Modeling the Fuel Cell Reaction

CHALLENGE

How do the redox reactions in a fuel cell generate electricity?

In the previous activity, Mariyah saw fuel cells in action. Now it's time for her to learn the details about how they work.

In the preceding activity, you used a proton exchange membrane (PEM) fuel cell. This type of fuel cell is already in use in buses, cars, and power generators, and may be widely used in the future. Like a battery, a fuel cell converts chemical energy into electricity. Unlike a battery, a hydrogen fuel cell continues to provide electricity as long as it is supplied with hydrogen and oxygen.

The chemistry of fuel cells has been understood since the 1830s. Like batteries, fuel cells create electricity through chemical reactions that involve the transfer of electrons. Chemists call these reactions **oxidation-reduction**, or **redox**, reactions. Redox reactions can be split into two parts, the oxidation half and the reduction half. Half-reactions that release electrons are called **oxidation reactions**; half-reactions that accept electrons are called **reduction reactions**.

Inside a PEM hydrogen fuel cell, electric current is generated using the two chemical half-reactions shown below.

Oxidation: $H_2 \rightarrow 2H^+ + 2e^-$

Reduction: $4H^+ + O_2 + 4e^- \rightarrow 2H_2O$

These equations can be added to obtain the complete equation. But first the oxidation reaction must be multiplied by two, so that the number of electrons in the reactants balances with the number of electrons in the products.

Oxidation: $2H_2 \rightarrow 4H^+ + 4e^-$

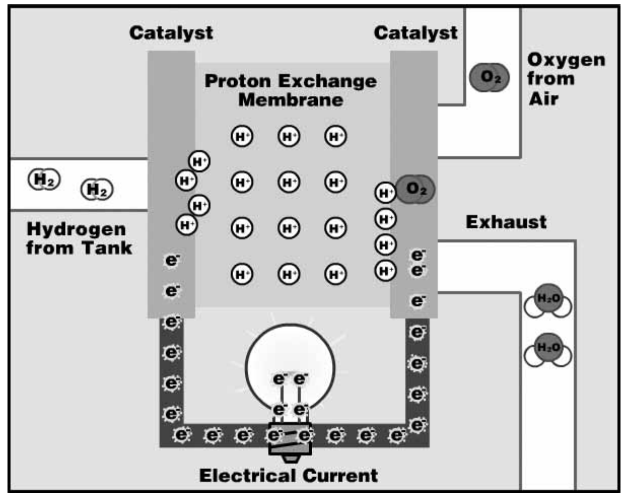
Reduction: $4H^+ + O_2 + 4e^- \rightarrow 2H_2O$

$$2H_2 + O_2 \rightarrow 2H_2O + \text{energy}$$

Inside the fuel cell are two electrodes. Each electrode has a platinum catalyst that speeds up the redox reaction.

The electrode where oxidation occurs is called the anode. At the **anode**, hydrogen is oxidized and electrons are delivered to an external electrical circuit. In the previous activity, this circuit provided the power that let the electric motor turn the propeller. The electrons travel through this external circuit to the **cathode**. Reduction occurs at the cathode, where oxygen is reduced and the reactants combine to form water.

A proton exchange membrane separates the two electrodes. This membrane conducts protons through to the cathode, but blocks electron transport. Electrons are forced to flow through an external circuit and generate current. At the cathode, these protons join in the reduction reaction to form water.



Since we can't see the electric current or the chemical reactions inside a fuel cell, using models and computer simulations can help us understand what is happening.

MATERIALS

For each group of two students

fuel cell molecular modeling set (11 pieces)

computer with access to SEPUP Fuel Cell Simulation

PROCEDURE

PART A: COMPUTER SIMULATION OF A FUEL CELL

1. The simulation of a fuel cell is available at the student page of the *Hydrogen & Fuel Cells* website at *sepuplhs.org/hydrogen*. Open the simulation on your computer screen and view the entire process. After clicking on "See Catalyst" and "See Exhaust Closeup," click "Run Animation" and discuss the following with your partner or group.

   a. Identify the anode and the cathode.

   b. Describe what happens to the hydrogen and oxygen.

   c. Explain how water gets generated at the exhaust port.

2. Click on "See Hydrogen Closeup." Write the half-reaction for what happens at the anode. Then write one or more sentences explaining what is happening.

3. Click on "See Exhaust Closeup." Write the half-reaction for what happens at the cathode. Then, explain what is happening in your own words.

4. Click on "See Exchange Membrane." Explain what would happen if the membrane were altered in a way that allowed electrons to pass through (in addition to protons).

5. Click on "See Electricity Closeup."

   a. What keeps electrons flowing through the circuit?

   b. What could cause the lightbulb to go off?

6. Click on "See Exhaust Closeup." Why are fuel cells potentially better for the environment than internal combustion engines?

PART B: MODELING THE FUEL CELL REACTION

1. Working with a partner, use the appropriate pieces of the modeling set to build two hydrogen gas (H_2) molecules and one oxygen gas (O_2) molecule. In your notebook, draw each molecule.

2. Examine your models. Describe how the bonds in your O_2 and H_2 molecules are represented.

3. Place the two H_2 molecules on the anode side of the fuel cell diagram and the O_2 molecule on the cathode side.

4. Model the break up of H_2 at the anode. Move the broken pieces along the appropriate paths on the fuel cell diagram. Electrons should go through the circuit with the lightbulb. The protons pass through the membrane.

5. Model the creation of water at the cathode. In your notebook, draw one of the two water molecules that are created.

6. Using the shapes of the molecular models and the picture of the fuel cell as a guide, create a storyboard of at least four frames depicting the chemical reactions that happen inside a fuel cell to create electricity. Be sure to label all parts as needed.

ANALYSIS QUESTIONS

1. With your group, draw a diagram of a fuel cell bus on poster paper. Indicate parts, such as hydrogen storage tanks, fuel cell, electric motor, hydrogen and oxygen intakes, the exhaust pipe, and any other necessary parts with clear labels. Try drawing the bus from the side, the top, and the inside. Be prepared to share your diagram with the class.

2. Note that oxygen for fuel cell vehicles is obtained from the surrounding air. Why do you think this is?

3. Gasoline internal combustion engines release chemical energy through the combustion reaction shown below. Octane (C_8H_{18}) is a major constituent in gasoline.

   $$2C_8H_{18} + 25O_2 \rightarrow 18H_2O + 16CO_2 + \text{energy (heat, light, and sound)}$$

   a. What are the main similarities between the H_2 fuel cell reaction and this internal combustion engine reaction?

   b. What are the main differences between the H_2 fuel cell reaction and this internal combustion engine reaction?