Lesson Plan: How Fuel Cells Work!

FOR THE TEACHER

Summary
In this lesson students will investigate how fuel cells provide energy in modern cars. Students will have the opportunity to explore redox reactions, through both an online animation and a simulation in order to understand the potential of a fuel cell.

Grade Level
High School

NGSS Alignment
This lesson will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS1-2**: Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- **HS-ETS1-3**: Evaluate a solution to a complex real-world problem based on priorities criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

- **Scientific and Engineering Practices**:
  - Using Mathematics and Computational Thinking
  - Engaging in Argument from Evidence
  - Obtaining, Evaluating, and Communicating Information

AP Chemistry Curriculum Framework
This lesson plan supports the following units, topics, and learning objectives:

- **Unit 4: Chemical Reactions**
  - **Topic 4.7**: Types of Reactions
    - **TRA-2.A**: Identify a reaction as acid-base, oxidation-reduction, or precipitation.
  - **Topic 4.9**: Oxidation-Reduction (Redox) Reactions
    - **TRA-2.C**: Represent a balanced redox reaction equation using half-reactions.

- **Unit 9: Applications of Thermodynamics**
  - **Topic 9.7**: Galvanic (Voltaic) and Electrolytic Cells
    - **ENE-6.A**: Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.

Objectives
By the end of this lesson, students should be able to

- Identify the major components of a Proton Exchange Membrane (PEM) Fuel Cell.
- Describe how a Proton Exchange Membrane (PEM) fuel cell works.
- Write half-reactions for the oxidation and reduction reactions that occur in a Proton Exchange Membrane (PEM) fuel cell.

Chemistry Topics
This lesson supports students’ understanding of

- Electrochemistry
- Redox Reactions
- Galvanic Cells

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Thanks to:
2016 AACT-Ford Content Writing Team
• Oxidation
• Reduction
• Half-Reactions
• Fuel Cell Technology

**Time**

**Teacher Preparation:** 15 minutes  
**Lesson:** 90 minutes

**Materials**

- Paper/Pencil
- Computer/device with internet access
- Fuel Cell Model Car (optional)

**Safety**

- No specific safety precautions need to be observed for this activity.

**Optional Fuel Cell Model Car Lab:**

- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the lab, instruct them how to clean up their materials and dispose of any chemicals.
- Students should wear proper safety gear during chemistry demonstrations. Safety goggles and lab apron are required.

**Teacher Notes**

- **Engage:** This activity can be used in the electrochemistry unit after watching and discussing “Pump,” a film on the history of the internal combustion engine and the challenges of reducing CO₂ emissions. The film can be streamed on Netflix. This frames the activity in a way that has kids naturally ready to hear about alternative fuel vehicles and the challenges of global climate change. Alternative options for engaging students can replace this movie such as presenting students with data showing the need for alternative fuel vehicles to replace traditional fossil fuel vehicles. This could include climate change data or information about fossil fuel reserves.

- **Explore:** The activity starts with a review of the basics of oxidation and reduction reactions (simulation) and then takes them through an exploration of how fuel cells work on a chemical level, and then into an exploration of the advantages and disadvantages of fuel cell vehicles. Students should follow the activity and explore several different websites and graphics to develop their knowledge of how fuel cells work.

- **Explain:** Students could present their findings to each other about how fuel cells work or the pros/cons of fuel cell vehicles, or the teacher could lead a discussion. It might also be helpful to discuss how fuel cells are similar/different from voltaic cells (batteries). Teacher could explain how the Proton Exchange Membrane fuel cell works or have students explain it using a blank diagram or other medium. The explanation should include the oxidation at the anode, the passage of the protons through the membrane, the flow of electrons around the device, and the reduction of oxygen to water at the cathode.

- **Elaborate:** Teacher could extend/elaborate on this topic by discussing other applications of fuel cells, such as ethanol or methanol fuel cell vehicles, or ethanol fuel cells used in alcohol detection devices (breathalyzers or Continuous Alcohol Monitoring bracelets) to deter drunk driving offenders. The fuel cells in these devices work in a very similar fashion but use methanol
or ethanol as the fuel. If budget and time permit, it would be great if students could build and operate a fuel cell model car. Kits are available starting at less than $100 and The Fuel Cell Store provides worksheets and lesson plans as well for teacher and student. They’re very good and can be approached from RedOx or Energy Conservation and Transformation context. They even include NGSS standards in the teacher guides. Follow the link below for the kit and lesson plans/activities.

- Hydrogen Proton Exchange Membrane (PEM) Fuel Cell Model Car Kit

**Evaluate:** Students will be evaluated on the conclusion section of the activity by answering the post-lab questions. Follow-up evaluation is at the teacher’s discretion.

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**FOR THE STUDENT**

**Lesson**

**How do Hydrogen Fuel Cells Work?**

**Background**

Before starting this activity, you should review oxidation/reduction reactions (RedOx) and OilRig to remember which species gains and loses electrons in a RedOx reaction.

