Subject Area(s) **Chemistry, General Science, Information Technology,** Physics, Mechatronics and Mathematics

Associated Unit **Electrochemistry**

Lesson Title: How can we retool the BOE-BOT to run on a 6 V Solar hydrogen electric fuel cell

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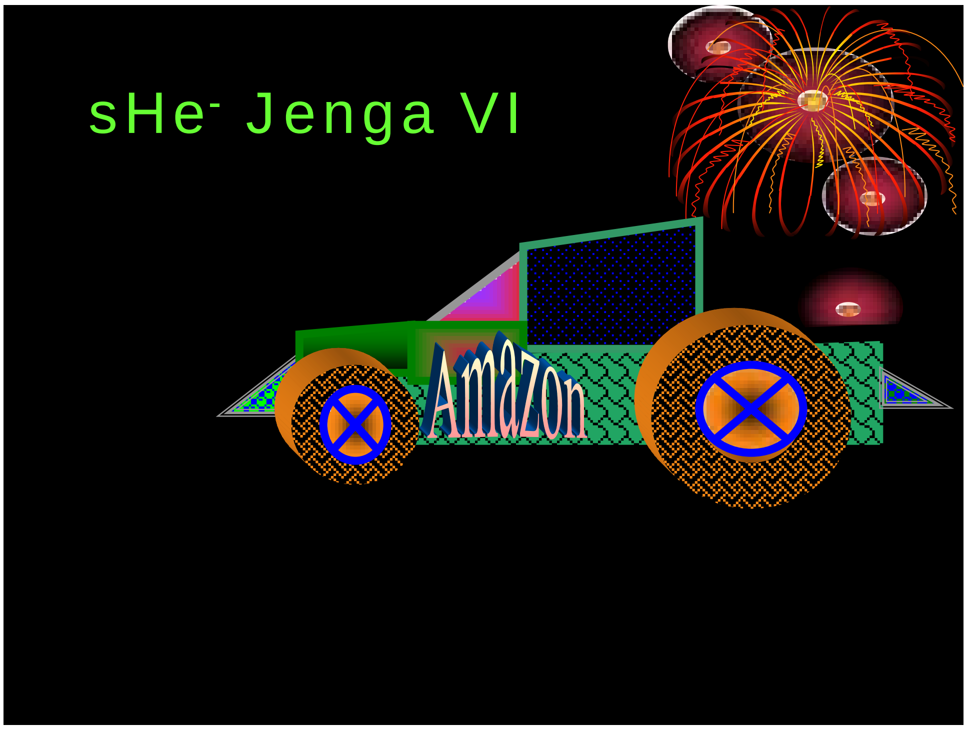

oxygen. The students will then work in teams of three or four students per team. Each team will be assigned a BOE-BOT Kit and a solar hydrogen electric kit.

Each team will then design by computer soft ware a platform, which can be bolted onto the BOEBOT. The design and construction of the platform will be an assignment completed prior to inserting the sHe components onto the BOEBOT. They will then extract the solar hydrogen reactor components from the sHe car and insert it on a platform bolted on the BOEBOT. Two 3V fuel cells will be connected in series with two 3V solar panels. The 24 ml and 12 ml sealed cartridges for hydrogen and oxygen and the 40 ml water reservoir are disconnected from the car kit and attached to the platform on the BOE-BOT. The water reservoir is then filled with water and the fuel cell and gas lines purged of air. The reactor is set on the electrolytic mode, in which electricity from the illuminated solar panels split water into hydrogen and oxygen. Each gas will diffuse into the appropriate cartridge and displace the water. When the cartridges are filled, the circuit is broken and the reactor set in the voltaic mode, in which the hydrogen and oxygen are allowed to react in the two fuel cells in series to generate electricity. A program for the autonomous operation of the BOE-BOT is used on the basic stamp. Antenna sensors are attached on the BOE-BOT to ensure that the vehicle will reverse direction if it collides with objects. The BOE-BOT is then allowed to auto-pilot itself for 100 m along the hall way and return to its starting point. The volumes of hydrogen and oxygen consumed are measured. The voltage and current of the fuel cell unit are recorded.

