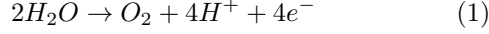


Water Electrolysis

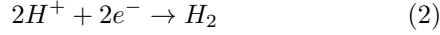
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I. INTRODUCTION

Water electrolysis is the process of separating the molecules of water H_2O into its constituents H_2 and O_2 gas. This is done in two separate chemical reactions the oxidation of water.



and the reduction of Hydrogen ions.



The reaction described above does not happen all by itself. An electrical field needs to be applied over the substance and catalysts are used to make the process happen at all. The thermodynamical minimum voltage that needs to be applied is 1.23V.

In order to make electric charges travel through the water more effectively electrolyte is mixed in with it. Now what previously was a quite straight forward reaction has become quite the intricate process that can be tested extensively with different components acting all by themselves in a way that effects the production of the various gases.

The usage of this method as a tool for hydrogen production has a lot of upsides. The usage of water as a source of fuel and the only byproduct being oxygen makes the process comparably environmentally friendly to its alternatives [1]. As of today water electrolysis is responsible for about 4% of the global Hydrogen production. The reason for the quite low marketshare in spite of all the aforementioned upsides is that the process is simply too inefficient and its materials expensive [2].

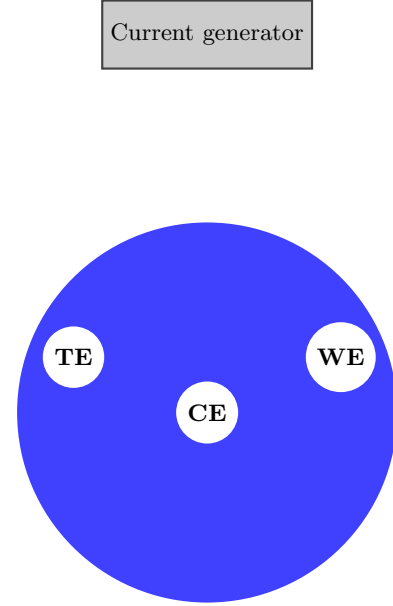
To find a different set of circumstances to make the process more efficient is currently an active field of research.

The aim of the experiment is to find what catalysts correlate to the most effective form of hydrogen and oxygen production.

II. METHOD

A. Catalyst testing

Three electrodes were lowered down into water with the electrolyte mixed into it. One Working Electrode (**WE**) from which all the measurements are made. One counter electrode (**CE**) that was placed in the water in order to establish a homogenous electric field. And lastly



a final measuring electrode were inserted into the mixture in order to make proper measurements of the working electrode.

On the end of the **WE** and the **CE** two metals are attached acting as catalysts for the chemical reaction.

Current was sent through the working electrode via a current generator. Increased from zero to a set value and working down to that same set value but with changed polarity.

See 1 for an example of what the procedure described above might produce.

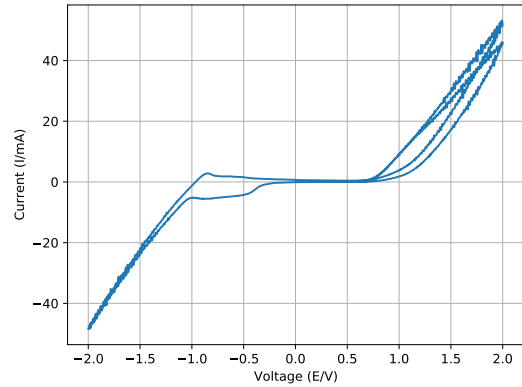


FIG. 1: Plot from the first Platinum Platinum measurement

This procedure is repeated testing different metals acting as catalysts.

B. Gas collection

Empty tubes are lowered down into the water resting above the catalysts and subsequently have their air sucked out of them. Allowing the bubbles that inevitably form on the catalysts to float up into the empty tubes.

Far from all of the gas make it into the tubes but the amount that does are about equal for either reaction so the gas that is in fact trapped inside of the tube is representative of the actual gas produced.

When placing down the tubes and sucking all the air out of them there is a need to get into physical contact with the electrolyte. Since "ELECTROLYTE 1" is highly corrosive we change it out for standard *HCL* (salt) which is a lot safer.

Instead of cycling between positive and negative polarity at each of the electrodes. A simple direct current is sent through the circuit using some of the catalysts that we found interesting from the results from the previous experiment.

C. Analytical methods

The current generator changes goes through a set number of cycles for each measurement. This is done in order to make minimize any random errors that might occur. Unfortunately each cycle wasn't exactly the same length as the previous one, for reasons probably only known to the makers of the current generator, so in order to take sensible averages some points from the longer data cycles were cropped in order to average the cycles.

The removed sections of data comes from the middle of the data sets, points that, for reasons that will be revealed below won't be used for further analysis anyway.

In order to standardize the measurements we need to control for the differing sizes of the catalysts that were in the water. Therefore we divide each datapoint by the area of the corresponding catalyst in order to attain the current density.

