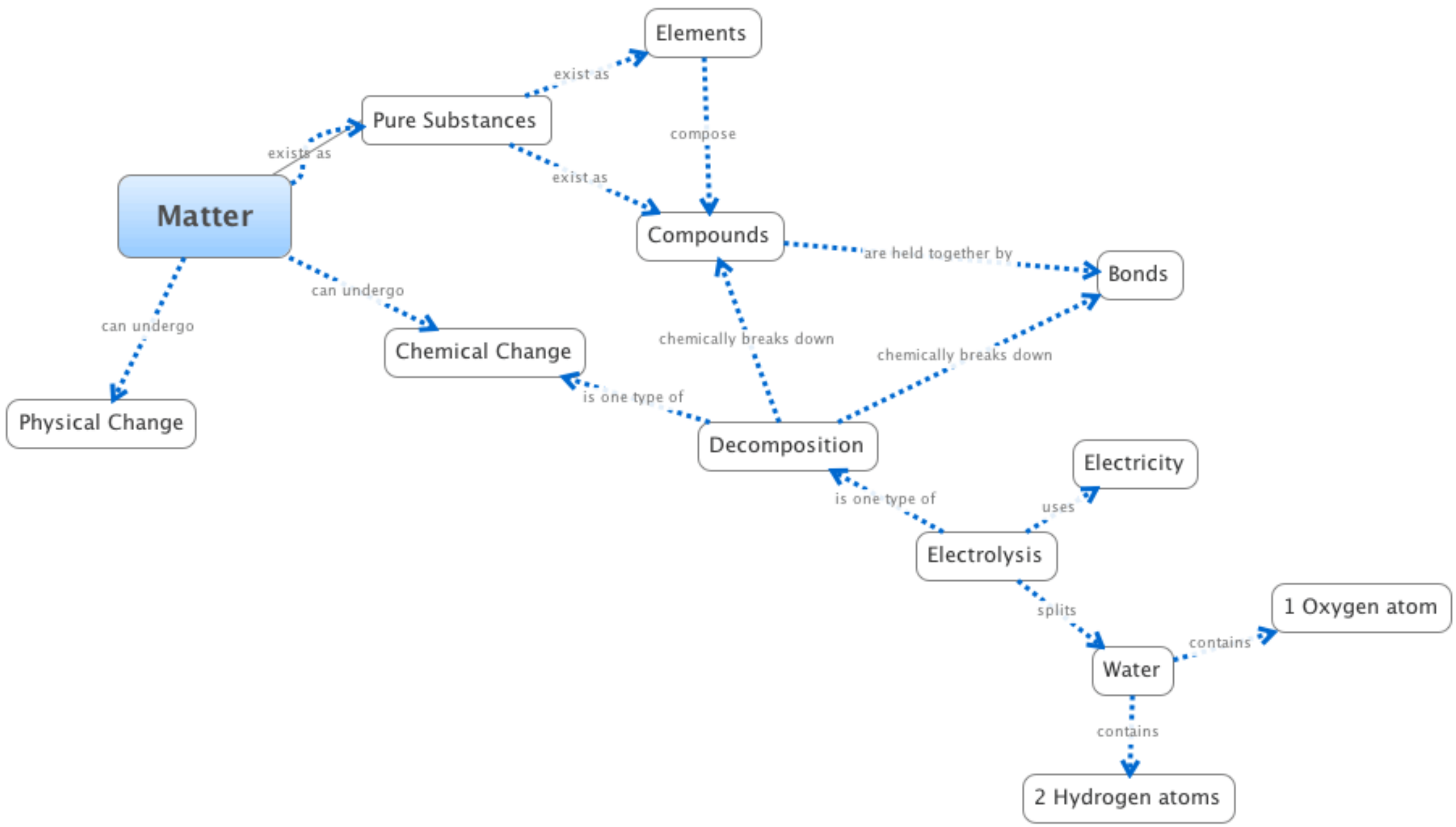
1.3 DECOMPOSING MATTER (DM)



