An Electrolysis Experiment for a Middle School Summer Science Camp

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Abstract

Higher education is often culturally deemphasized in the geographic area served by our rural, regional campus. As a result, faculty members have the opportunity to spearhead teaching efforts designed to educate the community about the importance of obtaining a post-secondary degree. To this end, we recently held a Science Summer Camp for middle school students, designed to infuse young people with an increased excitement for STEM (Science, Technology, Engineering, and Math) education. In this report, we summarize a chemical electrolysis experiment we carried out with middle school students for our annual Science Summer Camp. We also provided procedural guidelines for small- and large-scale experiments. In the latter case, evolved H_2 gas can be detonated for effect. Two modifications from literature procedure include: (1) using glass burettes, instead of test tubes, to collect the evolving H_2 and O_2 gases for the small-scale setup; and (2) prefilling the 100-mL graduated collection cylinders with aqueous NaOH prior to beginning electrolysis. Because these modifications provide aqueous solution in the collection reservoirs *prior* to starting the experiment, the total time required for the experiment is greatly reduced (~30 minutes).

Introduction

Higher education is often culturally deemphasized in the geographic area served by USU's Uintah Basin regional campus.[1] As a result, faculty here have both the opportunity *and* responsibility of teaching the community about the benefits of a university degree. A significant part of that work involves efforts to infuse the rising generation with an excitement about math and science. To that end, we recently organized our first "Summer Science Camp," designed for local middle school students.[2] The camp featured four eighty-minute classes per day, over two days, in various STEM (Science, Technology, Engineering, and Math) subjects. The event was attended by 62 students, ranging from 11 to 13 years in age, who came from private, public, and home schools located throughout our two-county region.[3] Classes were delivered and directed by university faculty, staff, and local field experts, who were assisted by resident high school students and community volunteers. In light of the positive response, we intend to continue holding the camp every year.

Day 1, "Chemistry and Biology Day," featured classes on avian digestion, electrolysis, entomology, and comparative anatomy and dissection (see Table 1). For Day 2, "Geology, Physics, and Engineering Day," students learned about robotics, paleontology, and the physics of gravity.[4] For our chemistry class, students conducted an electrolysis experiment that was modified from a published procedure[5] and directed through an interactive lecture from the instructor. Considering students' positive feedback, we anticipate that other chemistry educators may have an interest in delivering a similar class. We therefore disclose here the full details of our experiment, including our procedural modifications, for chemistry teachers. For further utility, this disclosure also includes links to three instructional videos on the experiments' designs, which are posted on YouTube.[6] It should be noted that the experiment can be safely and reproducibly carried out with students from age 11 and up.

Table 1. Summer Science Camp two-day schedule.

	Day 1: Chemistry and Biology				**Day 2: Geology, Physics, and Engineering**			
Group	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Class 1 9:30 – 10:50 a.m.	A.D.	C.E.	Ent.	C.A.D.	Rb.	B.L.	Pal.	E.D.
	Break 10:50 – 11:00 a.m.				Break 10:50 – 11:00 a.m.			
Class 2 11:00 – 12:20 a.m.	C.A.D.	A.D.	C.E.	Ent.	E.D.	Rb.	B.L.	Pal.
	Lunch 12:30 – 1:20 p.m.				Lunch 12:30 – 1:20 p.m.			
Class 3 1:30 – 2:50 a.m.	Ent.	C.A.D.	A.D.	C.E.	Pal.	E.D.	Rb.	B.L.
	Break 2:50 – 3:00 a.m.				Break 2:50 – 3:00 a.m.			
Class 4 3:00 – 4:20 a.m.	C.E.	Ent.	C.A.D.	A.D.	B.L.	Pal.	E.D.	Rb.
	Break 4:20 – 4:45 p.m.				Break 4:20 – 4:45 p.m.			
	Load on buses 4:45 – 5:00 p.m.				Load on buses 4:45 – 5:00 p.m.			

Key: A.D. = avian digestion, C.E. = chemical electrolysis, Ent. = entomology, C.A.D. = comparative anatomy/dissection, Rb. = robotics, B.L. = the physics of gravity using balloon launchers, Pal. = paleontology, E. D. = the physics of gravity using an egg drop experiment.

