



Water Splitting Experiment

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Abstract—This experiment investigates the process of water electrolysis to produce hydrogen and oxygen gases. We explore this effect using deionized water, tap water, and solutions of NaCl and MgCl₂ as electrolytes, and measure the hydrogen evolution at the cathode. The results indicate that hydrogen production increases notably in the presence of electrolytes compared to pure deionized water, demonstrating the role of ionic conductivity in enhancing electrolysis efficiency.

I. INTRODUCTION

Electrolysis is a process in which an electric current drives a chemical reaction, with applications across various fields, including electroplating, metal extraction and purification, chemical production, waste treatment, electrosynthesis, and battery reconditioning. Among these, water electrolysis, or water splitting, is particularly valuable as it produces hydrogen and oxygen gases. During this process, water molecules are split, releasing oxygen at the anode (positive electrode) and hydrogen at the cathode (negative electrode). Hydrogen produced through electrolysis is an important clean energy source, particularly for fuel-cell-powered vehicles.

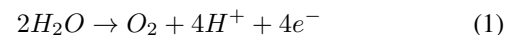
In this water-splitting experiment, we focused on generating hydrogen gas through the electrolysis of water. However, due to the low conductivity of pure water, the process is typically inefficient. To enhance the reaction rate and increase hydrogen yield, we added electrolytes such as NaCl and MgCl₂, which release ions that improve conductivity and accelerate the electrolysis process. Variations in the electrolyte type and electrode material can significantly impact electrolysis efficiency. As hydrogen fuel continues to grow in importance as a sustainable energy source, optimizing electrolysis conditions is essential for more effective production.

II. THEORY

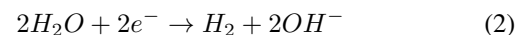
A. Water Electrolysis

Electrolysis involves the application of an electric current to induce a chemical reaction, typically by adding or removing electrons from a substance, a process known as oxidation or reduction.

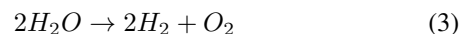
Oxidation, or the loss of electrons, occurs at the positively charged anode, where oxygen gas is released:



Reduction, which is the gain of electrons, takes place at the negatively charged cathode, where it attracts cations (positively charged ions) and releases hydrogen gas:



The overall reaction for water electrolysis is:



The efficiency of this reaction is influenced by several factors:

- **Ion Concentration:** Higher ion concentrations improve solution conductivity, allowing more current to pass through and increasing the electrolysis rate.
- **Ion Mobility:** Smaller ions or ions with a high charge density (e.g., Mg²⁺) can move more freely, promoting a faster reaction.
- **Electrolyte Strength:** Strong electrolytes such as NaCl and MgCl₂ fully dissociate into ions, enabling faster electrolysis compared to weaker solutions like tap water.
- **Electrode-Specific Reactions:** The type of ions available at each electrode affects the rate of gas production.

B. Electrolyte

An electrolyte is a solution containing free ions, which are atoms or molecules with an electric charge, making it capable of conducting electricity. When salts, acids, or bases dissolve in water, they break down into positive and negative ions, forming an electrolyte solution.

The electrolysis efficiency in various electrolytes is as follows:

- **Distilled Water:** Due to its minimal ion content, distilled water conducts electricity poorly, leading to a very slow electrolysis process.
- **Tap Water:** Tap water contains dissolved minerals, resulting in moderate conductivity and a somewhat faster reaction than distilled water.
- **NaCl Solution:** Sodium chloride dissociates fully into Na^+ and Cl^- ions, greatly enhancing conductivity and accelerating electrolysis compared to both distilled and tap water.
- **MgCl₂ Solution:** The Mg^{2+} ions with their higher charge and two accompanying Cl^- ions contribute to high conductivity, making MgCl_2 the most efficient electrolyte among the four tested solutions.

III. EXPERIMENTAL PROCEDURE

A. Apparatus and Materials Used

- **Test Tubes:** Used to hold small samples of solutions for testing and observation.
- **Copper Wire:** Acts as a conductor, connecting the battery to the electrodes.
- **Graphite Rods:** Serve as electrodes where oxidation and reduction reactions occur.
- **Graduated Burette:** Measures the volume of gases (hydrogen and oxygen) produced during electrolysis.
- **Battery (9V PP3):** Provides the electric current necessary to drive the electrolysis reaction.
- **Distilled Water:** Used as a solvent and control solution, with minimal ions to study the impact of electrolyte addition.
- **Tap Water:** Contains natural minerals and ions, serving as a comparison to distilled water in the electrolysis process.
- **NaCl:** Added to create an electrolyte solution, improving water's conductivity and increasing electrolysis efficiency.
- **MgCl₂:** Used as another electrolyte to enhance conductivity, with higher ion mobility due to Mg^{2+} ions.
- **Beaker:** Holds the electrolyte solutions and supports the setup of the inverted burette.

B. Methodology

- 1) Fill the beaker with 150 ml of electrolyte.
- 2) Secure the inverted graduated burette onto the sponge.
- 3) Insert the electrodes into the inverted burette and immerse it in the beaker.