T-DM Fig. 1.1 Decomposing matter concept map

<u>Goals</u>
Students will…

1. Describe the process of water electrolysis
2. Interpret evidence from electrolysis to confirm the composition of water

Ocean Literacy Principles
<u>Principle 1: *The Earth has one big ocean with many features.*</u>

Ocean Literacy Fundamental Concept: *Most of Earth's water (97%) is in the ocean. Seawater has unique properties: it is saline, its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic. The salt in seawater comes from eroding land, volcanic emissions, reactions at the seafloor, and atmospheric deposition. (OLP 1e)*

<u>Principle 2: *The ocean and life in the ocean shape the features of the Earth.*</u>

Ocean Literacy Fundamental Concept: *Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks. (OLP 2a)*

Standards Addressed

T-DM Table 1.1. HCPS III Benchmarks

Science		
Standard 2	Nature of Science	Understand that science, technology, & society are interrelated.
Code		
6.2.1	Use models and/or simulations to represent an investigate features of objects, events, and processes in the real world.	
Standard 6	Nature of Matter and Energy	Forms of energy, transformations & structure of universe.
6.6.8	Recognize changes that indicate that a chemical reaction has taken place.	
PS.6.8	Describe interactions among molecules	
PS.6.11	Describe a variety of chemical reactions	

Background and Introduction

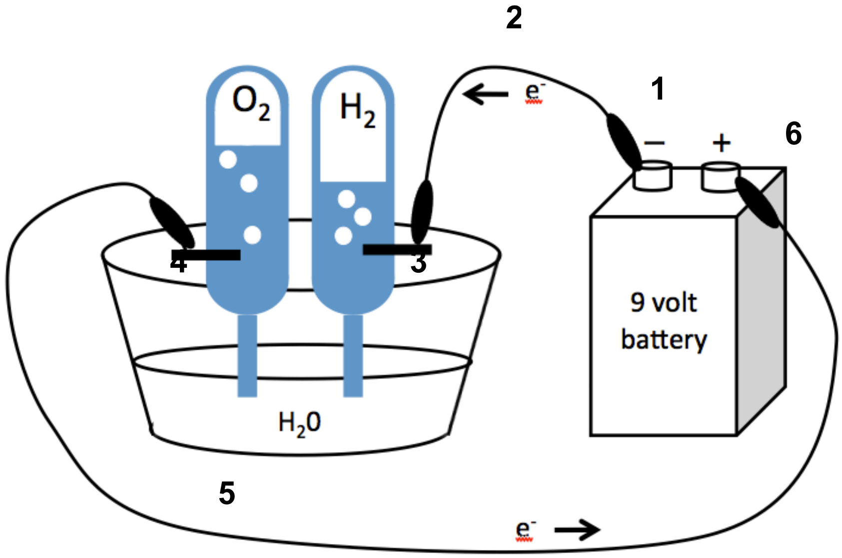
Electrolysis generally refers to the process of applying a direct electrical current to drive a reaction that would normally be non-spontaneous. Electrolysis was used to discover several new chemical elements such as potassium, sodium, barium, calcium, magnesium, gallium, and fluorine.

Electrolysis is used in this activity to decompose water (H_2O) into its two component elements: hydrogen and oxygen. The end result of the electrolysis of water is hydrogen gas (H_2) and oxygen gas (O_2). A complete circuit is needed in order for electrons to flow and electrolysis to occur (See T-DM Table 1.2).

