

In order to understand how a battery works, the reactivity of different metals was first observed. The

students compared the reactivities of four metals: Cu, Zn, Mg and Ag by observing the reactions with the aqueous solutions of the ionic form of each of the metals and with H_2SO_4 . I had the students design their own procedure, which I do not do very often, so it was interesting to see which pairs figured it out first. I gave them a very big hint by providing them with a blank data table. Most of the students figured out to react each of the metals in the different solutions and if the metal reacted, then it was more active compared to the metallic ion in solution. For instance, zinc metal reacts in $\text{Cu}(\text{NO}_3)_2$ solution because Zn is more active than Cu. From the data table, the metal that had the most evidence of reactions was labeled as the most active metal and similarly, the metal that showed the least evidence of reactions was labeled the least active. This is a standard lab performed by many chemistry students and is recommended by the College Board. I modified it from the Chemistry in the Community lab manual. It helps the students to understand reduction potentials used to calculate the voltage of batteries. It was performed on a microscale to minimize the amount of waste. We were fortunate enough to have silver donated from former students whose parents owned a chain of jewelry stores.

All of my students did determine for themselves what procedure to use although some took longer than others. The lab provides consistent results and will be used every year. The day before we performed this lab, the students were introduced to galvanic cells. Therefore they were asked to calculate voltages for five batteries based upon the table of standard reduction potentials. They had to apply their knowledge of the more active metal being oxidized and the least active metal being reduced, reversing the voltage for the oxidation half reaction.

7) Demonstration-Citrus, Potato and Car Batteries (B-VI)

The lead storage battery has been a major factor in making the automobile a practical mode of transportation. It is considered the "work horse" of car batteries, since it can withstand extreme temperatures and punishment from rough roads. It is important for students to understand this application of galvanic cells, one that they use every day. I borrowed a cut-away car battery from our auto shop and showed it to the students while we discussed the charging and discharging of the lead/acid battery. I then had a lemon battery and potato battery on display at one of the lab benches. I used zinc and copper electrodes and a

voltmeter to show the voltage produced. The lemon battery produced a voltage slightly lower than when the copper and zinc were the electrodes in a more conventional electrolyte. The potato battery seemed to have too much resistance and produced a significantly lower voltage than predicted. (The juicier lemon was a better conducting medium than the more solid potato). The students liked the demonstration and it was very relevant to our discussion, so this demo will be used again in the future.

8) Lab-Batteries (B-I)

The voltaic cell or galvanic cell converts chemical energy into electrical energy. This process is what occurs in a battery. The students made three wet cells and one dry cell which is similar to those used in common household batteries.

The students prepared three batteries with Cu, Zn and Al electrodes. They made Cu/Zn, Cu/Al and Al/Zn wet cells. They used beakers for the solutions and connected them with U-tubes filled with KNO_3 which were stoppered with cotton swabs. Alligator clips were used to connect the electrodes to computer-based voltage probes. I had all of the equipment on the lab benches and the students had to make

all of the appropriate connections. Besides the computer, a universal lab interface (ULI) from Vernier and a voltage probe are needed. My directions were shown to be very clear and the students were pretty adept at putting everything together. Out of a pair of students, one student was always more comfortable with computers than the other. We did not have any problems with the computers except sometimes the students had an error which read "cannot find interface on COM 1". They then had to click to "COM 2". In addition, the ULI must be turned on **before** the computer program is started, otherwise the computer will not recognize the probe. This was the second time the students used the ULIs and computers for a lab (the first was a titration lab) so the set-up went smoothly. The computer defaults to a voltage program, so we did not have to switch to a different program in Logger Pro (also available from Vernier). If the students registered "zero" volts, then the alligator clips had to be switched from one electrode to the other because they were reversed and they were trying to force the **nonspontaneous** reaction to occur.

The 30 students in the study were split into two sections, one section performing the lab first, then listened to a lecture by my colleague on Gibb's free

energy, then we switched. Each group spent 45 minutes on the lab and this was sufficient time to complete the task. The students obtained very good results with the Cu/Zn cell, but the Cu/Al and Zn/Al cells' voltages were rather low. The aluminum electrodes that we used were just aluminum foil twisted into a cylinder. There was probably too much resistance in this method, so next year I will try aluminum strips or buy aluminum electrodes from a chemical supply catalog.

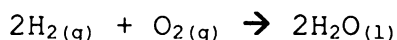
The final part of the lab was to make a dry cell. The students made a thick paste of aluminum chloride, manganese(IV) oxide and distilled water. Putting the paste in a paper muffin cup inside a beaker kept the clean up to a minimum. A zinc electrode and a graphite electrode were inserted into the paste. The electrodes were then hooked up to the voltage probe with alligator clips. The students all registered a voltage, but the values were varied, perhaps as a result of the amount of water they added. The muffin cups were then disposed of in the waste basket, no more waste than a AAA battery.

In this lab I also tried to address the misconception of electrons moving through the solution when I asked them to diagram the Cu/Zn cell and trace the path of the

electrons and show what ions are moving in the salt bridge. All of the students could correctly identify the zinc as the anode with the electrons leaving it through the wire and NO_3^{-1} ions migrating through the salt bridge to maintain electrical neutrality. Therefore, I felt the lab was successful in demonstrating how a battery worked, the use of technology and addressing the misconception that electrons are somehow flowing in the solutions or salt bridge.

**9) Internet Activity-Fuel Cells and History of the Battery
(B-VIII) and (B-IX)**

The purpose of this activity was to learn how fuel cells generate electricity. A fuel cell is a galvanic cell for which the reactants are continuously supplied (Zumdahl, 1997). The best example is the one used by the US space program:



The hydrogen is not burned but stripped of electrons (oxidized) and the oxygen is reduced. The flowing of the electrons creates a current of electricity. I found three web sites (<http://www.sciam.com/explorations/122396/explorations.html>, <http://www.i-way.co.uk~ectechnc/HOME.html> and <http://ballard.com>) that described how a fuel cell works, its advantages and

disadvantages and even a fuel cell animation. I scheduled the computer lab weeks in advance and even though it is set up for 28 students, some of the computers did not work, so we had to pair up. I would say this activity has the most room for improvement. Some students had difficulty in logging on: their passwords were not accepted, they had terrible time delays in getting to the sites or the site was nonfunctional. This was the most frustrating day of the unit. Too many things are not under your control on the Internet. Basically, I scrapped the entire activity and then discussed what they were suppose to see from the various sites in a 15 minute discussion back in the classroom.