Engineering Connection

The students will work in teams to design a platform to accommodate the fuel reactor unit on to the chassis of the BOE-BOT.

Engineering Category

Keywords

Solar Hydrogen electric car, BOE-BOT, Solar Panels, Fuel Cells, Photoelectric effect.

Educational Standards

.Science Standards: S1, 2, 3 and 4.

State math: AA 29-AA38

Pre-Requisite Knowledge

Chemistry I

Learning Objectives

After this lesson, students should be able to:

- **Operate a solar Hydrogen electric car manually**
- **Operate a BOE-BOT**
- **Retool the BOE-BOT to function on solar hydrogen electrical energy**
- **Differentiate between a voltaic and electrolytic cell**
- **Apply basic Stoichiometric Principles**

Introduction / Motivation

How can we enable a robotic vehicle to operate autonomously, in which water is its fuel.

Lesson Background & Concepts for Teachers

The operation of the hydrogen fuel cell is based on the catalytic reaction of hydrogen and oxygen to form water and the opposite reaction. The fuel cell can operate as a voltaic cell and an electrolytic cell.

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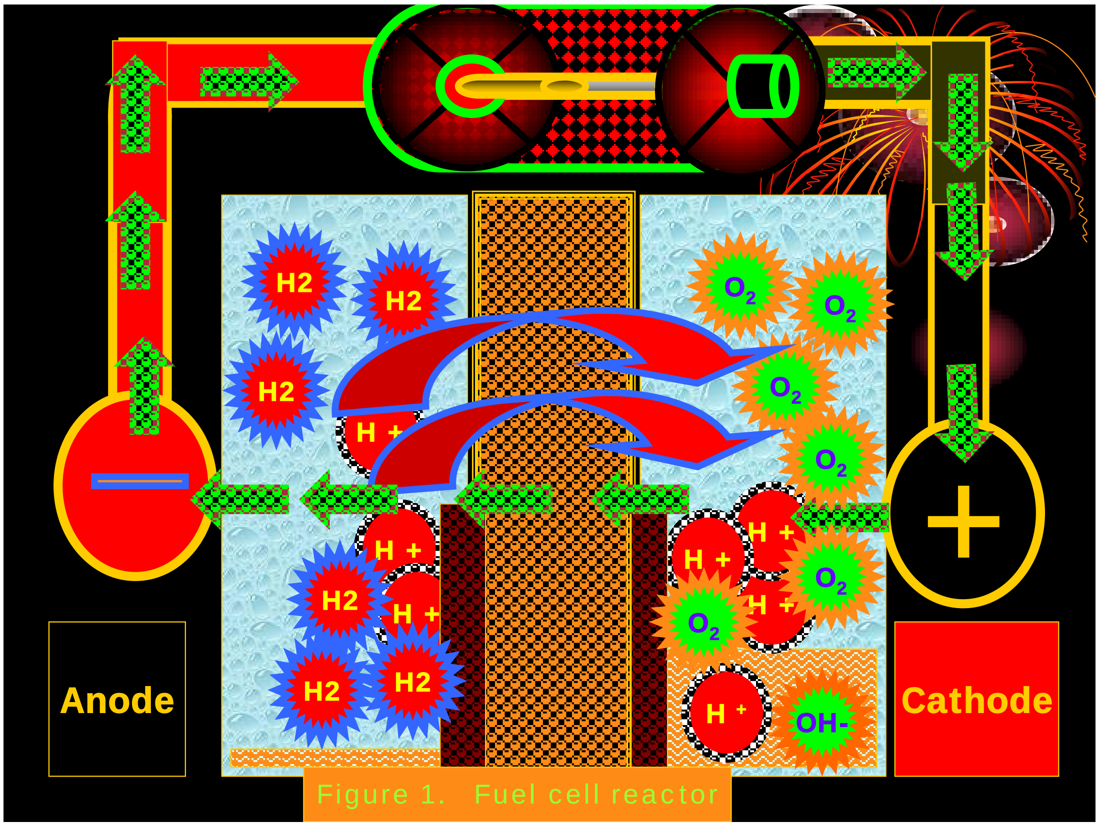

Figure 1. Fuel cell reactor

Fuel Cell reactor

During the Voltaic mode, hydrogen combines with oxygen to produce electricity.