Methods

Group Organization and Class Introduction

The 62 students who attended the two-day summer camp were divided into four separate groups of 15 to 16, which rotated through the four classes shown in Table 1. Students wore appropriate personal protective equipment at all times.[7]

Our electrolysis instruction began with a discussion of the flammability of hydrogen gas and the molecular structure of water, as detailed in the Experimental section below. Students were then invited to make physical models of water using handheld model kits and to propose their own structures for theoretical byproducts that water might form. Through this discussion, students were able to use their models to propose different structures for water. The instructor then introduced the concept of balancing chemical equations, and students used their handheld models to propose an equation for water's decomposition ($2H_2O \rightarrow 2H_2 + O_2$), which they then recorded on "observations" papers supplied by the instructor.

At this point, the instructor taught students about the scientific method, and the following hypothesis was formulated from observations: "When water is separated into hydrogen and oxygen gases, the hydrogen and oxygen gases should form in a 2:1 ratio." Students were then introduced to electrolysis as a means of separating water into hydrogen and oxygen gases, according to Equations 1-3:

Equation 1: Reduction (cathode): $2\ H_2O(l) + 2e^- \rightarrow H_2(g) + 2\ OH^-(aq)$

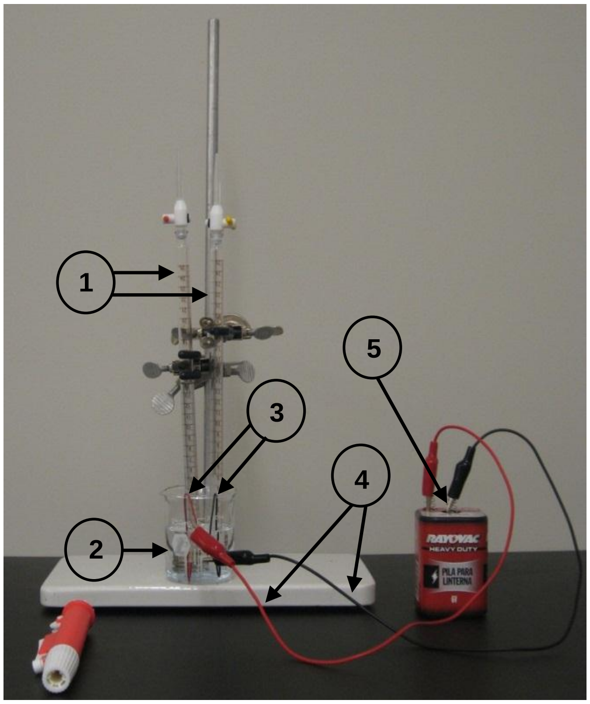
Equation 2: Oxidation (anode): $4\ OH^-\ (aq) \rightarrow O_2(g) + 2\ H_2O(l) + 4\ e^-$

Equation 3: Overall reaction: $2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$

Small-Scale Electrolysis Apparatus Setup (Student)[6a]

At this point, each class of 15-16 students was divided into five groups of three, and each group was asked to assemble the small-scale electrolysis apparatus shown in Figure 1 (further details are provided in the Experimental section below). Thus, two 25 mL glass burettes were mounted next to each other, valve sides up, with their open ends pointing down into an empty 250 mL glass beaker charged with aqueous sodium hydroxide. This modification differs from the literature procedure,[5] which calls for test tubes instead of glass burettes, and allows the experiment to proceed more quickly. This is because the burettes' stopcock valves can be used to draw up ionic solution into them from the 250 mL beaker, instead of waiting for the NaOH ions to disperse gradually. Because electrolysis requires the burettes to be charged with ionic solution,[5] this change significantly reduces the total time needed, allowing the entire class to be readily finished within an 80-minute timeframe.

Figure 1. Small-Scale Electrolysis Apparatus Setup (Student).



1. Two 25 mL glass burettes
2. 250 mL Beaker
3. Insulated copper electrodes
4. Alligator lead wires
5. 6-volt battery

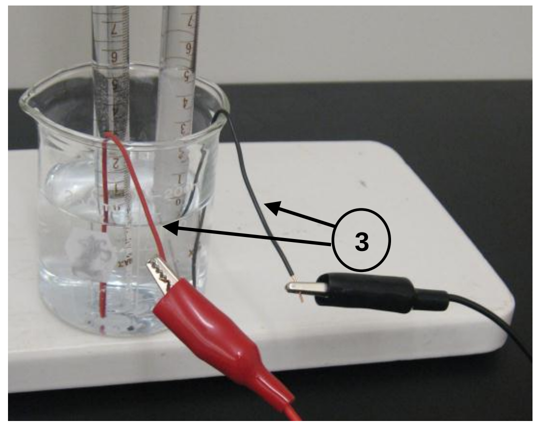
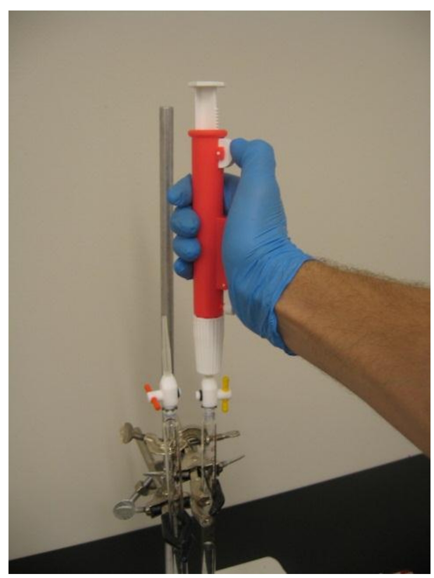


