Redox Reactions

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 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.

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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.

Observations

Experimentation

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

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

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

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

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.

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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:

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?

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

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

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Analysis

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

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

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

4. Based on your observations, how could you tell that a reaction was taking place during electrolysis and synthesis?

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Conclusions

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

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

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?