Investigation of a PEM fuel cell stack

Aims of the experiment

- To produce hydrogen and store it in a metal hydride storage container
- To withdraw hydrogen safely from a metal hydride storage container and use it for experiments
- To investigate a single PEM fuel cell
- To construct a PEM fuel cell stack
- To investigate a PEM fuel cell stack

Principles

A fuel cell converts chemical energy directly into electrical energy. However, in contrast to a battery, fuel can be supplied continuously to a fuel cell and reaction products continuously removed from it. Fuel cells are therefore suitable for applications in which more power needs to be accessed over a longer period of time.

Just like other galvanic elements, fuel cells are also constructed from two half cells that are separated by a membrane. But it is important to remember here that fuel can be supplied to and products can be removed from both half cells.

A well-known fuel cell is the hydrogen/oxygen fuel cell. Here, hydrogen and oxygen react with the release of energy to produce water (see reaction equation). The reverse reaction, the electrolysis of water, produces the two gases hydrogen and oxygen with the consumption of energy.

Release of electrical energy

Fuel cell

$$2\,H_2 + O_2 \rightleftharpoons 2\,H_2O$$

Electrolyser

Consumption of electrical energy

During the reaction of hydrogen with oxygen, energy is released. If one ignites the two substances directly, the energy is released in a large detonation. However, this energy can be converted directly into electrical energy using an appropriately constructed fuel cell (see Fig. 1). Decisive for this is having a suitable catalyst.

A fuel cell contains electrodes made from platinum or some other catalytically active noble metal. The gases arriving as molecules are initially split into atoms on the surface of the catalyst. Each hydrogen atom releases one electron (e^-) that can flow through an external electrical circuit and provide electrical energy. The resulting protons (H^+) flow through a membrane. For this, a proton exchange membrane (PEM) is used. It consists of Nafion, a sulfonated Teflon-like polymer which in a wet condition is permeable only to protons. At the same time, this membrane serves as an electrolyte.

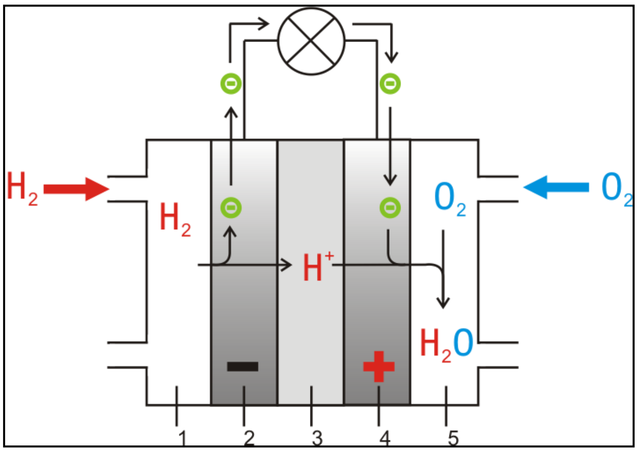

Fig. 1: Model of a fuel cell. 1 – H_2 chamber, 2 – Anode with catalyst, 3 – PEM (proton exchange membrane), 4 – Cathode with catalyst, 5 – O_2 chamber.

On the oxygen side, molecular oxygen is adsorbed onto the same catalyst and splits into atomic oxygen (2 O). The electrons moving though the electrical circuit together with the protons passing through the membrane produce water.

The reaction equations are:

H_2 side (anode)	H_2	→	$2\,H^+ + 2\,e^-$
O_2 side (cathode)	$O_2 + 4\,H^+ + 4\,e^-$	→	H_2O
Overall reaction	$2\,H_2 + O_2$	→	$2\,H_2O$

The fuel cells used here are supplied with oxygen from the air. The small amounts of water produced evaporate on the surface. 1 L of hydrogen produces 0.75 mL of water.

One disadvantage of hydrogen fuel cells is the difficulty of handling hydrogen. This mainly comes from pressurised gas cylinders. As an alternative, metal hydride storage containers can be used, in which hydrogen is present as a hydride absorbed onto metals.

When charging these metal hydride storage containers, hydrogen is pressed into the titanium alloy at a pressure of up to 3 bar. The hydrogen is absorbed. A chemical reaction takes place to form the metal hydride (MeH). Heat is released in the process. In the reverse reaction, the release of hydrogen, heat needs to be consumed. The container therefore cools down.

