Chemical Elements and Fuel Cell Curriculum

for Upper Elementary Grades
(4^{th} – 6^{th})

Basic introduction for upper elementary grades (4^{th} – 6^{th}) in: 1) selected chemical elements hydrogen and oxygen, 2) fuel cells with a major emphasis on understanding how a Proton Exchange Membrane Fuel Cell (PEMFC) operates.

TEACHER NOTES

By
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Introduction:

A. Program Overview:

This Program Overview will cover the project history, goals, correlation to National Science Content Standards and California Science Standards*, what is expected of teachers, lesson plan format, curriculum information, material list, and definitions.

In the State of the Union Address, January 28, 2003, President George W. Bush spoke about promoting energy independence for our Country. He said we can do this while dramatically improving the environment and promoting energy efficiency, conservation, developing cleaner technology and to produce more energy at home. We need to make our air cleaner and our country much less dependent on foreign sources of oil.

According to the Department of Energy (DOE) Hydrogen Posture Plan, February 2004, "energy is the life-blood of our Nation. It is the mainstay of our standard of living, economy and national security.

In the United States demand for oil is predicted to increase by nearly 50 percent by 2025. Oil brought into our country by ships and other means, already supply more than 55 percent of U.S. needs, and those imports are predicted to increase to more than 68 percent by 2025. Our growing needs on foreign supply of energy threatens our national security. If we don't have enough energy to keep the lights on and our cars moving we are not safe. As a Nation, we must work to reduce our need on foreign sources of energy in a way that is affordable and keeps our environment from being polluted."

It is essential to understand that the United States of America of tomorrow will be shaped by what we do in classrooms today. Teaching our students about clean air, the environment, and alternative forms of clean energy will stimulate students to ask intelligent and probing questions about their future. They will be interested in furthering their education in all types of engineering, chemistry, physics, social ecology, and non-technical areas like policymakers graphic design, marketing, technical writing, political science, education, human resources, business, economics, finance, and fields related to construction and more.

As a response to the above the "Chemical Elements and Fuel Cells: A Curriculum for Upper Elementary Grades (4^{th} – 6^{th}) was developed.

* Correlation to Standards by: Virginia Bergquist, PhD., vbergquist@BrainEdCare.com

Project History:

The “Chemical Elements & Fuel Cells: A Curriculum for Upper Elementary Grades (4^{th} – 6^{th}),” (The Curriculum) is designed around a Pre-Activity Discussion and a Six Lesson Unit using science to teach students about how fuel cells use the chemical energy of hydrogen to generate electricity, cleanly, and efficiently. Hydrogen fuel cells have the potential to strengthen our national energy security and reduce the generation of greenhouse gases, air pollution, and global climate changes. Teaching students about this important technology will give them an edge in this developing field. We hope students will play an important part in making fuel cells part of our technological future.

An Upper Elementary Teacher Workshop was held in October 2005 in Irvine, California at the Irvine Unified School District to train Science Specialists on The Curriculum. Nineteen Science Specialists attended the workshop and were given material for 1000 Fifth and Sixth Grade Students. Once the program concluded data was collected and the curriculum was updated.

This curriculum is set to National Science Content Standards and California Science Standards. It is designed to teach science and use hands on experiments incorporating all disciplines; Science, (Chemistry and Physics), Math, English/Language Arts, and History/Social Science. The goal is to educate these students while they perform hands on activities and doing critical thinking by observation, measurement, and prediction using a fuel cell car kit, and learn about the emerging hydrogen energy economy while having fun.

Goals:

- To teach science concepts relating to energy that are correlated to the National Science Content Standards and California Science Standards.
- Provide opportunities for active learning integrated with Science, Math, English / Language Arts, and History/Social Science.
- To teach upper elementary grade students about selected chemical elements and how fuel cells work through a comprehensive, educational, and fun curriculum to teach.

Standards Based Curriculum*:

The Curriculum education program has been designed for students in the forth through sixth grades and meets the following National Science Content Standards and California State Science Standards.

I. Correlation to National Science Content Standards:

i. *Science as Inquiry*
  - Abilities to do scientific inquiry
  - Understanding about scientific inquiry

ii. *Physical Science*
  - Properties and changes of properties in matter
  - Motions and forces
  - Transfer of energy

iii. *Science and Technology*
  - Abilities of technological design
  - Understanding about science and technology

iv. *Science in Personal and Social Perspectives*
  - Populations, resources, and environments
  - Natural hazards
  - Risks and benefits
  - Science and technology in society

v. *Life Science*
  Populations and ecosystems

II. Correlation to California Science Standards:

The study of chemical elements and hydrogen in particular along with fuel cell technology in California schools will demonstrate to students that “scientific progress is made by asking meaningful questions and conducting careful investigations” as stated in the California Science Standards. The Curriculum unit of study is designed for students in the fourth through sixth grades and meets the following California Science Standards:

(The immediate following numbering system under each grade follows the numbering system used in the California Science Standards.)

i. **<u>4th Grade</u>**

Investigation and Experimentation

6. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content students should develop their own questions and perform investigations. Students will:

a. Differentiate observation from inference (interpretation) and know scientists' explanations come partly from what they observe and partly from how they interpret their observations.
b. Measure and estimate the weight, length, or volume of objects.
c. Formulate and justify predictions based on cause-and-effect relationships.
d. Conduct multiple trials to test a prediction and draw conclusions about the relationships between predictions and results.
e. Construct and interpret graphs from measurements.
f. Follow a set of written instructions for a scientific investigation.

ii. <u>5th Grade</u>

Physical Sciences

1. **Elements and their combinations account for all the varied types of matter in the world. As a basis for understanding this concept students will:**

a. know that during chemical reactions the atoms in the reactants rearrange to form products with different properties.
b. know all matter is made of atoms, which may combine to form molecules.
c. know metals have properties in common, such as high electrical and thermal conductivity. Some metals, such as aluminum (Al), iron (Fe), nickel (Ni), copper (Cu), silver (Ag), and gold (Au), are pure elements; others, such as steel and brass, are composed of a combination of elemental metals.
d. Students know scientists have developed instruments that can create discrete images of atoms and molecules that show that the atoms and molecules often occur in well-ordered arrays.
e. Students know differences in chemical and physical properties of substances are used to separate mixtures and identify compounds.

f. Students know properties of solid, liquid, and gaseous substances, such as sugar ($C_6H_2O_6$), water (H_2O), helium (He), oxygen Students know that each element is made of one kind of atom and that the elements are organized in the periodic table by their chemical properties.
g. (O_2), nitrogen (N_2), and carbon dioxide (CO_2).
h. Students know living organisms and most materials are composed of just a few elements.
i. Students know the common properties of salts, such as sodium chloride (NaCl).

Investigation and Experimentation

6. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

a. Classify objects (e.g., rocks, plants, leaves) in accordance with appropriate criteria.
b. Develop a testable question.
c. Plan and conduct a simple investigation based on a student-developed question and write instructions others can follow to carry out the procedure.
d. Identify the dependent and controlled variables in an investigation.
e. Identify a single independent variable in a scientific investigation and explain how this variable can be used to collect information to answer a question about the results of the experiment.
f. Select appropriate tools (e.g., thermometers, meter sticks, balances, and graduated cylinders) and make quantitative observations.
g. Record data by using appropriate graphic representations (including charts, graphs, and labeled diagrams) and make inferences based on those data.
h. Draw conclusions from scientific evidence and indicate whether further information is needed to support a specific conclusion.
i. Write a report of an investigation that includes conducting tests, collecting data or examining evidence, and drawing conclusions.

iii 6th Grade

Heat (Thermal Energy) (Physical Science)

3. Heat moves in a predictable flow from warmer objects to cooler objects until all the objects are at the same temperature. As a basis for understanding this concept students will:

a. know energy can be carried from one place to another by heat flow or by waves, including water, light and sound waves, or by moving objects.

b. Students know that when fuel is consumed, most of the energy released becomes heat energy.

c. Students know heat flows in solids by conduction (which involves no flow of matter) and in fluids by conduction and by convection (which involves flow of matter).

d. Students know heat energy is also transferred between objects by radiation (radiation can travel through space).

Resources

6. Sources of energy and materials differ in amounts, distribution, usefulness, and the time required for their formation. As a basis for understanding this concept students will:

a. know the utility of energy sources is determined by factors that are involved in converting these sources to useful forms and the consequences of the conversion process.

b. know different natural energy and material resources, including air, soil, rocks, minerals, petroleum, fresh water, wildlife, and forests, and know how to classify them as renewable or nonrenewable.

c. know the natural origin of the materials used to make common objects.

Investigation and Experimentation

7. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

a. Develop a hypothesis.

b. Select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tests, collect data, and display data.

c. Construct appropriate graphs from data and develop qualitative statements about the relationships between variables.

d. Communicate the steps and results from an investigation in written reports and oral presentations.

e. Recognize whether evidence is consistent with a proposed explanation.

B. How to use the Teacher Notes:

What is expected of teachers?

This curriculum takes a minimum of seven total hours of classroom time. In addition, Teachers must have prep time to learn how to use the fuel cell kit, discuss safety, general electricity concepts, the periodic table and adding negative and positive numbers with students. Classroom consumables will need to be pre-purchased. Each lesson describes the required consumables.

Lesson Plan Format:

The Curriculum Lessons need to be followed sequentially to be effective. However, the lessons are designed in PowerPoint format to allow teachers to alter the curriculum to build on earlier learning or to insert changes that help achieve understanding of more complex concepts or long term activities. The Lesson and Activity is built on a 50 minute class, 20 minutes of instruction time, 20 minutes for the activity and 10 minutes of cleanup.

Each Lesson presented within The Curriculum Teacher Guide follows the same format presented below:

Teacher Notes:
Title:
Key Concept: Brief 1-2 sentence description of the lesson to help teachers understand the academic learning objectives taught in the lesson.
Activity: Brief description of the activity
Important Words: These are key words that help understand the lessons and activities.