During the electrolytic mode, solar electricity splits water into hydrogen and oxygen.

Vocabulary / Definitions

Word	Definition
Solar Hydrogen electric fuel Cell	A fuel cell in which electricity from solar panels splits water to produce hydrogen and oxygen. The two gases can then be combined to produce water and electrical energy.
Fuel Cell	A sealed compartmentalized container, in which a reaction can be carried out for production of energy.

Associated Activities

Machines

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cub_/lessons/cub_simp_machines/cub_simp_machines_lesson01.xml

Architects and Engineers

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cub_/lessons/cub_intro/cub_intro_lesson03.xml

Electrifying the World

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/duk_/lessons/duk_eenergy_mem_less/duk_eenergy_mem_less.xml

Electrons on the move

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cub_/lessons/cub_electricity/cub_electricity_lesson03.xml

Energy Basics

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cla_/lessons/cla_lesson3_energy_basics/cla_lesson3_energy_basics.xml

Energy Conservation

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cub_/lessons/cub_energy2/cub_energy2_lesson02.xml

Energy Efficiency

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cla_/lessons/cla_lesson6_efficiency/cla_lesson6_efficiency.xml

Energy Forms, States and Conversion

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cla_/lessons/cla_lesson4_forms_states_conversions/cla_lesson4_forms_states_conversions.xml

Renewable Energy

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cub_/lessons/cub_environ/cub_environ_lesson09.xml

Red Rover

http://teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cub_/lessons/cub_mars/cub_mars_lesson02.xml

Lesson Closure

How can water be used as a fuel without causing a global shortage of water?

Assessment

Students will prepare a 5 page science report on the investigation in the class room.

The paper should have the following structure:

Titler

Name of Authors

Abstract

Introduction

Materials and Methods

Results

Conclusions

Discussions

References

Acknowledgements

Lesson Extension Activities

Additional Multimedia Support

Student will have access to lap top computer in the class room to enable them to program the BOE-BOTs and to design the retooling platform.

References

1. California Fuel Cell Partnership. (2000). Fuel Cell Buses [WWW Document]. URL http://cafcp.org/fuel-vehl_buses.html (visited 2006, September 23)

2. Garman, D.K., (2003). Fuel Cell Report to Congress. [WWW Document]. URL http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fc_report_congress_feb2003.pdf#search=%22fuel%20cell%20technology%20makes%20energy%20electrochemically%20%22 (visited 2006, September 23)

3. Arkins, P and Jones, L. Chemical Principles- Quest For Insight. WH Freeman, New York, 2002, p 210

4. Arkins, P and Jones, L. Chemical Principles- Quest For Insight. WH Freeman, New York, 2002, p 642-660

Attachments

Calculations

Four equations were used in estimating the energy exchanges of the solar hydrogen reactor in the drone boat, for the voltaic phase and electrolytic phase

Equation 1 is used to calculate the number of moles of hydrogen and oxygen, generated when water is electrolyzed in four proton exchange membranes, using four solar panels.

Equation 2 is used to calculate the number of moles of electrons required for the electrolysis of water, based on the current measured and the voltage of the four solar panels in series.

Equation 3 calculates the energy required to generate 1L of hydrogen and 0.5 L of oxygen at atmospheric pressure and ambient temperature, when water undergoes electrolysis. This energy should, in theory equal the free energy available when 1L of hydrogen reacts with 0.5 L of oxygen at atmospheric pressure and ambient temperature in the proton exchange membrane.

Equation 4 calculates the free energy available, from the combination of hydrogen and oxygen, in the proton exchange membrane, to all the electrical systems in the boat.

Equation 5 summarizes the hypothesis.

The Universal Gas Law Equation:

$$PV = nRT \qquad (1)$$

P = Pressure of hydrogen or oxygen, which was equilibrated to atmospheric pressure;
V = Volume of hydrogen or oxygen;

N = number of moles of each hydrogen or oxygen;

The number of moles of hydrogen are important, because 1 of hydrogen produces 2 moles of electrons. 2 moles of hydrogen or 4 atoms of produce 4 moles of electrons. The four moles of electron are exchanged during the redox reaction of hydrogen and oxygen, during the voltaic phase and electrolytic phase of the solar hydrogen electric reactor.