SW-2014-06

Hydrogen desorption

Heat consumption

$$MeH_n \rightleftharpoons Me + n/2\ H_2$$

Heat release

Hydrogen absorption

In this experiment, hydrogen is produced electrolytically and stored as a metal hydride. The fuel cells then to be investigated will be fed with hydrogen from the metal hydride storage container.

Risk assessment

When working with hydrogen, there is always the inherent risk of a detonating gas reaction. For this reason, only release hydrogen when there are no open flames in the vicinity. In the HydroStik PRO metal hydride storage container, there can only be a maximum of 10 L of hydrogen.

Hydrogen	
 **Signal word: Hazard**	**Hazard statements** H220 Extremely flammable gas. H280Contains gas under pressure; may explode if heated. **Precautionary statements** P210Keep away from heat/sparks/open flames/hot surfaces. No smoking. P377Leaking gas fire: Do not extinguish unless the leak can be stopped safely. P381Eliminate all ignition sources if safe to do so. P403Store in a well-ventilated place.

Equipment and chemicals

1 PEM fuel cell stack, CPS........................666 4812
1 HydroStik PRO, CPS.............................666 4795
1 Bubble counter, CPS.............................666 4794
1 Electric load, CPS 666 4831
1 HydroFill PRO 666 4798
1 Sensor-CASSY 2...................................524 013
1 CASSY Lab 2 ....524 220
and 1 PC with Windows XP/Vista/7/8
1 CASSY-Display USB.............................524 020USB
1 Connecting leads 19 A, 25 cm, pair 501 44
1 Connecting leads 19 A, 50 cm, pair 501 45
1 Panel frame C50, two-level, for CPS.......666 425
1 Silicone tubing, 2 mm diam., 1 m 667 198
2 Blank panel 100 mm, CPS 666 464
1 Water, pure, 1L 675 3400

Set-up and preparation of the experiment

1. Suspend the CPS module in the C50 panel frame as shown in Fig. 2.

2. Fill the bubble counters on the CPS module "Bubble Counter" with distilled or deionised water until about 5 mm of the inner tube is under water.

3. Connect the regulating valve of the CPS module "HydroStik PRO" to the upper bubble counter using a piece of tubing. Ensure that the HydroStik PRO is connected to the inner tube.

4. Set up the CPS module "PEM fuel cell stack" as described in the instructions for use. For this:

   a. Insert the fuel cells into the CPS board. Connect the individual fuel cells with one another using short pieces of tubing. All tubings, and therefore the hydrogen side, are located on the left.

   b. Wet the fuel cells with distilled water. To do this, connect a further piece of tubing to the lower fuel cell. Using a syringe, inject water into the fuel cells until it drips out of the uppermost fuel cell. Remove the syringe and allow the water to run out again.