The Curriculum Download:

The Curriculum Download includes all the information contained in the Teacher Notes, Handouts, Pre-Activity Discussion, and Six Lessons. The Curriculum Download can be found at http://www.bpa.gov/Energy/N/projects/fuel_cell/education.

Materials List:

The Inventory List may be used by the instructor to replenish consumables which can be purchased locally.

Lesson One: Introduction to the Periodic Table and 3-D Atomic Model
Activity: Build a 3-D Atomic Model
Whiffel Balls (to represent the nucleus)
Beads (to represent the electrons)
Balloons (to represent the electron cloud)
Plastic bag (to represent the electron cloud – shell level two)
Twist tie
Marker

Lesson Two: Composition, Let's Make Salt and Water!
Activities: Static Electricity and Chemical Equation Game
Paper plates
Salt and pepper
Balloon
element sheets (slides provided on CD or Download)
space the students to move around and bond. If necessary you may want to photocopy the elements so more students can participate or use information to create more elements for more combinations.

Lesson Three: Decomposition, Let's Make Hydrogen! and an Introduction to How a Solar Panel Works
Activity: Use a Solar Panel to Create Hydrogen and Oxygen From Distilled Water by Using a Fuel Cell Kit

Fuel Cell Model Car Kits. (In the kit is a solar panel that will be used to decompose (electrolyze) distilled water and make hydrogen and oxygen.)
75 watt PAR30 incandescent lamp
extension cord
distilled water

Lesson Four: Introduction to Fantastic Fuel Cells!
Activities: Watch a video of how a Proton Exchange Membrane Fuel Cell (PEMFC) works and make a Solid Oxide Fuel Cell (SOFC) Tube

Construction paper folded into cylinders
White – air tube (thinnest cylinder)
(a straw can be substituted instead)
Green – Cathode layer
Grey – Electrolyte Membrane layer
Blue – Anode layer
Tape
Foil – 5" x 5" square - used to seal the bottom of the tube
12" piece of yarn – the electric circuit channel
Labels (provided)
Light bulb clip art (provided) this is the load.
Scissor

Lesson Five: Learn about Exothermic and Endothermic Reactions
Activity: See what happens when we expose iron, water, activated carbon and salt to air? What happens when we mix ammonium nitrate and water?

Toe warmers
Cold pack

Lesson Six: Critical Thinking: Observe - Measure - Predict
Activity: Use a Solar Panel and Fuel Cell Car Kit

Fuel Cell Model Car Kit
distilled water
data sheets
stop watch or clock with second hand (not included)
75 watt PAR30 incandescent lamp (not included)

Supplemental activities and resources:

MISSION H2 Scavenger Hunt can be found at:
http://www.bpa.gov/Energy/N/projects/fuel_cell/education
How a methanol fuel cell system works video:
http://www.bpa.gov/energy/n/projects/fuel_cell/education/HowAFuelCellWorks.cfm
What is Electricity?
http://www.eia.doe.gov/kids/energyfacts/sources/electricity.html
Student information on electricity: http://www.peakstudents.org/.
http://www.kcet.org/lifeandtimes/archives/200607/20060706.php
NEED h2 Educate teacher and student guides http://www.need.org,
http://www.energystar.gov/
Department of Energy for elementary students:
http://www1.eere.energy.gov/education/science_projects.html#elementary
State of California's Department of Energy information for students:
http://www.energyquest.ca.gov/
http://www.nfcrc.uci.edu/EnergyTutorial/index.html
http://www.aqmd.gov/
http://www.fuelcells.org
http://www.hydrogen2000.com
Other websites:
http://www.kids4hydrogen.com/newsbulletin.htm
http://www.cafcp.org/,
http://www.fypower.org/
http://www.californiahydrogen.org/
http://www.usfcc.com/,
www.**hydrogenassociation**.org,
http://www.nfcrc.uci.edu/fcresources/FCexplained/index.htm,
http://dodfuelcell.cecer.army.mil/,
http://ull.chemistry.uakron.edu/periodic_table/,
http://www.nsta.org/resources,
http://www.iit.edu/~smart/garrear/fuelcells.htm,

Other resources:
Harcourt Science California Edition, Harcourt School Publishers, 2000
ASME PTC 50-2002 Fuel Cell Power Systems Performance, 2002,
Chemistry: The Molecular Nature of Matter and Change, Silberberg, Mosby 1996
Chemistry: Sixth Edition, Zumdahl/Zumdahl, Houghton Mifflin Company, Boston, New York 2003
The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs, National Research Council
and National Academy of Engineering, the National Academies Press, Washington, D.C. 2004
Fuel Cell Handbook: Seventh Edition by EG&G Technical Services, Inc. U.S. DOE NETL, 2004

Fuel Cell Partnerships – An Overview, Research Report 4, August 2003, Kettering University, Etim U. Ubong, PhD and Rajani P. Satti, M.Sc.
Taking Sides: Clashing Views on Controversial Environmental Issues, Eleventh Edition, McGraw-Hill/Dushkin, 2005 by Thomas A. Easton
Transistor Electronics: Basic Instruction in Electricity and Electronics, With Major Emphasis on Solid State Components, The Goodheart – Willcox Company, Inc., 1981 by Howard H. Gerrish
Powering the Future, The Ballard Fuel Cell and the Race to Change the World, John Wiley & Sons, by Tom Koppel
The Solar Hydrogen Civilization: The Future of Energy is the Future of Our Global Economy, American Hydrogen Association, 2003, by Roy McAlister.

* Correlation to Standards by: Virginia Bergquist, PhD., vbergquist@BrainEdCare.com

** Some definitions taken from: Fuel Cell Partnerships – An Overview, Research Report 4, August 2003, Kettering University, Etim U. Ubong, PhD. And Rajani P. Satti, M.Sc.

*** The Hydrogen Economy, Opportunities, Costs, Barriers, and R&D Needs, Ntional Research Council and National Academy of Engineering, The National Academies Press, Washington, D.C., 2004, pg 1, www.nap.edu

**** Teachers Guide to Eight Fuel Cell Car Activities, 2003/2004, Funded by a US DOE grant, Copyright 2004 Heliocentris, Second Edition, 2004 http://www.bpa.gov/Energy/N/projects/fuel_cell/education/Docs/Curriculum.pdf

C. Definitions of Fuel Cells**:

A fuel cell is a device that continuously changes the chemical energy of a fuel (as hydrogen) into electrical energy. It operates at different temperatures and has different applications: residential; portable; transportation; wastewater treatment plants; stationary power; and industrial applications.

Proton Exchange Membrane Fuel Cell (PEM). A type of fuel cell in which the exchange of protons (H+) from the anode to the cathode via a membrane is involved in the chemical reaction producing electricity. The electrolyte is called a proton exchange membrane (PEM). The fuel cells typically run at low temperatures (<100 °C) and pressures (<5atm). The electrolyte is a solid.
Solid Oxide Fuel Cell (SOFC). A type of fuel cell in which the electrolyte is a solid, non porous metal oxide. The oxygen is transported from the cathode to the anode. Temperatures of operation are typically 800-1000 ° C.
Direct Methanol Fuel Cell (DMFC). A type of fuel cell in which the fuel is methanol (CH3OH), in a gaseous or liquid form. The methanol is oxidized directly at the anode with no reformation to hydrogen. The electrolyte is typically a PEM. The operating temperature range is generally 50ºC-120ºC.
Alkaline Fuel Cell (AFC). A type of hydrogen/oxygen fuel cell in which the electrolyte is concentrated KOH (35-50%, a liquid) and hydroxide ions (OH-) are transported from the cathode to the anode. Temperature of operation is typically in the range of 60-90 °C. The electrolyte is a liquid.
Phosphoric Acid Fuel Cell (PAFC). A type of fuel cell in which the electrolyte consists of concentrated phosphoric acid (H_3PO_4) and protons (H+) are transported from the anode to the cathode. The operating temperature range is generally 160-220 °C. The electrolyte is a liquid.
Molten Carbonate Fuel Cell (MCFC). A type of fuel cell consisting of a molten electrolyte of Li_2CO_3/Na_2CO_3 in which the species CO_3^{2-} is transported from the cathode to the anode. Operating temperatures are typically near 650 ° C. The electrolyte is a liquid.

Other Definitions:

Anode: An electrode in a fuel cell where electrons are produced.
Catalyst: A chemical substance that increases the rate of a reaction without being consumed.
The catalyst lowers the activation energy required, allowing the reaction to proceed more quickly or at a lower temperature.
Cathode: The electrode in a fuel cell where electrons are consumed.
Composition: the manner in which the parts of a thing are put together
Conduction: The transfer of electrical current through a solid or liquid.
Conserve: to keep in a safe or sound state, to avoid wasteful or destructive use of : use carefully <conserve natural resources> <conserve energy>

Decomposition: the separation of a chemical substance into simpler chemical substances and especially the elements of which it is made up <decomposition of water into hydrogen and oxygen

Electric Circuit: The path along which electrons flow. (like a pipeline)

Electric Current: The flow of electrons from a negatively charged object to a positively charged object.
(in the pipeline)

Electric Force: The attraction or repulsion of objects due to their electric charges.

Electrode: _An electric conductor through which an electric current enters or leaves a medium.

Electrons: an elementary particle that has a negative charge of electricity

Electrolyte: A non-metallic insulating material in which current flow in an external circuit is made possible By the movement of ions through the electrolyte. (The type of Electrolyte determines the type of fuel cell):

Elements: one of the four substances air, water, fire, or earth formerly believed to make up the physical universe

Endothermic: A change occurs when there is absorption of heat from the surroundings.

Exothermic: A change occurs when heat is given off to the surroundings.

Hydration: in water.

Investigation: to study by close examination

Inquiry: a careful examination

Membrane: The separating layer in a fuel cell that acts as an electrolyte as well as a barrier film separating the gases in the anode and cathode compartments of the fuel cell.

