Lab sessions LMAPR-2231 (2024-2025)

Lab session I (18/04/2025):

Basic study of water electrolyzer and fuel cell

Lab session II (09/05/2025):

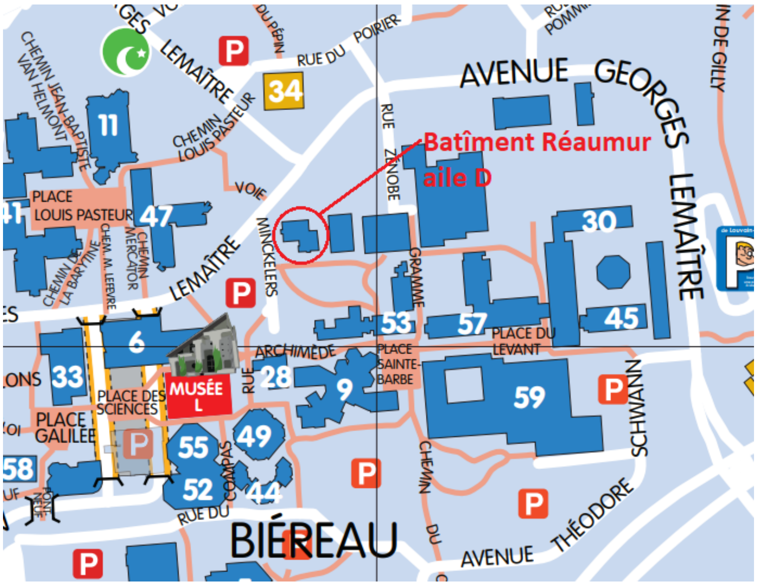
Advanced electrochemical characterisation of fuel cells

For this lab, a setup of one electrolyzer and one fuel cell is available for each group.

Before starting each experiment, an assistant is going to check your experimental set up.

All points in italics must be discussed in your report

All data tables must be inserted into your report



Meet 15 minutes before in the Reaumur (entrance D) building, Voie Minckeleers, 1

Reports must be sent in in .pdf format ***before Friday 16/05/2025 13hr*** *to* [***joris.proost@uclouvain.be***](mailto:joris.proost@uclouvain.be)***,*** [***nathan.wauthy@uclouvain.be***](mailto:nathan.wauthy@uclouvain.be) ***and*** [***xavier.pinon@uclouvain.be***](mailto:xavier.pinon@uclouvain.be)

Theoretical background

(Please refer also to the course LMAPR 2231 chapter IX)

A fuel cell or an electrolyzer, as any electrochemical system, is made of the three following components:

1) a cathode, the electrode where reduction occurs;
2) an anode, the electrode where oxidation occurs;
3) an electrolyte, to transport active species between both electrodes ;

The reaction involves chemical species (oxidant, reductant) plus a transfer of one or several electrons.

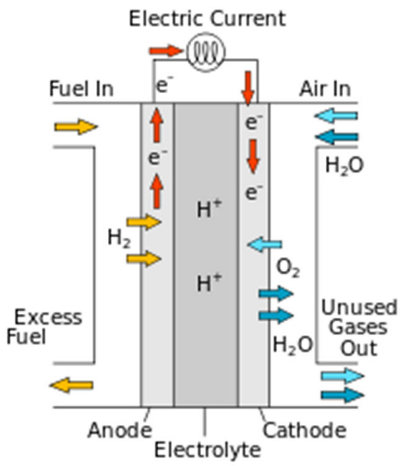


Figure 1: Schematic view of a Proton Exchange Membrane (PEM) fuel cell

The system studied in this experimental lab involves oxygen and hydrogen as chemical species. For the PEM fuel cell, the electrochemical reactions are:

$$H_{2(g)} \rightarrow 2H^+_{(aq.)} + 2e^-_{(m)} \qquad \text{(Anodic reaction, oxidation)}$$
$$O_{2(g)} + 4e^-_{(m)} + 4H^+_{(aq.)} \rightarrow 2H_2O_{(l)} \qquad \text{(Cathodic reaction, reduction)}$$
$$O_{2(g)} + 2H_{2(g)} \rightarrow 2H_2O_{(l)} \qquad \text{(Overall reaction)}$$

At standard conditions, determine the Gibbs free energy change of the overall electrochemical reaction of a PEM fuel cell and the theoretical maximum voltage a fuel cell can deliver.
Do the same reasoning with a PEM electrolyzer producing oxygen and hydrogen (picture, equation etc…).
What is the theoretical minimum voltage to apply in order to activate the electrolyzer?

A fuel cell can be considered as a generator while an electrolyzer as a load. Indeed, a fuel cell produces electricity from chemical energy through electrochemical reaction whereas an electrolyzer works in the reverse way (electricity to chemical energy).

