H2fromH2O Lesson Plans and Worksheets
Updated: Thursday, February 8, 2018

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I. Curricular Information

A. Texas Essential Knowledge and Skills (TEKS)

The following TEKS are objectives that have specifically been addressed in our lesson plans. They include:

§112.18. Science, Grade 6

(7) Matter and energy. The student knows that some of Earth's energy resources are available on a nearly perpetual basis, while others can be renewed over a relatively short period of time. Some energy resources, once depleted, are essentially nonrenewable. The student is expected to:

(A) research and debate the advantages and disadvantages of using coal, oil, natural gas, nuclear power, biomass, wind, hydropower, geothermal, and solar resources

§112.35. Chemistry

(8) Science concepts. The student can quantify the changes that occur during chemical reactions. The student is expected to:

(A) define and use the concept of a mole;
(B) use the mole concept to calculate the number of atoms, ions, or molecules in a sample of material;
(D) use the law of conservation of mass to write and balance chemical equations; and
(E) perform stoichiometric calculations, including determination of mass relationships between reactants and products, calculation of limiting reagents, and percent yield.

(9) Science concepts. The student understands the principles of ideal gas behavior, kinetic molecular theory, and the conditions that influence the behavior of gases. The student is expected to:
(A) describe and calculate the relations between volume, pressure, number of moles, and temperature for an ideal gas as described by Boyle's law, Charles' law, Avogadro's law, Dalton's law of partial pressure, and the ideal gas law;
(B) perform stoichiometric calculations, including determination of mass and volume relationships between reactants and products for reactions involving gases

(10) Science concepts. The student understands and can apply the factors that influence the behavior of solutions. The student is expected to:
- (A) describe the unique role of water in chemical and biological systems;

Complete TEKS may be found at the Texas Education Agency website:
http://ritter.tea.state.tx.us/rules/tac/chapter112/index.html

B. Next Generation Science Standards (NGSS)

The following NGSS have been addressed through our lesson plans; however, TEKS (Texas Essential Knowledge and Skills) remain the primary set of objectives since the inception of the program in Texas. Middle school objectives include:

MS-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MS-PS1-5. Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.

High school physical science objectives include:

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-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

Complete NGSS may be found at the National Science Teachers Association website:
http://ngss.nsta.org/AccessStandardsByTopic.aspx

II. Summary of Supplemental Lesson Materials

Avogadro's Law Lesson Plan (1) and Worksheet

Gas laws were of interest given the gaseous nature of the product of the water splitting reaction. For courses where the complete Ideal Gas Law was not of interest, an Avogadro's Law lesson plan was developed. The lesson plan (pgs. 5-6) and accompanying worksheet (pgs. 7-8) were developed to conceptually integrate the water splitting and gas laws minimizing calculations needed for the experiment.

Ideal Gas Law Lesson Plan (2) and Worksheet

The ideal gas law was of interest for use in advanced general chemistry and AP chemistry classes. The lesson requires calculations using the Ideal Gas Law and is more rigorous conceptually. The lesson plan (pgs. 9-10) and student worksheet (pgs. 11-13) are included in this document.

Stoichiometry Lesson Plan (3) and Worksheet

A worksheet was also adapted to highlight the stoichiometry of the reaction without the use of Gas Law's. This was useful for teachers who desired to use experiment before Gas Laws were discussed in the curriculum. A lesson plan can be found on pgs. 14-16 and an accompanying worksheet can be found on pgs. 17-18 of this document.

Electrochemistry Worksheet

Many teachers elected to combine stoichiometry and electrochemistry concepts in the experiment. Consequently, the stoichiometry lesson plan was adapted to also contain electrochemistry. This less plan can be found on pgs. 19-20.

Fuel Cell Efficiency Worksheet

A lesson plan was developed to combine many concepts where a more rigorous adaptation of gas laws data analysis was used to calculate the efficiency of device. This also included physics and electrochemistry concepts and was of interest to advanced, interdisciplinary classrooms. The efficiency is determined by calculating the number electrons used to produce gas and dividing it by the number of electrons flowing through the device. Page 21 contains a more detailed Data Sheet for students to record the data and pgs. 22-23 guide students through the data analysis.

Sustainability/Middle School Lesson Plan (4) and Assessments

We developed a lesson plan designed for middle school students and/or classes where little quantitative analysis is desired. This lesson plan can be found on pgs. 24-28.