Neutrons: an uncharged atomic particle that has a mass nearly equal to that of the proton and is present in all known atomic nuclei except the hydrogen nucleus

Nucleus: a central point

Observation: an act of gathering information (as for scientific studies) by noting facts or occurrences.

Oxidation: The loss of electrons accompanied by an increase in oxidation number. The Oxidation number is equal to the number of charges a bonded atom would have.

Periodic Table: an arrangement of chemical elements in order of atomic number that groups elements with common characteristics in the same area of the table

Planar Cells: Fuel cells that are formed in a planar fashion and allow fuel and oxidant to flow on the surfaces of the plane.

Prediction: forecast

Protons: an arrangement of chemical elements in order of atomic number that groups elements with common characteristics in the same area of the table

Reforming: Changing a fuel to a more hydrogen rich gas.

Tubular Cells: Fuel cells that are formed in a cylindrical fashion and allow fuel and oxidant to flow on the inner or outer surfaces of the pipe.

D. Any Questions? Contact me:

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Pre-Activity Discussion: What is Energy? What is Electricity?

Teacher Notes for Pre-Activity Lesson:
This Unit is about understanding fuel cells, but first students need to be familiar with electricity. In order to expedite that learning the following notes on electricity is taken from the Department of Energy's Energy Information Kid's Page http://www.eia.doe.gov/kids/energyfacts/sources/electricity.html, "…electricity is the flow of electrical power or charge. It is a secondary energy source which means that we get it from the conversion of other sources of energy, like coal, natural gas, oil, nuclear power and other natural sources, which are called primary sources. The energy sources we use to make electricity can be renewable or non-renewable, but electricity itself is neither renewable nor non-renewable.

Electricity is a basic part of nature and it is one of our most widely used forms of energy. Many cities and towns were built alongside waterfalls (a primary source of mechanical energy) that turned water wheels to perform work. Before electricity generation began slightly over 100 years ago, houses were lit with kerosene lamps, food was cooled in iceboxes, and rooms were warmed by wood-burning or coal-burning stoves. Beginning with Benjamin Franklin's experiment with a kite one stormy night in Philadelphia, the principles of electricity gradually became understood. Thomas Edison helped change everyone's life -- he perfected his invention -- the electric light bulb. Prior to 1879, direct current (DC) electricity had been used in arc lights for outdoor lighting. In the late-1800s, Nikola Tesla pioneered the generation, transmission, and use of alternating current (AC) electricity, which can be transmitted over much greater distances than direct current. Tesla's inventions used electricity to bring indoor lighting to our homes and to power industrial machines.

Despite its great importance in our daily lives, most of us rarely stop to think what life would be like without electricity. Yet like air and water, we tend to take electricity for granted. Everyday, we use electricity to do many jobs for us -- from lighting and heating/cooling our homes, to powering our televisions and computers. Electricity is a controllable and convenient form of energy used in the applications of heat, light and power.

THE SCIENCE OF ELECTRICITY ***developed by the National Energy Education Development Project***
In order to understand how electric charge moves from one atom to another, we need to know something about atoms. Everything in the universe is made of atoms—every star, every tree, every animal. The human body is made of atoms. Air and water are, too. Atoms are the building blocks of the universe. Atoms are so small that millions of them would fit on the head of a pin.

Atoms are made of even smaller particles. The center of an atom is called the **nucleus**. It is made of particles called **protons** and **neutrons**. The protons and neutrons are very small, but electrons are much, much smaller. **Electrons** spin around the nucleus in shells a great distance from the nucleus. If the nucleus were the size of a tennis ball, the atom would be the size of the Empire State Building. Atoms are mostly empty space.

If you could see an atom, it would look a little like a tiny center of balls surrounded by giant invisible bubbles (or shells). The electrons would be on the surface of the bubbles, constantly spinning and moving to stay as far away from each other as possible. Electrons are held in their shells by an electrical force.

The protons and electrons of an atom are attracted to each other. They both carry an **electrical charge**. An electrical charge is a force within the particle. Protons have a positive charge (+) and electrons have a negative charge (-). The positive charge of the protons is equal to the negative charge of the electrons. Opposite charges attract each other. When an atom is in balance, it has an equal number of protons and electrons. The neutrons carry no charge and their number can vary. (taken from http://www.eia.doe.gov/kids/energyfacts/sources/electricity.html)

The number of protons in an atom determines the kind of atom, or **element**, it is. An element is a substance in which all of the atoms are identical (the Periodic Table shows all the known elements). Every atom of hydrogen, for example, has one proton and one electron, with no neutrons. Every atom of carbon has six protons, six electrons, and six neutrons. The number of protons determines which element it is.

Electrons usually remain a constant distance from the nucleus in precise **shells**. The shell closest to the nucleus can hold two electrons. The next shell can hold up to eight. The outer shells cans hold even more. Some atoms with many protons can have as many as seven shells with electrons in them.

The electrons in the shells closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost shells do not. These electrons can be pushed out of their orbits. Applying a force can make them move from one atom to another. These moving electrons are electricity.

More information on magnetism and how electricity is generated can be found at http://www.eia.doe.gov/kids/energyfacts/sources/electricity.html

Some websites to review for research:

http://www.eia.doe.gov/kids/energyfacts/
sources/electricity.html
http://www.epa.gov/globalwarming/kids/
http://www.britannica.com/search?query=
energy&submit=Find&source=MWTEXT
http://www.wordcentral.com/
http://www.balancedenergy.org/abec/
http://www.eia.doe.gov/emeu/states/_multi_states.html

Lesson One: Introduction to the Periodic Table and 3-D Atomic Model

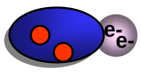
In Lesson One the first slide is of an aerial map. The students are already familiar with aerial map views. I introduced this slide with the intention of starting with a picture of something the students are already familiar with. Then by looking at the map your eye starts moving from one spot to another. I am hoping to transfer this concept of getting your eye to move over the map to getting your eye to move over the periodic table, over the rows and columns. Possibly transferring the ideas of neighborhoods and roads or from a start point to an ending point to rows and columns on the periodic table.

Some of the following notes about the Periodic Table are taken from http://www.chem4kids.com/files/elem_intro.html.

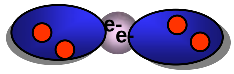
“Now we're getting to the heart and soul of the way the universe works. Elements are the building blocks of all matter. In the periodic table, elements are organized into rows and columns. They are organized according to similar patterns of behavior. Elements have something in common if they are in the same row. The periodic table has a special name for its columns, too. When a column goes from top to bottom, it's called a group. The elements in a group have the same number of electrons in their outer shell. Every element in the first column (group one) has one electron in its outer shell. Every element on the second column (group two) has two electrons in the outer shell. As you keep counting the columns, you'll know how many electrons are in the outer shell. There are some exceptions to the order when you look at the transition elements but you get the general idea.”

A 3-D Atomic Model shows a simple model of electron group arrangements. This representation of the 3-D Atomic Model is different from the planet model and wave model. The picture in the slide represents the element Neon. It has a total of 10 electrons, is in the Noble Gas group and is stable. It really doesn’t want to bond with another element because all of its electron shells are full. Depending on time, you can build any element you want as long as you follow the rules. You can pre-fill the electron clouds (balloons w/ beads). The students like to help with this.

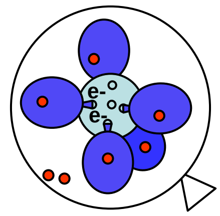
The first shell is closest to the nucleus (whiffel ball). You can draw up to two e- on the whiffel ball. One **e-** on the nucleus will represent hydrogen, two **e-** on the nucleus will represent helium. This represents the first shell level. If the element has another electron, put an electron (bead) into the electron field (balloon), slightly fill the balloon with air and tie a knot. You can put up to two electrons (beads) in each electron field. (Technically, one electron spinning in one direction producing a magnetic field N and the other electron spinning in the opposite direction producing a magnetic field S.) Atoms can form a couple of different bonds. This lesson is about building a 3-D atomic Model. We will get into bonding of electrons with other elements in Lesson Two.



or



or



As the electron's get further away from the nucleus it has more energy and naturally wants to bond.

For more info:
<u>Chemistry: The Molecular Nature of Matter and Change</u>, Silberberg, Mosby 1996.

<u>Chemistry: Sixth Edition</u>, Zumdahl/Zumdahl, Houghton Mifflin Company, Boston, New York 2003.

http://chemfinder.cambridgesoft.com/

http://www.chemicool.com/

http://chemistry.about.com/od/chemistryforkids/

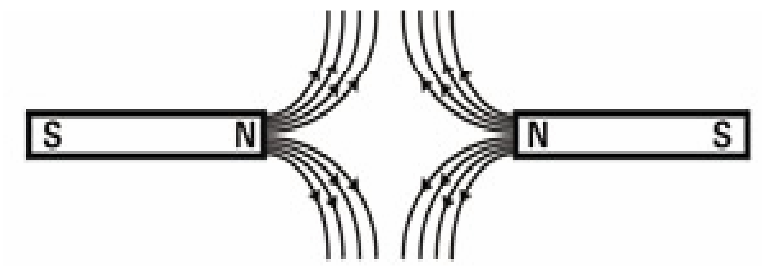
http://ull.chemistry.uakron.edu/periodic_table/

http://www.nsta.org/resources

Lesson Two: Composition
Let's Make Salt and Water!

In the first part of Lesson Two static electricity and magnetism are briefly introduced. Teaching about static electricity and magnetism will help the students understand composition and decomposition of chemical equations. However, there are no magnets in this lesson. Some of the following notes were taken from: http://www.eia.doe.gov/kids/energyfacts/sources/electricity.html. Please search this site for more information if necessary.