We also tried to log onto the Duracell web site (www.duracell.com) to learn about the history of the battery. On this site the students can take a battery quiz that is graded by Duracell. Only two pairs of students actually got to the site, the others were told it was not working. After talking to my colleagues about my disaster, they suggested "burning" the information from the web sites onto a CD Rom. In this way you do not have to be at the mercy of a company's site or at the mercy of the speed of the Internet provider. The students were pretty

understanding of the problems and helped each other try to navigate around the web problems. To them any day cruising the web, however fruitful, is better than another day of lecture.

EVALUATION

In order to gather information on student progress, I utilized four tools: a pre-test/post-test (Appendix A), summary lab questions, a quiz (Appendix A-III) and a survey (Appendix A-II). The pre-test had six questions for a total of 20 points. It was given before we started the unit. I chose to make the pre-test a short answer format since my quizzes and tests are mainly problems and short answers. Since I did not want blank responses on the pre-tests or the classic "I don't know", I tried to give them something to respond to by showing them both a galvanic and electrolytic cell. I did receive responses and most of the students did have prior knowledge from previous chemistry classes, of how current flows in a metal and in an electrolyte and also how to balance redox reactions. Table 2 summarizes the students' responses to the pre-test. An x in the "metallic" column meant they correctly identified electrons as carrying the current. An x in the "ionic" column meant they correctly identified ions as carrying the current. An x in the "balance" column meant they could correctly balance the redox equation. An x in the "battery" column meant they correctly labeled the battery with electrons moving in the wire from the more active

metal to the least active metal and showed ions moving in the right direction through the salt bridge. An x in the "electrolysis" column meant they correctly predicted the products and wrote half reactions for the electrolysis of a solution of CuCl_2 . Table 2 shows 57% of the students knew electrons are moving in metallic conduction and 60% knew ions are moving in electrolytic conduction. Since we had just finished a unit on balancing and calculating using redox equations, 67% of the students could balance the redox equation.

Table 2 Pre-test Scores

Student	Metallic	Ionic	Balance	Battery	Electrolysis
1	X				
2	X	X	X		
3		X	X		
4	X	X			
5	X	X	X		
6					
7	X	X	X		
8	X	X	X		
9	X		X		X
10	X	X	X		
11	X		X		
12			X		
13	X	X			
14	X	X	X		
15	X	X	X		
16					
17	X	X	X		
18	X	X			
19					
20			X		
21	X	X	X		
22	X	X	X		
23					
24		X			
25		X	X		
26			X		
27	X	X	X		

28			X		
29		X	X		
30			x		
Total %	57%	60%	67%	0%	3%

While showing the galvanic cell, I asked, "What is happening to the metals and how were the electrons moving". Only one student or 3% could correctly say that hydrogen gas was evolving, due to the electrolysis of NaCl in the electrolysis demo. Other typical responses I received were "the electrons are moving" but which metal was giving and which metal was receiving electrons and how they were traveling was unknown. Typically they simply drew a picture of the set-up with no explanation. Some students also stated that "charges from the metal are going into the solution". The correct response was that zinc was being oxidized, copper was being reduced, the electrons were leaving zinc and the electrons were associating with the copper. Nitrate ions were also traveling through the salt bridge. Because of the low percentages of students who knew what was occurring in a battery or the process of electrolysis, it was clear that this topic was completely brand new for the students.

A comparison of the pre-test and post-test scores for each student can be found in Figure 1. The tests were identical; the scores are based on the 20 points possible and I did give partial credit for an answer. The average of 23% for the pre-test is essentially based on knowledge of metallic/electrolytic conduction and balancing of redox equations. The post-test shows a significant increase of knowledge of how current flows in a battery and how electrolysis occurs in a solution.

Figure 1 Comparison of Pre-test and Post-test Scores

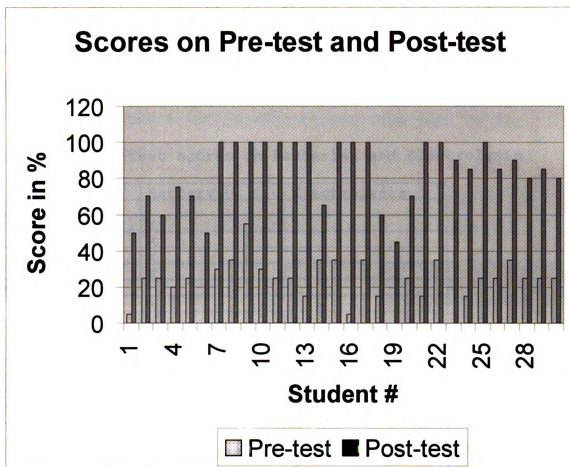


Table 3 shows post-test scores of the two questions on batteries and electrolysis. For this comparison, I did not score each question for partially correct answers. I looked for full or no credit: was the battery/electrolysis explanation completely correct or not?. Eighty-three percent of the students knew the processes occurring in a battery and 60% knew those for the electrolytic cell. The post-test was given after the unit test with the same

demonstration set-up for them. The scores showed a significant improvement over the scores (essentially zero) on the pre-test. The growth of knowledge in the "fertile teaching territory" was profound.

