FUEL Cell Lab

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The efficiency of converting various forms of energy to and from electrical energy were experimentally measured. The efficiency of a Silicon-based Solar Cell was found to be 15 ± 2 %, in agreement with typical performance which is also around 17.5%. The efficiency of an Electrolyzer was found to be 87 ± 6 %, which is higher than typical performance of 80%. The efficiency of a Hydrogen Fuel Cell was found to be 49 ± 5 %, which is lower than typical performance of 60%.

INTRODUCTION

Energy in various forms is of incredible relevance in the world today. Especially, electrical energy is the medium through which most forms of energy are transmitted before being used. In this lab we explore the translation of energy from electromagnetic radiation, or light, to electrical energy, to chemical energy, and back to electrical energy.

A photovoltaic cell is a diode that forces any charge carriers freed by a photon hitting an electron through an electric circuit. Because of intrinsic properties of this problem efficiency is quite low, between fifteen and low-twenties percent. An electrolyzer uses electricity to remove the bonds between hydrogen and oxygen in water, producing oxygen an hydrogen gas. Hydrogen gas is of particular relevance as the output, as oxygen is abundant in the atmosphere to react with the hydrogen. A hydrogen fuel cell does exactly this, essentially serving as a battery after separating the electrons and protons within hydrogen.

APPARATUS

The apparatus consisted of the following.

- Hydrogen fuel cell apparatus, H-Tec, Model T-126
- Optical Power Meter, Thorlabs, Model PM100-121C
- 2 DVMs; decade resistor (1-100MΩ)
- Strong light source (flood light); 2.0V/ 2A power supply

EFFICIENCY OF A PHOTOVOLTAIC CELL

Procedure

A photovoltaic cell was used to power a simple circuit as given by 1, while converting energy from a strong light source. In order to measure the efficiency of the PV cell, the incident power in the form of light and the output power were both measured. A ThorLabs power meter was used to measure the intensity of the light at each individual PV cell, (intensity is given by power divided by area) and the average intensity across the PV cell was multiplied by its measured area to find the power input to the system in the form of light.

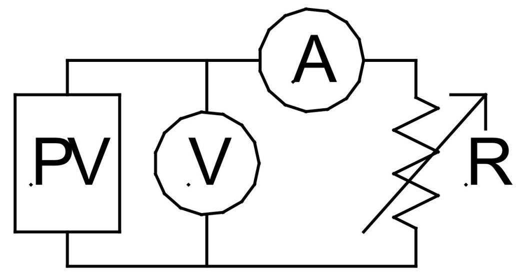

FIG. 1. Electrical circuit for measuring photovoltaic (PV) output voltage and current through a variable resistor (R). This curve reasonably matches theory.

In such a system, in order to measure the output power it is necessary to match the resistance of the circuit to some unknown internal resistance of the PV cell. As such, a variable resistor was used to test various resistances in a logarithmic scale, and the peak output power was considered the optimal power of the system.

Results

The intensity of light measured across the eight PV cells was found to be a distribution of mean 28 W/m^2 and standard deviation 4 W/m^2. Multiplied by the area of the PV cells, the total light power hitting the PV cell was calculated at 0.22 Watts.

The power response of the circuit was found to be a normal distribution when viewed on a logarithmic scale, with a maximum at 70 Ω and 32.5 mW.

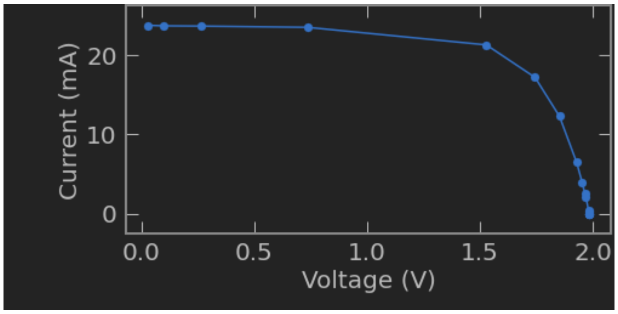

FIG. 2. Current as a function of Voltage as resistance was varied.

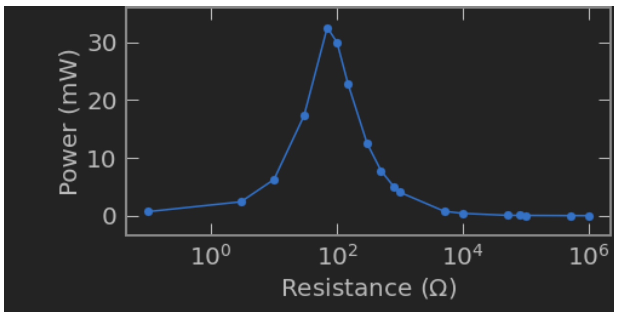

FIG. 3. Power response of the circuit at various resistances.

$$\eta_{PV} = P_E/P_L \tag{1}$$

Where η is the efficiency of the fuel cell and P is Power.