Starting with a Bar Magnet the rule basically is opposites attract. On a bar magnet you have a N end and a S end, similar to a + end and a - end. Have you ever held two magnets close to each other? They don't act like most objects. If you try to push the South poles together, they repel each other. Two North poles also repel each other. Turn one magnet around and the North (N) and the South (S) poles are attracted to each other. The magnets come together with a strong force. Just like protons and electrons, opposites attract.



Like poles of magnets (N-N or S-S) repel each other.

These special properties of magnets can be used to make electricity. Moving magnetic fields can pull and push electrons. Some metals, like copper have electrons that are loosely held. They can be pushed from their shells by moving magnets. Magnets and wire are used together in electric generators.

Static Electricity

Lesson Two's first activity is about static electricity. You've all heard of static electricity. You know that thing that happens when you rub your head with the balloon and watch your hair stand on end. In this lesson we talk about what happens for the split second the salt and paper leaves the plate and attaches itself to the balloon. It's an electric charge!

Notes below taken from:
http://www.eia.doe.gov/kids/energyfacts/sources/electricity.html

Electricity has been moving in the world forever. Lightning is a form of electricity. It is electrons moving from one cloud to another or jumping from a cloud to the ground. Have you ever felt a shock when you touched an object after walking across a carpet? A stream of electrons jumped to you from that object. This is called static electricity.

Have you ever made your hair stand straight up by rubbing a balloon on it? If so, you rubbed some electrons off the balloon. The electrons moved into your hair from the balloon. They tried to get far away from each other by moving to the ends of your hair.

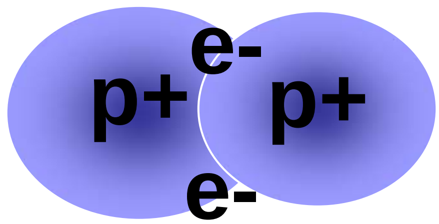
They pushed against each other and made your hair move—they repelled each other. Just as opposite charges attract each other, like charges repel each other.

Bonds & Molecules

The information below is taken from Chemistry: Sixth Edition, Zumdahl/Zumdahl, Houghton Mifflin Company, Boston, New York 2003, pg 56, paragraph 2.

"The forces that hold atoms together in compounds are called chemical bonds. One way that atoms can form bonds is by sharing electrons. These bonds are called covalent bonds, and the resulting collection of atoms is called a molecule."

Covalent Bond
(Electrons are shared)



This lesson refers to covalent bonds. Students will learn basics about forming molecules through an activity called the "Chemical Equation Game." What they actually will be doing is forming chemical equations. They will add electrons together. The rule here is the equation must equal zero (or neutral) and attain noble gas electron configuration – stable compounds.

The students will follow rules and compose (bond or come together). To understand this concept it is strongly urged to review adding positive and negative numbers.

$$(+1) + (-1) = 0$$

$$(+2) + (-2) = 0$$

$$[2 \times (+1)] + (-2) = 0$$

Next, you need to find an element's oxidation state (a way to keep track of electrons). In the planetary model of elements, each has a different combination. Some have +1, +2, -1, -2 and other combinations. However, the equation must equal zero so you will have to pick what you need to make the equation zero. Below is some information on the element Hydrogen and Oxygen. There is a lot of information below but we will just concentrate on the oxidation state. All the elements mentioned in this lesson have the oxidation state listed in the format below.

Hydrogen

Atomic Symbol	H
Atomic Number (Protons)	1
Atomic Weight (Protons & Neutrons)	1.00794
Oxidation States (a way to keep track of electrons)	+1, -1
State at room temperature	Gas, Non-metal
Melting Point, K SI unit base of temperature is Kelvin (K) T (in K) = T (in °C) + 273.15	14.01
Boiling Point, K	20.28

http://ull.chemistry.uakron.edu/periodic_table/

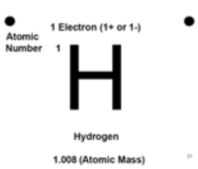
Oxygen

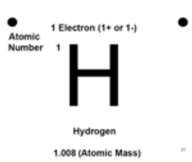
Atomic Symbol	O
Atomic Number (Protons)	8
Atomic Weight (Protons & Neutrons)	15.9994
Oxidation States (a way to keep track of electrons)	-2
State at room temp.	Gas, Nonmetal
Melting Point, K	54.8
Boiling Point, K	90.19

http://ull.chemistry.uakron.edu/periodic_table/

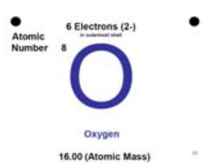
Two Hydrogen + One Oxygen = Water

(+1) + (+1) + (-2) = 0





+



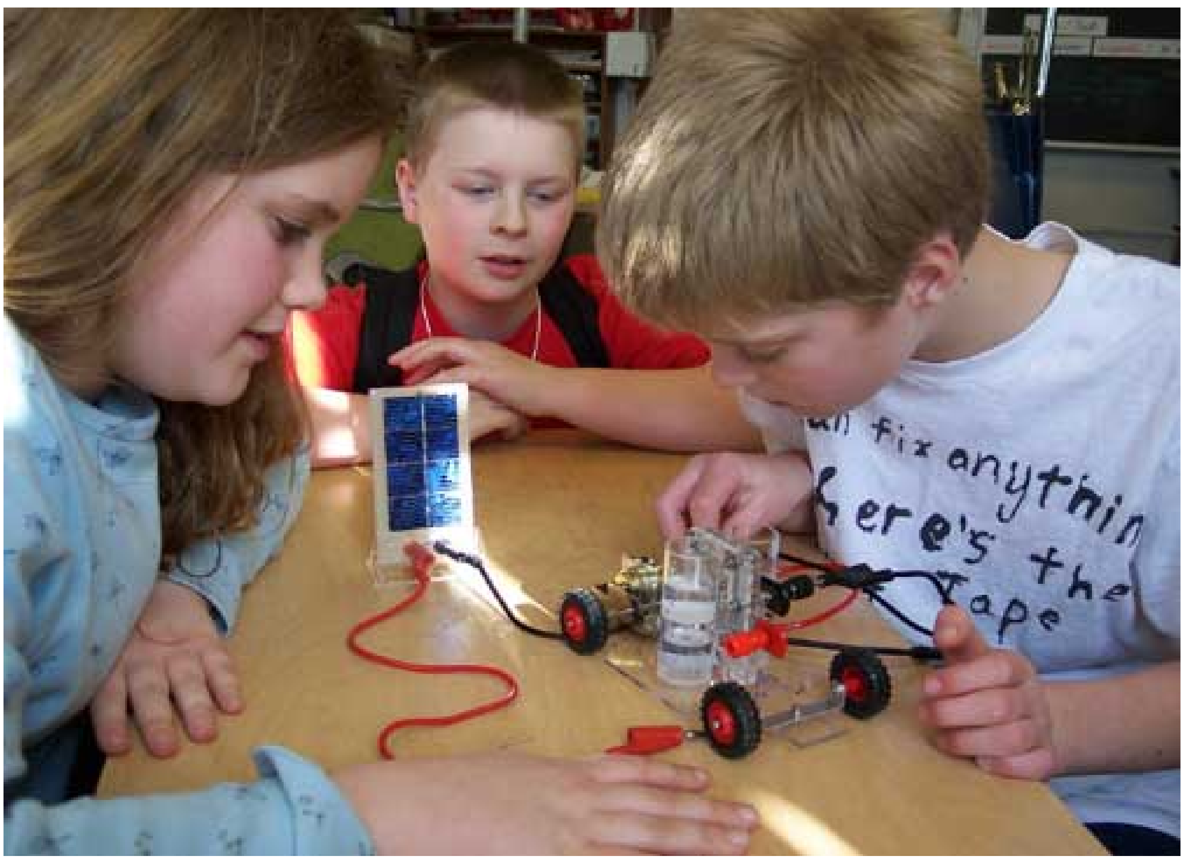
=H_2O

In order to make this complicated concept simple I designed an activity called the "Chemical Equation Game." Each student receives a sheet with an element on it. The sheet shows the element symbol, name, atomic number, mass, number of electrons, and oxidation state. The students will find the oxidation state number on their element. The goal is to find another element with an oxidation state number that will make the equation 0 or neutral.

As long as the students follow the ionization state rules (the equation has to equal zero) they are allowed to form any molecule. Have them line up to see what "work" they did. (Did they behave like a gas, (move around quickly) liquid, (not as quickly) or solid (very slowly)? Once you check the accuracy of the student's chemical equation you can try to break a bond… apply a (gentle) force. Talk about decomposition. This will lead you into Lesson Three's concept of decomposition.

If you like, you can use the slide provided, edited it and make more elements to make more molecules.

In Lesson Three you will actually decompose (electrolyze) water into hydrogen and oxygen gases. The process of composing and decomposing molecules can produce heat (exothermic reaction), or absorb heat (endothermic reaction) and electricity. The exothermic and endothermic process will be discussed in Lesson Five.



For more info:

<u>Chemistry: Sixth Edition</u>, Zumdahl/Zumdahl, Houghton Mifflin Company, Boston, New York 2003.

<u>Chemistry: The Molecular Nature of Matter and Change</u>, Silberberg, Mosby 1996.

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Lesson Three: Let's Make Hydrogen! And an Introduction to How a Solar Panel Works

In Lesson Three decomposition will be demonstrated by using a solar panel to create the electricity needed to separate water (**distilled only**) into hydrogen gas and oxygen gas. The students will be able to see the two gas bubbles. The water will be displaced. Below is a decomposition equation from Lesson Two.

Decomposition

Product | **Reactants**

$$H_2O \text{ (Water)} \xrightarrow{\text{Energy}} H^{1+}_2(g) + O^{2-}(g)$$

The solar panel changes the waves of light from the sun into a stream of electrons (electricity).

The solar panel that we will be using has several solar cells connected together.

Photons striking its surface knock electrons loose from one layer. The electrons are drawn to the other layer. If the two layers are connected through an external circuit, electrons will flow though that circuit. The flow of electrons is observed as an electric current. As more light is supplied to the solar cell, more photons are available to knock the electrons loose, and more current is generated.