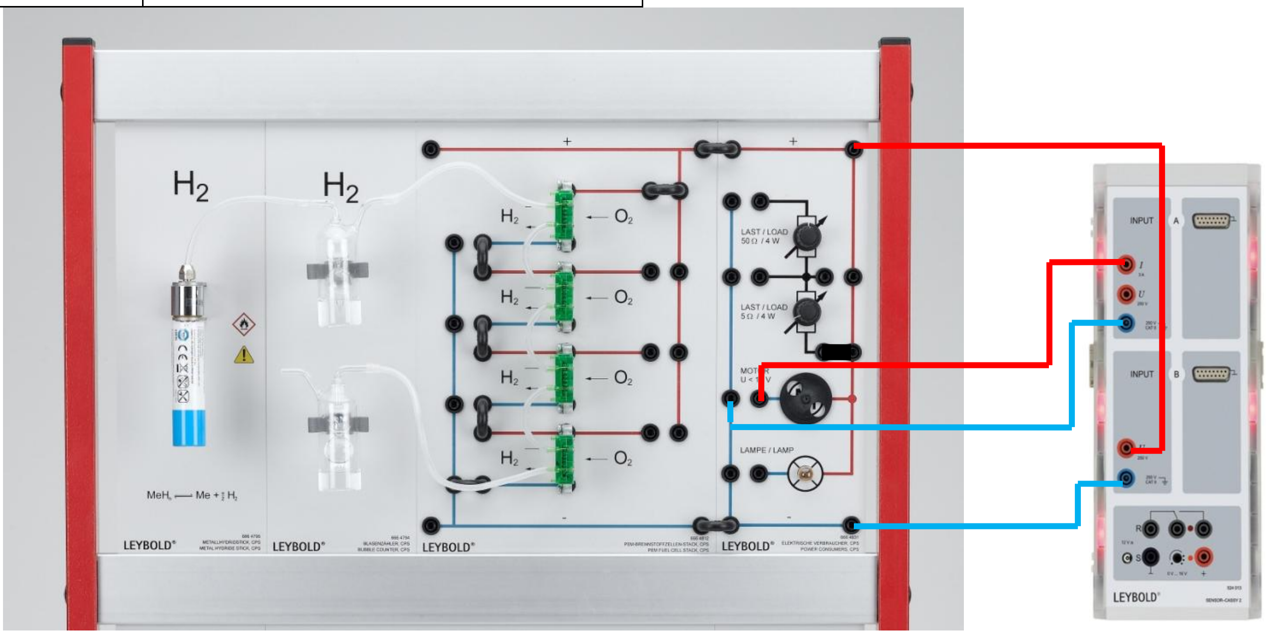

Fig. 2 Experimental set-up for investigation of the fuel cell stack. The fuel cells are connected in series. Blue and red lines: Connections from the CPS module "Electric Load" to the Sensor-CASSY 2 using connecting leads. In this example, the motor is connected.

5. Now connect the lowermost fuel cell with the lower bubble counter. Also here, ensure that the tubing is connected to the inner tube.

6. Connect the fuel cell stack with the CPS module "Electric Load" using safety connectors.

7. Connect the whole construction to a Sensor-CASSY 2 or another measuring instrument.

   a. To measure voltage, connect the electric load with Input B of the Sensor-CASSY 2 using connecting leads, as shown in Fig. 2.

   b. To measure current, connect the motor or lamp with Input A of the Sensor-CASSY 2, as shown in Fig. 2. In Fig. 2, the motor is connected in this way.

Note: The Sensor-CASSY 2 can now be connected via a USB cable to a computer running the Software CASSY Lab 2. Alternatively, a CASSY-Display can be used, which makes it possible to work without a computer and Sensor-CASSY 2.

Performing the experiment

Experiment C4.4.7.1 can be separated into two different aspects. On the one hand it is a matter of the risk-free supply of hydrogen, and on the other hand of investigating fuel cells.

Working with the metal hydride storage container HydroStik PRO

In this experiment, hydrogen is supplied from the HydroStik PRO metal hydride storage container. It is charged with hydrogen from the HydroFill PRO. The HydroFill PRO is an electrolyser which produces hydrogen from water and electric current.

1. Open the cover of the HydroFill PRO and carefully pour in distilled water up to the inner rim. Close the cover.

2. Connect the AC-DC adaptor and plug it into an AC mains socket. The status indicator will now flash green.

3. Screw the HydroStik PRO into the HydroFill PRO. The status indicator will now change from green to red to show that the connection has been made. Firmly screw in the HydroStik PRO.

4. The HydroStik PRO will become warm during charging. It is fully charged when no further heat development can be felt.

5. The HydroFill PRO also measures this. When the status indicator changes to green, the HydroStik PRO is fully charged and can be removed. A brief hissing sound will occur at this time.

6. A further HydroStik PRO can now be charged. For this, repeat the instructions from step 3.

7. When charging is complete, disconnect the HydroFill PRO from the mains socket and empty the water tank.

8. Carefully screw the HydroStik PRO onto the regulating valve until bubbles of hydrogen appear in the upper bubble counter. Screw it carefully further into the valve until larger amounts of hydrogen escape.

9. Feel the temperature of the HydroStik PRO. It becomes cold. Condensed water is formed.

Starting up the fuel cell

This experiment can be divided into two part experiments. Firstly, a single cell can be investigated. In the second part experiment, the entire stack is investigated, i.e. all four cells.

a) Investigation of a single fuel cell

1. Connect the uppermost fuel cell electrically to the load. To do this, insert a bridge connector horizontally to the left and to the right of the fuel cell.

2. Measure the no-load voltage of the fuel cell and note the value.

3. Connect the motor to the Sensor-CASSY 2 using a pair of connecting leads, as shown in Fig. 2.

Note: Make sure that there is a continuous supply of hydrogen. This can be recognised by the fact that bubbles are also visible in the second bubble counter.