Lab session I: Basic study of water electrolyzers and fuel cells

Materials list:

- *an electrolyzer (PEM electrolysis) and fuel cell;*
- *a power source;*
- *a hydrogen and oxygen storage reservoir;*
- *2 multimeters;*
- *a measurement board;*
- *electric cables and tubings;*

The aim of this part is to understand the behavior of a water electrolyzer and a fuel cell. After this first session, you will be able to study different experimental conditions to optimize the properties of the fuel cell (lab session II)
Attention: your electrolyzer/fuel cell may be composed of multiple cells (in serie).

Experiment 1: Current-voltage characteristic of a water electrolyzer

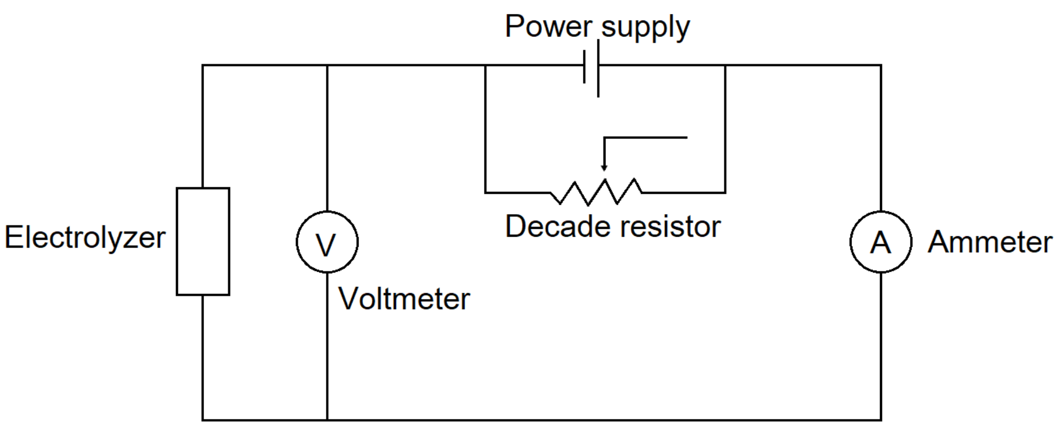


Figure 2: Set up for determining the current-voltage characteristic of a water electrolyzer

Connect the power supply to port 2 of the measurement board and the electrolyzer to port 1. Connect a multimeter in the mode voltmeter and the other in the mode (2A) ammeter. Initially, the cell voltage should be set to 0 V (R = 0). Continually increase the cell voltage by increasing the resistance on the decade resistor. Record both voltage and the corresponding current in a table. To obtain representative results, it is recommended that a minimum of 20 seconds elapse between two measurements to reach a stable state. Carefully observe the start of gas production and mark the corresponding voltage in the table.

-insert the table in the report

-use the data to plot a graph of current versus voltage.

What is the experimental water decomposition voltage you obtain? Compare to the theoretical value calculated before and explain the difference.

<u>Experiment 2</u>: Energy efficiency and Faraday efficiency of a water electrolyzer
Warning: the water level must coincide with the 0 cm² graduation.

First, you must determine a meaningful voltage to carry out the electrolysis based on previous experiment. Start measuring the time from the moment you connect the electrolyzer to the measurement board. Record the voltage applied to the electrolyzer and the current flowing through it. Record time, voltage and current when graduations are reached. Take the final measurements when the hydrogen storage tank is completely filled with gas.

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- *plot the produced volume of gas as a function of time on a graph and estimate the average production rate*

Calculate the energy efficiency and the Faraday efficiency of the electrolyzer. The energy efficiency η_{en} is the ratio of the usable energy and input energy. The usable energy is the chemical energy stored in the produced hydrogen, while the input energy is the electrical energy consumed by the electrolyzer. For the usable energy, you can choose between the high heating value and the low heating value for hydrogen, justifying your choice. Compare the energy efficiency with the Faraday efficiency and interpret your results.

To calculate the Faraday efficiency, you can assume the produced hydrogen is dry and an ideal gas, allowing the use of the following equations:

- Faraday's law of electrolysis: $Q = i \times t = n \times z \times F$

- the equation of state for an ideal gas : $p \times V = n \times R \times T$

Experiment 3: Voltage-current characteristic and power curve of a PEM fuel cell

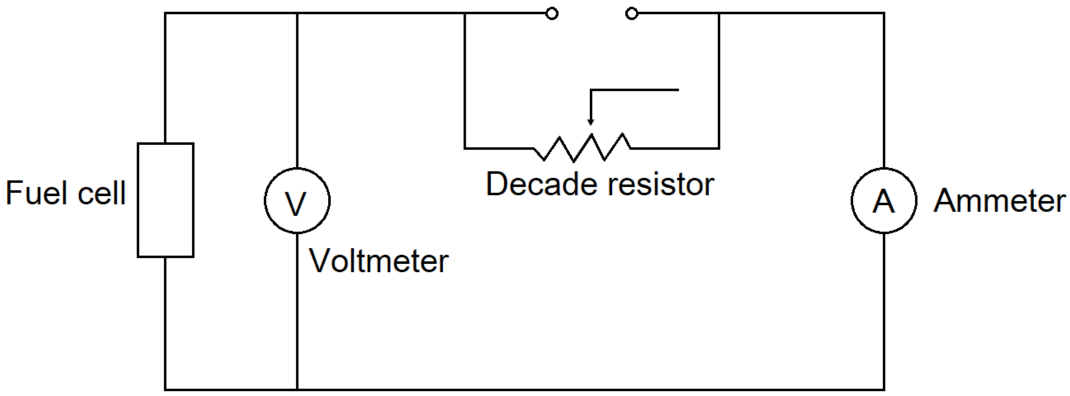

Figure 3 : Set up for determining the current-voltage characteristic of a PEM fuel cell

To prevent the fuel cell from using any hydrogen before the measurements are taken, the decade resistor must be switched to open circuit ($R = \infty$).
Connect the outlet of the electrolyzer to the inlet of the fuel cell. Close the outlet of the electrolyzer (using a clamp) and the fuel cell (using a cap). Connect directly the electrolyzer to the power supply to produce hydrogen (do not plug the electrolyze/power source to the measurement board).
After producing enough hydrogen, open the outlet of the electrolyzer. Then, briefly open the outlet of the fuel cell to vent the system. This removes residual gas and must be done to avoid measuring errors.
Now, close the circuit by switching the decade resistor to produce electricity from hydrogen. Start recording the current and voltage values. Then, switch the decade resistor to smaller values. Measure and record the voltage and current for each resistance. To obtain representative results, it is recommended that a minimum of 20 seconds elapse between two measurements to reach a stable state.

- plot the obtained voltage-current data;
- plot the power output as a function of current, and identify the Maximum Power Point (MPP)

Troubleshooting: the performance can change if the separator is not moistened enough. The quickest and simplest way to re-moisten the membrane is to connect the two sides of the cell together by means of a hose, and to blow through them physically several times. After some time of fuel cell operation, water accumulates at the anode. It is recommended to remove this water from one experiment to another by blowing through the anode inlet.

<u>Experiment 4</u>: Energy efficiency and Faraday efficiency of a fuel cell

First, you must determine a meaningful voltage to carry out the experiment based on previous experiment and specify it in your report.
Keep the same configuration as in experiment 3.
But this time, disconnect the power source of the electrolyzer once the purge is done and the storage of hydrogen is full. Disconnect the electrical connection between the fuel cell and the measurement board. Reconnect the circuit between fuel cell and measurement board once you started to record the time.
Record the measured time, voltage and current at constant intervals of decreasing volume. Do not change the resistance. Ensure that the values for the current do not fluctuate too much. Any substantial reduction in the current during your experiment will probably be due to gas residues or water that impair the operation of the fuel cell. Most likely, this will not be a significant problem as it only arises when there is a small volume of hydrogen remaining in the storage tank.

The duration of this experience may be long, use this time to already prepare the lab session II. There are many possibilities regarding the material available (and parameters to study) for this second session, do not hesitate to discuss with an assistant.

- *plot the storage content or the consumed volume of gas as a function of time*

Calculate the energy efficiency and the Faraday efficiency of the fuel cell.
Compare the energy efficiency with the Faraday efficiency and interpret your results.

Lab session II: Advanced electrochemical characterisation of a fuel cell

Materials list:

- *an electrolyzer and one or more fuel cells;*
- *a power source;*
- *a hydrogen and oxygen storage tank;*
- *2 multimeters;*
- *a measurement board;*
- *electric cables and tubings;*

Warning: To compare effects you must use the different fuel cells at the same power (voltage)

To realize this lab, no experimental indication is given. You must choose yourself the experimental set up(s) to study the properties of the fuel cell. You can be inspired by the previous lab. Information about the different setups can be found in the manufacturer website: www.h-tec-education.com
In this lab session, you can play around with different fuel cell conditions and compare different electrochemical behaviours. Several parameters can influence the properties of the fuel cell.
The parameter to be studied depends on the fuel cell of your set up. In this lab session you can study different set ups but again, be careful to compare what is comparable!

To carry out the electrolysis in order to generate the hydrogen, you can use the previously defined parameters in lab session I.
To finish, you must establish the relevant parameters and determine the power, energy efficiency and Faraday efficiency.

In your report, you must present the different curves for each modified parameter, preferably in one single plot to be able to compare directly.

- *the voltage-current curve*
- *the power-current voltage curve*
- *the hydrogen consumption against the time*

Calculate, for each parameter that you decide to vary, the energy efficiency and the Faraday efficiency of the fuel cell, compare the obtained results (if possible graphically), and interpret your results.