T-DM Table 1.2. Components of an electrolysis circuit

Component	Definition	Component in Electrolysis Activity
Electrolyte	An ionic compound that can dissociate completely. This facilitates the flow of charge.	Baking soda
Electrolyte solution	Electrolyte dissolved in water. This is part of the complete circuit.	Saturated baking soda solution
Direct current (DC) supply	Produces and drives the flow of electrons	9 V battery
Two electrodes	Electrical conductor that is the interface for electron exchange in electrolyte solution	0.7 mm graphite
Two wires	To connect battery and electrodes. This is part of the complete circuit.	Alligator clip wires

For any electrical device, the flow of electrons is from anode to cathode outside of the device. Considering only the battery, electrons flow out of the negative terminal (anode) and flow back into the positive terminal (cathode). Considering only the portion of the apparatus in solution, electrons flow out of the oxygen side (anode) and back into the hydrogen side (cathode). In other words, the anode of the battery is connected to the cathode in solution (both negative), while the cathode of the battery is connected to the anode in solution (both positive). This convention may create confusion, so for purposes of simplicity, this explanation has been left out of the student text, referring only to the positive and negative terminals of the battery. For the teacher text, the cathode and anode of both the battery and the solution are referenced.



T-DM Fig. 1.2. Completed electrolysis circuit. See T-DM Table 1.3 for explanations of each step.

T-DM Table 1.3. Process of electrolysis of water.

Step	General Description	Notes	Chemical Reaction
1	Electrons are produced at the negative terminal of the battery	This is the **anode** of the battery. Electrons are produced by chemical reactions in the battery.	
2	Electrons travel through wire, away from battery		
3	Negative electrode is site of donation of e- from battery to water. Hydrogen gas forms.	This is the **cathode** in solution.	$2\ H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (reduction)
4	Positive electrode is site of donation of e- from water to battery. Oxygen gas forms.	This is the **anode** in solution.	$2\ H_2O \rightarrow O_2 + 4H^+ + 4e^-$ (oxidation)
5	Electrons travel through wire, toward battery		
6	Electrons return to battery positive terminal of battery.	This is the **cathode** of the battery. Electrons participate in further chemical reactions in battery.	

T-DM Fig. 1.2 and T-DM Table 1.3 illustrate the process of water electrolysis. At the cathode in solution, a reduction reaction takes place. Hydrogen goes from a 1^+ oxidation state to a 0 oxidation state by gaining electrons as in equation (1).

$$(1) \qquad 2\ H_2O + 2e^- \rightarrow H_2 + 2\ OH^-$$

Note also that hydroxide is formed at the cathode. This production of negative charges in solution attracts the cations from the electrolyte to balance charge. The production of hydroxide creates a basic solution around the cathode.

At the anode in solution, an oxidation reaction takes place. Oxygen goes from a 2^- oxidation state to a 0 oxidation state by losing electrons.

$$(2) \qquad 2\ H_2O \rightarrow O_2 + 4\ H^+ + 4\ e^-$$

Note that hydrogen ions are formed at the anode. This production of positive charges in solution attracts the anions from the electrolyte to balance charge. The production of hydrogen ions creates an acidic solution around the anode.

One mnemonic device for remembering oxidation and reduction is “LEO the lion goes GER”

L	Lose	G	Gain
E	Electrons	E	Electrons
O	Oxidation	R	Reduction

Note that equations (1) and (2) do not give the equation for the decomposition of water. To do so, start from the two half-reactions above and balance the electrons by multiplying equation (1) by 2 to yield a total of four electrons for each half reaction. Then add these half reactions together producing equation (3).

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

$$\underline{+\ 2\ H_2O \rightarrow O_2 + 4\ H^+ + 4\ e^-}$$

$$(3) \qquad 6\ H_2O \rightarrow 2\ H_2 + 4\ OH^- + O_2 + 4\ H^+$$

Adding the OH^- and H^+ on the right side of the equation produces four H_2O, shown in equation (4) below

$$(4) \qquad 6\ H_2O \rightarrow 2\ H_2 + O_2 + 4\ H_2O$$

Four H_2O on the right side can be cancelled with four H_2O on the left side to yield the equation for the decomposition of water, equation (5) below

