# Electrolysis of Water Using Different Electrolytes to Produce Hydrogen Gas

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## Abstract

This experiment tests different electrolytes: lime water, baking soda water, salt water, or tap water to see which is the most effective at producing hydrogen gas in one minute. The experiment was performed by creating a circuit with graphite electrodes, a battery and different electrolytes: lime water, salt water, baking soda water and tap water. After 15 minutes, the battery was disconnected and the volume of the bubble was measured. The results show that salt is the most efficient electrolyte, producing approximately $4\pi$ $cm^3$ of hydrogen gas. The implications of this are that salt water is the preferred electrolyte within the scope of this experiment for the production of hydrogen because it is quick, readily available and efficient.

## Introduction

The electrolysis of water, from the prefix “electro-” meaning electricity, and suffix “-lysis”, meaning separation, is the process of separating water into its constituent elements, hydrogen and oxygen gas. The reaction that happens in the water is

$$2H_2O + \text{electrical energy } (+ \text{ heat energy}) \rightarrow O_2 + 2H_2 \text{ [1].}$$

The hydrogen gas produced through this process can be collected by placing two electrodes (conductors through which electricity is transmitted to a solution containing an electrolyte) at the anode (negative terminal) and cathode (positive terminal) in submerged upside-down bottles or test tubes and allowing the gas produced to displace the electrolyte (substances that create ions in solution and transmit electricity to complete a circuit) in the bottles.

However, using salt as an electrolyte changes the equation of the electrolysis, because the salt ions react with the ions produced by electrolysis. “Electrolysis of an aqueous solution of table salt (NaCl, or sodium chloride) produces aqueous sodium hydroxide and chlorine, although usually only in minute amounts” [2]. The equations for the reactions are as follows:

$2Cl^- \rightarrow Cl_2 + 2e^-$
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
$2Cl^- + 2H_2O \rightarrow Cl_2 + H_2 + 2OH^-$ [2].

Michael Faraday created two laws of electrolysis: “The amount (in ‘Faraday’ units) of electric charge required to discharge one mole of substance at an electrode is equal to the number of ‘excess’ elementary charges on that ion” [3]. and “The mass of a substance produced at an electrode during electrolysis is proportional to the number of moles of electrons (the quantity of electricity) transferred at that electrode” [3]. These laws accurately describe the process of electrolysis and allow us to calculate the specific amounts of substances used and created in these reactions.

This experiment could also be performed with other electrolytes, such as vinegar, bleach or drain cleaner. However, depending on the electrolyte used, the experiment could become more dangerous, because the compounds created may react and contaminate the water or corrode the electrodes. The scope of my experiment is only 15 minutes and one tablespoon of electrolyte, and either of these quantities could be made larger or smaller to change the experiment.

Lime juice is predicted to be the best electrolyte based on pH level. Baking soda has a pH of 9 [4], but since I will be mixing it with water, the pH will probably be slightly lowered to 8. “Since adding salt to water does not result in any chemical reactions, the salt will not alter the pH level of water” [5]. Therefore, salt water will have a pH of 7. Lime juice has a pH of about 2.0 to 2.4 [6], and mixed with water, it will be slightly raised to 3. Because lime juice has the most extreme pH, it is most likely that it will conduct electricity the best, because pH is a measure of the concentration of hydrogen ions, and the more ions there are, the easier it should be to conduct electricity. “pH is really a measure of the relative amount of free hydrogen and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic” [7]. “[W]e point out that when an ionic compound dissolves in water, the positive and negative ions originally present in the crystal lattice persist in solution. Their ability to move nearly independently through the solution permits them to carry positive or negative electrical charges from one place to another. Hence the solution conducts an electrical current” [8]. It would make sense that the more $H^+$ carriers there are in solution, the easier it will be to conduct electricity.

**Materials**

- Nine-volt Battery
- One Tbsp/15 mL Lime Water
- One Tbsp/15 mL Baking Soda
- One Tbsp/15 mL Salt
- One Liter Tap Water
- Eight Sticks of Pencil Lead
- 1.5 Liter Basin
- 500 mL Glass Measuring Cup
- 1.5 Liter Glass Pitcher
- Two Crocodile Clips
- Nine-volt Battery Connector
- Waterproof Tape
- Two 95 mL Plastic Test Tubes/Bottles
- Two Rubber Bands (at minimum)
- Stopwatch
- Ruler

**Objective**

This experiment will test different electrolytes: lime water, baking soda water, salt water, to see which is the most effective at producing hydrogen gas in one minute.

