Energy Conservation and Transformation

Next Generation Science Standards

NGSS Science and Engineering Practices:

- ☑ Asking questions and defining problems
- ☐ Developing and using models
- ☑ Planning and carrying out investigations
- ☑ Analyzing and interpreting data
- ☐ Using mathematics and computational thinking
- ☑ Constructing explanations and designing solutions
- ☐ Engaging in argument from evidence
- ☑ Obtaining, evaluating, and communicating information

NGSS Cross-cutting Concepts:

- ☐ Patterns
- ☐ Cause and effect
- ☐ Scale, proportion, and quantity
- ☐ Systems and system models
- ☑ Energy and matter
- ☐ Structure and function
- ☑ Stability and change

NGSS Disciplinary Core Ideas:

- ☑ PS1.B: Chemical Reactions

Initial Prep Time

Approx. 10 min. per apparatus

Lesson Time

1 – 2 class periods, depending on experiments completed

Assembly Requirements

- Scissors
- Small Philips screwdriver

Materials (for each lab group):

- Horizon Fuel Cell Car Science Kit
- Distilled water
- AA batteries
- Stopwatch
- Horizon Renewable Energy Monitor or multimeter (optional)

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Lab Setup

- Be sure to set aside enough time to assemble your fuel cell cars before starting this activity. You'll need AA batteries, scissors, a ruler, a small Philips-head screwdriver, and plenty of distilled water to assemble the cars. See the Fuel Cell Car Science Kit Assembly Guide for complete assembly instructions.
- Please note that the PEM fuel cell's membrane should be kept from drying out. It's best to seal it in a plastic bag between uses. Before students use the cell, be sure it's filled with water and that the two small pieces of tubing are attached.
- Some of the parts of the car are quite small (such as tube caps) and can be lost easily. Setting up resource areas on lab tables with labeled containers for each group's pieces can prevent loss of these small parts and help keep the parts of each group's kit separate.
- If you don't have access to a multimeter or Horizon Renewable Energy Monitor, omit the Measurements section of this activity.

Safety

- Battery packs can short out and heat up if the red and black contacts touch each other while the unit is in the on position. Be sure to keep them off when not in use.
- Using regular tap water instead of distilled water will severely shorten the lifespan of the fuel cells. Distilled water can be found at most pharmacies or drug stores.
- Running electric current through dry fuel cells or attaching the battery packs backwards can destroy the fuel cells. Be sure to always connect red to red and black to black.
- Beware of water spills, and don't be surprised if someone tries to start a syringe water fight.

Notes on Fuel Cell Cars

- The car's front wheels may not touch the ground if the motorized wheels stick out too much, but that shouldn't affect the car's performance.
- Though the car can detect and steer around objects that it bumps into, it won't detect the edge of a table. It may be best to put them on the floor when it's time to have them run.

Common Problems

- If performance decreases, purge your fuel cells by opening up the tube caps to allow trapped air to escape.
- If the water level doesn't change after purging the cells, make sure the gaps on the base of the inner cylinders are open so that water can fill them.