$$(5) \qquad 2\ H_2O \rightarrow 2\ H_2 + O_2$$

Avogadro's Law states that at equal temperature and pressure, equal volumes of gas have equal numbers of particles. Thus, in the Electrolysis Activity, the volume of hydrogen generated is twice the volume of oxygen gas, because the number of hydrogen molecules is twice that of oxygen molecules. This is the same ratio of hydrogen and oxygen atoms in the water molecule due to the Law of Conservation of Mass, which states that no matter can be created or destroyed in a chemical reaction. All of the hydrogen and oxygen generated by electrolysis came from the water.

Many different apparatuses can be used for the electrolysis of water. If the goal is not to collect the gases, electrodes can be put directly into a Petri dish of water and bubbling will be observed. A Hoffman apparatus is specially designed to collect and dispense the gases that evolve. A Brownlee apparatus, of which the equipment in the activity is a modification, is designed to collect, but not dispense, the evolved gases.

Common Misconceptions

T-DM Table 1.4 Decomposing matter misconceptions

Misconception	Explanation
Current and electrons Free electrons flow through solution.	Electrons flow between the power source, the electrons, and the ions in solution. Charged ions move through solution, facilitating the flow of electricity.
Matter Particles are not conserved in chemical or physical changes	Particles of matter are not destroyed during chemical or physical changes. They merely change in their form and properties.
State of Matter A change of state is a chemical change	A change in the phase or state of matter of a substance is a physical change, not a chemical change. The chemical composition of solid water (ice) is the same as the chemical composition of liquid water.
State of Matter and Chemical Reactions Cooling causes hydrogen and oxygen to combine to form water.	Temperature changes alone do not cause chemical reactions (e.g. changing hydrogen and oxygen into water). Cooling hydrogen or oxygen would only change its state of matter (e.g. from common gas phase to liquid phase or even solid phase).
Chemical Reactions Heat causes water to break up into hydrogen and oxygen, i.e., water is destroyed when it evaporates.	Temperature changes alone do not cause chemical reactions (e.g. changing water into hydrogen and oxygen). Electrolysis causes a chemical reaction of water with hydrogen and oxygen as its products. When liquid water is heated, it is not destroyed, but rather it is changed to a gas phase (water vapor).

Activity: Electrolysis of Water

T-DM Table 1.5. Suggested activity progression, if adhering closely to activity as written with no major modifications, assuming class periods of 40 minutes.