- 4) Use the rubber suction to fill the inverted burette with electrolyte and seal the knob.
- 5) Connect the electrodes to a 9V battery to provide the power supply.
- 6) Start the timer when the hydrogen gas forms till the 0 mark of the graduated burette.
- 7) Record the volume of hydrogen gas produced every 3 minutes and analyze the resulting data trends.
- 8) Repeat this process for each of the following electrolytes: tap water, distilled water, NaCl solution and MgCl_2 solution.
- 9) Dissolve 15 - 20 ml of 1 M solution of NaCl and MgCl_2 in 150 ml of distilled water to make electrolyte solution of NaCl and MgCl_2 respectively.

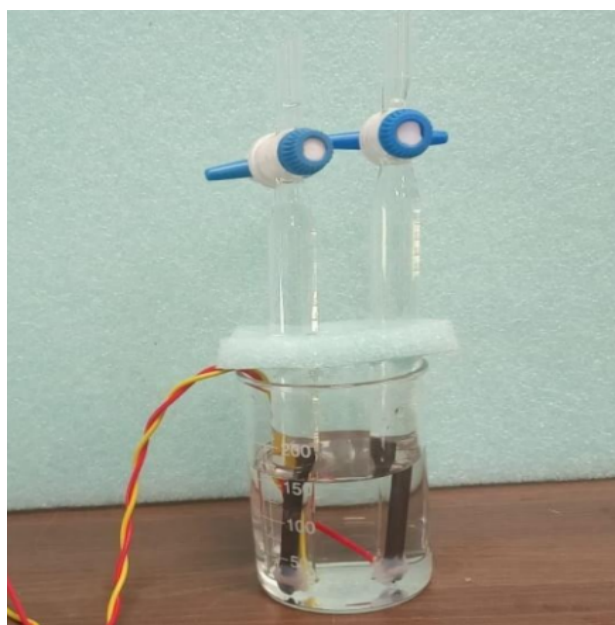


Fig. 1. Experimental Setup

IV. RESULTS

The volume of NaCl over time is shown in the table below:

TABLE I
VOLUME OF NaCl OVER TIME

Time (minutes)	Volume (Hydrogen gas)
0	0.0
3	0.8
6	1.6
9	2.3
12	3
15	3.6
18	4.3
21	5
24	5.7
27	6.4
30	7.1

The volume of MgCl_2 over time is shown in the table below:

TABLE II
VOLUME OF MgCl_2 OVER TIME

Time (minutes)	Volume (Hydrogen gas)
0	0.0
3	1.2
6	2.4
9	3.9
12	5.1
15	6.2
18	7.4
21	8.4
24	10.2
27	11.4
30	13.4

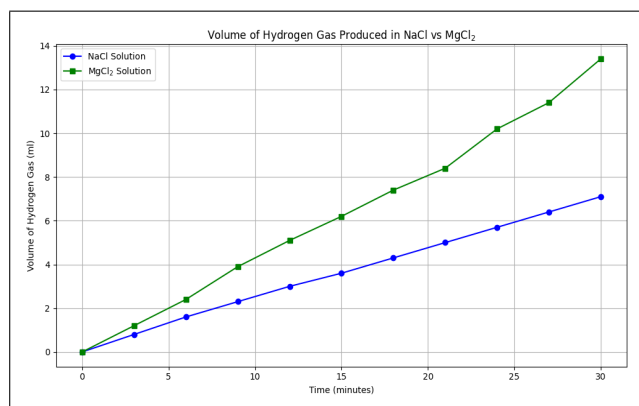
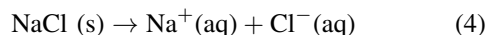


Fig. 2. Volume of hydrogen gas produced in NaCl vs MgCl_2

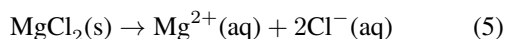
A. Observation

- 1) **Distilled Water:** No visible hydrogen gas bubbles were observed at the cathode. This is due to distilled water's lack of ions (such as minerals and salts), making it a poor conductor and resulting in negligible electrolysis activity.
- 2) **Tap Water:** Some hydrogen gas bubbles were observed, though production was minimal and challenging to measure. Tap water contains minerals and ions, providing slight conductivity to support a limited electrolysis reaction.
- 3) **NaCl Electrolyte Solution:** Significant effervescence was noted, with a measurable amount of hydrogen gas released.



The oxygen production was less than half the volume of hydrogen. After 30 minutes, a total of 7.1 ml of hydrogen gas was collected.

- 4) **MgCl_2 Electrolyte Solution:** Greater effervescence was observed compared to the NaCl solution, with measurable hydrogen gas produced.



Here also, oxygen production was less than half the volume of hydrogen. After 30 minutes, 13.4 ml of hydrogen gas was produced.

In both NaCl and MgCl_2 solutions, hydrogen gas bubbles were visible immediately after connecting the battery to the electrodes.