Lesson Plans

(1) Avogadro's Law Lesson Plan

Author: Aubrey Bleier
Date: Spring 2016 (Revised September 2016)
Subject / grade level: On-level chemistry; could be adapted for AP Chemistry as well for refresher or as part of a bigger unit on gas laws.
Materials/Safety: Electrolysis station kits, water, power, sodium sulfate (or other electrolyte), lab notebook (or worksheet) for data and calculations Students do not generally need any PPE for this experiment. They should exercise caution with the nickel wires as they can be sharp. They should also avoid getting water on the electrolysis kit. As in every chemistry experiment, no chemicals should be ingested during the experiment and students should wash their hands when finished.
Standards: **§112.35. Chemistry, Beginning with School Year 2010-2011** (9) Science concepts. The student understands the principles of ideal gas behavior, kinetic molecular theory, and the conditions that influence the behavior of gases. The student is expected to: (A) describe and calculate the relations between volume, pressure, number of moles, and temperature for an ideal gas as described by Boyle's law, Charles' law, Avogadro's law, Dalton's law of partial pressure, and the ideal gas law; (B) perform stoichiometric calculations, including determination of mass and volume relationships between reactants and products for reactions involving gases
Lesson objective(s): SWBAT: - Use the balanced equation for the electrolysis of water to determine the amount of moles of gas produced in the reaction. - Use Avogadro's Law to find changes in volume and moles produced. This lesson is intended to be a short demonstration of Avogadro's Law and can be used as part of a whole unit on gas laws.
Differentiation strategies to meet diverse learner needs: - Visual instructions as well as written instructions provided for use of the electrolysis kits. - Demonstrations on how to set up the kits and perform a reaction will be given by the teacher so that students can follow along. How detailed the demonstration is (teachers should be familiar enough with the setup in order to explain intricacies; a video can be viewed here - https://www.youtube.com/watch?v=8_TmHGYk1qw) - Students work in groups of two to three students to facilitate peer learning.
ENGAGEMENT (10 minutes) ● Teacher can blow up two balloons – one large, one small. ● Ask students about how much gas might be in each. (one should be noticeably bigger) What kind of gas is in the balloon? (Carbon dioxide, oxygen, nitrogen).   o Misconception alert – students may incorrectly believe that only carbon dioxide

is exhaled. This is incorrect and would affect the behavior of the gas in the balloon.

- Use a KWL chart at this point – what do we already know about the behavior of ideal gases? What can we predict about their behavior?
- Engagement should not necessarily directly introduce Avogadro's Law or the equation – students can have this for data analysis, but should not necessarily know the definite relationship between volume of a gas and moles of a gas. This is so that students do not get caught up in collecting data that they think should be correct, but rather make only observations that are actually happening as part of the experiment..

EXPLORATION (~15 minutes)

- The teacher will introduce the electrolysis kits and perform a demonstration on how to set it up so that students have a correct setup. They can do this either using a video (view video above) or by leading the students through a setup – like on a document camera so that the students can follow along with the teacher's actions.
- Once all students have a correct setup, they will record the amount of gas in each of their tubes before starting.
  - Students will have different volume measurements depending on how much water they were able to keep in the tubes while inverting them. However, make sure students have approximately the same volume of water in each of their two tubes – this is important for balanced reaction purposes.
- Students will make volume recordings at 5 and 10 minutes. This extra time can be used to perform parts of the Explanation.

EXPLANATION (Can occur during experiment as well as after)

- Student observations will be elicited from the teacher as well as on the worksheet. What reaction is occurring?
- Students will figure out the reaction as well as balance it.
- Students will complete the rest of the worksheet and perform data analysis with their group.

ELABORATION

- Return to KWL chart – what did we learn about ideal gases? How does this contribute to what we already understood?
  - If we want to tie back into our Engagement, can we properly define then how many moles of gas we had in the balloons? Why or why not?
- How can we apply Avogadro's Law in relation to other gases?
- Good segue into the combined Ideal Gas Law ($PV = nRT$)
  - What are the values for this equation in our experiment? (we are at STP – good chance to define STP, since we have some 'experimental' conditions, and not to mention that the worksheet requires using these values. What do students think these values are?)

EVALUATION

- KWL chart serves as form of formative assessment.
- Student worksheets can serve as a method of both formative and summative assessment.
- Checkpoints at times 5 and 10 minutes can assure that students are on track.

Additional Documents: Student Worksheet (Pgs. 7-8)

Avogadro's Law Worksheet

Name: ___________________________ Date: ________________

Reaction:

Observations and Questions:
What was happening in the tube before the power was switched on?

What happened in the tubes when the power was switched on?

Do you notice any differences between the two tubes?