Day	Task
1	Introduction to activity
	Activity
2	Class discussion

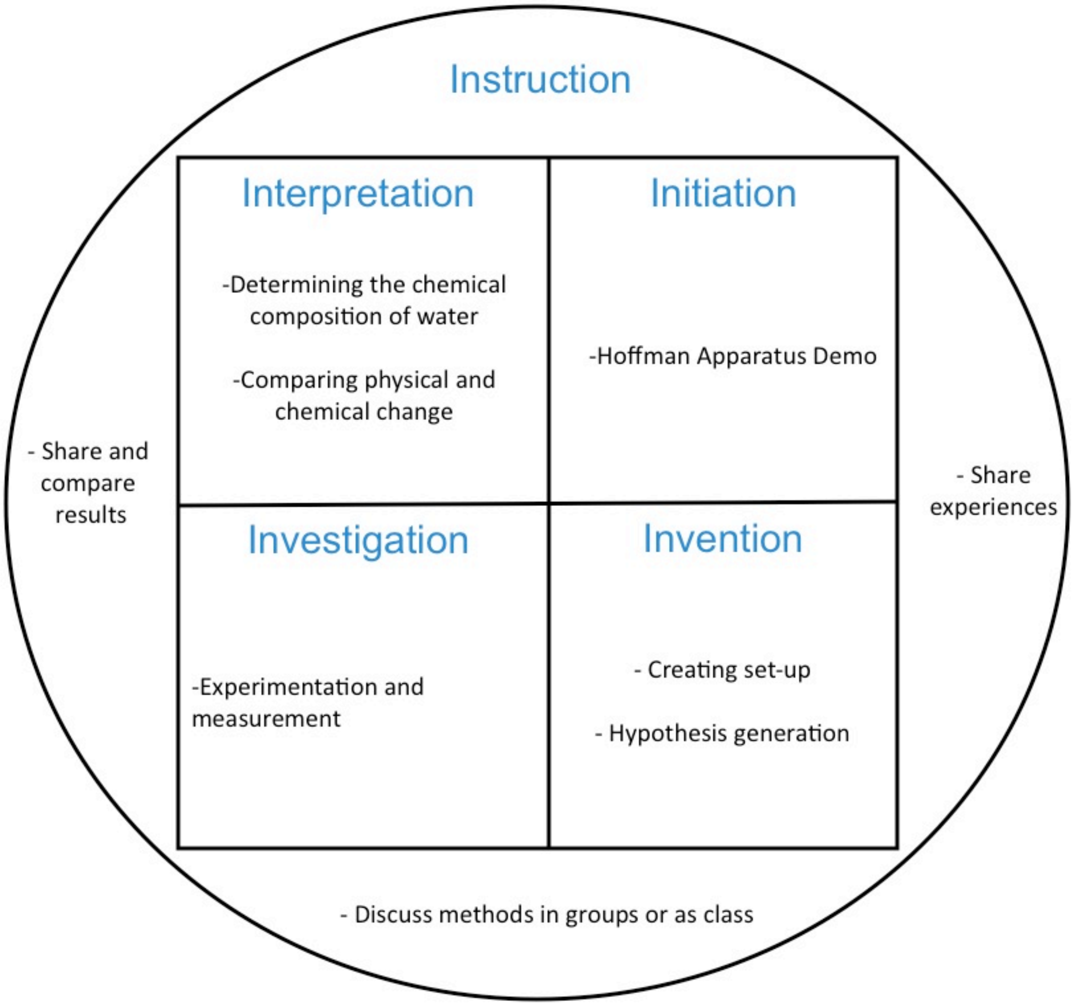
T-DM Table 1.6. Materials, if adhering closely to activity as written with no major modifications, assuming class of 32 students divided into groups of two (16 groups).

Materials	Quantity	Per	Class Total	Notes on Material Number or Material Modification
Goggles	2	Pair	32	
1-mL wide stem transfer pipettes	2	Pair	32	
1-mL graduated pipette	1	Pair	16	
Scissors	1	Pair	16	
Ruler	1	Pair	16	
0.7 mm graphite stick	1	Pair	16	Graphite breaks easily, have extra on hand
Pin	1	Pair	16	Straight pin
Small cup	1	Pair	16	
Baking soda		Pair	500 mL	To make a saturated baking soda solution, mix baking soda into water until no more will dissolve. It is important to use distilled water. Tap water has an unknown ion concentration which may allow for the creation of gases other than hydrogen and oxygen (thus ratio may not be as close to 2:1)
Distilled water	~30 mL	Pair	500 mL	
9-V battery	1	Pair	16	Age of batteries will determine how fast reaction runs
Alligator clip wires	2	Pair	32	
Permanent marker	1	Pair	16	

Activity Inquiry Prompts

1. What do you observe happening after the battery is connected?
2. What is being produced inside each pipette bulb?
3. What type of change is happening? What is your evidence?
4. How is this different than boiling?
5. What happens if you unclip the alligator wire?
6. What happens if you remove the bulb from the solution?
7. What happens if the level of liquid in the bulb goes below the electrode?

Planning with TSI



T-DM Fig. 1.3. Planning Conductivity through TSI phases

Focus Modes(s):

- Experimentation
  - Using a chemical reaction by electrolysis to confirm the composition of water
- Replication
  - Class consensus on liquid levels inside each pipette bulb
- Induction
  - Observing bubbles form on the electrodes and clear gases fill the pipette bulbs will help students develop a sense of electrolysis as a chemical reaction.