Figure 2. Burettes were filled with NaOH solution by pipette pump.



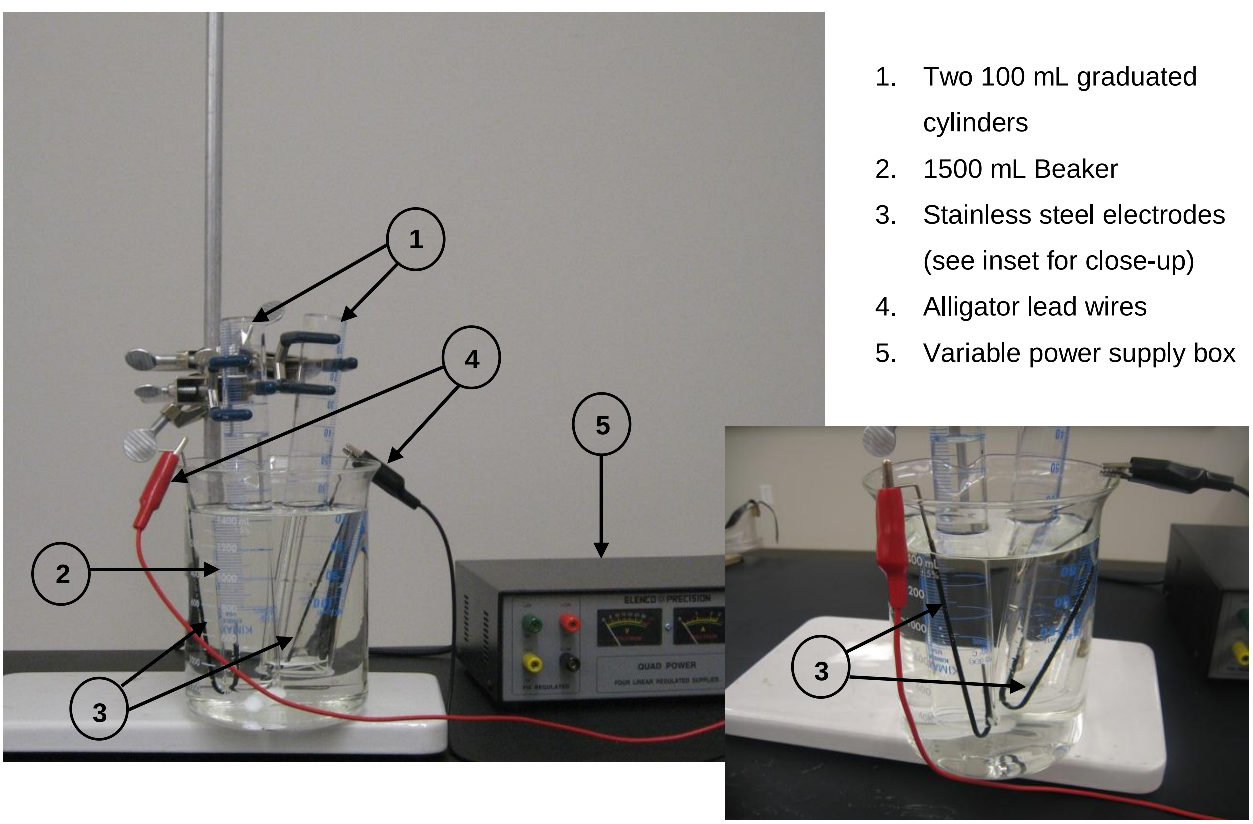
Each burette was now fixed with an insulated copper electrode,[8] as shown to the right in Figure 1, and the electrodes were then attached to flexible alligator lead wires.[9] With the burettes' open ends immersed in the NaOH solution, each burette valve was independently opened and affixed to a pipette pump[10] according to Figure 2. Sodium hydroxide solution was then drawn up and into the burette, filling it to the 25 mL line.[6a]

At this point, the circuit was completed by connecting the alligator lead wires to a 6-volt battery (see Figure 1), with the black wire connected to the central terminal (the cathode) and the red wire to the offset terminal (the anode). Gaseous evolution immediately ensued from the immersed ends of the copper electrodes at the base of each burette. After 10-15 minutes, enough hydrogen and oxygen gases had evolved to allow their respective 2:1 volumes to be clearly seen. As this transpired, the instructor and teaching assistants conversed with the individual groups, pointing out this volumetric ratio and asking students to explain it.

