APPLICATIONS FOR HYDROGEN FUEL CELL TECHNOLOGY IN HIGH SCHOOL SCIENCE AND MATHEMATICS.

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Summary

This unit is not a single module for a single course. It uses hydrogen fuel cell technology as a framework for introducing students to the basic concepts of electromagnetism as well as mathematical curve fitting and graphical analysis.

Intended Audience

This module contains several labs intended for use in an 11^{th} grade Algebra/Trigonometry (Algebra II) course as well as a 12^{th} grade physics course. The labs can be adapted for teaching mathematical applications and graphical analysis in Algebra II, and are scalable to courses in applied statistics or basic algebra. The physics portion can be scaled down to fit in physical science or and equivalent level general science course.

Estimated Duration

The duration for this module is intended for three days in a typical mathematics course and five days as part of a larger electromagnetism unit for high school physics.

A brief summary of the project follows:

Algebra II Unit

> *Data Collection* – Setting up a Wet Lab or Dry Lab and gathering data
>
> *Curve Fitting* – Finding the mathematical functions that the data represents
>
> *Analysis* – Either optimizing a characteristic or performing statistical analysis

Stats/Algebra I Uses:

> Part I: Set up & data collection
>
> Part II: Analysis of V/I Plot using Excel scatter plots with emphasis on best line fitting & linear functions.
>
> Part III: Analysis of P/I Plot using Excel scatter plots with emphasis on best line

fitting & quadratic functions.

Part IV. Analysis of max power for varying metals in wet lab & commercially made fuel cells. 95% confidence intervals for max power will be calculated using central limit theorem(for honors stats only).

Physics Unit

Session I – Fuel Cell 101

PEM Fuel Cell Demonstration

Presentation: Fuel Cell Basics

Session II – Wet Cell Lab

Session III – Dry Cell Lab

Session IV – "hydrogen economy" Discussion

Generating Hydrogen Lab

Session V – Assessment

Introduction

Surveys indicate that students in middle and high school typically do not have enough information to thoroughly consider engineering as a career. As teachers, we are less likely to stimulate interest if we have not had opportunities to learn about engineering. Beyond career considerations, understanding engineering is important so that citizens can make informed decisions about the impact of technology on society. So as to improve the learning curve across the board, Washington State University, with funding from the National Science Foundation, conducts a 6-week, hands-on engineering program that serves to familiarize middle and high school teachers with engineering processes, which they can then carry into their classrooms in the form of comprehensive, in-depth learning modules (SWEET, 2003-7). The goal of the program is to develop teachers who are prepared and committed to nurture student-interest in the sustained study and application of various forms of engineering. This module represents one product of that effort.

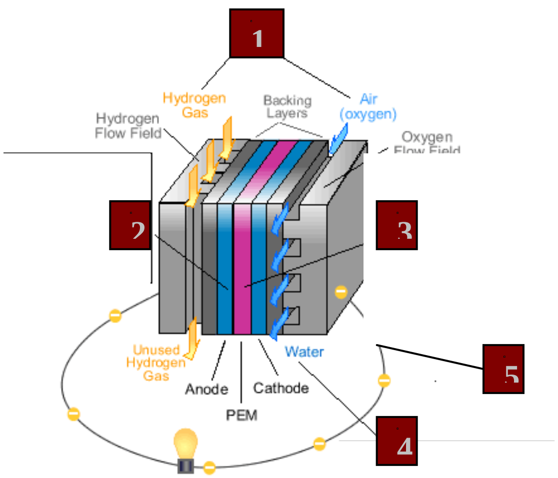
Fuel Cell History & Operation

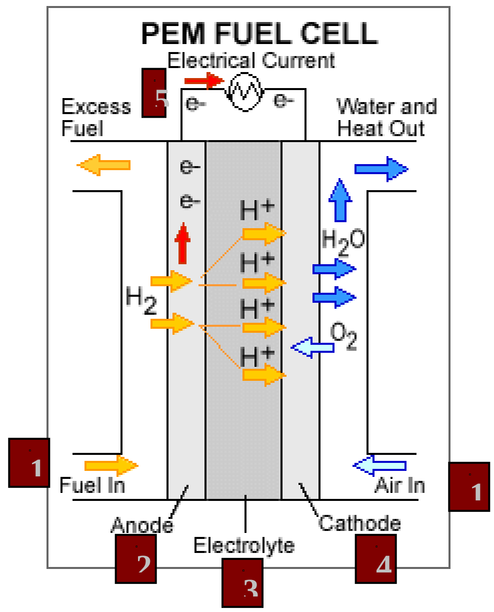
A fuel cell is an electrochemical energy conversion device – like a chemical cell battery. However, in a chemical cell, the fuel is used up and the battery eventually dies; whereas in a fuel cell the fuel is continually supplied to the cell from some outside source and thus will run as long as fuel is supplied. The fuels used in fuel cells are hydrogen and oxygen and the byproducts are water and heat.