Procedure

**NOTE* Figures and tables in this section refer to figures and tables in EOFE unless otherwise noted.*

Safety Warning(s):

- Handle pins and batteries carefully.
- Wear goggles during reaction.

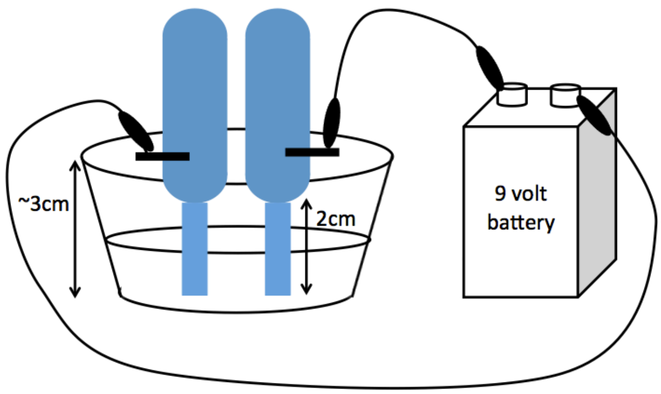


Fig. 1.8. Equipment set-up for electrolysis of water

1. If necessary, cut the cup so it is approximately 3 cm high.

2. Cut each of the wide stem pipettes 2 cm below the bulb. Each cut pipette should be the same height.

3. Break the graphite stick so you have at least two pieces that are about 1.5 cm.

4. Push the pin into *one* side of each of the pipette bulbs about 1/3 of the way up the bulb from the stem (see Fig. 1.8).
    a. Create the hole in the smooth part of the bulb, not in the seam.
    b. Into each hole, gently push a piece of graphite. If the hole is not large enough, you may have to wiggle the pin in the hole to make it bigger.

    If the hole is created in the seam, it will be much more difficult to get graphite into hole.

    Having unequal lengths of graphite sticking into the pipettes does not affect the reaction. The length of the graphite electrode may affect the apparent rate of gas production or bubble size, but will not change the total volume of gas production.

5. Make a saturated solution of baking soda by mixing baking soda into distilled water until it no longer dissolves. Pour the baking soda solution into your small cup, to about 1/3 full.

    Modification: Create a saturated baking soda solution for your students.

6. Fill the cut pipettes completely with baking soda solution.
    a. Use the graduated pipette to fill the cut pipettes with water.
    b. When filling the pipette bulbs, do not squeeze the area of the bulb with the graphite or the graphite might break.

    Pipettes can also be filled from a large container and then a small amount of solution poured into the small cup.

7. Place the pipettes stem down in the remaining solution in the small cup, with the pipette stem holes completely submerged in the solution. See Fig. 1.8.

8. Clip the alligator clips to the graphite electrodes carefully, so as not to break the graphite.

9. Clip the alligator clips to the battery, one clip on each terminal.

10. Observe the system as it runs. Keep in mind the following questions:
    a. Which electrode on the battery is each connected to each electrode on the electrolysis apparatus?
    b. What is happening at each electrode?

    It may take as little as 10 and as much as 30 minutes to generate a good volume of gas. The system can be left running; once the liquid level goes below the graphite, the circuit is broken and it will stop running. Alternately, as long as the bulbs are not squeezed and the stem remains in the solution, wires can be disconnected and then reconnected at a later time without losing gas.

9. When you finish running the system, mark the level of the liquid in each pipette with a permanent marker (see Fig. 1.9.).
    a. You can pull the pipettes out of the cup to do this, just be careful not to squeeze them.
    b. Make a second mark on each pipette where the bulb stops curving and becomes straight.
    c. Measure the distance between each mark on each pipette and record your results.