**Procedure**

1. Secure the necessary electrical connections.
    a. Connect the battery connector’s wires to the crocodile clips.
    b. Tape the crocodile clips and battery connector wires in the locations where the bottles will be placed.
    c. Cut all pencil lead to two centimeters. Place one graphite stick in each crocodile clip.
2. Place two rubber bands in an X shape across the top of the basin. For more security, add rubber bands lengthwise as well.
3. Prepare the electrolyte in the basin and bottles.
    a. If not using water, mix one tablespoon of substance to be tested with one liter of water for approximately 30 seconds.
    b. Using the measuring cup, fill the basin with about 500 mL of the electrolyte.
    c. Fill each bottle with the remaining 500 mL until the electrolyte is about to overflow. Place a finger across each bottle opening, making sure that there are no bubbles. Flip the bottle upside down, and once the bottle opening is fully submerged, let go.

d. Carefully maneuver the bottles so that they are directly above each crocodile clip, making sure not to break the graphite electrode in the process. Secure the bottles with the rubber bands. The setup should now look like Figure 1. This will be the same initial setup for every electrolyte.

Figure 1: Electrolysis experiment setup with baking soda


4. Start the stopwatch and attach the battery to the battery connector at the same time. There should soon be visible bubbles rising up. If nothing happens, wait for a few moments to allow the reaction to properly start before ending the experiment. After 15 minutes, disconnect the battery and measure the volume of the bubble.
5. Empty and wash the measuring cup, bottles and basin. Start again from step 3, testing all electrolytes.

**Results**

Table 1: Amount of hydrogen gas produced by each electrode

| **Type of Electrolyte** | **Approximate Volume of Hydrogen Gas (cm$^3$)** $\pi \approx 3.1415$ |
|---|---|
| Water | N/A |
| Salt Water | $4\pi$ |
| Baking Soda Water | $0.35\pi$ |
| Filtered Lime Water | N/A ($0.68\pi$ after 20 minutes) |

According to Table 1, the water produced no bubbles at either the anode or cathode, and so the experiment was quickly stopped. The salt water was initially slow in creating bubbles, but created the largest bubble in the end. As can be seen in Figure 2, as soon as the solution from the bottle containing the anode spread into the rest of the solution, the entire solution became yellow. The baking soda water was even slower to create bubbles. It was found that the bubbles sometimes escaped the bottle, so not all of the hydrogen gas was collected. The lime water test did not produce any bubble, but after being accidentally left running for five minutes longer than the scope of the experiment, it consequently produced a measurable bubble. Generally, the anode did not produce any gas except in the baking soda trial.

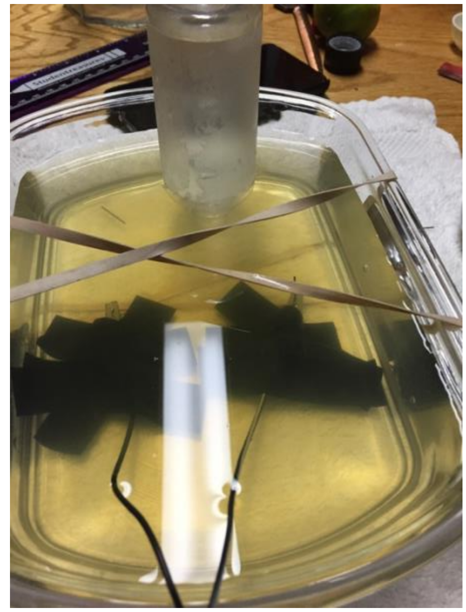

Figure 2: The effects of the anode bottle solution spreading

**Analysis**

The yellow water produced during the salt water trial was most likely due to the dissociation of NaCl into its constituent ions, $Na^+$ and $Cl^-$, and then creating chlorine dissolved in the water. As soon as the contents of the anode bottle was exposed to the rest of the experiment, the chlorine likely reacted with the metals present in the wires, forming yellow water. When the experiment was disassembled, it was found that one of the wires had disconnected from the electrode, which may be the reason why no gas was produced at the anode (positive electrode) in the lime water trial, as the electrode created too little gas to be visible. However, the bubbles measured were of hydrogen gas, which is only produced at the cathode, which means this did not affect the experiment. Furthermore, the bottles used were jerry-rigged for this experiment, so the volume measurement is not as accurate as it could have been.

Although the lime water did not produce a bubble, the significant volume of the bubble produced later leads me to believe that the lime water merely a slower electrolyte. This experiment used the same amounts of all electrolytes, mixed with the same amount of water. However, because each electrolyte had different efficacy, this resulted in some trials not producing any bubbles at all within the allotted time.

The salt water is the most efficient electrolyte, producing $4\pi$ $cm^3$ of hydrogen gas in the allotted amount of time, more than any other electrolyte. If the results of this experiment are able to be scaled up, hydrogen generators will use salt water as their electrolyte, because it is a readily available resource that can produce a large quantity of hydrogen gas.

## Reference List


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