Large-Scale Electrolysis Apparatus Setup (Instructor)[6b]

We initially hoped that enough hydrogen and oxygen gases would form in these experiments to let students ignite them by opening their pipette valves near a flame source. Unfortunately, the scale of the reactions proved too small to give this outcome. Thus, the instructor set up a large-scale apparatus (shown in Figure 3), which ran while students' experiments were going. Its setup was analogous to the small-scale apparatus just described, with the alterations detailed in the Experimental section below. Though large burettes would be amenable to this setup, we used 100 mL graduated cylinders, which were prefilled with aqueous NaOH using a procedure described in the Experimental section below.

Figure 3. Large-Scale Electrolysis Apparatus Setup (Instructor).



1. Two 100 mL graduated cylinders
2. 1500 mL Beaker
3. Stainless steel electrodes (see inset for close-up)
4. Alligator lead wires
5. Variable power supply box

Explosive Balloon Demonstration[6c]

To further demonstrate and compare the explosive natures of hydrogen and oxygen gases, four separate balloons were inflated and detonated in the presence of student attendees. These four balloons individually contained the following: (1) exhaled gases, (2) oxygen gas, (3) hydrogen gas, and (4) a 50/50 O_2/H_2 mix. Balloons were ignited using a lit candle fastened to the end of a 2.5-meter-long stick, made by securing two yardsticks together. During detonation proper care was exercised, and appropriate safety procedures were followed. Students accordingly stood at a 24-foot distance from the balloons and were instructed to plug their ears. The instructor also wore proper ear protection, safety goggles,[7] and a flame-resistant lab coat.

Results and Discussion

Five of the recorded experiments gave the measurements shown in Table 2, reflecting an average 1.9:1 hydrogen-to-oxygen volumetric ratio. By comparison, the large-scale apparatus, for which only one trial was measured, produced 15.7 mL of oxygen and 28.0 mL of hydrogen (1:1.78 ratio). When asked to draw conclusions, students noted that this ratio was roughly consistent with that proposed by their original hypothesis. When asked further how we could test the identity of the gas that was presumed to be hydrogen, students enthusiastically responded, “By lighting it on fire.” At this point, the hydrogen gas produced by the large-scale apparatus was ignited.[6c]

Table 2. Recorded experimental H_2 and O_2 volumes.

Experiment	Volume of O_2 produced (mL)	Volume of H_2 produced (mL)
1	10	19.5
2	9.6	18.2
3	6.8	12.5
4	8.7	16.5
5	7.2	13.8
Average volume	8.46	16.1
Ratio	1	1.9

Conclusions

In this report, we summarized a chemical electrolysis experiment we carried out with middle school students for our annual Science Summer Camp, designed to infuse young people with an increased excitement for STEM (Science, Technology, Engineering, and Math) subjects. We also provided procedural guidelines for small- and large-scale experiments. In the latter case, evolved H_2 gas can be detonated for effect. Two modifications from literature procedure[5] include: (1) using glass burettes, instead of test tubes, to collect the evolving H_2 and O_2 gases for the small-scale setup; and (2) prefilling the 100-mL graduated collection cylinders with aqueous NaOH prior to beginning electrolysis. Because these modifications provide aqueous solution in the collection reservoirs *prior* to starting the experiment, the total time required for the experiment is greatly reduced to about 30 minutes, versus ~80 minutes for the traditional setup.

Experimental

General Information

Students were given molecular model kits,[11] pencils, and blank sheets of paper ("observations" papers), on which to record their observations and hypotheses. Students were also issued safety goggles,[7] which they were required to wear while working in the lab. The instructor was assisted by three undergraduate students. The class was repeated four times, in sequence, to four different groups of 15 students. The class length was fairly consistent, at 1 hour and 10 minutes.