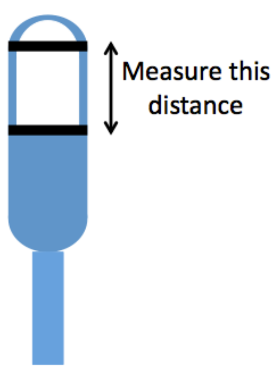


Fig. 1.9. Measure the distance from the bottom of the curve to the top of the solution level on each pipette.

Answers to Questions

1. What did you observe as the system ran?

Gases are being produced in each bulb. Bubbles are formed at each electrode.

2. Why was it important that the pipettes were both resting in the baking soda solution?

The solution completes the circuit. Electricity must flow through the solution.

3. What is the chemical formula of water?

The chemical formula of water is H_2O.

4. Answer the following questions based on the gas formed at each electrode.
    a. How much gas formed at each electrode?
    b. How do the volumes of the gases compare?
    c. How might you explain any differences?
    d. How does this provide evidence for or against the chemical formula for water?

Twice as much gas formed at the negative electrode than the positive electrode. Since we know that the formula for water is H_2O, gas formed at the negative electrode was hydrogen and the gas formed at the positive electrode was oxygen, this finding supports notion that there is twice as much hydrogen in water as oxygen.

NOTE: The way battery manufacturers label the anode and cathode terminals of their batteries as positive and negative is not standardized. Our diagram (answer) is right, but compared to some regular battery labels might appear wrong.

5. What was the gas generated at the electrode connected to the positive (+) pole of the battery? Give your evidence.

The gas at the positive electrode was oxygen. There was twice as much gas generated at this electrode.

6. What was the gas generated at the electrode connected to the negative (–) pole of the battery? Give your evidence.

The gas at the negative electrode was hydrogen. There was less gas generated at this electrode.

Activity: Hoffman Apparatus

Goals

Students will…

1. Interpret evidence from electrolysis and splint tests to confirm the composition of water
2. Distinguish between physical and chemical change

T-DM Table 1.7. Suggested activity progression, if adhering closely to activity as written with no major modifications, assuming class periods of 40 minutes.

Day	Task
1	Activity (demonstration or video) and class discussion

T-DM Table 1.8. Materials, if adhering closely to demonstration as written with no major modifications

Materials*	Quantity	Notes on Material Number or Material Modification
Goggles	3	One for you, one for each assistant
Hoffman Apparatus	1	All glassware is fragile. Platinum electrodes are expensive, take care when handling.
Baking soda solution	~100 mL	Must be saturated solution using distilled water. Mix baking soda into water until no more will dissolve.
9-V battery	1	
Alligator clip wires	2	
Test tubes	2	
Piece of rubber tubing	1	~6”
Splints	10	May need more or less depending upon success of demo
Matches	2	May need more or less depending upon success of demo
Candle	1	To light splints

*Alternatively, you can watch a video of this demonstration, e.g. www.youtube.com/watch?v=OTEX38bQ-2w

Demo Inquiry Prompt Questions

1. How is this similar to the setup you made? How is it different?
2. What is being produced?
3. What type of change is happening? What is your evidence?
4. How is this different than boiling?
5. What do the results of the test indicate?

Procedure

NOTE Figures and tables in this section refer to figures and tables in EOFE unless otherwise noted.

Safety Warning(s):

- You and any student assistants should wear goggles.

Practice makes better! This is a tricky demo and practice will certainly help, but have extra materials and make sufficient gas, so that you can attempt the demo multiple times in class. The popping noise made by the hydrogen test can be loud, so practicing will also ensure that you are not startled.

1. Set up the Hoffman apparatus, making sure all connections are hand-tightened.

2. Open the stopcocks and pour baking soda solution into the thistle tube top of the apparatus. Make sure to pour slowly enough that solution has time to level and does not shoot out of the top of the apparatus. When apparatus is full, close stopcocks.

