Stoichiometry

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:

- ☑ PS3.D: Energy in Chemical Processes and Everyday Life

Initial Prep Time

Approx. 10-15 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 Solar Hydrogen Science Kit
- Distilled water
- AA batteries
- Protractor
- Stopwatch
- Colored construction paper
- Various colored light filters
- Heat lamp and/or UV lamp (optional)
- Horizon Renewable Energy Monitor or multimeter (optional)

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Lab Setup

- We recommend completing steps 1 and 2 in the Assembly Guide for each electrolyzer so your students do not have to cut tubing or fill the electrolyzer initially.
- Lab includes small parts that can go missing easily. Set up a resource area for each lab table or for the entire class to minimize lost pieces.
- 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 the Solar Hydrogen Kit

- Direct sunlight, or a strong electric light, is necessary for operation. Overcast and indirect sunlight may not provide sufficient energy. Be sure any artificial light source is close to the solar panel.
- Be sure to line up the gaps on the inner cylinders of the H2 and O2 tanks so that bubbles can escape.
- You may need to inject more water into the O2 side of the cell if the electrolysis reaction is being sluggish. Wait 3 minutes and then try again.

Common Problems

- The motor's fan sometimes needs a little push to get started.
- If there's hydrogen left but the motor doesn't run, you may have to purge the fuel cell. Unplug the black plug and then quickly replace it to purge impure gases.
- 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

- Predict reaction yields with stoichiometry
- Use an electrolyzer to generate H2 and O2
- Make calculations based on data

Background

When reactants combine in a chemical reaction, they always do so in known ratios. Molecules contain precise ratios of atoms, so we can calculate the ratios of products in any known reaction. Stoichiometry is the the name given to the calculations of these ratios, which enable us to predict the yields of chemical reactions.

The law of conservation of mass says that matter can neither be created nor destroyed in a chemical reaction. So the amount of matter in the reactants must be equal to the amount of matter in the products. Consider the following reaction:

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H2O$$

A molecule of methane reacts with two molecules oxygen to yield one molecule of carbon dioxide and two molecules of water. The molecules on either side of the equation are different, but the number of each type of atom is the same.

The ratios of the molecules involved can also be thought of as moles of reactant and product in the reaction. So in the above reaction, one mole of methane would combine with two moles of oxygen, yielding one mole of carbon dioxide and two moles of water. Since we can convert moles to grams, we can predict how much product should be produced with given amounts of reactants.

In this activity, we will use the simple reactions of water in an electrolyzer and fuel cell to study the stoichiometric ratios of the reaction and compare them to our measured yields.

Procedure

1. You can use the electricity from the solar panel to generate hydrogen gas using the electrolyzer. The electrolyzer is the square with "H2" and "O2" printed on either side. What do you think will happen if you connect it to a source of electricity like the solar cell?
2. Your electrolyzer is also a hydrogen fuel cell that can generate electricity from hydrogen and oxygen. It has two small tubes attached to it. Is there anywhere else on the fuel cell that you could attach the longer tubes?
3. Look at the remaining pieces of your kit. If the fuel cell splits water into hydrogen and oxygen gases, what could you use to trap the gases so they don't float away?
4. Connect the tubes of your fuel cell so that you can trap the gases. To generate hydrogen, you'll need to supply an electric current. You can do this with the battery pack or the solar cell. Try both. Which is better at producing hydrogen? How do you know?
5. When you've produced hydrogen, you can use the fuel cell to power the motor just like you did with the solar cell. Plug the motor into the fuel cell and it should start turning. Note in your observations if you see any difference in how the motor works with the fuel cell instead of the solar cell.

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Observations

Experimentation

1. With the fuel cell attached, try tilting the solar panel so that it changes the angle of the light that hits it. Can you tilt it far enough that the fuel cell stops generating hydrogen and oxygen? Does it matter which direction you tilt the panel? Using a protractor, measure the biggest angle at which you can still run the fuel cell.

Maximum angle will change based on type of light source. A powerful light source may be able to keep an almost perpendicular solar cell running. Students should present data to determine whether one direction of tilt is better or worse than another.

2. Generate more hydrogen and oxygen using the fuel cell, as before. Can you tell how much hydrogen you've generated? What is the volume of hydrogen and oxygen produced? Does your data match what you would expect?

Students should be able to read mL of hydrogen on the cylinder. Answers here should note a roughly 2:1 ratio of hydrogen to oxygen, as expected by the stoichiometric ratio.

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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 and the voltage in Volts while generating hydrogen and oxygen using the solar panel and fuel cell. Record your answers below:

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

Current: ______________ A

Voltage: ____________ V

2. Voltage is equal to the current multiplied by the resistance (V = IR), so according to your data what is the resistance of the fuel cell?

Resistance: _____________ Ω

3. Measure the current in Amps and the voltage in Volts while combining the hydrogen and oxygen to produce water using the fuel cell. Record your answers below:

Current: ______________ A

Voltage: ____________ V

4. Does it take more energy to split the hydrogen and oxygen or combine them? Explain your reasoning.

Student answers should reference their measurements in the prior questions and compare the current and voltage of each process.

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Analysis

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

Claim should reference the electrolysis reaction and/or the recombination reaction.
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."

4. Use your observations to design an experiment you could run to increase the amount of electricity generated by the fuel cell. Describe your experiment below.

Many answers are acceptable, but students should describe what parameter or parameters they would change and why that change would be expected to increase the electricity generated. There should be clear control and experimental groups in the description.

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Conclusions

1. How did the volumes of hydrogen and oxygen that you measured reflect the stoichiometry of the reaction that produced them?

Answers should compare the approximate ratio of the volumes measured to the expected molar ratio based on stoichiometry.

2. What were some potential sources of error that might have made your measurements differ from the expected ratio of hydrogen to oxygen?

Inaccurate measurements due to lack of precision on cylinder mL markings, presence of air in the tubes and cylinders, relatively small amount of product, and other answers may be acceptable here.

3. We know that reaction products are always created in known ratios of moles. But if all products are gaseous, would a reaction always create products in the same ratios for the volumes of those gases? Why or why not?

Students could answer “yes” or “no,” as long as they acknowledge the role of pressure and temperature in determining the volumes of gases.