Small-Scale Electrolysis Apparatus (Student)[6a]

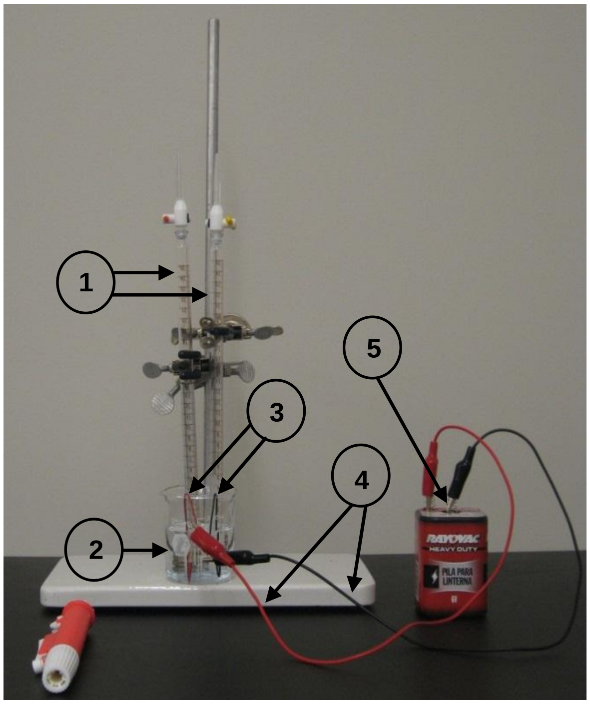
Parts List (per apparatus)

- Safety goggles[7]
- Two 25 mL glass burettes
- Ring stand
- Two three-prong clamps
- One 250 mL glass beaker
- Two insulated, S-shaped copper electrodes with the copper ends exposed[8]
- 150 mL of distilled water
- 25 mL of 5N aqueous sodium hydroxide. A two-liter stock solution was prepared in advance by dissolving 400 grams of solid sodium hydroxide pellets (CAS #1310-73-2) in two liters of distilled water. This was stored in a downdraft fume hood during use.
- One pipette pump filler/dispenser[10]
- Two alligator lead wires[9]
- One 6-volt battery

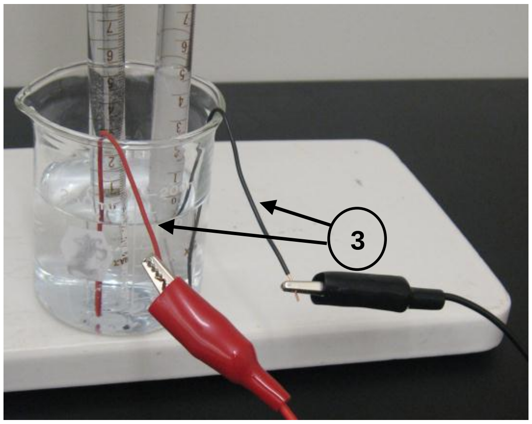
Setup

As Figure 1 indicates, two 25 mL glass burettes (**1**) were secured by two three-prong clamps attached to the same ring stand.[6a] The burettes were suspended (valves pointing up) next to each other, so that their open ends (pointing down) were immersed in an empty 250 mL glass beaker (**2**). An insulated copper electrode (**3**) was positioned at the base of each burette, with one of its exposed ends protruding up into the burette and the other pointing out of and down the side of the beaker (see Figure 1, inset).

Figure 1. Small-Scale Electrolysis Apparatus Setup (Student).



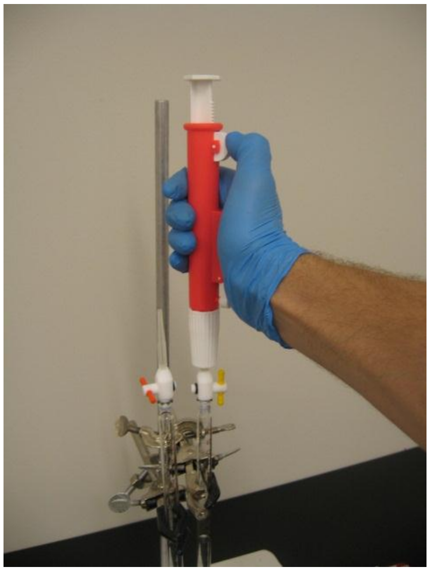
1. Two 25 mL glass burettes
2. 250 mL Beaker
3. Insulated copper electrodes
4. Alligator lead wires
5. 6-volt battery



To the 250 mL glass beaker were added 150 mL of distilled water, followed by 25 mL of 5N aqueous sodium hydroxide. Students then waited 3 minutes for dispersal of the ions into solution. We found that the experiment worked best if the burettes were filled with distilled water that was already charged with aqueous sodium hydroxide. This differs from some literature sources[5] that suggest prefilling test tubes with distilled water before introducing the sodium hydroxide. Although both methods work, we observed the former to proceed much more quickly and efficiently. Thus, with the burettes' open ends now immersed in the NaOH solution, each burette valve was independently opened and affixed to a pipette pump filler/dispenser, according to Figure 2.[6a] This pipette pump dispenser was then used to draw sodium hydroxide solution up and into each burette, filling it to the 25 mL line.