R = Universal Gas Constant = 8.314 L KPa K^{-1} mol^{-1}

The Faraday's Law of Electrolysis Equation:

n_e- = It/F____ 2

n_e = number of moles of electrons used in the redox reaction for the electrolytic or voltaic phase of the solar hydrogen reactor

I = the current generated by the photoelectric effect in the solar panels and used for the electrolysis of the water.

F= Faraday's Constant = 9.64 x 10 4 C mol^{-1}

E = IVt____ 3

E = Energy (J or Volts. Coulombs per second); I = Current (amps or Cs^{-1});
V = Voltage (Volts) and; t = time (seconds)

The Equation relating cell potential and reaction free energy:

ΔG_f = nFE____ 4

ΔG_f = Gibbs Free Energy; n = number of moles of electrons used in the redox reaction; F = Faraday's Constant = 9.64×10^{4} C mol^{-1}

E = Voltage of the four or six Proton Exchange Membranes connected in series with the hydrogen and oxygen in the gas containers.

<u>Using Equation 1,</u>

when T = 294 K, P_{H2} = 100KPa, R = 8.314 l KPa K^{-1} mol^{-1}

n = PV/RT

n = 0.0409 moles of Hydrogen gas = 0.0818 moles of electrons

<u>Using equation 2</u> , when I = 2.02 amps, t = 4 x 60 x 60 s and

F = 9.64×10^{4} C mol^{-1}

This equation is used to calculate the number of moles of electrons required when water under goes electrolysis to generate 1 L of hydrogen and 0.5 L of oxygen at atmospheric pressure and ambient temperature, during 4 hours of electrolysis. The current is produced from the light interacting with the solar panels.

n_e- = It/F [Faraday's Law of Electrolysis]

n_e- = 2.02 Cs^{-1} x 4 x 60 x 60 s /9.64×10^{4} C mol^{-1}

= 0.301476 moles of electrons

By using Equation 3,

When n= 4, F = and E = 12 Volts,

ΔG_f = nFE_

ΔG_f = 4 x 9.64×10^{4} C mol^{-1}
x 12 V

= 4627.2 KJ mol^{-1}

By mean of Equation 4,

E = IVt

This equation calculates the energy required to charge up the solar hydrogen electric unit so as to generate 1L of hydrogen and 0.5 L of oxygen, within a four hour period, from the electrolysis of water.

A current of 2.02 amps and a voltage of 13 V were measured when four solar panels were connected in series to the proton exchange membrane.

It took four hours to generate 1L of hydrogen and 0.5 L of oxygen.

= (2.02 Coulombs/s)(13 J/Coulombs)(4 x 60 x60) = 378.144 KJ

when, I = 2.02 amps, V = 13 Volts and t = 4 hours of charging the solar hydrogen electric unit to induce photo-electrolysis of water;

= (2.02 Coulombs/s)(13 J/Coulombs)(4 x 60 x60) = 378.144 KJ

However, from equation 1, 0.0818 moles of hydrogen atoms are present in 1L of hydrogen at atmospheric pressure and ambient temperature.

= 378.144 KJ = 378.144 KJ/0.0818 moles of H atoms = 4674.2508 KJ mol^{-1}

$\Delta G_f \cong IVt$ ____5

ΔG_f = Free Energy available when hydrogen reacts with oxygen in the proton exchange membrane. I = current released, when the hydrogen reacts with the oxygen in four proton exchange membranes connected in series.; V= the total voltage across the four proton exchange membranes, which are connected in series. The time t is the duration for the 1 L of hydrogen and 0.5 L of oxygen to be consumed.

One hypothesis is: The free energy released from the reaction of 1L of hydrogen and 0.5 L of oxygen = the current generated and voltage across four proton exchange membranes, during a time period of 1 Hour.

i.e., $\Delta G_f \cong IVt$

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Contributors

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Supporting Program

This lesson is part of the SMART program of NYU-Poly

Version: April 2010