The fuel cell was invented by Sir William Grove in 1839. Grove knew that water could by split into hydrogen and oxygen sending an electric current through it. He theorized that if the process were run in reverse then water and electricity would be produced. Grove was successful in building a primitive device that proved his theory and called it a gas voltaic battery. More practical models have been made since then and have been called fuel cells since the late 1800s. Fuel cells have since been used in a wide variety of recent applications ranging from British submarines to NASA space missions.

There are a wide variety of types of fuel cells, each varying their source of hydrogen and ways to successfully conduct the chemical reactions involved.

The type of fuel cell that this module is focused on is a PEM fuel cell. PEM stands for Proton Exchange Membrane (or sometimes Polymer Electrolyte Membrane). There are 5 main parts of a PEM fuel cell.





1: **Fuel:** Hydrogen (source of electrons) & Oxygen (air – to complete reaction & current)

2: **Anode:** A platinum catalyst separates the hydrogen into positively charged hydrogen ions and negatively charged electrons.

3. **PEM:** The proton exchange membrane is made of an acid (electrolyte) mixed into a polymer thin sheet. The membrane allows the hydrogen protons to pass through but not the electrons.

4. **Cathode:** At the cathode, the protons combine with the electrons and oxygen to form water. This process is induced by another platinum catalyst.

5. **Current:** As the electrons flow from the anode to the cathode, a useful electrical current is formed.

The chemical reactions are summed up below:

Anode:	$2H_2 \;\text{--->}\; 4H^+ + 4e^-$
Cathode:	$4e^- + 4H^+ + O_2 \;\text{--->}\; 2H_2O$
Overall:	$2H_2 + O_2 \;\text{--->}\; 2H_2O$

For our wet labs in this module, we use a HCL & Zinc reaction for our hydrogen source which is bubbled onto the anode which is platinum mesh suspended by alligator clips into a 0.5 M H_2SO_4 solution. Air is bubbled at the cathode onto a platinum wire suspended by alligator clips into a 0.5 M H_2SO_4 solution. Instead of using a PEM, we use a salt bridge of KCL solution.

Current Applications of Fuel Cells

The PEM Fuel Cell has many characteristics that make it very applicable. It is very stable, operates at low temperatures, can be compact/portable, and has relatively high power density. As a result the PEM Fuel Cell has been used in various prototypes and applications, and is a good choice for transportation, portable electronics, and stationary power.

Fuel cells have already been used to power vehicles such as cars and buses. The technology is ready for fuel cell cars, but the hydrogen production and availability is not at a point where it can sustain mass produced Fuel Cell Cars. PEM Fuel Cells are also used in stationary power. In test production they have been used to power residences, and also to provide back-up power for power companies to service areas with downed power lines. The compactness and portability of PEM Fuel Cells is finding a market in the portable electronics industry. These fuel cells have powered cell phones, laptops, and MP3 players in prototype demonstrations. The characteristics of the PEM Fuel Cell make it very attractive as a power source for many different applications and more applications are continuously being developed.

The Future of Fuel Cells

The use of Hydrogen to replace fossil fuels is a popular trend in technology. The idea of using an abundant clean energy source with water being the only major by-product is very alluring. As mentioned, Fuel cells also have the potential to replace lithium ion batteries in portable technologies. Their superior "battery life" and power output make them the ideal candidate The primary limiting factors on fuel cell development are the cost of fabrication and fuel generation.

There are some severe problems to be overcome, however. Current research is aimed at finding ways to create less expensive catalysts and alternative fuel sources. The requirement of extensive amounts of platinum, make the cell's base price very expensive. In addition, hydrogen has its own limitations:

1. Current production of hydrogen gas is primarily derived from steam reformation of methane. Thus fossil fuel use is not lowered, simply centralized.