B. Explanation

- The 2:1 hydrogen-to-oxygen ratio in electrolysis is theoretically derived from the balanced chemical equation for water splitting (Equation (3)), where two molecules of hydrogen gas (H_2) are produced for each molecule of oxygen gas (O_2). However, practical results often deviate from this ideal ratio for several reasons:

- **Oxygen Solubility in Water:** Oxygen is more soluble in water than hydrogen. Some of the oxygen generated during electrolysis may dissolve in the water instead of being released as gas, which results in a lower observed volume of oxygen gas and thus affects the expected 2:1 ratio.
- **Peroxide Formation:** Under certain conditions, especially if side reactions occur with the electrolyte or electrode materials, some oxygen may form hydrogen peroxide (H_2O_2) instead of O_2 gas. This also decreases the volume of observed oxygen gas, further disturbing the 2:1 hydrogen-to-oxygen ratio.

Additionally, other factors, such as electrode overpotentials or side reactions, can contribute to deviations from the ideal gas ratio in practical electrolysis.

- Theoretically, hydrogen production in the MgCl_2 electrolyte should be higher than in the NaCl electrolyte, as each MgCl_2 molecule dissociates into three ions, compared to two ions from each NaCl molecule.

In our experiment, we observed a higher production of hydrogen for MgCl_2 , as predicted. However, in some cases, this may not occur due to:

- **Solution Concentration:** A higher concentration of NaCl solution compared to the MgCl_2 solution may provide more ions in the NaCl electrolyte, making it more conductive than the MgCl_2 solution.
- **Battery Depletion:** Since the MgCl_2 electrolysis was performed after the NaCl electrolysis, the battery may have partially drained, leading to a lower-than-ideal potential difference between electrodes.
- **Incomplete Dissociation or Impurities:** If the MgCl_2 solution was not fully dissociated or contained impurities, its conductivity might be lower than expected, which would reduce the rate of hydrogen production.
- **Electrode Surface Interactions:** Mg^{2+} ions may interact with the electrodes, altering their surface

chemistry. This could result in the formation of an insulating layer, such as magnesium hydroxide, on the electrode surface, reducing reaction efficiency and slowing hydrogen production. In contrast, Na^+ ions are less reactive and less likely to interfere with electrode surfaces, allowing for more consistent hydrogen generation.

V. CONCLUSION

Observing hydrogen gas formation across different electrolyte solutions during the electrolysis of water, we can conclude that as ion concentration in the solution increases, the rate of H_2 bubble formation also rises. This increase is due to the enhanced conductivity of the electrolyte with higher ion concentration.

The final order for the rate of electrolysis observed is as follows:

Deionised water < Tap water < NaCl solution < MgCl_2 solution

Additionally, the volumes of hydrogen and oxygen gases do not strictly follow the expected 2:1 stoichiometric ratio. This deviation can be attributed to oxygen's involvement in side reactions, such as peroxide (H_2O_2) formation, and its higher solubility in water compared to hydrogen gas.

This experiment highlights the crucial roles of electrodes and electrolytes in influencing the efficiency of electrolysis. It also illustrates that electrolysis is a cost-effective and environmentally friendly method for producing pure hydrogen, a clean energy source that holds promise for use in fuel cell vehicles and other applications.

VI. PRECAUTIONS & CHALLENGES

- Always wear gloves, safety goggles, and all necessary protective equipment.
- Hydrogen tended to accumulate at the bottom of the test tubes holding the electrodes due to the electrode's thick diameter and the presence of glue and wires attached to it. Gentle tapping helped release most of the trapped hydrogen.
- Ensure that all equipment is thoroughly cleaned before performing electrolysis with different solutions.

VII. ACKNOWLEDGMENT

We would like to express our sincere gratitude to lab staff at IIT Gandhinagar for their invaluable guidance and support throughout this experiment. Special thanks to the laboratory staff for providing the necessary equipment and ensuring a smooth experimental process. We also extend our appreciation to our group members for their teamwork and contributions. Lastly, we acknowledge IIT Gandhinagar for providing the resources and facilities to conduct this experiment.

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Group-5

Page No.

Date

NaCl:

<u>Time</u>	<u>Reading</u>
$t_0 (0)$	0
$t_0 + 3 \text{ min}$	0.8
$t_0 + 6 \text{ min}$	1.6
$t_0 + 9 \text{ min}$	2.3
$t_0 + 12 \text{ min}$	3
$t_0 + 15 \text{ min}$	3.6
$t_0 + 18 \text{ min}$	4.3
$t_0 + 21 \text{ min}$	5
$t_0 + 24 \text{ min}$	5.7
$t_0 + 27 \text{ min}$	6.4
$t_0 + 30 \text{ min}$	7.1

MgCl₂

<u>Time</u>	<u>Reading</u>
$t_0 (0)$	0
$t_0 + 3 \text{ min}$	1.2
$t_0 + 6 \text{ min}$	2.4
$t_0 + 9 \text{ min}$	3.9
$t_0 + 12 \text{ min}$	5.1
$t_0 + 15 \text{ min}$	6.2
$t_0 + 18 \text{ min}$	7.4
$t_0 + 21 \text{ min}$	8.4
$t_0 + 24 \text{ min}$	10.2
$t_0 + 27 \text{ min}$	11.4
$t_0 + 30 \text{ min}$	13.4

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