**Prelab Questions**

1. Define the following vocabulary:
   - Cathode:
   - Anode:
   - Reduction:
   - Oxidation:
   - Catalyst :
   - Voltaic cell:
   - HOR:  
     (Hint: it’s an acronym about hydrogen)
   - ORR:  
     (Hint: it’s an acronym about oxygen)

2. What does it mean to be a strong oxidizing agent?

3. Are strong oxidizing agents oxidized or reduced?

4. Write the half-reaction for the reduction of Oxygen gas:

5. Write the half-reaction for the oxidation of Hydrogen gas:

6. Why is platinum such an effective oxidation catalyst? What particular chemical properties does it have? How does this relate to the activity series of metals?
**Problem**
Hydrogen fuel cell vehicles promise to provide a clean alternative to traditional gasoline vehicles with internal combustion engines. How do they work? Are they really better for the environment? Let’s find out.

**Part 1:**
Review of Oxidation & Reduction: You should begin this activity by completing the [Voltaic Cells simulation](#) and completing the questions below.

1. Begin by assembling a zinc-copper cell. Choose the aqueous solution that matches each metal you choose (i.e. CuSO₄ (aq) for Cu). Please be sure to follow the instructions on the screen. Then do the same for the other combinations.

<table>
<thead>
<tr>
<th></th>
<th>Zinc – Copper</th>
<th>Copper – Silver</th>
<th>Zinc – Silver</th>
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<tbody>
<tr>
<td>Is there an electron transfer between species?</td>
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<tr>
<td>Which species loses electrons?</td>
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<tr>
<td>Write down the oxidation half reaction under the species that is undergoing oxidation.</td>
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<tr>
<td>Which species gains electrons?</td>
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<tr>
<td>Write down the reduction half reaction under the species that is undergoing reduction.</td>
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<td>Identify the cathode and anode</td>
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<tr>
<td>What is the electrical potential of this cell?</td>
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2. Write the complete balanced equation for each reaction
a. Zinc + Copper:

b. Copper + Silver:

c. Zinc + Silver:

Fill in the diagram for the first reaction, the zinc-copper cell. Include the following components and show the flow of electrons with arrows:

Anode, cathode, CuSO₄ (aq), ZnSO₄ (aq), salt bridge, Cu (s), Zn (s)

Part 2
What is a Proton Exchange Membrane (PEM) hydrogen fuel cell and how does it work? What chemical reactions are involved and what is the source of energy?

**Directions**
Follow this link and click on the play button in the [Animation of a Hydrogen Fuel Cell](#) to see a step-by-step animation of the process. Then click on each label of the diagram to see more information about the components.

- The Basics of Fuel Cells
- Diagram of a Proton Exchange Membrane Fuel Cell
- Oxidation and Reduction Reactions in a Fuel Cell
- Pragma Industries
- Hydrogen Production: Electrolysis

1. Using the diagrams, animations, and articles above, describe the reactions that take place in a PEM fuel cell.
   a. Step 1: Hydrogen from the storage tank enters the fuel cell
   b. Step 2:

   c. Step 3:

   d. Step 4:

   e. Step 5:

2. What is the “waste” product of a hydrogen fuel cell (what comes out of the tailpipe?)

3. How is electricity produced in a hydrogen fuel cell?

4. What is the average efficiency of a modern hydrogen fuel cell?
5. Write the half-reaction for the oxidation of Hydrogen

6. Write the half-reaction for the reduction of Oxygen

7. Why is platinum such an effective oxidation catalyst? What particular chemical properties does it have? How does this relate to the activity series of metals?

**Part 3**

What is the future of hydrogen fuel cell vehicles?

- Department of Energy Fuel Economy Information
- Benefits and Challenges of Fuel Cell Vehicles
- The Future of Cars: www.futurecars.com
- Consumer Energy Center
- Alternative Fuels Data Center
- Bitesize Chemistry Hydrogen as a Fuel
- Energy Currencies
- Why hydrogen fuel cells are dumb, by Elon Musk, CEO of Tesla (skip to 10:00 minutes)
- 2016 Tucson Fuel Cell Vehicle Specs
- 2016 Tucson Vehicle Specs (Internal Combustion Engine)

**Directions**

Using the sources provided above answer the following questions:

1. What are some of the benefits of fuel cell vehicles?

2. What are some of the drawbacks of fuel cell vehicles?
3. Do you think fuel cell vehicles are a viable solution to replace traditional gas-powered vehicles with internal combustion engines? Why or why not?

4. Would you consider buying a hydrogen fuel cell vehicle? Why or why not?

5. What changes might need to occur before you could or would consider buying a hydrogen cell vehicle?

6. What did you think of Elon Musk’s comments in the video link? Does this clip impact your point of view about the viability of hydrogen cell vehicles? Explain how it changed your point of view, if it did, or why it didn’t change your point of view.

Challenge yourself
1. Calculate the electrical potential if 1 mole of Hydrogen is consumed by a PEM fuel cell.

2. If the efficiency is 40-60%, how much electricity can be produced?

3. How far can a Hydrogen fuel cell car (Ford Focus, Nissan Leaf, or Hyundai Tucson) travel on a mole of Hydrogen gas (H₂)?

4. A traditional, internal combustion engine can travel about 1 mile per mole of gasoline (octane). How does this compare to your answer from question #3? Is the hydrogen fuel cell vehicle more or less efficient than an internal combustion engine burning gasoline? Does this answer surprise you? Why or why not?