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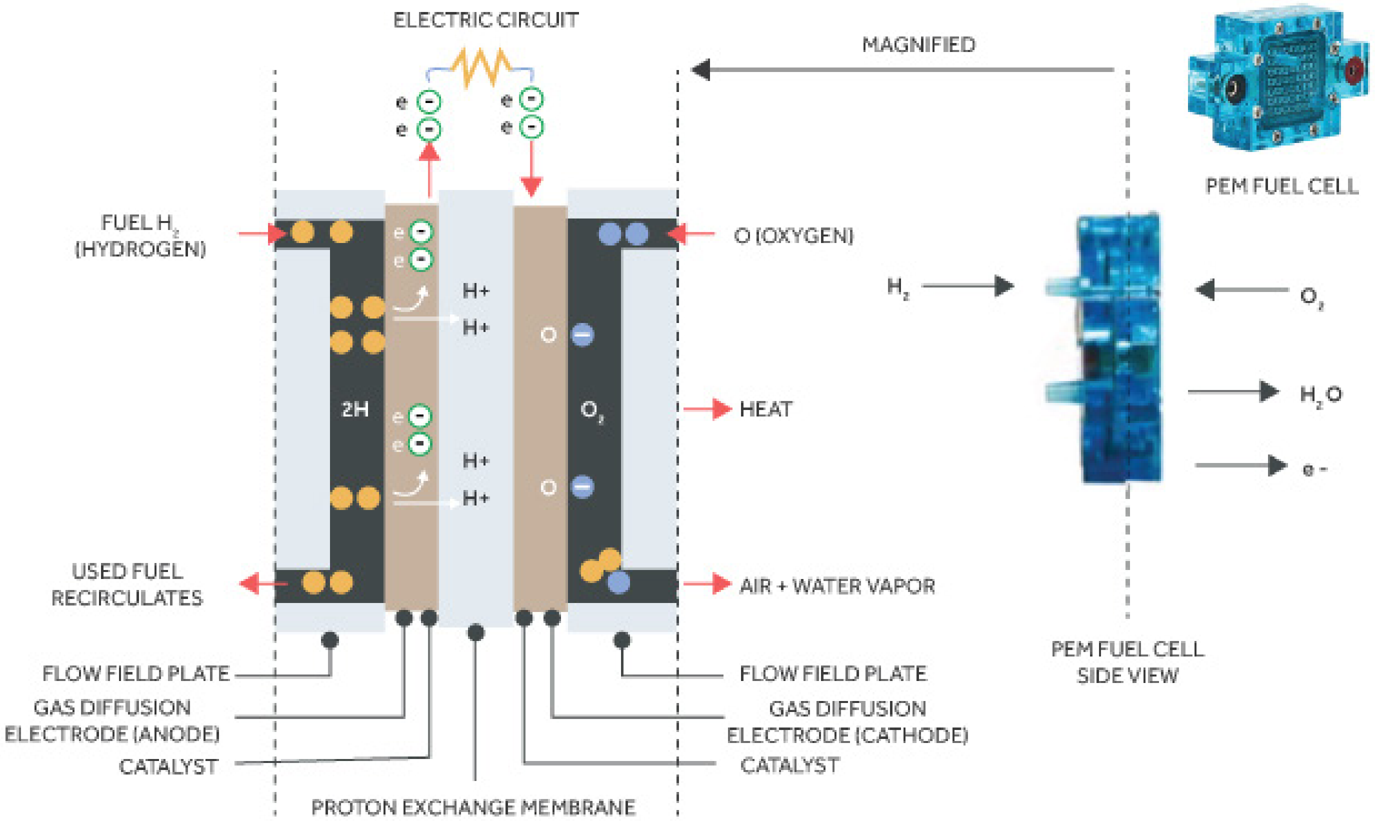
Goals

- Understand how redox reactions work
- Perform an electrolysis reaction
- Make calculations based on data

Background



For every action, there's an equal and opposite reaction, even at the atomic level. When electrons travel between atoms, opposite reactions occur: reduction and oxidation. Reduction takes place when an atom gains an electron (the negative electron reduces the atom's overall oxidation state), while oxidation takes place when an atom loses one. So the movement of even just one electron between atoms requires both reactions. Since they're two halves of a larger reaction, they're often referred to collectively as reduction-oxidation, or redox.

The word "oxidation" was first used to describe an actual reaction with oxygen, which was one of the first oxidizing reagents recognized by scientists. Even when other substances were found to behave similarly, the term stuck. Now anything that causes the loss of electrons is said to be an oxidizer.

"Reduction" originally meant the physical loss of mass that occurred when a metal ore such as metal oxide was heated to extract the metal. A larger mass of ore was "reduced" to yield the pure metal. It was only later that scientists realized that metal atoms

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gained electrons during the process, so now any gain of electrons is referred to as reduction.

A simple redox reaction can be demonstrated through the electrolysis of water, decomposing it into hydrogen and oxygen, which can be accomplished by running an electrical current through the water. A reversible fuel cell can accomplish this, while also being able to reverse the reaction and generate an electric current while recombining hydrogen and oxygen into water.

The half-reactions of oxidation and reduction take place at two electrodes: the anode and cathode. The anode is the positive electrode, where electrons come out of the water and oxygen gas appears. The cathode is the negative electrode, where electrons enter the water and hydrogen gas appears. You can read more about electrodes here.

The hydrogen protons can pass through the membrane in between the anode and cathode, joining the electrons that traveled through the wire to the other side. A full explanation of how a fuel cell works can be found here.

In redox reactions, we write out the electrons in the half-reactions so we can balance them not just by the atoms, but also by the electric charges. The half-reactions for electrolysis are as follows:

Cathode (reduction):

$2\ H_2O(l) + 2e^- \rightarrow H_2(g) + 2\ OH^-(aq)$

Anode (oxidation):

$4\ OH^-(aq) \rightarrow O_2(g) + 2\ H_2O(l) + 4\ e^-$

How does a redox reaction work and how can it be used as a source of energy? During this activity we will try to use redox reactions to power a fuel cell car.