Record any other important observations here, like experimental conditions.

Data Collection:

Effect of Reaction Time on Gas Production:

Tube	0 minutes	5 minutes	10 minutes
#1, gas in mL			
#2, gas in mL			

Tube 1 contains _________________________.

Tube 2 contains _________________________.

<u>Data Analysis</u>:

Formulas for Avogadro's Law:

22.4 L/mol = $\frac{V}{n}$, where 22.4 L/mol is the volume of one mole of an ideal gas at STP, V is volume in L, and n is the number of moles

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

1. Using the first formula above, calculate the number of moles of oxygen and hydrogen that were produced during your reaction at 5 minutes and 10 minutes.

2. If the volume of an ideal gas increased from 2.5 L to 4.6 L, how many moles of gas are in the 4.6 L sample?

(2) Ideal Gas Law Lesson Plan

Author: Jerry Yang
Date: 2/14/2017
Subject / grade level: 11-12th Grade, Upper-level/AP Chemistry
Materials/Safety: Electrolysis station kits, water, source of power, sodium sulfate (or other electrolyte), and lab notebook (or worksheet) for data and calculations *Ideal, but not necessary: 1 thermometer and 1 barometer Hydrogen is safe in quantities generated in this experiment (<15mL) and will dissipate without effect, but H_2 should not be generated in any great quantity than that suggested here! The Na_2SO_4 used as an electrolyte is non-corrosive, safe (if splashed on skin, simply wash it off_ and can be disposed in a conventional drain.
Standards: (From 2014 AP Chemistry Course Description) **Essential Knowledge 2.A.2:** **LO 2.4 The student is able to use KMT and concepts of IMFs to make predictions about macroscopic properties of gases, including ideal and non-ideal behaviors.** **LO 2.5 The student is able to refine multiple representations of a sample of matter in the gas phase to accurately represent the effect of changes in macroscopic properties on the sample.** **LO 2.6 The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases.** **LO 2.12 The student can qualitatively analyze data regarding real gases to identify deviations from ideal behavior and relate these to molecular interactions.**
Lesson objective(s): ● **Use experimental data to compute quantitative properties (# moles, density) of a non-ideal gas** ● **Predict changes in properties of a gas using the Ideal Gas Law** ● **Explain the cause of deviations of non-ideal gases from ideal gases based on intermolecular forces and the van der Waals equation** ● **Justify the deviations of non-ideal gases from ideal behavior using experimental data**
Differentiation strategies to meet diverse learner needs: ● **A written lab protocol will be provided, which will state materials and procedure** ● **The leader should explain the instructions to the students prior to starting the experiment using auditory and visual means** ● **The leader should move around the lab area to ensure that all students understand the protocol during the experiment**
ENGAGEMENT ● **How do peanut butter manufacturers get peanut butter into the jar? How do syrup manufacturers get syrup into the jar without getting their equipment sticky?** ● **The answer: pneumatics. Pneumatics, or the use of gases to do work, can easily and (relatively) efficiently package highly viscous materials without human intervention.** o **http://hydraulicspneumatics.com/200/IndZone/FoodProcessing/Article/False/87069/IndZone-FoodProcessing** ● **We will explore how pressure, temperature, volume, amount, and density of gas affect each other. We will also calculate the universal gas constant from experimental data.**
EXPLORATION ● The teacher will introduce the electrolysis kits and perform a demonstration on how to set it up so

that students have a correct setup. They can do this either using a video or by leading the students through a setup – like on a document camera so that the students can follow along with the teacher's actions.

- Once all students have a correct setup, they will record the amount of gas in each of their tubes before starting.
    - Students will have different volume measurements depending on how much water they were able to keep in the tubes while inverting them. However, make sure students have approximately the same volume of water in each of their two tubes – this is important for balanced reaction purposes.
- Students will make volume recordings at 5 and 10 minutes. This extra time can be used to perform parts of the Explanation.

EXPLANATION

- Student observations will be elicited from the teacher as well as on the worksheet. About how much gas is being generated in each tube? How does the amount of gas in each tube compare with each other?
- Students will calculate the number of moles of gas produced in each tube.
- Students will complete the rest of the worksheet and perform data analysis with their group.

ELABORATION

- This can be done in lab groups or as class.
- Ask students to describe the gas on a molecular level using the Kinetic-Molecular Theory.
- Assume that there are IMFs between gas molecules (thus violating KMT). How would the data change?
    - Good place to introduce van der Waals equation wrt IMFs - note that nRT not affected by IMFs.