Table 3 Post-test scores on Batteries and Electrolysis

Student	Battery	Electrolysis
1		
2	X	
3	X	
4	X	X
5	X	X
6		X
7	X	X
8	X	X
9	X	X
10	X	X
11	X	X
12	X	X
13	X	X
14	X	
15	X	X
16	X	X
17	X	X
18		X
19		
20		
21	X	X
22	X	X
23		
24	X	
25	X	X
26	X	
27	X	
28	X	
29	X	X
30	X	
Total %	83%	60%

The second evaluation I utilized was a series of questions asked in the battery lab report (B-I). I asked

them to diagram the copper/zinc battery labeling the electron flow and migration. One hundred percent of them showed the electrons leaving the zinc electrode and flowing through the wire toward the copper electrode. They also showed the nitrate ion flowing through the salt bridge toward the ZnSO_4 solution to insure electrical neutrality. In the introduction to this thesis, I stated I wanted to make sure that the misconception of electrons flowing through the solution did not enter the students' minds. You could say that they do not believe this misconception based on their answers given in this lab. But, we shall see that this is not entirely true.

The third evaluation I utilized was a 40 point quiz on batteries (Appendix A-III), where the misconception mentioned in the previous paragraph was really tested. Most of the questions were based on diagrams and problems, but I used two multiple choice questions from Greenbowe and Sanger's research. I asked: *Given a galvanic cell with a silver electrode in a solution of silver ions and a nickel electrode in a solution of nickel ions, connected with a salt bridge, fill in the following statement: Electrons in the cell flow through the _____ toward the _____.* The options were (1) wire, silver

electrode (2) wire, nickel electrode (3) salt bridge, nickel electrode and (4) salt bridge, silver electrode. Sixty-seven percent of the students picked the correct response (1) and 3% or one student picked (3) which verifies the misconception. The other 30% got reversed in Ni being the most active and Ag being the least active.

The second question I asked was: *In an electrochemical cell, conduction through the electrolyte is due to: (1) electrons moving through the solution attached to the ions. (2) electrons moving from ion to ion through the solution.*

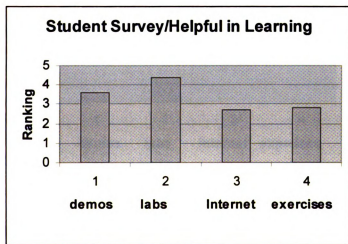
(3) the movement of both positive and negative ions.

(4) the movement of water molecules.

(5) electrons moving across through the solution from one electrode to the other. Forty-seven percent of the students answered the question correctly as #3. No one chose #4; therefore, 53% were telling me that electrons were moving in the electrolyte answers 1,3 or 5. This was exactly the misconception I was trying to avoid. Asked in a different format, a multiple choice question, the misconception of electrons flowing through ionic conduction was still apparent.

The final evaluation I used was a student survey (Appendix A-II) at the end of the unit. I asked on a scale of 1-5 (1 least helpful, 5 most helpful) the students to rate the demonstrations, labs, Internet activities and exercises from the textbook based on helpfulness in learning and enjoyment. Figure 2 shows the results of this survey.

Figure 2. Student Survey/Helpful in Learning

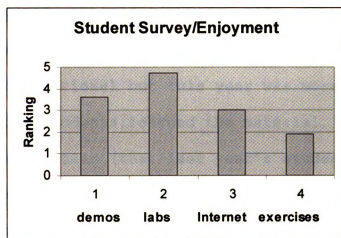


n = 30

The students felt the labs were the most helpful in learning with a score of 4.4. The Internet activities, which I knew did not work well, were scored as 2.7, rather low, which coincided with my opinion. They ranked the same groups of activities in terms of enjoyment with 1 least, 5 the most (see Figure 3). Again, labs were the most

enjoyable to perform and completing the exercises from the textbook (mainly homework) as the least enjoyable. The demonstrations were both scored as 3.6. So when asked, the students came to the same conclusion I did: labs teach the material in a more enjoyable way and the Internet activities needed improvement.

Figure 3. Student Survey/Enjoyment



n = 30

DISCUSSION AND CONCLUSIONS

My hypothesis was: If students are actively engaged in a variety of activities (experiments, demonstrations, computer based activities) then their understanding of electrochemistry will increase compared to the knowledge they bring with them. I feel that the changes I made did increase students learning and enjoyment in learning. There were too many variables to compare the previous year's scores to this year's scores (change in schedule, addition of all the activities, different lab rooms due to renovations) but this year was more of a success in that the students learned the material, enjoyed the hands on activities (that last year's students told me was lacking) and are better prepared for college and life through the use of technology.

As demonstrated through my student survey, the students felt that the labs were effective in learning the material and liked doing them. Three labs that were particularly effective were the metal reactivity lab, the battery lab and the electrolysis lab. In the metal reactivity lab, based on answers to the questions (Appendix B-III) the students understood **why** the metals are arranged on a standard reduction potential table according to how

they react with other metals. It was like a math teacher doing a proof for the students instead of just giving them the equation to use and saying, "its true, just memorize this". In the battery lab, the students made their own batteries instead of just diagraming them from an exercise in a book and had to measure the voltage using a computer. This was probably my greatest success in that it worked and we obtained decent results. The students found the electrolysis lab easy to perform and, as I mentioned in the implementation section, the students told me it was cool to see the effervescence and observe the products produced from the current.

I will use the structure of this unit as a model for other units in terms of activities, demos and the use of technology. It was effective in breaking up the block and engaging the students' interest. If you look at the basic outline of the unit, we did some kind of activity everyday except when introducing the history, key terms and concepts at the beginning and reviewing for the test at the end. My students and I felt more comfortable using conventional (=lecture) methods for those parts. I looked forward to each day to see whether or not what I had planned was

successful. My enthusiasm went up and so did my students' interest.

Aspects of the unit that need improvement were also mentioned earlier. The Internet can be a frustrating tool and I will try my colleague's suggestion for "burning" web sites onto a CD-ROM to ensure access to them. I still think the Internet is a valuable tool for learning and keeping students' interest, but I did not want them to "surf" the web. I had specific goals and places to visit and when they couldn't get there or were delayed, something should change.