As seen in Figure 1 above, the alligator lead wires (**4**) were now attached to the exposed ends of the electrodes, and then to a 6-volt battery (**5**), with the black wire being connected to the central terminal (cathode) and the red wire being attached to the offset terminal (anode). Gaseous evolution emanated immediately from the submerged ends of the copper electrodes at the base of each burette. After 10 to 15 minutes, enough hydrogen and oxygen gases had evolved so that their 2:1 relative volumes could be clearly observed.

Figure 2. Burettes were filled with NaOH solution by pipette pump.



Cleanup and Disposal

Once complete, the experiment was stopped by disconnecting the alligator lead wires from the battery. The sodium hydroxide solution was lowered to pH 6-8 (measured using pH paper) by slow addition of 2N aqueous HCl. It was then poured down the sink drain. [Note: A one-liter stock solution of 2N HCl was prepared by dissolving 164 mL of concentrated HCl (CAS #7647-01-0) in 836 mL of distilled water].

Large-Scale Electrolysis Apparatus (Instructor)[6b]

Parts List (per apparatus)

- Safety goggles
- Nitrile gloves
- Lab coat
- Two 100 mL glass, graduated cylinders
- Large ring stand
- Two three-prong clamps
- One 1500 mL glass beaker
- Two stainless steel, S-shaped electrodes[8]
- 1200 mL distilled water
- 150 mL of 5N aqueous sodium hydroxide. A two-liter stock solution was prepared in advance by dissolving 400 grams of solid sodium hydroxide pellets (CAS #1310-73-2) in two liters of distilled water. This was stored in a downdraft fume hood during use.
- Parafilm[12]
- Two alligator lead wires[9]
- One quad-power four linear regulated power supply box[13]
- Scissors
- Funnel
- Matches
- One yardstick
- One candle
- Clear adhesive tape