Hydrogen Safety:

Although the amount of hydrogen you will make in this lesson is so minimal the following does not apply. However, the information is worth mentioning.

Hydrogen is lighter than air and diffuses rapidly. Hydrogen diffuses much faster than natural gas. Hydrogen rises 2 times faster than helium and 6 times faster than natural gas at a speed of almost 45 mph. (20m/s). Therefore, unless a roof, a poorly ventilated room or some other structure contains the rising gas, the laws of physics prevent hydrogen from lingering near a leak (or near people using hydrogen-fueled equipment). As the lightest element in the universe, confining hydrogen is very difficult. Industry takes these properties into account when designing structures where hydrogen will be used. The designs help hydrogen escape up and away from the user in case of an unexpected release.

The photo below shows a Hydrogen car (left) and a gasoline car (right). The photo compares fires from an intentionally lit hydrogen tank release to a small gasoline fuel line leak. At the time of this photo (60 seconds after ignition), the hydrogen flame has begun to subside, while the gasoline fire is intensifying. After 100 seconds, all of the hydrogen was gone and the car's interior was undamaged. (The maximum temperature inside the back window was only 67 degrees F!) The gasoline car continued to burn for several minutes and was completely destroyed. Photo/Text: Dr. Swain, University of Miami.

What back seat would you rather be sitting in?

http://www.hydrogenassociation.org/general/factSheet_safety.pdf#search=%22hydrogen%20safety%20video%20miami%20university%22h

The *Hindenburg*

The fire that destroyed the *Hindenburg* in 1937 gave hydrogen a misleading reputation. Hydrogen was used to keep the airship buoyant and was initially blamed for the disaster. An investigation by Addison Bain in the 1990s provided evidence that the airship's fabric envelope was coated with reactive chemicals, similar to solid rocket fuel, and was easily ignitable by an electrical discharge. The Zeppelin Company, builder of the *Hindenburg*, has since confirmed that the flammable, doped outer cover is to be blamed for the fire. For more information, view a short video at: www.HydrogenAssociation.org.

Hydrogen Applications:

Transportation, Stationary Power: Utilities and Residential Uses, and the Industrial Sector

Hydrogen Production, Storage and Distribution: :

Hydrogen will be produced from natural gas, coal, nuclear energy, electrolysis, wind energy, biomass and by photobiological processes, and solar. The key economic factors for a future hydrogen-based economy will be cost and safety of the fuel distribution system from where it is manufactured to the end user. A good resource for more information is http://www.nrel.gov/hydrogen/proj_production_delivery.html.

Implications for National Goals***:

A transition to hydrogen as a major fuel in the next 50 years could fundamentally transform the U.S. energy system, creating opportunities to increase energy security through the use of a variety of domestic energy sources for hydrogen production while reducing environmental impacts, including atmospheric CO_2 emissions and criteria pollutants. (lead, sulfur dioxide)

There is a potential for replacing essentially all gasoline with hydrogen over the next half century using only domestic sources. And there is a potential for eliminating almost all CO_2 and criteria pollutants from cars. However, there are currently many barriers to be overcome before that potential can be realized.

There are other strategies for reducing oil imports and CO_2 emissions, and the DOE should keep a balanced portfolio of R&D efforts and continue to explore supply-and-demand alternatives that do not depend upon hydrogen. For example, all electric vehicles or hybrid electric vehicle technology is commercially available today, and benefits from this technology can therefore be realized immediately. Fossil-fuel-based or biomass-based synthetic fuels could also be used in place of gasoline.

KIT INSTRUCTIONS****

Lighting the Solar Panel

The solar panel can be permanently damaged by overheating, usually the result of being too close to the light source.

The 75 watt PAR30 incandescent lamp supplied with many *Fuel Cell Model Car Kits* should be kept a minimum of 12 inches (20 cm) away from the solar panel. If you are using a different light source, you could occasionally touch the surface of the solar panel to ensure it is not overheating. The solar panel can be safely operated in bright sunlight. Do not use homemade reflectors made of foil or paper as they may cause overheating.

<u>In the Electrolizer Use only distilled water</u>

It is absolutely required that only distilled (de-ionized) water be used in the reversible fuel cell. Damage to the membrane and reduced performance will be the result if tap water is allowed to enter the device. If students are using the fuel cell without close supervision, it might help to put flagging tape or a sign on the water taps to prevent mistakes. There is no need for any tap water when using the fuel cell.

*** "The Hydrogen Economy, Opportunities, Costs, Barriers, and R&D Needs," national Research Council and National Academy of Engineering, The National Academies Press, Washington, D.C., 2004, pg 1 www.nap.edu.

Filling the electrolyser

Before starting the electrolyser, the bottom of the fuel cell storage cylinders should be filled with distilled water. If you need to add distilled water to the fuel cell, do so in this way:

Place the fuel cell on a flat surface and turn it upside down, so that the removable stoppers are facing up. Remove the stopper from the hydrogen storage cylinder. Add distilled water to the storage cylinder until it starts to overflow through the small tube in its center. Replace the stopper, making sure it fits tightly with no bubbles of air inside.

Fill the oxygen storage cylinder in the same way.

Turn the fuel cell right side up. (Open ends of the cylinders are now facing up.) The lower portion of both cylinders should be completely filled with water.

Keeping the membrane hydrated

If the fuel cell has not been used for many days, and has become dry, its first use after filling will not work at full capacity. Gas production will be slow, and power from the fuel cell will be limited. To obtain reproducible behavior after a prolonged period of non-use, it is only necessary to put the device through a short cycle (10 minutes will be enough) generating some hydrogen and then using it.

To avoid letting the fuel cell dry out, if you expect to use the fuel cell within the next few days, leave it with water in the reservoir. If the investigation requires starting with an empty device, you can discard the water just before the class.

Alternatively, you can store the fuel cell in a closed sandwich bag to keep it humidified.

Goggles

Although goggles may be seen as not necessary, it is good practice to have your students wear them throughout their science experiences with chemicals. No experimenters have had their vision damaged by wearing appropriate eye protection but many have suffered eye damage because they did not put their eye protection in place! Students should wear goggles even for demonstrations.

More teacher notes:

1. Put on your goggles. Remember that they will only protect you if you wear them properly.

2. The bottom of the fuel cell storage cylinders should be filled with distilled water, with no air space or other gas in the cylinders.

3. With the patch cords, connect the solar module to the reversible fuel cell, which we are using here as an electrolyser. Red goes to red and black goes to black. Position the solar panel so it directly faces the light source at the distance your teacher recommends and turn on the light.

READY-SET-GO! LET'S MAKE HYDROGEN!!!

**** Teachers Guide to Eight Fuel Cell Car Activities, 2003/2004, Funded by a US DOE grant, Copyright 2004 Heliocentris, Second Edition, 2004
http://www.bpa.gov/Energy/N/projects/fuel_cell/education/Docs/Curriculum.pdf

For more info:

MISSION H2 Scavenger Hunt can be found at:
http://www.bpa.gov/Energy/N/projects/fuel_cell/education

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http://www.chemicool.com/

http://chemistry.about.com/od/chemistryforkids/

www.hydrogenassociation.org

http://www.usfcc.com/

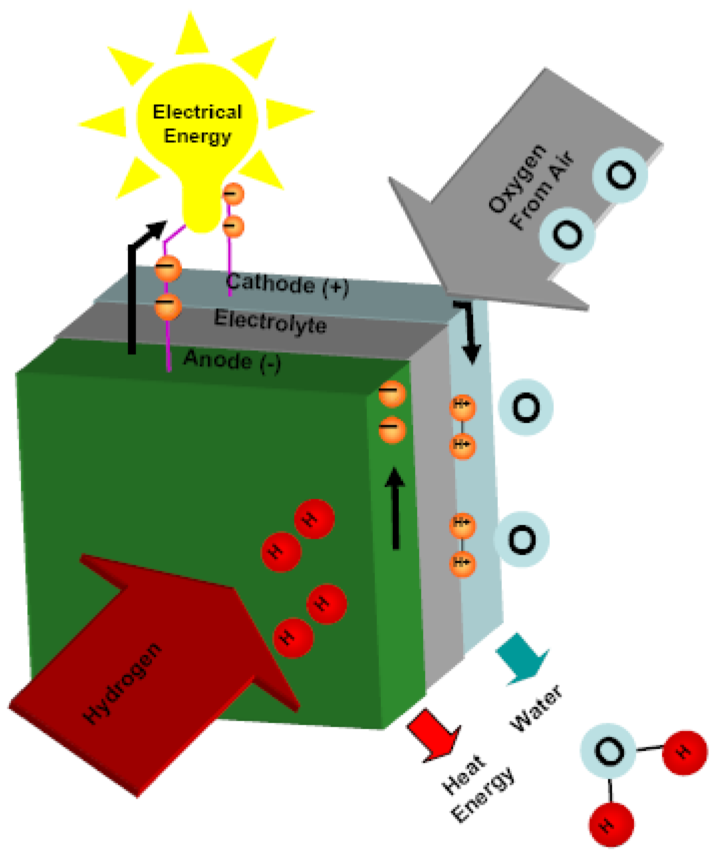
http://www.californiahydrogen.org/

http://www.kids4hydrogen.com/newsbulletin.htm

Lesson Four:
Introduction to Fantastic Fuel Cells!

In Lesson Four students watch a video clip of a Heliocentris Proton Exchange Membrane (PEM) Fuel Cell (approx. 40 sec), it states: “Firstly, hydrogen molecules come in contact with the fuel cell membrane as shown on the left. Oxygen molecules enter on the right. In an oxidation reaction, the hydrogen molecules release their electrons. This is made possible by platinum on the membrane surface which acts as a catalyst to assist the hydrogen bonds to be broken. The free electrons then travel as electricity through an external circuit providing electrical power to the load. The hydrogen protons in a hydrated state travel through the thin membrane and bond with the oxygen ions on the other side of the membrane to form water.”