In addition, I will improve the electroremediation demo to make it bigger and more impressive to students. Another way I could improve is to directly address the misconception of electrons traveling through the electrolyte instead of charged ions. I could discuss it with them in a lecture or I could include it as a question in the battery lab, saying "some students think...." Either way would be more effective than just diagraming cells and asking them where the electrons are moving. I did not take this direct approach, I thought the misconception was addressed with lecture, homework problems and lab, but with

only 47% getting this question correct on the quiz (Appendix A-III), obviously it wasn't.

In conclusion, I should ask myself the question: "what did I learn?" I learned that technology does not have to be frustrating or overwhelming if the teacher takes the time to learn about it. I also learned that the Internet could be unreliable and how to work around this problem. As far as misconceptions in learning, I learned that you have to ask questions in a different manner in order to ferret out any problems in thinking. A more effective way to demonstrate to students that electrons are only moving in the wire and ions in the electrolyte, would be to find a galvanic cell animation either on a CD-ROM or web-page. This would hopefully help them visualize these differences in current flow.

Overall, I was reminded of the fact that as teachers we are constantly learning ourselves and growing professionally. It is not enough to know your subject area and be content with the ways you present the ideas. I enjoy learning, that is probably why I went into teaching, and because of this experience I will strive to continue to make changes for the better in my students' learning.

APPENDIX A
EVALUATION TOOLS

A-I Electrochemistry Pre-Test/Post-Test.....	52
A-II Student Survey.....	53
A-III Battery Quiz.....	54

Answers are in italics

1. How does conduction of electricity occur in (a) a metal?
(b) an electrolyte?

Electrons moving for metallic conduction, ions moving for electrolytic conduction

2. On the lab bench is a set-up of a galvanic cell or battery using copper and zinc. Make a diagram of the set-up and then describe what is happening to the metals and how the electrons are moving.

Electrons are leaving the zinc as it is getting oxidized, Electrons are gaining at the copper electrode as it is getting reduced. (Nitrate ions are also traveling through the salt bridge from the copper cell to the zinc cell).

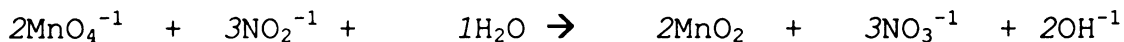
3. On the lab bench is a set-up of an electrolytic cell using a battery to force the reaction to occur, the solution is copper(II) chloride. Make a diagram of the set-up and then describe what is happening at the electrodes and how you know.

Effervescence occurs at the anode as chlorine gas is produced $2\text{Cl}^{-1} \rightarrow \text{Cl}_2 + 2\text{e}^{-}$ and copper metal is plating out at the cathode $\text{Cu}^{+2} + 2\text{e}^{-} \rightarrow \text{Cu}$

4. What is the difference between batteries and fuel cells?

I accepted many correct answers but the best answer was batteries eventually "run out" of reactants, fuel cells the reactants are continuously supplied so they never "run out".

5. Balance the following equation:



6. Make a venn diagram of a galvanic cell and an electrolytic cell to show how they are the same (intersection) and how they are different.

Galvanic cell spontaneous, electrolytic cell nonspontaneous, both have electrons moving through the wire, both have ions moving in solution

1. On a scale of 1 to 5, with 1 being the least helpful and 5 being the most helpful, please rate the following activities on how well they helped you learn the material.

demonstrations _____
(electrochemical remediation, anode and cathode of copper, lemon and potato battery)

hands on lab activities _____
(oxidation # and color lab, metal reactivity lab, battery lab, electrolysis lab)

internet activities _____
(duracell, fuel cell)

exercises from textbook _____

2. On a scale of 1 to 5, with 1 being the least enjoyable and 5 being the most enjoyable, please rate the following activities as to how well you enjoyed them.

demonstrations _____
(electrochemical remediation, anode and cathode of copper, lemon and potato battery)

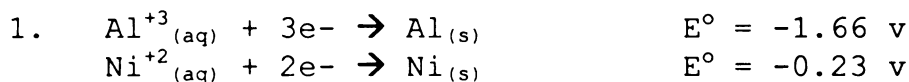
hands on lab activities _____
(oxidation # and color lab, metal reactivity lab, battery lab, electrolysis lab)

internet activities _____
(duracell, fuel cell)

exercises from textbook _____

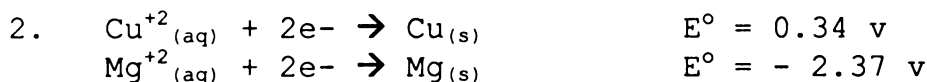
A-III AP CHEM QUIZ BATTERIES

Sketch the galvanic cells based on the following half-reactions. Determine the E° for the cells. Show the direction of electron flow, the direction of the ion migration through the salt bridge and identify the cathode and the anode. Give the overall balanced equation. Assume that all concentrations are 1.0 M and that the partial pressures are 1.0 atm. The salt in the bridge is KNO_3 .



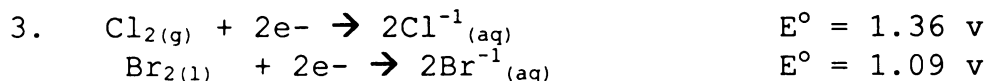
Balanced equation _____

Standard line notation _____



Balanced equation _____

Standard line notation _____



Balanced equation _____

Standard line notation _____

A-III continued

4. Given a galvanic cell with a silver electrode in a solution of silver ions and a nickel electrode in a solution of nickel ions, connected with a salt bridge, fill in the following statement: Electrons in the cell flow through the _____ toward the _____.
- (1) wire, silver electrode
 - (2) wire, nickel electrode
 - (3) salt bridge, nickel electrode
 - (4) salt bridge, silver electrode
5. In an electrochemical cell, conduction through the electrolyte is due to:
- (1) electrons moving through the solution attached to the ions.
 - (2) electrons moving from ion to ion through the solution.
 - (3) the movement of both positive and negative ions.
 - (4) the movement of water molecules.
 - (5) electrons moving across through the solution from one electrode to the other.
6. Why do you get a "tingling" sensation in your mouth when you chew a metallic gum wrapper? What is acting as the electrolyte? (you have metallic fillings)