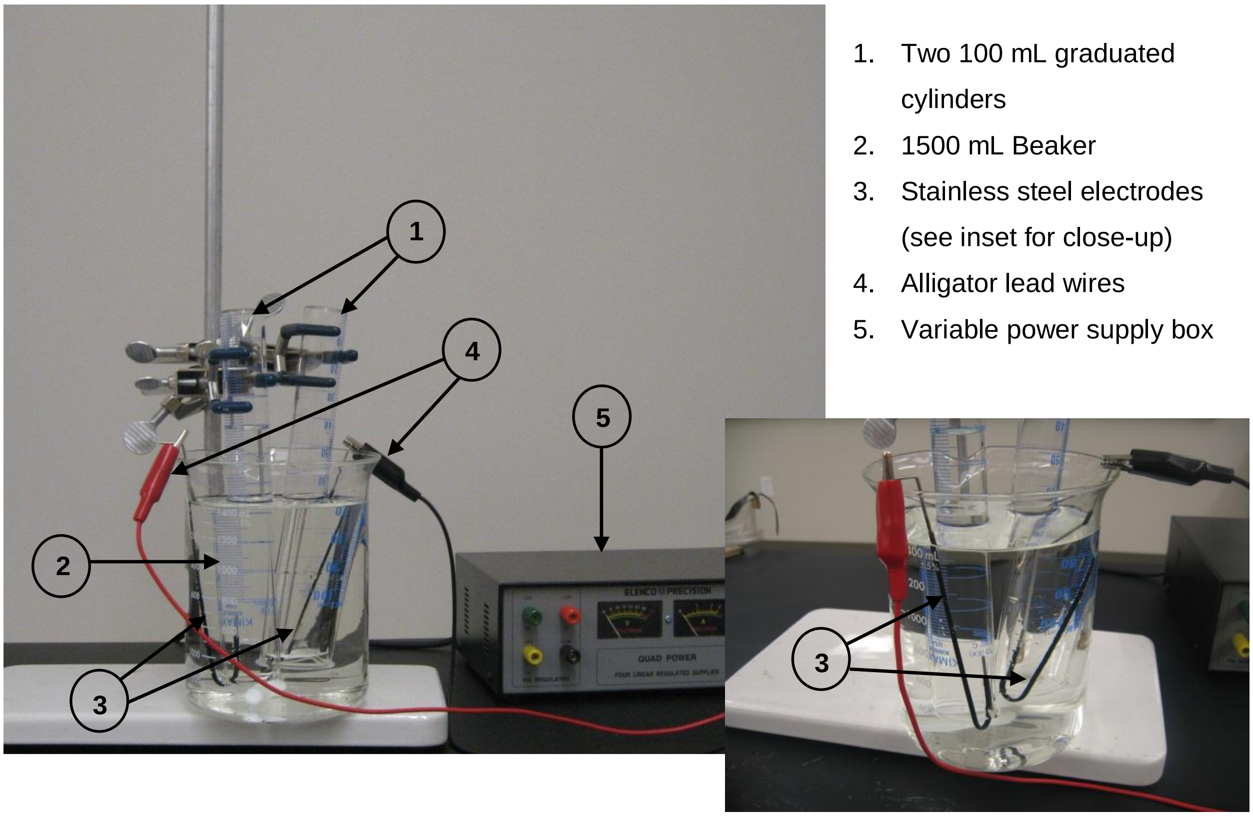
Safety Information

Be sure to wear proper personal protective equipment (safety goggles, nitrile gloves, and a lab coat) while doing this procedure. If you get aqueous sodium hydroxide on your skin, rinse with copious amounts of tap water. When igniting the product hydrogen, the instructor and students should always wear safety goggles, and students should stand at a safe distance.

Setup

As Figure 3 below indicates, to a 1500 mL glass beaker (**2**) were added 1200 mL of distilled water and 150 mL of 5N aqueous NaOH. Separately, two 100 mL graduated cylinders (**1**) were filled (using a funnel) nearly to the 100-mL fill mark with 5N aqueous NaOH solution. The mouth of each graduated cylinder was then sealed using two pieces of 6x6 cm parafilm.[6b] Handling one cylinder at a time, each graduated cylinder's plastic base and bumper were then removed. Being careful to avoid spillage, each graduated cylinder was inverted and quickly submerged, mouth side down, into the 1500 mL beaker filled with the aqueous NaOH solution.[6b] Once both cylinders were submerged, the parafilm was removed using long scissors or forceps.[6b] This was done to ensure that the graduated cylinders were charged with aqueous NaOH solution, roughly to the 100-mL mark.

Figure 3. Large-Scale Electrolysis Apparatus Setup (Instructor).



1. Two 100 mL graduated cylinders
2. 1500 mL Beaker
3. Stainless steel electrodes (see inset for close-up)
4. Alligator lead wires
5. Variable power supply box

With the graduated cylinders' mouths pointing down into the filled beaker, these were now suspended using two three-prong clamps attached to the same ring stand, according to Figure 3. Three minutes then elapsed to allow the ions to disperse into solution. At this point, two large, stainless steel electrodes (**3**) were installed in a manner analogous to the small-scale apparatus, with each electrode positioned at the base of each graduated cylinder, so that one of its ends protruded up into the cylinder and the other pointed out of the beaker (see Figure 3, inset). Now one end of each alligator lead wire (**4**) was attached to the exposed electrodes, and the other end to the power supply box.[13] The power supply box was plugged in and turned on, and gaseous evolution was instantly observed from the submerged electrodes' termini at the base of each graduated cylinder.

After 15 minutes at full amperage, enough hydrogen and oxygen gases had evolved so their ~1:2 relative volumetric ratios could be clearly observed. When asked to explain this observation, students readily concluded that the ratio was consistent with our proposed hypothesis: that hydrogen and oxygen gases are present in a 2:1 atomic ratio in water. When asked how we could further ensure that the gas that we presumed here actually *was* hydrogen, students regularly and enthusiastically responded, “By lighting it on fire.”

At this point, the experiment was stopped by turning off the power box, and the product hydrogen was ignited.[6b] This was accomplished by first using its three-prong clamp to raise the graduated cylinder containing the hydrogen up and out of the beaker. Because hydrogen is less dense than air, the pocket of product hydrogen remained trapped in the graduated cylinder. A candle fastened to the end of yardstick was now lit, and the open flame was placed at the base of the hydrogen-containing graduated cylinder. This detonated the hydrogen, causing an audible “pop” sound to emit,[6b] which provided further evidence that the presumed gas was indeed hydrogen.

Cleanup and Disposal

The sodium hydroxide solution was lowered to pH 6-8 (measured using pH paper) by slow addition of 2N aqueous HCl. It was then poured down the sink drain. [Note: A one-liter stock solution of 2N HCl was prepared by dissolving 164 mL of concentrated HCl (CAS #7647-01-0) in 836 mL of distilled water].