2. Electrolysis requires prodigious amounts of electricity. Even at 90% efficiency the electrical requirements to generate significant hydrogen would require an exponential increase of electrical production in the United States.
3. At current efficiencies, a raw hydrogen gas system in a vehicle would require three times greater volume of hydrogen stored at 700psi to replace the same energy level of gasoline.
4. Liquid sources of hydrogen fuel such as Methanol contaminate the cathodes with CO, reducing efficiency over time.

The key to hydrogen's future lay in research into effective means of hydrogen production and lowering the cost per Watt price of fuel cells.

Rationale for Module

This module is intended to introduce students to the basics of PEM fuel cell operation. The intent was to create a set of labs that could be plugged into several different areas of a physics or mathematics to provide enrichment and application. The engineering and fabrication aspect of the module also makes it appropriate as part of a materials science or applied technology program.

Basic Mathematic Concepts

Functions - Depending on the level of mathematics you can choose to use the following functions to fit the curves to. This allows you to tailor this to a variety of levels.

- Linear
- Quadratic
- Exponential
- Polynomial

Regression / Correlation – Fitting the data, and using correlation to determine the best function

Central Limit Theorem

95% Confidence Interval

Standard Deviation

Basic Science Concepts

The unit will cover several basic concepts in electromagnetism including:

Potential and Potential Difference (V, Volts)

Current (I, Amp)

Resistance (R, Ohms)

Ohm's Las

Power (P, Watts)

Fuel Cells

Chemical Batteries

Oxidation/reduction reactions

Kinetic Theory

Electrolysis

Internal Resistance

Grade Level Expectations (GLEs) and EALRS met.

The following are extracts from the Washington Grade Level Expectations that are addressed in this module. This includes the GLEs themselves as well as vocabulary and detailed investigation criteria.

Math EALRS Grade 9/10

1.1.4 Apply understanding of direct and inverse proportion to solve problems.

1.2.6 Understand and apply strategies to obtain reasonable measurements at an appropriate level of precision.

1.4.3 Apply appropriate methods and technology to collect data or evaluate methods used by others for a given research questions.

1.4.4 Understand and apply techniques to find the equation for a reasonable linear model.

1.4.5 Analyze a linear model to judge its appropriateness for a data set.

1.4.6 Apply understanding of statistics to make, analyze, or evaluate a statistical argument.

1.5.2 Analyze a pattern, table, graph, or model involving repeated addition (linear) or repeated multiplication (exponential) model to write an equation or rule.

1.5.4 Apply understanding of equations, tables, or graphs to represent situations involving relationships that can be written as repeated addition (linear) or repeated multiplication (exponential).

1.5.6 Apply procedures to solve equations and systems of equations.

2.2.2 *Apply mathematical tools to solve the problem.*

3.1.1. Synthesize information from multiple sources in order to answer questions.

3.3.2 Analyze thinking and mathematical ideas using models, known facts, patterns, relationships, counter examples, or proportional reasoning.

4.1.1 Understand how to develop or apply an efficient system for collecting mathematical information for a given purpose.

4.1.2 Synthesize mathematical information for a given purpose from multiple, self-selected sources.

4.2.2 Understand how to express ideas and situations using mathematical language and notation.

5.1.1 Apply multiple mathematical concepts and procedures in a given problem or situation.

5.1.2 Understand how use different mathematical models and representations in the same situation.

5.2.1 Analyze mathematical patterns and ideas to extend mathematical thinking and modeling in other disciplines.

5.3.1 Understand situations in which mathematics can be used to solve problems with local, national, or international implications.

5.3.2 Understand the mathematical knowledge and training requirements for occupational/career areas of interest

Science Grade Level Expectations

1.1.4 Analyze the forms of energy in a system, subsystems, or parts of a system

1.2.1 Analyze how systems function, including the inputs, outputs, transfers, transformations, and feedback of a system and its subsystems

1.2.2 Analyze energy transfers and transformations within a system, including energy conservation

1.2.3 Understand the structure of atoms, how atoms bond to form molecules, and that molecules form solutions.

1.3.1 Analyze the forces acting on objects

1.3.3 Analyze the factors that affect physical, chemical, and nuclear changes and understand that matter and energy are conserved

2.1.1 Understand how to generate and evaluate questions that can be answered through scientific investigations.

2.1.2 Understand how to plan and conduct systematic and complex scientific investigations

2.1.3 Understand how to construct a reasonable explanation using evidence

2.1.3 Synthesize a revised scientific explanation using evidence, data, and inferential logic.

2.1.4 Understand how to use simple models to represent objects, events, systems, and processes.

2.1.4 Analyze how physical, conceptual, and mathematical models represent and are used to investigate objects, events, systems, and processes.