A Fantastic Fuel Cell



Proton Exchange Membrane Fuel Cell - PEMFC

The Fuel Cell converts the energy of a fuel and oxygen from air directly into electrical and heat energy. It converts the energy from chemical to electrical form. There are no moving parts and no emissions. The only by products are heat and water. Fuel cells work like batteries. The more batteries you have the more power you have. However, batteries store energy while fuel cells can produce electricity continuously as long as fuel and air are supplied.

In general, fuel cells are defined by the chemistry of the materials used in the cell components and the operating temperature. There different applications such as: Residential; Portable; Transportation; Wastewater Treatment Plants; Stationary Power; and Industrial Applications. In this Curriculum we will discuss a PEM fuel cell and the geometry of a Solid Oxide Fuel Cell (SOFC). The most common classification of fuel cells is by the type of electrolyte used in the cells and includes**:

- Proton Exchange Membrane Fuel Cell (PEM). A type of fuel cell in which the exchange of protons (H+) from the anode to the cathode via a membrane is involved in the chemical reaction producing electricity. The electrolyte is called a proton exchange membrane (PEM). The fuel cells typically run at low temperatures (<100 °C) and pressures (<5atm). The electrolyte is a solid.
- Solid Oxide Fuel Cell (SOFC). A type of fuel cell in which the electrolyte is a solid, non porous metal oxide. The oxygen is transported from the cathode to the anode. Temperatures of operation are typically 800-1000 ° C.
- Direct Methanol Fuel Cell (DMFC). A type of fuel cell in which the fuel is methanol (CH3OH), in a gaseous or liquid form. The methanol is oxidized directly at the anode with no reformation to hydrogen. The electrolyte is typically a PEM. The operating temperature range is generally 50ºC-120ºC.
- Alkaline Fuel Cell (AFC). A type of hydrogen/oxygen fuel cell in which the electrolyte is concentrated KOH (35-50%, a liquid) and hydroxide ions (OH-) are transported from the cathode to the anode. Temperature of operation is typically in the range of 60-90 °C. The electrolyte is a liquid.
- Phosphoric Acid Fuel Cell (PAFC). A type of fuel cell in which the electrolyte consists of concentrated phosphoric acid (H3PO4) and protons (H+) are transported from the anode to the cathode. The operating temperature range is generally 160-220 °C. The electrolyte is a liquid.
- Molten Carbonate Fuel Cell (MCFC). A type of fuel cell consisting of a molten electrolyte of Li2CO3/Na2CO3 in which the species CO32- is transported from the cathode to the anode. Operating temperatures are typically near 650 ° C. The electrolyte is a liquid.

More Definitions:
Anode: An electrode in a fuel cell where electrons are produced.
Catalyst: A chemical substance that increases the rate of a reaction without being consumed.

The catalyst lowers the activation energy required, allowing the reaction to proceed more quickly or at a lower temperature.

Cathode: The electrode in a fuel cell where electrons are consumed.

Conduction: The transfer of electrical current through a solid or liquid.

Electric Circuit: The path along which electrons flow. (like a pipeline)

Electric Current: The flow of electrons from a negatively charged object to a positively charged object. (in the pipeline)

Electric Force: The attraction or repulsion of objects due to their electric charges.

Electrode: An electric conductor through which an electric current enters or leaves a medium.

Electrolyte: A non-metallic insulating material in which current flow in an external circuit is made possible By the movement of ions through the electrolyte. (The type of Electrolyte determines the type of fuel cell):

Hydration: in water.

Membrane: The separating layer in a fuel cell that acts as an electrolyte as well as a barrier film separating the gases in the anode and cathode compartments of the fuel cell.

Oxidation: The loss of electrons accompanied by an increase in oxidation number. The Oxidation number is equal to the number of charges a bonded atom would have.

Planar Cells: Fuel cells that are formed in a planar fashion and allow fuel and oxidant to flow on the Surfaces of the plane.

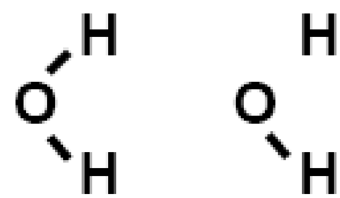
Reforming: Changing a fuel to a more hydrogen rich gas.

Tubular Cells: Fuel cells that are formed in a cylindrical fashion and allow fuel and oxidant to flow on the inner or outer surfaces of the pipe.

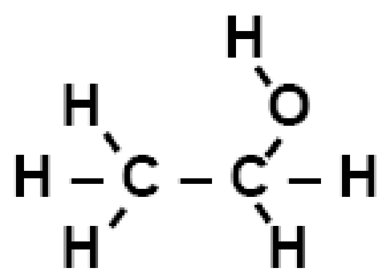
Hydrogen fuel can come from different sources. It is the most abundant element in the universe in the forms of a solid, liquid and gas. However, it bonded with a lot of other elements. The process of separating the hydrogen from a fuel is called reformation (re-forming).

As you can see below hydrogen is bonded to form water, ethanol, methane. It is also bonded to many more chemical elements.

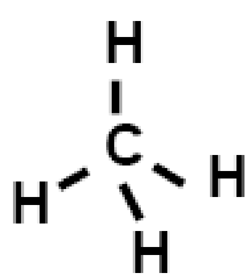
Water:
$2H_20$



Ethanol:
CH_3CH_2OH



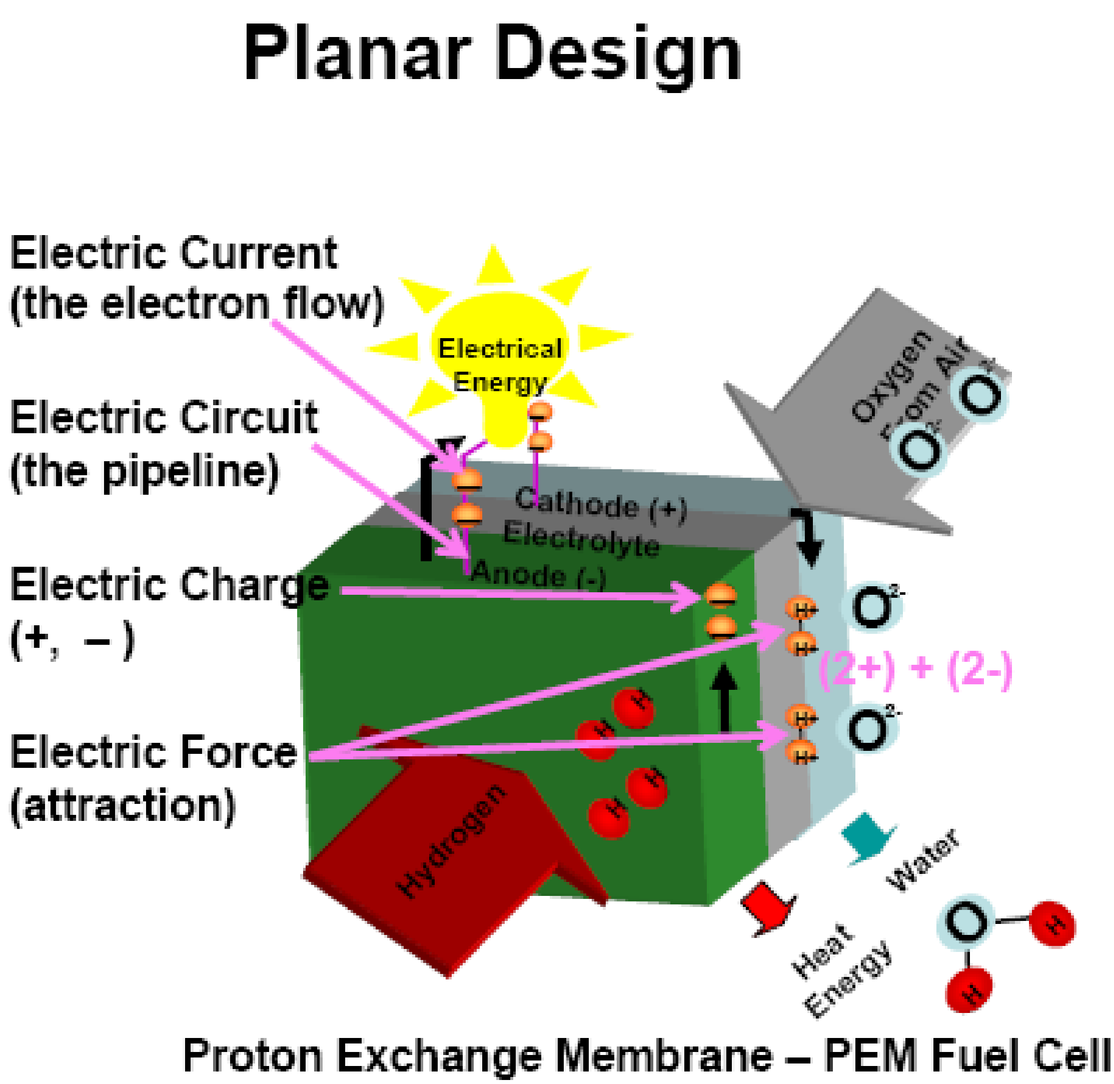
Methane:
CH_4



In the following slides I attempted to explain - in plain language- what happens inside a planar designed PEM. The Heliocentris PEM Video Clip provided in this lesson shows a good example of how the PEM works.