Finally, the efficiency of the cell was computed by 1 to be 15 $\pm$ 2%.

Conclusions

While there is a wide variety in efficiencies of PV Cells [**??**], this falls somewhere inside it on the lower end. However, the significant uncertainty in this calculation is worth discussing. Primarily, this uncertainty stems from the wide distribution of light intensity hitting the cell at different points. In future verions of this experiment, more sophisticated models for the intensity mapping onto the PV Cell can significantly increase the measuring precision. This uncertainty was found to be much larger than the 3% uncertainty in the power meter itself.

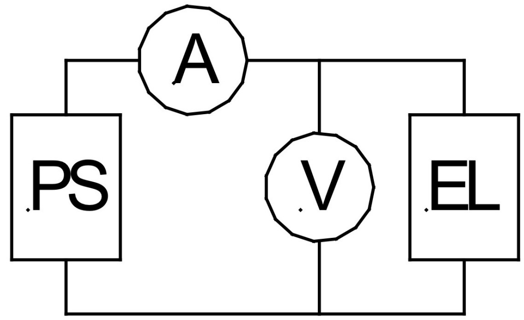

FIG. 4. Electrical circuit for measuring Electrolyzer input voltage and current.

ELECTROLYZER

Procedure

An electrolyzer was supplied distilled water and electricity to produce a given quantity of Hydrogen gas, where the current and voltage were measured via the circuit given in 4. The amount of time to produce a target amount of Hydrogen was measured, with the total energy drawn by the circuit and the total chemical energy produced by the electrolyzer compared to compute the electrolyzer efficiency.

Results

$$PV = \frac{nRT}{m} \tag{2}$$

Where P is pressure, V is volume, n is the number of molecules, R is a constant, T is temperature, and m is mass.

$$E_{H_2} = m_{H_2} \times HHV \tag{3}$$

Where E is energy, m is mass, and HHV is Higher Heat Value.

The total time to produce 5 cm^3 of Hydrogen gas was found to be 112 seconds, at constant voltage and current of 1.892 V and 0.3215 A. Multiplying these quantities E = PIT, the energy consumed was found to be 68.4 joules. The mass of the Hydrogen was calculated using 2, assuming ideal conditions, and the chemical energy was estimated by multiplying by the accepted value for the Higher Heat Value of hydrogen, 141.9 MJ/kg 3. With a mass of $4.19 \cdot 10^{-7} kg$, the stored chemical energy was found to be 59 joules via 3. Finally, the efficiency of the electrolyzer was found by 4 to be 87 $\pm$ 6%.

$$\eta_{EL} = E_{Hydrogen}/E_E \tag{4}$$

Conclusions

This efficiency is higher than usual industrial values for electrolyzer efficiency given by [3]. Assuming this particular electrolyzer is not more efficient than most, this error most likely stems from several measurements related to the volume of gas. Specifically:

- The graduations on the reservior are 1 cm^3, which is 1/5 the total volume we were measuring.
- The volume is used to trigger the timer, where discerning the exact point the marking is reached is difficult.

HYDROGEN FUEL CELL

Procedure

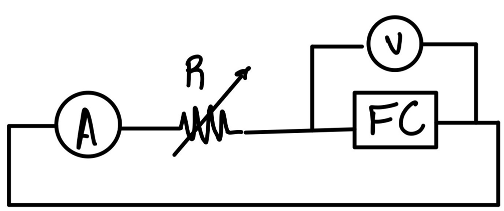

FIG. 5. Electrical circuit for measuring Fuel Cell output voltage and current.

A hydrogen fuel cell was supplied with hydrogen gas, in order to power a circuit given by 5. In the first stage of this phase of the experiment, an optimal resistance was found by varying R using a decade resistor, so as to match the internal resistance of the Fuel Cell.

The second stage of this phase of the experiment was to then use this optimal resistance, and a few values on either side of it, to find how much electrical energy was produced by consuming a given quantity of hydrogen gas. The quantity of gas and the electrical power output over time were then compared to compute the efficiency of the Fuel Cell.

Results

The optimal resistance in terms of the power response of the circuit was found to be 15 Ω given the curve

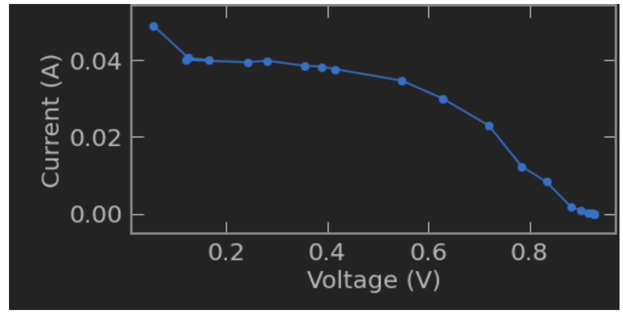

FIG. 6. Current as a function of Voltage as resistance was varied.