Explosive Balloon Demonstration[6c]

Parts List

- Safety goggles
- Lab coat
- Ear protection
- Four ring stands
- Four regular party balloons
- One hydrogen gas source (i.e., a hydrogen gas tank), with regulator
- One oxygen gas source (i.e., an oxygen gas tank), with regulator
- Permanent marker
- Matches
- Two yardsticks
- One candle
- Clear adhesive tape

Safety Information

Be sure to wear proper personal protective equipment (safety goggles, nitrile gloves, a flame-resistant lab coat, and ear protection) while doing this demonstration. Each balloon to be detonated should not be near anything else that is flammable or explosive (including the other balloons!). Keep a five-foot minimum distance between the explosive balloon and any other flammable object or substance. All students should stand at least 24 feet from the balloons during detonation and should wear safety goggles. They should also plug their ears (or wear noise-protective earmuffs) during each detonation.

Setup

Four separate balloons were individually inflated with one of the following gases: (1) lung air, inflated by the instructor, (2) oxygen gas, (3) hydrogen gas, and (4) a 50/50 oxygen/hydrogen mix. Each balloon was labeled using permanent marker and taped to a ring stand at the front of the classroom during the demonstration. (Note: because hydrogen gas is less dense than air, it will float away if released.) Balloons were detonated with a lit candle fastened to the end of a 2.5-meter-long stick, made by securing two yardsticks together, end-to-end.

Cleanup and Disposal

Following the demonstration, balloon shrapnel were collected and discarded in the trash.

Acknowledgements

We would like to thank Dr. Charley Langley for his assistance in experimental setup and design, as well as Cathy L. Crawford and Chad D. Mangum for helping us to teach the class.

References and Notes

1. In the two counties served by our campus, the percentages of adults with bachelor's degrees are 14.48 and 13.87, respectively, compared with 27.53 percent nationwide (source: 2010 U.S. Census).
2. For news coverage of the event, see: (a) Liesik, G. USU camp teaches kids the science of Angry Birds. *Deseret News,* June 1, 2012. (b) Liesik, G. Kids learn science of Angry Birds at USU camp. *KSL News.* [Online] **2012.** http://www.ksl.com/?nid=960&sid=20662672&title=kids-learn-science-of-angry-birds-at-usu-camp&s_cid=queue-11 (accessed June 26, 2012).
3. Students were pre-registered by their parents on a webpage designed by our campus' IT staff.
4. Christiansen, M.A.; Edwards, B. F.; Sam, D. D. "Schematics of a Water Balloon Launcher Design and Reproducible Water-Balloon-Filling Procedures Used for a Middle School Summer Science Camp." *USU Uintah Basin Faculty Publications* **2013**, Paper 1. http://digitalcommons.usu.edu/ub_facpubs/1 (accessed Jul 17, 2013).
5. Shakhashiri, B. Z. *Chemical Demonstrations*; The University of Wisconsin Press: Madison, WI, 1992; Vol. 4, pp 156-169.
6. See: (a) Christiansen, M. A. "Setting up an Electrolysis Experiment (Small)." https://www.youtube.com/watch?v=cZqJc2CYn2Y&list=PLBwHfJmqJz5i86aUIHzY6q4kURaGNdokv&index=5 (accessed Jul 17, 2013). (b) Christiansen, M. A. "Setting up an Electrolysis Experiment (Large)." https://www.youtube.com/watch?v=VB0GKjU-2AM&list=PLBwHfJmqJz5i86aUIHzY6q4kURaGNdokv&index=7 (accessed Jul 17, 2013). (c) Christiansen, M. A. "Detonating Explosive Balloons." https://www.youtube.com/watch?v=_UL1kIEMjR0&list=PLBwHfJmqJz5i86aUIHzY6q4kURaGNdokv&index=8 (accessed Jul 17, 2013).
7. Safety Goggles were purchased from Carolina Biological Supply Company, catalog number 646704B.
8. Fisher Scientific, Electrolysis Kit, catalog number S52017.
9. Carolina Biological Supply Company, Clip Cords 24 in. 6PK, catalog number 756521.
10. Fisher Scientific, Bel-Art Scienceware Fast-Release Pipette Pump 25mL, Filler/Dispenser, catalog number S32283F.
11. Fisher Science Education molecular model kits, catalog number S44052.
12. Fisher Scientific, Parafilm M, catalog number S37440.
13. Fisher Scientific, Four-In-One Power Supply, catalog number S441586.