APPENDIX B

EXPERIMENTS, DEMONSTRATIONS AND INTERNET ACTIVITIES

B-I Battery Lab.....	57
B-II Electrolysis Lab.....	62
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B-I BATTERY LAB

Introduction

From pacemakers and automobile garage door openers to portable hand-held computers, it seems that the everyday world runs on batteries. All of them work on the process of changing energy from one form to another. A battery changes chemical energy into electrical energy to perform various kinds of work. They all obtain their energy from a spontaneous chemical reaction that can be described in terms of oxidation and reduction half reactions. They can all be described as a voltaic cell after Alexander Volta who invented the first battery in 1800. The reaction in an electrochemical cell occurs at the interface between the electrode and the solution where the electron transfer occurs. Oxidation occurs at the anode and reduction occurs at the cathode. A galvanic or voltaic cell consists of an oxidizing agent in one compartment that "pulls" electrons through a wire from a reducing agent in the other compartment. The "pull" or driving force on the electron is called the cell potential or electromotive force (emf) of the cell. The unit of electrical potential is the volt and is defined as 1 Joule of work per coulomb of charge transferred. The amount of voltage produced depends on what metals are used.

The U-tube forming a connection between the two beakers is called a salt bridge. It provides a way for ions to move between the half-cells and ensures that electrical neutrality is maintained. We will use a solution of KNO_3 . The K^+ ions will migrate towards the anions (SO_4^{2-}) and the NO_3^- ions will migrate towards the metallic cations. You will construct 3 wet cells and 1 dry cell which is similar to those used in A, AA and AAA batteries.

Procedure

Setting up the three wet cells.

1. Put on your lab apron and safety goggles.
2. Obtain strips of Cu, Al and Zn. Be careful not to cut yourself on the sharp edges.
3. Measure 100 mL of 0.1 M CuSO_4 with a graduated cylinder. Add it to a 250 mL beaker. Label the beaker with a grease pencil. Measure 100 mL of 0.1 M ZnSO_4 with a graduate. Add it to another 250 mL beaker. Label it

B-I continued

- also. Measure 100 mL of 0.1 M $\text{Al}_2(\text{SO}_4)_3$ with a graduate, add it to a different 250 mL beaker and label it also.
4. Make three salt bridges by filling the U-tube with 1.0 M KNO_3 nearly full. Add $\frac{1}{2}$ of a cotton swab to each end of the tube so that the solution remains in the tube.
 5. Attach a Cu strip with an alligator clip and put it in the copper(II) sulfate solution. Attach a Zn strip with an alligator clip and put it in the zinc sulfate solution. Attach the other ends of the alligator clips to the voltage probe.

Setting up the ULI for voltage measurements.

6. First you have to attach the computer to the ULI.
 - a) Connect the AC adapter to the ULI board.
 - b) Connect the power line to the computer.
 - c) Connect the computer to the ULI.
 - d) Connect the voltage probe to DIN I input on the ULI board.
7. The ULI programs are saved on the hard drive. Click until you find ULI tools and Data Logger 4.06 and then experiment files. Choose "volt". Use the stored calibrations. Since we will be dealing with voltages between 0 and 2 volts, change the scale on the ordinate from 5 to 2.
8. Once it is all connected, you are ready to measure the voltage of the copper/zinc cell. Press start and let it run for 30 seconds. Record the voltage in the table below.
9. Set up the Cu/Al cell in the same manner using the Al foil pieces as the electrode. Be sure to use a new salt bridge to avoid contamination. Double click to clear the data. Again press start and let it run for 30 seconds. Record this wet cell voltage in the table below.
10. Set up the Zn/Al cell in the same manner. Again be sure to use a new salt bridge. Record the voltage in the table below. To clean up, discard the solutions down the drain and rinse and dry the electrodes. The cotton swabs can be thrown away in the garbage.

Determining the voltage of a dry cell

11. Mass 5.0 grams of ammonium chloride and 5.0 grams of manganese(IV) oxide. Combine the two solids in a muffin cup in the bottom of a 250 mL beaker. (this will facilitate the clean up later).

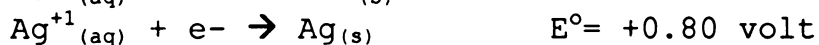
B-I continued

12. Add 25-30 drops of distilled water until you make a thick paste. Stir with the graphite electrode.
13. Place a zinc strip and the graphite electrode into the paste. Attach the alligator clips to each electrode and the other ends to the ends of the voltage probe. Using the ULI, as in the previous procedure for the wet cells, measure the voltage and record it in the table below.
14. Remove the electrodes, wipe with paper towels and rinse and dry. Carefully remove the muffin cup from the beaker and wrap it in paper towel. Throw away in the waste basket.

Cell	Measured Voltage (v)	Theoretical voltage (v)	% error
Cu/Zn			
Cu/Al			
Zn/Al			
Zn/ MnO ₂		1.5 volts	

Calculations

1. Calculate the theoretical potential of the cells tested by using the table of standard reduction potentials. (Note the conditions at the top of the table). The metal higher up on the table gets reduced. For example, for a Cu/Ag cell, the half reactions and the voltages are:



Since one of the reactions needs to be an oxidation and batteries supply a **positive voltage**, you must reverse the reaction and the sign of the potential that is the least positive and then add the two voltages.



In order to achieve the balanced chemical equation, the silver half-reaction must be multiplied by 2. However, since a standard reduction potential is an intensive property (it does not depend on how many times the reaction occurs) the **potential is NOT multiplied by the integer required to balance the cell reaction.**

B-I continued

2. Calculate the % error for the voltages measured. The accepted value is determined like the above example from standard reduction tables.

Analysis and Conclusions.

1. What variables exist within the voltaic cells that may account for the differences between the observed and the theoretical values?
2. Which of the cells would be the best source of electrical energy in an electrical device?