3. Clip the alligator clips to the electrodes and then to battery.

4. Allow apparatus to run until at least 10 mL of oxygen gas are produced. The more gas produced, the more times you will be able to attempt the demo. If running this demo for multiple classes, you may want to have two Hoffman apparatuses or stagger the demo, so that there is time to produce sufficient gas for each class.

5. Unclip the alligator clips from one electrode to break the circuit.

6. Light the candle.

7. Place one test tube over the tip of the hydrogen side of the U-tube. Open the stopcock and allow a volume of gas to flow out of the U-tube that is approximately equal to the volume of the test tube.

8. Keeping the test tube upright, close the stopcock, then place your thumb over then open end of the test tube.

9. Light the splint so that it on fire. Holding the test tube firmly, place the burning splint quickly inside the test tube. It should make a loud, high-pitched pop. (See Table 1.4)

Hydrogen "pops" when ignited by a lit splint. Hydrogen mixes with oxygen in the air to combust, creating a mini-explosion. At the same, as the hydrogen combusts and oxygen is depleted, a slight vacuum is creating, allow air to rush into the tube at a high speed. This sequence of events causes the high-pitched pop sound. Combusting hydrogen in a large, open space will create a boom, rather than a squeaky pop.

10. Place the rubber tubing over the tip of the oxygen side of the U-tube. Guide the tubing downward into a test tube. Open the stopcock and allow a volume of gas to flow out of the U-tube that is approximately equal to the volume of the test tube.

11. Keeping the test tube upright, close the stopcock, then place your thumb over then open end of the test tube.

12. Light the splint so that it on fire, then blow it out so that it is still glowing. Holding the test tube firmly, place the burning splint quickly inside the test tube. It should relight the splint. (See Table 1.4)

Table 1.4. Splint test for gases

Gas	Splint Test
Hydrogen (H_2)	When a burning splint is introduced to a sample of pure hydrogen gas, it will burn with a popping sound.
Oxygen (O_2)	When a smoldering splint is introduced to a sample of pure oxygen gas, the splint will reignite.
Nitrogen (N_2)	When a burning splint is introduced to a sample of pure nitrogen gas, it will be extinguished.
Water Vapor (H_2O)	When a burning splint is introduced to a sample of pure water vapor, it will be extinguished.
Air ~ 79% Nitrogen, (N_2) ~ 21% Oxygen, (O_2)	When a burning splint is introduced to air, it will continue to burn.

Answers to Questions

1. Which gas formed by the electrolysis of water is more dense? What is your evidence?

Oxygen must be more dense, because when it was dispensed into the test tube, the tubing pointed downward into the test tube. When hydrogen was dispensed, it was allowed to flow upward into the test tube. Oxygen must be more dense than air, which is more dense than hydrogen.

2. How do the properties of water differ from its individual elements?

At room temperature, water is liquid. At room temperature, oxygen and hydrogen are both gases. Water is not flammable, while oxygen and hydrogen both are. Oxygen is more dense than hydrogen, but they are both less dense than water. They formed bubbles, which floated out of the water.

3. Is the electrolysis of water a chemical or physical change? What is your evidence?

Electrolysis of water must be a chemical change because it produces two completely new substances that are different from each other and also different from the original substance.

Also, it is not possible to recombine the oxygen and hydrogen without another chemical change, burning.

4. Was there evidence that water formed during the splint tests? If so, under what conditions was it formed?

Condensation was observed on the side of the test tube. This is more likely to happen in the hydrogen tube, because there is a lot of oxygen in the air and it is possible that the hydrogen did not flush out all of the air in the tube. This is less likely to happen in the oxygen tube, as there are only traces of hydrogen in the atmosphere, so even if not all air was flushed out, water is unlikely to reform due to the reaction of hydrogen and oxygen. However, water is also a product of the combustion of hydrocarbons, so a trace amount of water may be formed due to the combustion of methane.