EVALUATION

- **Summative evaluation may consist of the worksheet provided**
- **Formative evaluation may consist of periodic checks by the lab leader to ensure proper following of protocol and lab data collected during the experiment.**

Additional Documents: Student worksheet (pgs. 11-13)

Ideal Gas Law Student Worksheet

Pre-lab Questions:

1. State the Kinetic-Molecular Theory.

2. With a few words, explain the relationship between the following properties of a gas:
    a. pressure and volume

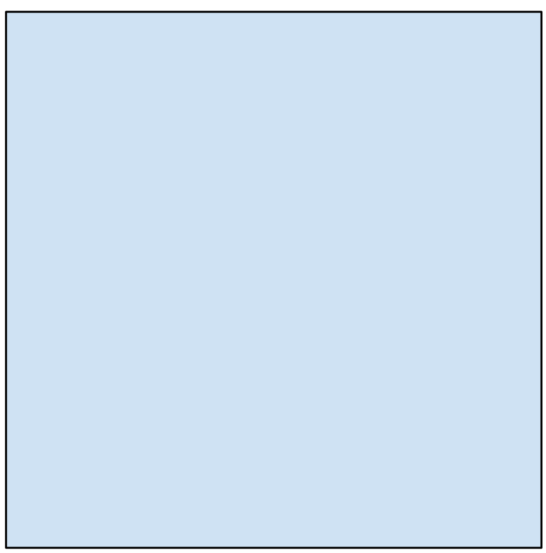
    b. volume and number of moles

    c. pressure and temperature

    d. pressure, volume and temperature

3. Write the equation for the electrolysis of water below. Be sure to include the phase of each species in your equation.

4. The 1 L container below is filled with oxygen gas. Draw 5-10 molecules of oxygen gas in the container below, paying particular attention to represent the species in a gaseous state. (Recall that oxygen gas is a diatomic molecule.)



Data Collection:

Pressure of room (measured with barometer, remember units!):
Temperature of room (measured with thermometer, remember units!):

Tube	1		2	
Alligator Clip Color:				
	Volume Measurement (Observed)	Gas Produced (Calculated)	Volume Measurement (Observed)	Gas Produced (Calculated)
Initial Reading (mL)				
After 5 minutes (mL)				
After 10 minutes (mL)				
After 15 minutes (mL)				
Total Gas Formed (Final – Initial)				

Observations:

Analysis:

1. From your observations, which tube has hydrogen gas, and which tube has oxygen gas? Justify your answer.

2. The Ideal Gas Law relates four properties of a gas: pressure, volume, temperature, and number of moles.
    a. Using your data and knowledge of chemistry, write the equation that represents the Ideal Gas Law.

    b. Calculate the number of moles of hydrogen and oxygen gas in each tube.

3. The Ideal Gas Law can be used to compute the density of a gas. Derive a formula for the density of a gas using the Ideal Gas Law, and calculate the density of the H2 and O2 in the tubes. (Recall that density = mass x volume, and # mol of a substance = mass x molar mass.)

4. Oxygen and hydrogen are not ideal gases; in fact, as real gases, O2 and H2 molecules experience slight intermolecular forces. How might this violation of KMT affect your results and the Ideal Gas Law?

Extension Questions:

1. If possible, repeat the experiment under different temperature and pressure conditions (perhaps in a refrigerator or pressurized container), and compare your results with the results you collected from this experiment. Is there a difference in the number of moles of gas evolved? Why/why not? Do you expect there to be a change?

2. Hydrogen gas can be combusted to form water. Using your data, compute the amount of water that can be created with the amount of gas you generated.