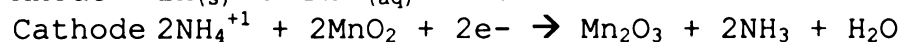
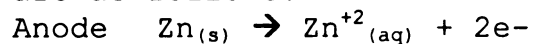
Write $\frac{1}{2}$ reactions and overall balanced equations for each of the three wet voltaic cells.

a)

b)

c)

- d) The half reactions for the dry cell are complicated and are as follows:



voltage = 1.5 v

This is the acidic version, there is an alkaline version also, found in most over the counter batteries.

B-I continued

3. Complete the following table:

	Zn/Cu	Cu/Al	Zn/Al
Oxidized	Zn		
Reduced	Cu^{+2}		
Oxidizing agent			
Reducing agent			

4. Consider the Zn/Cu electrochemical cell, which of the two metals is the anode, which is the cathode?
5. Sketch a diagram of the Zn/Cu cell and trace the path of the electrons.
6. Now on your diagram, show and then explain what ions are moving in the salt bridge and WHY.
7. Arrange the ions in order from best to worst oxidizing agents. (Cu, Al, Zn)
8. The Cu/Zn voltaic cell should theoretically have a potential difference of 1.10 volts. What would happen to this voltage if the voltaic cell was used over a period of time? Explain your answer in terms of changes that would take place in the voltaic cell.

B-II

AP CHEMISTRY LAB-ELECTROLYSIS

INTRODUCTION

In this experiment, you will apply an electric current from a 9 volt battery to aqueous solutions of potassium iodide, copper chloride and sodium chloride. The positive and negative ions will move toward the opposite electrodes. Color indicators will be used to identify the presence of the elements or ions produced at these electrodes.

PROCEDURE

1. Wear safety goggles and a lab apron at all times.
2. Fill the U-tube with 0.5 M KI solution and with an eyedropper add one drop of phenolphthalein indicator into each side of the U-tube. Use a rubber band to attach the U-tube to a styrofoam coffee cup. Be careful you do not put too much pressure on the ends of the U-tube or it will collapse. Attach alligator clips to the two graphite electrodes and the two terminals of the 9 volt battery. Rest the battery on the bottom of the styrofoam cup and put the two electrodes in the U-tube.
3. Let the current run for 5 minutes while observing any solution colors and gas production. (Remember phenolphthalein turns magenta in the presence of excess OH^{-1} ions.)
4. Add two drops of starch solution to each side of the U-tube and observe any changes. Record your observations in the table below. Remove the electrodes, empty the KI into the sink and rinse the U-tube .
5. Repeat the experiment using 0.5 M NaCl, again adding the one drop of phenolphthalein to each side of the U-tube. Check for the odor of chlorine by wafting the gas toward your nose. Record your observations in the table below. Remove the electrodes, empty the NaCl into the sink and rinse the U-tube.
6. Repeat the experiment using 0.5 M CuCl_2 , again adding the one drop of phenolphthalein to each side of the U-tube. Check for the odor of chlorine with the wafting technique and record your observations in the table below. Remove the electrodes, empty the CuCl_2 into the sink and rinse the U-tube. Disconnect the graphite electrodes and answer the lab questions.

B-II continued

DATA

KI		
	Red wire	Blue wire
Color of solution		
Gas produced		
Starch test		

NaCl		
	Red wire	Blue wire
Color of solution		
Gas produced		
Odor		

CuCl_2		
	Red wire	Blue wire
Color of solution		
Gas produced		
Odor		

DISCUSSION

For the electrolysis of KI:

1. At which electrode does reduction occur and why?
2. At which electrode does oxidation occur and why?
3. Write the reduction and oxidation half reactions and then the net ionic equation.

-
4. Explain why water rather than the potassium is reduced at the cathode.

For the electrolysis of NaCl:

B-II continued

5. At which electrode does reduction occur and why?
 6. At which electrode does oxidation occur and why?
 7. Write the reduction and oxidation half reactions and then the net ionic equation.
-

For the electrolysis of CuCl_2 :

8. At which electrode does reduction occur and why?
 9. At which electrode does oxidation occur and why?
 10. Write the reduction and oxidation half reactions and then the net ionic equation.
-

B-III

AP CHEMISTRY LAB- METAL REACTIVITY SERIES

The reactivity of metals is an extremely important property. The nonreactivity of gold, for instance is one of its important properties and helps account for its widespread use in coins and jewelry. Other metals are used for their ease of reactivity. As chemists, we hope to know not only the order of reactivities, but also learn why the order is the way that it is.

In this lab you will compare the reactivities of four metals (copper, zinc, magnesium and silver) by observing their reactivities with aqueous solutions of the ionic form of the metal and sulfuric acid. **You and your lab partner are to design a procedure for testing the metals to determine the order of reactivity from MOST active to LEAST active.** The results of your testing should be organized in a DATA TABLE like the one below. The following materials are provided:

- dropping bottles of 1 Molar solutions of $\text{Zn}(\text{NO}_3)_2$, $\text{Cu}(\text{NO}_3)_2$, $\text{Mg}(\text{NO}_3)_2$, AgNO_3 and 3.0 M H_2SO_4 .
- glass vials containing pieces of Zn, Cu, Mg and Ag.
- forceps for handling the metal pieces
- one piece of plastic wrap for the reactions to take place on since the lab is considered microscale
- one magnifying glass
- a piece of white paper to put under the plastic wrap

When cleaning up, remove the metal pieces and place in the waste container provided. The solutions can be drained into the sink and then the plastic wrap can be thrown away.