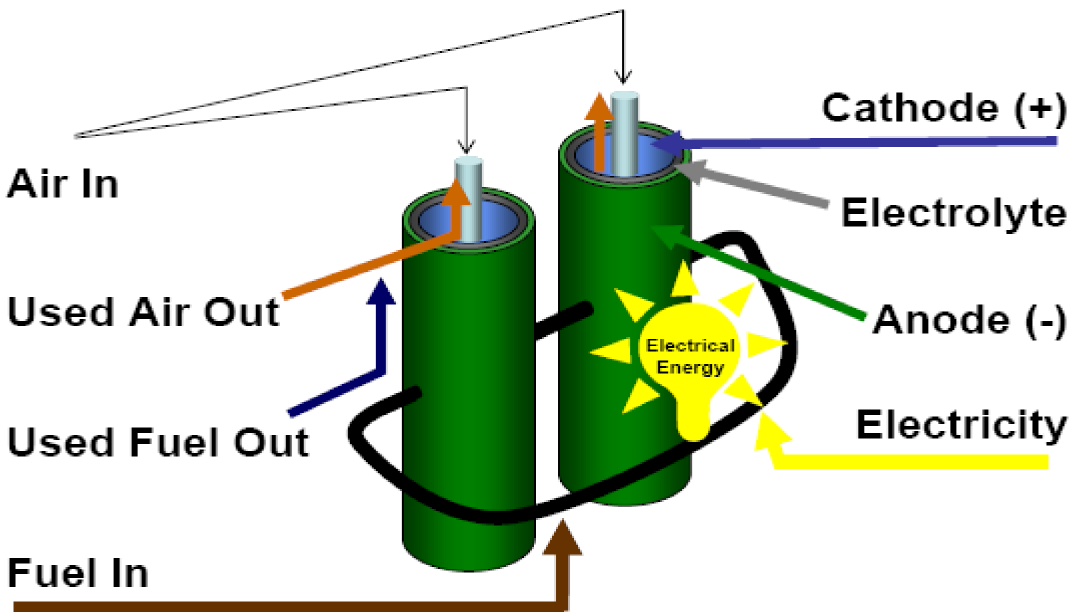
The inside of a single cell PEM Fuel Cell is represented by the drawing below. In a PEM the hydrogen fuel enters on the anode side.

The hydrogen travels from the anode to the electrolyte membrane. The hydrogen changes to a proton and the proton moves through the membrane. The electrons (current) do not move through the membrane but along a channel (designed in the plate) to an electrical circuit to produce electricity to power the load. In this case a light bulb.) Oxygen from air enters the cathode side and bonds with the hydrogen to form water. This “composition” also produces an exothermic reaction producing heat.

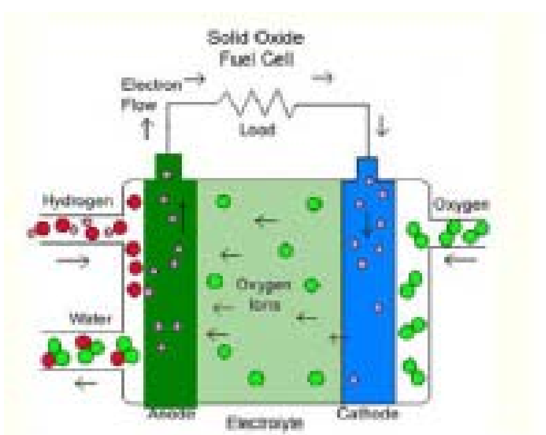


In a Solid Oxide Fuel Cell (SOFC) tubular design, the hydrogen fuel flows around the anode side of the tube as shown in the drawing below. Oxygen flows in through an inner tube. Depleted air flows along the outside of the tube. In this process the oxygen flows across the electrolyte membrane. The electrons move along the channel producing electricity. Like batteries, the tubes are bundled together to get more power.

Tubular Design



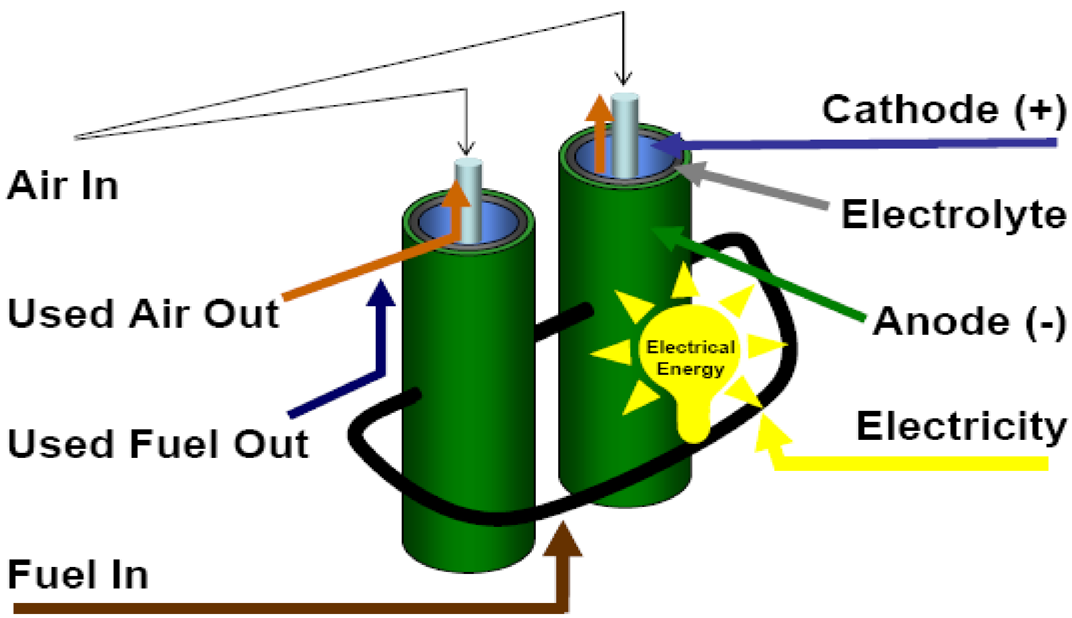
Solid Oxide Fuel Cell - SOFC



http://www.iit.edu/~smart/garrear/fuelcells.htm

Making a SOFC Tube

Materials needed:
Construction paper folded into cylinders
White – air tube (thinnest cylinder) (you can use a straw instead)
Green – Cathode layer
Grey – Electrolyte Membrane layer
Blue – Anode layer
Tape
Foil – 5" x 5" square - used to seal the bottom of the tube
12" piece of yarn – the electric circuit channel
Labels (provided)
Light bulb clip art (provided) this is the load.
Scissor
Marker



Solid Oxide Fuel Cell - SOFC

1. Make the "air in" tube by forming the paper into the thinnest cylinder shape taping the shape in place. Then put aside. (You can use a straw instead if you like.)
2. Take the blue sheet of paper and shape it into a cylinder making the" cathode". Tape this in place.
3. Take the grey sheet and add this layer to the blue cylinder you just made. You are adding the "membrane".

4. Take the green sheet and put your name on it. Add this layer next to the grey membrane making sure the student's name is on the outside of the cylinder. You are adding the "anode". Tape this in place. Take the foil and seal the bottom.
5. Tape each end of the yarn to each side of the "cathode". This represents the circuit. This is where the electrons will flow.
6. Tape the light bulb to the yarn.   This represents the load or what you are trying to supply electricity to.
7. Tape the "air tube" inside.
8. Tape the labels to their parts.
9. Have the students take home their SOFC Tubes and explain what they made to their families.

For more info:
Student information on electricity:
http://www.peakstudents.org/
http://www.need.org
http://www.energystar.gov/
http://www.energyquest.ca.gov/
Department of Energy for elementary students:
http://www1.eere.energy.gov/education/science_projects.html#elementary
State of California's Department of Energy information for students:
http://www.energyquest.ca.gov/

Information on Fuel Cells:
ASME PTC 50-2002 Fuel Cell Power Systems Performance, 2002
http://www.usfcc.com/
http://www.nfcrc.uci.edu/EnergyTutorial/index.html
http://www.fuelcells.org
http://www.iit.edu/~smart/garrear/fuelcells.htm
"The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs", National Research Council and National Academy of Engineering, the National Academies Press, Washington, D.C. 2004,
"Fuel Cell Handbook: Seventh Edition" by EG&G Technical Services, Inc. U.S. DOE NETL, 2004
"Fuel Cell Partnerships – An Overview, Research Report 4", Kettering University, Etim U. Ubong, PhD and Rajani P. Satti, M.Sc., August 2003.

Lesson Five: Learn about Exothermic and Endothermic Reactions

This Lesson is about understanding endothermic reactions (a change that occurs when there is absorption of heat from the surroundings) and exothermic reactions (a change occurs when heat is given off to the surroundings). Fuel Cells give off heat and water. This lesson will help the students understand what happens when elements come together or break apart. It will show one of the important attributes of a fuel cell is, how it works, and what the benefits are.

Below is taken from Chemistry: The Molecular Nature of Matter and Change, Silberberg, Mosby 1996. "The Law of Energy Conservation – Whenever a system gains energy, the surroundings supply that energy and thus lose an equal amount of energy. Also, when a system loses energy, the surroundings gain and equal amount. Energy can be converted from one form into another, but it cannot simply appear or disappear – it cannot be created or destroyed. The **law of conservation of energy** states this basic observation: *the total energy of the universe is constant.* This law is also known as the **first law of thermodynamics** because it is so essential to that science.

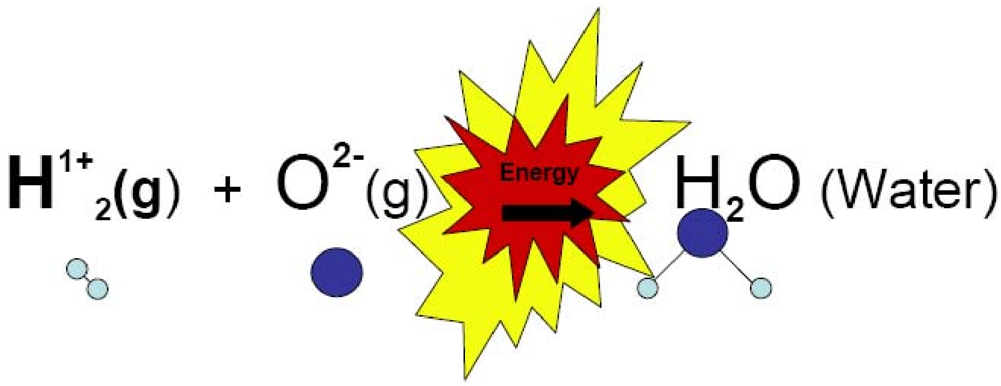
In this lesson, chemical energy is converted to both heat and work. Some of this energy is converted into electrical energy which powers the load. Also, energy transferred from a system to the surroundings, or vice versa, can take the forms of heat and various types of work, mechanical, electrical, chemical – but *the energy of the system plus the energy of the surroundings remains constant: energy is conserved.*"

In Chemistry, most physical and chemical changes occur under virtually constant atmospheric pressure. Pressure is mentioned here because it is important to how a system works but we will not get into it in this unit.