(3) Stoichiometry Lesson Plan

Author: The *H2fromH2O* Team
Date: Spring 2017
Subject area / course / grade level: Grade-level or Pre-AP/honors chemistry (9^{th}-11^{th} grade)
Materials: Electrolysis station kits, water, power, sodium sulfate (or other electrolyte), lab notebook (or worksheet) for data and calculations, timer Students do not generally need any PPE for this experiment. They should exercise caution with the nickel wires as they can be sharp. They should also avoid getting water on the electrolysis kit.
TEKS/SEs: §112.35. Chemistry – (8) Science concepts. The student can quantify the changes that occur during chemical reactions. The student is expected to: (D) use the law of conservation of mass to write and balance chemical equations; and (E) perform stoichiometric calculations, including determination of mass relationships between reactants and products (10) Science concepts. The student understands and can apply the factors that influence the behavior of solutions. The student is expected to: (A) describe the unique role of water in chemical and biological systems;
Lesson objective(s): **Students will be able to…** ● Determine the quantity of gas produced as part of the reaction ● Balance the reaction for water splitting ● Use stoichiometry to determine amounts of reactants based on the amount of product
Differentiation strategies to meet diverse learner needs: ● Material presented in variety of methods – visual and audio directions ● Video leads students through setup before having students perform it themselves
ENGAGEMENT ● Present students with the concepts behind baking. Set up an "equation" with the ingredients, the reactants, of chocolate chip cookies added together to get an x amount of cookie products. ex: _eggs + flour +_sugar +_chocolate chips +_butter → cookies ● Start with stating that basic amount of ingredients that make 12 cookies. Fill in the blanks appropriately, they do not have to exact it's all hypothetical, and explain the use of the coefficients. [Make sure to note that the reaction can happen in reverse, cookies can be 'dissociated' to regain the reactants. Not always true for all equations but for the sake of this example it could be helpful.] Coefficients are the numbers next to a reactant or product that tells how many are needed or created for a reaction.

- Once this is understood, the class should have a brief grasp on reactants, products, and coefficients. Then explain what would happen to the reactants if we only made 6 cookies? 24 cookies? 18 cookies? Let the students think pair share at their tables or with a partner for about 3 minutes and ask one student from each different group (3 total) to come to the board and show their answer. This will spark discussion of how the amount of product can be controlled by the amount of reactants.

- To introduce subscripts, replace sugar with actual chemical formula of glucose in the recipe.
  _eggs +_flour +_$C_6H_{12}O_6$ +_chocolate chips +_butter→ cookies
  Explain how the coefficient is then multiplied throughout each element if that element has any. For any without subscripts, it is assumed there is only one of those elements.

- End introduction by presenting real chemistry equations and starting discussion of how we can see how much product is getting made. Since the product isn't as visible as the number of cookies that change, there has to exist some knowledge about the components of the reactants and equation. Bring up Law of Conservation of Mass. (Should be review.)

- Some example equations:

$$NH_4^+ \leftrightarrow NH_3 + H^+$$

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

EXPLORATION

- Students can be arranged in groups of two to four.
- Teacher can lead students through the setup using this video: https://www.youtube.com/watch?v=8_TmHGYk1qw
- Once the setup is complete, students should take data from the graduated tubes before beginning the reaction. Once recorded, students can switch ON and turn both knobs at the bottom of the kit fully to the right.
- Ensure the reaction is taking place by observing the bubbles evolving from the end of the electrode in the beaker.
- On the worksheet provided, students can take data points at timed intervals. Be sure to have a timer displayed for students.
- Prompt students with questions about observations (what is happening in the tube? Do you notice any difference?)

EXPLANATION

- While the experiment is running, the teacher can prompt students about what they have observed in the experiment.
- How can this be used to determine the reaction that is occurring?
- Students should notice that the rate of gas evolution is faster in one tube than the other.
- Have students explain why this could be happening – what do we already know about the reaction that is occurring?
- Here the reaction for water splitting (water splits to become hydrogen and oxygen gas) can be explained and balanced.
    - Can use the balanced reaction to calculate moles, molecules (using Avogadro's number), etc

ELABORATION

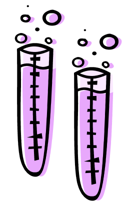
- How can we use hydrogen gas in different ways? Can we generate it in different ways?
- Teacher can use solar panel to run reaction – is this a more sustainable way to split water? (yes) Why? (we are not using energy from the power adapter)
- Teacher can also utilize hydrogen car to demonstrate the ability of hydrogen to produce energy when combusted.

EVALUATION

- Worksheets can be used to demonstrate understanding of how data collection should work (is the amount of gas increasing as time goes on?)
- Can be part of a larger unit on stoichiometry
- Teacher can circulate during experimentation and ensure that data collected by students looks correct (amount of gas in tube should be increasing as time increases)

Additional Documents: Student worksheet (pgs. 17-18).

Name: ___________________________ Date: ________________



Data Collection

Effect of Reaction Time on H_2 Production

Tube	**1**		**2**	
Alligator Clip Color:				
	Volume Measurement (Observed)	**Gas Produced (Calculated)**	**Volume Measurement (Observed)**	**Gas Produced (Calculated)**
Initial Reading (mL)				
After 5 minutes (mL)				
After 10 minutes (mL)				
After 15 minutes (mL)				
Total Gas Formed (Final – Initial)				

Data Analysis

Which tube contains more gas? By how much?

Which tube contains hydrogen (H_2)?