SAMPLE DATA TABLE

	$\text{Zn}(\text{NO}_3)_2$	$\text{Cu}(\text{NO}_3)_2$	$\text{Mg}(\text{NO}_3)_2$	AgNO_3	H_2SO_4
Zn					
Cu					
Mg					
Ag					

Based upon your observations, rank the metals in terms of reactivity (most to least, left to right)

_____ > _____ > _____ > _____

B-III continued

1. Describe (in a paragraph) your procedure for testing the reactivities of the various metals.
2. Using your table of standard reduction potentials, calculate the voltage from the following batteries:
3. Copper and silver electrodes in 1.0 M solutions of their respective ions.
4. Copper and zinc electrodes in 1.0 M solutions of their respective ions.
5. Copper and magnesium electrodes in 1.0 M solutions of their respective ions.
6. Magnesium and silver electrodes in 1.0 M solutions of their respective ions.
7. Silver and zinc electrodes in 1.0 M solutions of their respective ions.
8. After consulting a Table of Standard Reduction Potentials one would predict that aluminum metal should react with most of the metals in this activity. If you were to place a piece of aluminum in the other aqueous solutions, **no reaction would be observed for a very long time.** Suggest a **chemical** reason why such an observation might occur.

AP CHEMISTRY LAB-COLORS AND OXIDATION NUMBERS

Introduction

Please note: Since the permanganate is a strong oxidizing agent, it stains skin and clothing. Goggles and aprons are necessary and gloves are also available.

Test tube rack

dropper bottles

5 test tubes

Solutions Needed:

3.0 M HCl 4.0 M NaOH 0.1 M NaHSO₃ 0.00040 M KmnO₄

1. Label 5 test tubes 1-5. Fill each test tube with approximately 1-2 mL of KmnO_4 solution. This is about 1-2 cm of purple solution.
2. Note the color of Test tube #1, it will be the control color.
3. Test tube #2 will be the acidic reduction. Add equal drops of HCl and NaHSO_3 (35-50 drops) until a noticeable change is observed. Note the color.
4. Test tube #3 will be the neutral reduction. Add 1 drop of NaHSO_3 and add drops of KmnO_4 until a change is observed. Note the color.
5. Test tube #4 will be the basic reduction. Add drops of NaOH (about 30) and NaHSO_3 (about 15) until a change is observed. Note the color.
6. Test tube #5 will be a disproportionation. Prepare test tube #5 the same as test tube 4. Add 10 drops of HCl and stir. Repeat with 10 drop additions of HCl until you observe a change.

1. For test tubes #2-5, write the $\frac{1}{2}$ reactions labeling the oxidizing and reducing agents where necessary and then the overall balanced equation.

B-IV continued

Test tube #2 Acid reduction: permanganate ion reacts with bisulfite ion in acidic solution to produce bisulfate ion, manganese +2 ion and water.

oxidizing agent:

reducing agent:

Test tube #3 Neutral reduction: permanganate ion reacts with bisulfite ion to produce manganese (IV) oxide, sulfate ion, bisulfate ion and water. (For easier balancing use the change in oxidation number method).

Test tube #4 Basic reduction: permanganate ion reacts with bisulfite ion in basic solution to produce MnO_4^{-2} , sulfate ion and water.

Test tube #5 Disproportionation: MnO_4^{-2} reacts with acid to produce permanganate ion **AND** MnO_4^{-2} reacts with acid to produce manganese (IV) oxide and water.

oxidizing agent:

reducing agent:

Complete the following table:

Test tube #	Oxidation # of Mn	Color
1		
2		
3		
4		
5		

What is the trend in oxidation numbers of manganese with the color of the reaction? That is how does the oxidation # change with the wavelength?

B-V

AP CHEMISTRY DEMONSTRATION

Electrolytic Refining of Copper

Introduction

Energy absorbed or liberated in a chemical reaction can be in the form of electricity. A system in which such a process takes place is called an electrochemical cell. This demonstration uses an electrolytic cell which uses electricity to force a non spontaneous reaction to occur. We will use a six-volt commercial "lantern" battery as the source of electricity. It will be used to push electrons through an electrolytic cell made up of two copper electrodes in a copper sulfate solution. When a voltage is applied to the electrolytic cell, electrons are pushed onto the cathode. Positively charged Cu^{+2} ions in the solution then are attracted to the negatively charged cathode. At the cathode surface, electrons combine with Cu^{+2} ions to plate out copper metal at the cathode.

At the anode copper metal dissolves as Cu^{+2} and two electrons per copper atom flow from the anode into the attached wire. In the overall electrolytic cell reaction, electrical energy (from the battery) moves copper metal from the anode to the cathode.

In this demonstration the current has been monitored through the cell over a period of one hour (3600 seconds). The current will typically read 160-175 mA. In the electrolytic refining of copper on a commercial scale, the anode is "impure" copper and the cathode is "ultrapure" copper in the form of thin sheets.

Write the half-reaction for the anode:

Write the half-reaction for the cathode:

Noble metal impurities such as platinum, silver and gold are not oxidized at the voltage used and they fall to the bottom of the cell as "anode mud". The anode mud is very valuable and sold. Other metal impurities such as zinc and iron are oxidized at the anode and are found in the electrolyte solution.

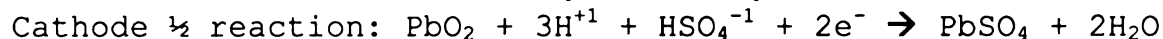
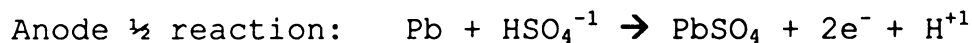
Why is it so important to produce ultrapure copper? The copper metal that is produced in this process is 99.95% pure, why is this necessary for copper wiring?

B-VI

AP CHEMISTRY—DEMONSTRATION—Citrus, Potato and Car Batteries

Introduction

In the early years of the automobile, it was necessary to turn the crank of a magneto (an alternator with permanent magnets) to generate the current necessary to start the automobile engine. In response to consumer demand for an easier system, the automobile industry introduced the lead-acid storage battery, a form of which is used today. It is pretty amazing that in the 80 years in which they have been used, no better system has been found. In a car battery, lead serves as the anode and lead oxide as the cathode. Both electrodes are immersed in a solution of sulfuric acid, which serves as the electrolyte. The balanced redox reaction is:



Each cell of the battery supplies _____ volts and a typical car battery is 6 cells connected in series to produce _____ volts of electricity, since the voltage is additive when the cells are added in series.

Set up on the lab bench are fruit wet-cells consisting of Cu, Zn and lemons.