We expect the relationship of the current density vs the overpotential to be of exponential characteristic so we plot the $\log()$ of a part of the data that represents the overpotential. More details of how this is done will be included in the discussion part of the article.

III. RESULTS

All the data for all the experiments can be found here along with the code for some of the data analysis. Due to the magnitude of data collected I won't be able to give

each and every data set collected a fair showing. I will be presenting a selected sets of data.

	Copper	Platinum	Nickel	Gold
Width (cm)	0.65	0.80	0.65	0.65
Length (cm)	0.60	1.50	1.30	1.60
Area (cm ²)	0.66	1.20	1.04	0.85

TABLE I: Table of measured lengths of catalysts submerged into water.

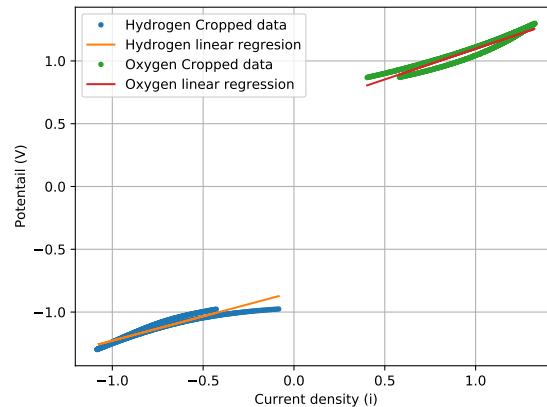


FIG. 2: Logarithm of the current exchange density. With linear regression for both the oxidation and the reduction.

In table I we can see the measurements of what part of the metal catalysts that ended up in the water. This was done by extracting the catalysts after the experiment was performed and measuring the wet parts of the catalysts with a ruler. Since the catalysts were hanging from cables into the water, they couldn't be held perfectly perpendicular to the water surface, which often resulted in a slanted mark of water on the electrode. In those cases we simply averaged the length of the wet sides and calculated the area as if it was a perfect rectangle.

In table II and III we see the exchange current densities. These values were as previously mentioned extracted by performing a linear regression on different parts of the logarithm of measured data. This is a good method a good chunk of the time, but some samples are bad enough catalysts for one of the chemical reactions as not to barely have a reaction happen at all an example of this can be seen in figure 3. Where gold is doing an almost impressively bad job at acting as a catalyst for the hydrogen reduction. This in turn leads to some very inaccurate exchange current densities. So if a very perceptive reader finds some of the values odd, compare to other literature values. That would be why.

The gas that was collected can be found in table IV. Originally we were supposed to measure the oxygen production as well as the hydrogen production, but after the

Material	i_{ecd} (A/cm^2)
Platinum	2.651
Copper	3.875
Gold	1.16
Nickel	7.281

TABLE II: Table of current exchange current density for the hydrogen reaction

Material	i_{ecd} (A/cm^2)
Platinum	-1.24
Copper	-1.19
Gold	0.62
Nickel	-0.03

TABLE III: Oxygen Exchange current densities

change of electrolyte the ammount of O_2 gas produced was to small in any of the reactions to produce.

IV. DISCUSSION

The question, what catalyst is best fitted to make either reaction as efficient as possible among those we tested is a rather intuitive experiment by itself. The graphs from the initial data is already a pretty good indicator weather the catalyst was an efective one or not. See the stark contrast between figure 1 and 3.

HER	V H_2 (mL)
Pt	2
Au	16
Co V 2	

TABLE IV: Collected Hydrogen gas

[1] K. G. dos Santos, C. T. Eckert, E. De Rossi, R. A. Baricatti, E. P. Frigo, C. A. Lindino, and H. J. Alves, Hydrogen production in the electrolysis of water in brazil, a review, Renewable and Sustainable Energy Reviews **68**,

563 (2017).
[2] S. Shiva Kumar and V. Himabindu, Hydrogen production by pem water electrolysis – a review, Materials Science for Energy Technologies **2**, 442 (2019).

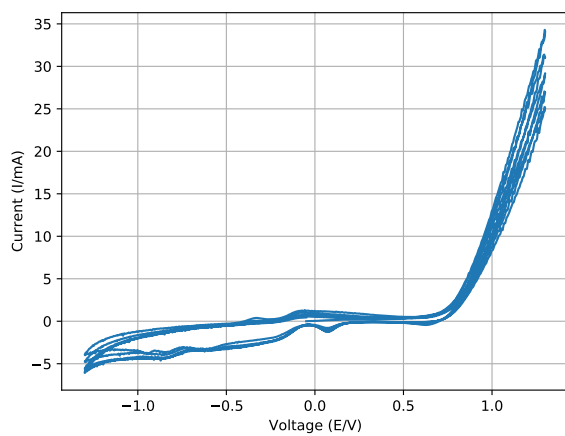


FIG. 3: Water electrolysis with gold as the **WE**, doing a particularly poor job (Pt is **CE**)