Which tube contains oxygen (O_2)

Post-Lab Questions

[1] In your own words, describe what you observed during the experiment.

[2] Describe the law of conservation of mass.

[3] Hydrogen (H_2) and oxygen (O_2) can be combusted with a flame by the following equation:

$$2\ H_{2\ (g)} + O_{2\ (g)} \rightarrow 2\ H_2O$$

a) Identify the reactants, products, subscripts, and coefficients in this equation

b) number of atoms of each element on the product and reactant sides.

Element	Reactant	Product
Hydrogen (H)		
Oxygen (O)		

[4] In this experiment water decomposes into hydrogen (H_2) and oxygen (O_2). Write the balanced equation for the reaction you performed today.

Name: ___________________________ Date: ________________

Pre-Lab Questions:

1. Write the balanced water splitting reaction (hint: water becomes hydrogen and oxygen gases).

2. Write the balanced half reactions that combine to form the reaction above:

   Reduction:

   Oxidation:

Data Collection:

Tube	1		2	
Alligator Clip Color:				
	Volume Measurement (Observed)	**Gas Produced (Calculated)**	**Volume Measurement (Observed)**	**Gas Produced (Calculated)**
Initial Reading (mL)				
After 5 minutes (mL)				
After 10 minutes (mL)				
After 15 minutes (mL)				
Total Gas Formed (Final – Initial)				

3. Observations – Note what you observe happening during the reaction:
   (i.e. What is happening in each tube? Is each tube the same? How much current is passing? Any other changes you observe)

Post-Lab Questions (Stoichiometry):

4. Did your tubes produce the same volume of gas? Explain these results.

5. Which tube produced Hydrogen (H_2)? Oxygen (O_2)?

6. If 25 mL of oxygen gas were formed, how much hydrogen gas has formed?

Post-Lab Questions (Electrochemistry):

7. Identify the cathode tube and the anode tube.

8. Is this reaction spontaneous? Is the cell galvanic or electrolytic?

9. Using the following reduction potentials, calculate the cell potential (E_{cell}) required to drive the reaction.
   $O_2 + 4\ H^+ + 4e^- \rightarrow 2\ H_2O$ 1.229 V
   $2\ H^+ + 2e^- \rightarrow H_2$ 0.000 V

Post-Lab Questions (Applications):

10. Hydrogen gas is a promising renewable fuel of the future!
    a. Write the reaction that will convert the chemical energy in the gases you generated today back to electrical energy.

    b. Would this cell be electrolytic or galvanic? Would it be spontaneous? What would be the cell potential?

    c. What is the product of the reaction? Why do you think scientists are excited about this fuel?

Calculating the Efficiency of the Fuel Cell - Data Sheet

Tube	**1**		**2**		**Current Reading (mA)**	**Current Reading (A)**	**Total Charge (Coulombs, C)**
Alligator Clip Color:					Ammeter on board	Convert units from mA to A	= Current (A) * 300 s
Time Elapsed (t)	**Volume Measurement (Observed, mL)**	**Gas Produced (Calculated, mL)** $\Delta V = V_f - V_i$	**Volume Measurement (Observed, mL)**	**Gas Produced (Calculated, mL)** $\Delta V = V_f - V_i$	**Observed**	**Calculated: A = mA/1000**	**Calculated: Q = I * *t* I in Amps (A) *t* in Seconds (s)**
0 min - initial							0
5 min							
10 min							
15 min							
Total					N/A	N/A	

After the experiment:

Pressure of room (in atm)	
Temperature of room (in K)	
Total Charge Generated in entire experiment (in C)	

Observations – What is happening in each tube? Is each tube the same? Any other changes you observe.

Calculating the Efficiency of the Fuel Cell - Post-Lab Questions

Useful information:

Ideal Gas Law: PV=nRT

- P is pressure in atmospheres (atm)
- V is volume of container in liters (L)
- n is amount of gas in moles (mol)
- R = 0.0821 L*atm/(mol*K)
- T is temperature in Kelvin (K); K = deg. Celsius + 273

Total Charge Equation: Q = I*t

- Q is charge in Coulombs (C)
- I is current in amperes (A)
- t is time in seconds (sec)

Avogadro's Number: 1 mole = 6.02 x 10^{23} molecules

Elementary charge: 1 electron = 1.6 x10^{-19} Coulombs

Let's determine how efficient our device is! To do this we will compare the number of electrons (or charge) that went to producing gas to the total number of electrons that flowed through our device! Perfect efficiency (100%) would mean that *every single* electron was used.