What students will understand is the exothermic and endothermic reaction in chemical composition and decomposition.

Chemical Equations

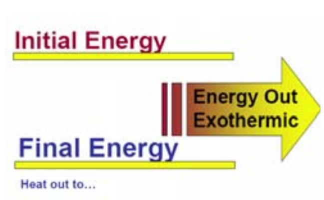
Composition

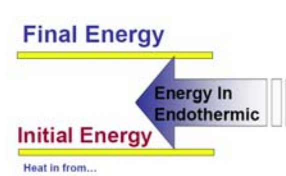


What happens here besides composition?

Students will be able to feel the changes in the initial temperature and the final temperature by touching the instant cold pack and toe warmers.

You can talk about the initial energy and final energy to define the Endothermic and exothermic reactions.





Materials:
instant cold pack and toe warmer (The students love this lesson!)

If you read the back of the instant cold pack you will see that it is made up of ammonium nitrate and water. When you apply work "force" (shake it) to it there is an endothermic reaction. It gets cold.

On the back of the toe warmer you will see that it is made up of iron, water, activated carbon and salt. When you apply work "force" to it (open the package and expose it to the air) there is an exothermic reaction. It gets warm.

For more information:

Chemistry: Sixth Edition, Zumdahl/Zumdahl, Houghton Mifflin Company, Boston, New York 2003.

Chemistry: The Molecular Nature of Matter and Change, Silberberg, Mosby 1996.

http://chemfinder.cambridgesoft.com/

http://www.chemicool.com/

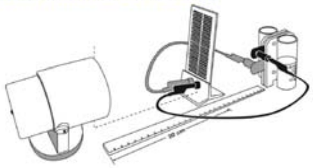
http://chemistry.about.com/od/chemistryforkids/

ASME PTC 50-2002 Fuel Cell Power Systems Performance, 2002

"Fuel Cell Handbook: Seventh Edition" by EG&G Technical Services, Inc. U.S. DOE NETL, 2004

Lesson Six: Critical Thinking
Observe – Measure - Predict

Step One:
Lets make some fuel!



Step two:
Ready – Set – Go!

Step three:
Lets Measure

In this lesson the students will:
Step One: use the lamp and solar panel to electrolyze the distilled water and make hydrogen, like in Lesson Three
Step Two: use the hydrogen gas generated to power the vehicle
Step Three: measure and record data

*Lighting the Solar Panel*****

The solar panel can be permanently damaged by overheating, usually the result of being too close to the light source.

The 75 watt PAR30 incandescent lamp supplied with many *Fuel Cell Model Car Kits* should be kept a minimum of 20 cm away from the solar panel. If you are using a different light source, you could occasionally touch the surface of the solar panel to ensure it is not overheating. The solar panel can be safely operated in bright sunlight. Do not use homemade reflectors made of foil or paper as they may cause overheating.

Use only distilled water
It is absolutely required that only distilled (de-ionized) water be used in the reversible fuel cell. Damage to the membrane and reduced performance will be the result if tap water is allowed to enter the device. If students are using the fuel cell without close supervision, it might help to put flagging tape or a sign on the water taps to prevent mistakes. There is no need for any tap water when using the fuel cell.

Filling the electrolyser
Before starting the electrolyser, the bottom of the fuel cell storage cylinders should be filled with distilled water. If you need to add distilled water to the fuel cell, do so in this way:

Keeping the membrane hydrated
If the fuel cell has not been used for many days, and has become dry, its first use after filling will not work at full capacity. Gas production will be slow, and power from the fuel cell will be limited. To obtain reproducible behavior after a prolonged period of non-use, it is only necessary to put the device through a short cycle (10 minutes will be enough) generating some hydrogen and then using it.

To avoid letting the fuel cell dry out, if you expect to use the fuel cell within the next few days, leave it with water in the reservoir. If the investigation requires starting with an empty device, you can discard the water just before the class.

Alternatively, you can store the fuel cell in a closed sandwich bag to keep it humidified.

Goggles
Although goggles may be seen as not necessary, it is good practice to have your students wear them throughout their science experiences with chemicals. No experimenters have had their vision damaged by wearing appropriate eye protection but many have suffered eye damage because they did not put their eye protection in place! Students should wear goggles even for demonstrations.

1. Put on your goggles. Remember that they will only protect you if you wear them properly.

2. The bottom of the fuel cell storage cylinders should be filled with distilled water, with no air space or other gas in the cylinders. Place the fuel cell on a flat surface and turn it upside down, so that the removable stoppers are facing up. Remove the stopper from the hydrogen storage cylinder. Add distilled water to the storage cylinder until it starts to overflow through the small tube in its center. Replace the stopper, making sure it fits tightly with no bubbles of air inside.

3. Fill the oxygen storage cylinder in the same way.

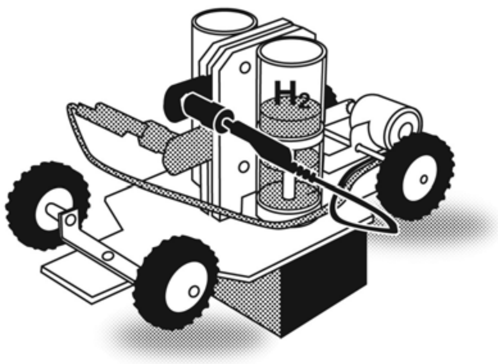
4. Turn the fuel cell right side up. (Open ends of the cylinders are now facing up.) The lower portion of both cylinders should be completely filled with water.

5. With the patch cords, connect the solar module to the reversible fuel cell, which we are using here as an electrolyser. Red goes to red and black goes to black. Position the solar panel so it directly faces the light source at the distance your teacher recommends and turn on the light.

6. When the hydrogen storage cylinder is filled to a little more than 4 ml carefully remove the solar panel from the system by disconnecting the patch cords from the reversible fuel cell.

7. On the top side of the car base directly in front of the gears, you will notice a felt-covered upright piece of plastic. Also notice that the bottom of the fuel cell has a slot between the two cylinders. Turn the fuel cell so that the red and black contacts are towards the front of the car. Carefully slide the fuel cell over the black felt and push down gently until the fuel cell is fully seated on the car base. You may need to hold the connecting cables out of the way as you do this.

8. Place the block of wood under the car base, so that the wheels on your car are free to turn. Connect the black and red wires from the motor to the fuel cell and let the motor run until the level of hydrogen in the hydrogen storage cylinder is exactly 4ml. At this point disconnect the black cable so the motor stops.



9. Carry your car to a clean test surface and turn the front wheels so that the car will run in a fairly small circle. (Don't turn the wheels so much they catch on the frame of the car.)

10. Position the car on the floor where it won't run into anything and connect the black cable. If your car does not move immediately give it a slight push to overcome the starting friction in the gears. Start a stopwatch (or record the time to the nearest second).

11. Record the time on the stop watch (or the current time) when the car stops. Check the level of hydrogen gas in the storage cylinder; there should be none left.

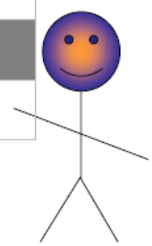
12 If there is enough time, repeat the procedure as many times as your teacher suggests, noting the duration your car was able to run for each filling.

13 Put your "elapsed seconds" data on the following graph, at the "4 ml" point.

**** Teachers Guide to Eight Fuel Cell Car Activities, 2003/2004, Funded by a US DOE grant, , Second Edition, 2004
http://www.bpa.gov/Energy/N/projects/fuel_cell/education/Docs/Curriculum.pdf

Step three:
Lets Measure

	Trial 1		Trial 2		Trial 3		
	time	elapsed seconds since 12 ml level	time	elapsed seconds Since 12 ml level	time	elapsed seconds since 12 ml level	Elapsed seconds of car travel (average of trials)
Time when 4 ml H_2 left							
Time when car stops, 4 ml H_2 used							



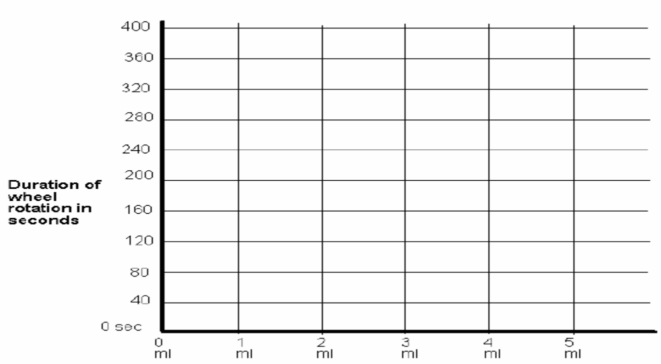
D R A F T Lesson Six 9-26-06

You can show the car going up a ramp and this will cause more work on the car's electric motor. You can talk about increased friction as the car is put on the ground. Talk about different road surfaces. The learning objectives:

Students will record that hydrogen is used up at a faster rate when the electrical motor does more work.

Students will note that repeating an experiment will produce similar results.

Students will use this data to produce a graph that will allow them to compare the duration of rotation for a given volume of hydrogen gas when the electric motor is doing more work.



Duration of Rotation per given volume of Hydrogen

2