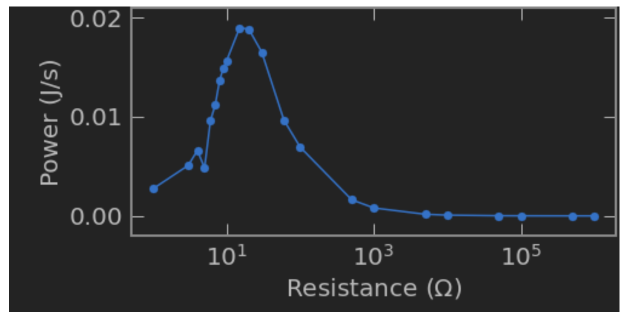

FIG. 7. Power response of the circuit at various resistances.

in fig. 7, however there was a delay after changing the resistance for the system to respond in terms of output power, which resulted in a difference between the optimal resistance computed in this stage and the optimal resistance computed at a later stage.

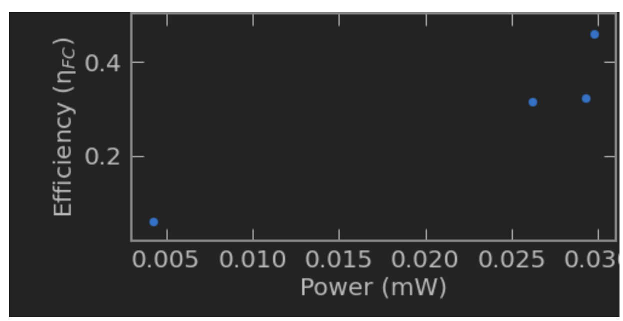

FIG. 8. Fuel Cell efficiency at several input powers, with varying resistance.

In the next stage of this phase of the experiment, different resistances were used to convert what was intended to be a single given quantity of hydrogen gas into electrical energy. However, due to time constraints some configurations of the circuit were only timed to consume 3 cm^3 of hydrogen gas, instead of 5.

The quantity of gas consumed was converted to mass using 2, assuming ideal conditions. This mass was then converted into energy using the accepted Lower Heat Value of hydrogen as given by 3. The electrical energy measured by E = tIV was then compared with the chemical energy in the hydrogen by 5, and plotted in 8.

$$\eta_{FC} = E_{FC}/E_{Hydrogen} \tag{5}$$

The peak efficiency was found to be 49 $\pm$ 5.

Conclusions

This efficiency is much lower than the accepted value given by [4]. As with the Electrolyzer experiment, the uncertainty in this experiment was in large part due to the graduations on the gas reservior. Another likely source of error is also our ability to find the optimal parameters for the circuit w.r.t the Resistance. Given the calculated values for Power and Time, it is likely an optimal resistance would have been between 9 and 10 Ohms. Where the capability of the decade resistor only allows resistances in steps of 1 Ohm, and the difference between 9 and 10 Ohms meant a very small change in power but a large change in the time required to consume a given quantity of hydrogen gas, it is clear we did not measure the Fuel Cell capability under ideal conditions.

SUMMARY

The efficiency of converting various forms of energy to and from electrical energy were experimentally measured.
The efficiency of a Silicon-based Solar Cell was found to be 15 $\pm$ 2 %, in agreement with typical performance, albeit lower than usual. The main source of error was the spread of intensity across the solar cell, which could be improved in future experiments.

The efficiency of an Electrolyzer was found to be 87 $\pm$ 6 %, which is higher than typical performance. The most significant source of uncertainty in this and the Hydrogen Fuel Cell experiment stemmed from the graduations on the gas reservior, especially because there are two measurements that stem from it. In all likeliness these errors may cancel, but error propogation was not handled in that way. It may be that this value was higher because of the difference between lab conditions and standard conditions, resulting in lower density of gas and overpredicting of the mass produced.

The efficiency of a Hydrogen Fuel Cell was found to be 49 $\pm$ 5 %, which is lower than typical performance. This again was likely in large part due to the graduations on the gas reservior, but also could be due to a limitation in our ability to optimize the circuit w.r.t. resistance. However, the same difference between ideal conditions and lab conditions leading to a high result would lead to a low measured efficiency in this experiment, as less gas would be actually being consumed than expected and as such the cell was actually using less energy than measured.

TABLE I. Measured and accepted values of the speed of light and refractive index of various materials.

Apparatus	η (%)	Accepted η value	Refs.	Deviation
Photovoltaic Cell	15 ± 2	17 ± 2.5	[2]	0σ
Elecrolyzer	87 ± 6	80	[3]	2σ
Hydrogen Fuel Cell	49 ± 5	60	[4]	-3σ

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[1] Wikipedia, Heat of Combustion:
https://www.wikepedia.com
[2] Energysage, Most Efficient Solar Panels
https://www.energysage.com/
[3] Carbon Commentary, Hydrogen made by Electolysis
https://www.carboncommentary.com
[4] Energy.gov, Fuel Cell Fact Sheet
https://www.energy.gov