<u>Data Analysis Questions:</u>

1. Write the balanced chemical equation for the electrolysis of water. For every 1 mole of water, how many moles of Hydrogen (H_2) are produced?

2. Using the Ideal Gas Law (given above), how many moles of hydrogen gas were present for each time interval? Don't forget to convert units! Record these values on your data table.

3. Based on your answer in #2, how many molecules of hydrogen gas was present for each time interval?

4. How many water molecules were split during each time interval?

5. For each water molecule that is split, two electrons are released. Calculate the number of electrons that were released from the total reaction.

6. From your result in #5, calculate the total charge (in Coulombs) generated by the reaction. Remember to convert units!

7. Now calculate the total charge passed through the board by multiplying each current reading by 300 seconds (5 min). Add these together to get the total charge passed during the experiment. Record these values on your data table.

8. Now calculate the efficiency of the device. Divide the charge generated by the reaction by the total charge measured through the board and multiply by 100. How efficient is the board?

Post-Lab Questions:

1. Did your tubes produce the same volume of gas? Explain these results.

2. Which tube produced Hydrogen (H_2)? Oxygen (O_2)? How can you tell?

3. If 25 mL of oxygen gas were formed, how much hydrogen gas has formed?

4. Identify the cathode tube and the anode tube. In what direction do electrons flow?

5. Why do you think the efficiency of the board is less than 100%? How do you think we can improve our efficiency?

(4) Sustainability/Middle School Lesson Plan

Author: Aubrey Bleier & the *H2fromH2O* Team
Date: Fall 2016
Subject area / course / grade level: 6th Grade (Afterschool Club or other)
Materials and Safety Considerations: Electrolysis setup (1 setup per group of 3-4): - Electrostation - Pair of alligator leads - Set of graduated tubes with nickel wire - 300 mL beaker - Power adapter (set to positive polarity and 12 V) - Sodium sulfate solution (can be premade or made by students) Solar panel Hydrogen powered car (optional) Students should wear goggles at all times to avoid getting the solution in their eyes. However, the solution is safe to use externally and can be poured down the sink when finished. The nickel wires can be sharp, so take care when using the tubes. Be sure not to get the electrostations wet. The H_2 that is generated is not present in a large enough quantity to be dangerous, but open sources of flame should still only be handled by adults as a demonstration only.
TEKS/SEs: TEKS: 6.7 Matter and energy. The student knows that some of Earth's energy resources are available on a nearly perpetual basis, while others can be renewed over a relatively short period of time. Some energy resources, once depleted, are essentially nonrenewable. The student is expected to: (A) research and debate the advantages and disadvantages of using coal, oil, natural gas, nuclear power, biomass, wind, hydropower, geothermal, and solar resources TEKS from higher grades can also be covered by this lesson, but are not listed here.
Lesson objective(s): 1. Students will describe and demonstrate the process of energy transformation by solar cells. 2. Students will collect data, make calculations, and create graphs to display scientific data. 3. Students will compare methods used for transforming energy in devices. 4. Students will identify solar energy as an inexhaustible resource.
Differentiation strategies to meet diverse learner needs: Working in teams facilitates peer learning. Presentation of the instructions through multiple methods (speaking, demonstrating, written) ensures that students understand how to set up the experiment.
ENGAGEMENT (Time – 5 minutes)

Activity	Questions and Misconceptions
As a group, the teacher can ask the students what they already know about energy. What it is, why we need it, and how it is generated can be covered here. Transition to Exploration – today we are going to be exploring hydrogen and how we can generate it through solar cells and use its potential to power our cars, homes, and businesses.	What types of energy are there? - Solar, fossil, geothermal, wind, nuclear, etc. Students can get very creative and almost 'competitive' here in trying to identify as many types as possible. Be sure that they aren't identifying subtypes as their own type (ex. coal, natural gas, and oil are all forms of fossil fuels) What makes a type of energy renewable or non-renewable? - Renewable resources cannot be 'used up' like non-renewable resources can. There is a finite amount of coal in the ground, for example, but an infinite amount of wind energy. (At least as long as the Earth keeps spinning!)