2.1.5 Apply understanding of how to report complex scientific investigations and explanations of objects, events, systems, and processes and how to evaluate scientific reports

2.2.1 Understand that all scientific observations are reported accurately and honestly even when the observations contradict expectations.

2.2.2 Analyze scientific theories for logic, consistency, historical and current evidence, limitations, and capacity to be investigated and modified.

3.1.2 Evaluate the scientific design process used to develop and implement solutions to problems or challenges.

3.2.3 Analyze the scientific, mathematical, and technological knowledge, training, and experience needed for occupational/career areas of interest.

GLE Grade 10 Vocabulary

controlled variable

electrical charge

electrical force

experiment

experimental control condition

investigative control

investigative plan

investigative question

Joules (J)

manipulated variable

principle

relationship

reliability

research question

solubility

solute

solvent

theory

thermal energy

Work

Potential

Potential Difference Current

Resistance

Equipment

See individual labs and lesson plans

Prerequisite Knowledge

See individual labs and lesson plans

Procedures

See individual labs.

Safety Precautions

The following are adapted from the Washington State GLE guide for science. OSPI has a color safety poster available at: **http://www.k12.wa.us/CurriculumInstruct/Science/default.aspx**.

- All science teachers must be involved in an established and ongoing safety training program, relative to the established safety procedures, that is updated on an annual basis.
- Teachers shall be notified of individual student health concerns.
- Materials intended for human consumption shall not be permitted in any space used for hazardous chemicals and or materials.
- Students and parents will receive written notice of appropriate safety regulations to be followed in science instructional settings.
- More specific to these labs: Ensure students wash there hands after the labs (especially after handling lead) , Ensure students do not try to eat/drink the simple sugar or glycerin.

Instructional Strategies

This module was designed to minimize direct instruction and maximize student involvement. The focus is on generating student interest through cognitive dissonance and/or inquiry questions. A short discussion of some possible strategies follows:

Scientific Inference: Labs and activities are structured to enable inferences that lead to accurate predictions for how systems work.

Hypothesizing: Focus on scientific methods. Students are given sufficient information to create a explanation that can be tested.

Interpreting: Labs require students to analyze data both quantitatively and qualitatively. Questions require them to interpret causality from their measurements, and then predict future outcomes by explaining how the manipulated variable caused the responding variable to change.

Data Collection

See individual labs.

Data Analysis

See individual labs.

Conclusions

See individual labs.

Evaluation Protocols

See individual labs and worksheets.

Appendix A -Instructional Materials

EM Unit Outline (Physics)

Fuel Cell 101 Presentation

Appendix B –Laboratory Write-Ups

Mathematics Labs:

Lab 1 What's going on in the fuel cell

Lab 2 Getting the Fuel Cell Function

Lab 3 Optimizing the Power Output of a Fuel Cell

Physics Labs:

EM Lab #5 Hydrogen Wet Cell

EM Lab #6 Dry cell comparison

EM Lab #7 Electrolysis

Appendix C –Student Worksheets

Experimental Design exercise

Appendix D –Supplemental Materials

Alternative Lab ideas

Basic Circuits presentation

References

Bledsoe, Jason, Micro channel Mixing and Fluid Dynamics, SWEET 2006.

Council of State Science Supervisors (CSSS). (1998). Science Safety: Making the Connection. Available: http://csss.enc.org/media/scisafe.pdf>.

Fuel Cell applications, website. Retrieved July 23rd , 2006 from http://www.bpa.gov/energy/n/tech/fuel_cell/pem_fuel_cells.cfm

Giancoli, Douglas C., Physics 4th Ed, 1995, Prentice hall, Englewood Cliffs NJ, 07632

Haber-Schaim, Uri, Introductory Physical Science 8th ed, 2005, Science Curriculum Inc., Belmont MA, 02478

NSTA. (2004). Inquiring Safely: A Guide for Middle School Teachers.

NSTA. (2004). Investigating Safely: A Guide for High School Teachers.

OSPI. (2000). OSPI: Health and Safety Guide, section K.

OSPI (2004). Science K–10 Grade Level Expectations: A New Level of Specificity. OSPI Document Number 04-0051

SWEET. (2006). Summer at WSU- Engineering Experiences for Teachers. Brochure. Retrieved July 17, 2006 from http://wsta.net/html/modules.php?name=News&file=article&sid=371.