Anode $\frac{1}{2}$ reaction:

Cathode $\frac{1}{2}$ reaction

The electrolyte is the _____ acid contained in the lemon.

This citrus battery theoretically could produce a 12 volt battery if we had enough lemons, but although it would have sufficient voltage, it does not generate sufficient

B-VI continued

amperage or current to start a car. Since the current from the battery is inversely related to the internal resistance (which for the citrus cell is quite high) the amps are _____.

In order to reduce the resistance and increase the current, a different electrolyte is needed and the surface area of the electrodes is increased. The greater the surface area, the greater the capacity for oxidation and reduction to occur since the reaction happens at the _____. The electrodes in automobile batteries are made of layered grids, therefore providing a large surface area for the transfer of the electrons to take place.

QUESTIONS

1. Why would car manufacturers look for a replacement to the lead/lead oxide battery? (Hint-pick up the brick of lead on the lab bench)
2. What causes a car battery to fail?
3. The recharging of the car battery occurs while you are driving and uses the gasoline fuel to reverse the entire process. Write the overall reaction for the recharging process. If your car battery needs a "jump start", why would this be considered dangerous?
4. A student in the auto shop was working on a car battery and accidentally some of the sulfuric acid electrolyte splattered on his t-shirt. The next day he noticed holes in the shirt. Calculate the molarity of the sulfuric acid if it is typically 38% by mass and has a density of 1.28 g/mL.

B-VII

AP CHEMISTRY—DEMONSTRATION

Electrochemical Remediation of the Environment

(Based on the microscale lab by Singh, Pike and Szafran, Journal of Chemical Education, Volume 75, #5 May 1998)

Introduction

The remediation (returning to normal) of contaminated subsurfaces (ground water and soil) is frequently the most time- and money consuming task of any site clean-up. One way of cleaning contaminated soil is electrolytically. For the remediation of a piece of land, suitable anodes and cathodes can be strategically placed in the ground and an electric field from a dc source is applied. In a process called electroosmotic transport, the soil particles in contact with aqueous solutions are frequently negatively charged owing to chemical and physical adsorption. The cations from the liquid tend to neutralize this charge producing an outer layer of liquid. The electric field that is produced from the power source creates a movement of this layer where the pollutants can be collected and removed. Our pollutants for this demonstration are solutions of copper(II) sulfate and potassium permanganate. It should be noted that the voltage applied is not sufficient enough to reduce the permanganate or copper so no new pollutants are being produced. The voltage is enough to reduce and oxidize water so the only waste products would be hydrogen and oxygen. You are using the voltage to just move the pollutants into a collection area.

QUESTIONS

1. What is the main advantage to using this type of electrolytical clean-up of a contaminated site?
2. What are the two drawbacks or disadvantages to using type of technique in terms of cost and the nature of the pollutants? That is, could this technique be used to clean up gasoline that has leaked from tanks under a gas station?

B-VIII

AP CHEMISTRY—FUEL CELLS INTERNET ACTIVITY

Introduction

The purpose of this activity is to learn how fuel cells work to generate electricity. Many believe they are the answer to our fuel needs for the future.

Open the Netscape Navigator program. Enter the following URL

<http://www.sciam.com/explorations/122396/explorations.html>

Read the information and answer the following questions.

1. What are the 3 advantages of using fuel cells as a power source?
2. What is the one disadvantage at the present time?
3. What is the main difference between batteries and fuel cells?
4. Write the chemical reaction in a typical fuel cell.
Then write the $\frac{1}{2}$ reactions for the production of oxygen and hydrogen. (you may have to consult your textbook)
5. What is the main waste product and secondary waste product?
6. What is meant by the term cogeneration?
7. What function does the proton-exchange membrane serve in a fuel cell? What is its main advantage?
8. An exciting application for fuel cells is their use in automobiles. What is the main difficulty for use in automobiles?

B-VIII continued

- b) How have the car companies tried to solve this problem chemically? Write the balanced chemical equation to show how lithium hydride reacts with water to form lithium hydroxide and hydrogen.
- 9. Write the balanced chemical equation to show how methanol can be broken down with heat and a catalyst to form hydrogen and carbon monoxide.
- 10. Another potential application would be for fuel cell power plants. What are the two chemical electrolytes that ERC and Westinghouse are proposing?
- 11. What is the main obstacle facing fuel cell production?

Now go to the URL

<http://www.i-way.co.uk/~ectechinc/HOME.html>

then click on "How does a fuel cell work?"

- 12. How does hydrogen normally burn? (As you saw in the hydrogen lab last year!)
 - b) How does the reaction differ in a fuel cell?
- 13. Explain how a fuel cell is set-up including what is the anode, the cathode and typical electrolyte.

Now go to the URL <http://ballard.com> to view a fuel cell animation. You need to click on products and fuel cell animation. Do not worry about downloading any programs.

- 14. What can flow through the proton-exchange membrane and most importantly what can not?

B-IX

AP CHEMISTRY INTERNET ACTIVITY HISTORY OF THE BATTERY

Introduction

Batteries are a great example of where redox reactions are applied in everyday life. Many people make their living from understanding and designing batteries. One such company is Duracell. You will investigate the chemistry and history of batteries at their company web site.

1. Log onto the computer and go the following URL:
www.duracell.com
2. Click on the "Fun and Learning" button then "Battery Science".
3. Click on the sidebar "Battery History". The small pictures next to each vertical time-line are buttons that link to explanations of different advancements in batteries over time. Use these to answer the following.
 - a) Who invented the earliest battery and why?
 - b) Benjamin Franklin is credited with many of the terms that we still use in electrochemistry. What terms did he introduce?
 - c) Describe the first primitive battery that Alessandro Volta developed in 1800.
 - d) What hazardous endeavor did Davy use for his room-sized battery in 1813?
 - e) What battery is George LeClanche credited with first developing?

Click on "Battery IQ Test" and take the interactive test, submit it and Duracell will check it for you.

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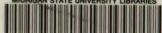
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