Procedure

1. The fuel cell is labeled H2 and O2 on either side. Which side is the cathode? Which is the anode? How do you know?
2. Once the fuel cell starts producing hydrogen and oxygen gas from water, we will need to trap the gases to be able to use them for the reverse reaction. How can the gases be trapped using the materials provided?
3. Knowing your half reactions, where should the water be introduced into the fuel cell? Does it matter which side? Does it matter whether the water is injected into the top or bottom outlet?
4. How can we tell how much gas has been generated by our reaction?
5. Does it matter how the battery pack is attached to the fuel cell? Why or why not?
6. If you're ready to capture the gases produced by the fuel cell, attach the battery pack. Observe what happens and record your observations below.

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Observations

Experimentation

1. You've produced hydrogen and oxygen from water. Now, connect the fuel cell to the motor. What happens?

Students should notice the motor begins to run and can make note of any particular aspect of the car's performance: sound of the motor, the flashing LEDs, when the car turns or backs up, how long it runs, etc.

2. Write the balanced reaction for the recombination of hydrogen and oxygen below:

$2H_2 + O_2 \rightarrow$ 2H2O

3. Generate more hydrogen and oxygen using the fuel cell, as before. What is the volume of hydrogen produced?

Students should use the mL markings on the cylinders to answer. Responses will vary, but should not exceed 10mL.

4. What is the ratio of hydrogen to oxygen generated? Does your measurement match the theoretical ratio?

Answers should be roughly 2:1 to match the theoretical ratio.

5. Assuming standard temperature and pressure, how many moles of hydrogen gas have you generated? How many molecules of hydrogen are in your cylinder?

Students should use the Ideal Gas Law (PV = nRT) and their volume measurement from above.

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6. How would you maximize the yield of this reaction? Devise an experiment that you could run to increase the amount of hydrogen and oxygen you produce. Describe your experiment below.

Change pressure/temperature of the water/gases, construct fuel cell with different materials, change characteristics or materials of the anode/cathode, and more are all ideas that could be tested. Students should identify control and experimental setups, and define the variable to be tested.

Measurement

For this section, you will need a multimeter or the Horizon Renewable Energy Monitor. For an introduction to using a multimeter, click here.

1. Measure the current in Amps while generating hydrogen and oxygen. Time how long it takes to fill your hydrogen cylinder. Record your answers below:

(Answers will vary, but check that they are within reason, i.e. not >1A.)

Current: ______________ A

Time: ____________ sec

2. One Amp is equivalent to 6.242x1018 electrons per second, so how many electrons were flowing through your wires while you generated hydrogen?

(Amps from above) x (6.242x1018) x (Seconds from above)

3. If you fill the cylinder, how many moles of hydrogen have you produced? How many atoms of hydrogen would that be?

Students should use the Ideal Gas Law (PV = nRT) and the volume of the cylinder to find moles. That answer is then multiplied by Avogadro's number to get a number of atoms.

4. Does each electron flowing through your wire correspond to an atom of hydrogen produced by this reaction? Explain your reasoning.

Compare the number of electrons calculated above to the number of atoms calculated. Are they roughly equivalent?

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Analysis

1. Make a scientific claim about what you observed while running the fuel cell.

Claim should reference the electrolysis and synthesis reactions they observed.
Example: "Stoichiometry accurately predicts the ratios of products in electrolysis."

2. What evidence do you have to back up your scientific claim?

Evidence should cite data in Observations and/or Experimentation sections.
Example: "We measured 10mL of hydrogen and 5 mL of oxygen from our reaction."

3. What reasoning did you use to support your claim?

Reasoning can draw from Background section and/or other materials used in class.
Example: "We know from the chemical formula of water that the ratio of H:O should be 2:1."

Conclusions

1. Using the cathode and anode equations from the Background section, what would be the overall reaction during electrolysis?

$2H_2O \rightarrow 2H_2 + O_2$

2. Does the synthesis of hydrogen and oxygen require more activation energy than the electrolysis reaction?

Students should cite their data and/or materials used in class to support their answer.

3. Describe the way that electrons move during the electrolysis and recombination reactions in the fuel cell. Which side of the cell is the anode and which is the cathode in each reaction?

Students should recognize that the anode and cathode "flip" during the different reactions because electrons flow in two different directions.