EXPLORATION (Time – 30 minutes)

Activity	Questions and Misconceptions
The teacher(s) will lead the students through the experiment setup. A video tutorial on this can be viewed here: https://www.youtube.com/watch?v=8_TmHGYk1qw In addition, it will be helpful if the teacher demonstrates how to set up the experiment in real time. Having pre-made the sodium sulfate solution will help; otherwise, students can make it themselves by dissolving the sodium sulfate salt in their beakers filled with water. Written instructions on kit setup: 1. Fill the tall beaker about 3/4 full with deionized or tap water, and dissolve about 20 g of Na2SO4. (The exact amount does not matter – we are just trying to saturate the solution.) 2. Make sure the ON/OFF switch is set to OFF, and	Why are we using sodium sulfate? (It is a salt that dissolves to help conduct an electric current, which is called an electrolyte.) Although not an objective of this experiment, some students may have questions or have heard of electrolytes.

the dial is set to MIN. Make sure the kit is in RUN mode (on the bottom right of the circuitboard). 3. Fill the electrode assembly with the solution, and then submerge the electrode assembly by inverting them quickly at 45° angle into the beaker which is held also at 45°.	
This step is really tricky. Should definitely do a demonstration beforehand and allow students several tries. Or have assistants to help all students.	Make sure that students have completed a circuit; this may seem intuitive to some students, but not others. (Why do we need to make a circuit?)
4. Using clip leads, connect the two electrodes to the "(+) Electrode (-)" leads on the electrostation (in any order, it doesn't matter).	Make sure that students are able to accurately determine the amount of H_2 and O_2 produced
5. Note the gas level in each electrode test tube, and write it down in your pre-made data table. Make sure to write this down for each tube, 6. Turn the electrostation ON, and adjust the dial for maximum current.	What is occurring in each of the tubes? Is it similar or different? (Similar in that gas should be evolving from the end of each electrode, but different in that one should be evolving gas at a higher rate.)
7. Watch as gaseous bubbles evolve from the very tips of the electrodes. Write down observations on your data sheet. Run the reaction for 5-15 min (this time is up to the instructor).	Is there any difference between the two? Why? (can go into the balanced reaction for water splitting, $2H_2O \rightarrow 2H_2 + O_2$, and how that influences how much gas is produced)
8. In your data table, write down the final water level in each electrode.	
9. May choose to repeat experiment for a number of different trials.	
10. Turn off the amperostat, disconnect the clip leads, and dump the solution down the drain. Rinse the beaker with water and clean up your lab station so it looks better than the way you found it!	

EXPLANATION (Time – 15 minutes)

Activity	Questions and Misconceptions
This is where students evaluate and attempt to explain what happened in the experiment – and most important of all, how in the world is this related to solar cells? The teachers can explain that the water was split by running the electric current through it. We were able to generate hydrogen this way. What are some other ways we can generate hydrogen? Photovoltaic cells can generate H2!!	What did we see happen as part of the experiment? - Bubbles, gas formed, etc. - Electricity made the reaction occur What did we generate? - Hydrogen and oxygen gas Why is this useful? Does anyone know? - We can use it for energy What's wrong with our experiment? Any drawbacks? - We aren't generating our hydrogen in a 'clean' way – we still got our electricity likely from fossil fuels. How can we generate hydrogen in a clean way? - Solar cells

ELABORATION (Time – 10 minutes)

Activity	Questions and Misconceptions
http://energy.gov/eere/energybasics/articles/solar-photovoltaic-technology-basics ^ a short overview of how photovoltaic cells actually work Students can think, pair, share their ideas regarding solar cells – the video may have some vocabulary that students may be unfamiliar with, so it is helpful to define these terms. (Semiconductor, photon, etc.)	What are some drawbacks you can think of that solar cells have? - Expensive, not efficient enough, only work where it's sunny/during the day, etc.

EVALUATION

- Pre-assessment and post-assessment materials available
- Certain natural 'checkpoints' exist at different points of the experiment to ensure that students are keeping up with what's occurring in the reaction. (for example, if the goal of the experiment is to run it as a function of time, students can be stopped at certain time intervals to ensure they are recording data and observations.)

Additional Documents: Pre- and post- assessment questions (pg. 33).

Additional Documents:

Pre-Assessment (can also be used as a post-assessment if desired, or post-assessment can be different)

1. What is solar energy?
2. Why is solar energy more desirable than using fossil fuels?

Data Tables for Gas Production

	Tube 1	Tube 2
Initial Volume of Gas		
Volume after 5 Minutes		
Volume after 10 Minutes		
Total Volume (Subtract the initial volume of gas from the volume after 10 minutes.)		

Post-Assessment

1. Define renewable energy.
2. Why is using the solar panel preferable to using the AC outlet?
-natural source of energy
3. Why is burning hydrogen better than burning gasoline?
-no carbon dioxide produced which is bad for the environment
4. We talked about some drawbacks to using solar energy. Name one idea you have for changing one of these to make solar cells better.