4. Observe the motor and note the current and voltage values.

5. Now connect the lamp in the same way and note the current and voltage values again. Is the lamp lit?

b) Investigation of several fuel cells

1. Successively connect two, three and four fuels cells with one another in series (see Fig. 3, left).

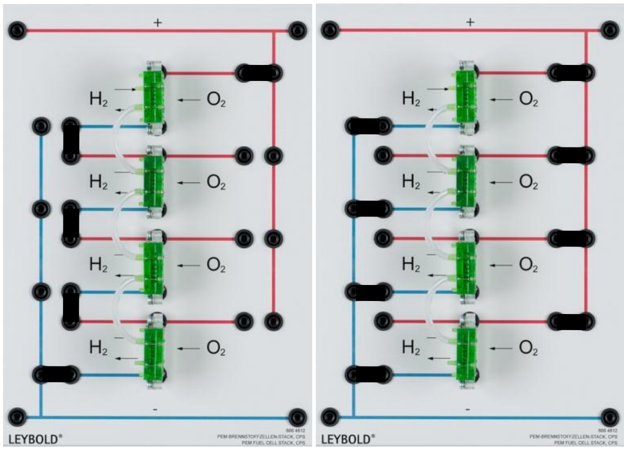

Fig. 3: Left: series connection, right: parallel connection.

2. Measure the no-load voltage in each case.

3. Switch the motor into the circuit for every combination of fuel cells and note the current and voltage values. What is the relationship between the number of fuel cells and the speed of the motor?

4. Now connect two, three and four fuel cells in parallel (see Fig. 3, right).

5. Measure the no-load voltages again.

6. Again switch the motor in and note the current and voltage values. How does the number of fuel cells influence the speed of the motor here?

7. Turn off the hydrogen supply by screwing the HydroStik PRO out of the regulating valve. For how long does the motor continue to run?

Note: It is possible to easily identify the consumed hydrogen in the second bubble counter. If no bubbles are to be seen here, then more hydrogen is being consumed than supplied. When the hydrogen supply is closed off, the water level in the bubble counter rises slowly, as hydrogen from the fuel cell is being "sucked out" of the tube.

8. Repeat the experiment using the lamp as the load.

Result of the experiment (example)

Starting up the fuel cell

Measured values from the experiment:

Series connection

Number of cells	No-load voltage	Motor Voltage [V]	Motor Current [A]
1	0.82	0.72	0.014
2	1.66	1.42	0.014
3	2.50	2.14	0.014
4	3.39	2.92	0.018

Number of cells	Lamp Voltage [V]	Lamp Current [A]
1	0.64	0.030
2	1.30	0.043
3	1.89	0.052
4	2.58	0.061

Parallel connection

Number of cells	No-load voltage	Voltage Motor [V]	Current Motor [A]
1	0.82	0.72	0.014
2	0.85	0.78	0.015
3	0.85	0.79	0.018
4	0.86	0.82	0.018

Number of cells	Voltage Lamp [V]	Current Lamp [A]
1	0.66	0.031
2	0.73	0.032
3	0.76	0.033
4	0.79	0.033

Evaluation of the experiment

Working with the metal hydride storage container HydroStik PRO

The metal hydride storage container warms up on charging and cools down during discharge. It contains sufficient hydrogen for the following experiments.

Starting up the fuel cell

a) Investigation of a single fuel cell

As soon as a fuel cell is supplied with hydrogen and is connected to an electrical circuit, a voltage is measurable. This is the no-load voltage. When a motor is then connected as a load, this will begin to turn. The amount of hydrogen that is consumed for this is small.

The voltage and the current are insufficient to allow the lamp to light. However, it does glow on close inspection. One single fuel cell is not able to produce sufficient power. Connecting several fuel cells together to form a stack is therefore unavoidable.

b) Investigation of several fuel cells

In a series connection, the no-load voltage increases additively with the number of cells. If the motor is connected, this effect can be observed again. In contrast, the current value hardly changes. The motor turns more quickly with every added cell. The fuel cell therefore behaves like any other producer of electricity. In a series connection, the voltages are added together.

When the lamp is used, a further effect becomes visible. The lamp becomes brighter with every cell until it illuminates distinctly with four cells. The current also increases in this case. Here, a higher current can also flow owing to the increased voltage.

In a parallel connection, the voltage is independent of the number of cells. For this reason, the current hardly changes with the loads investigated here. The advantages of a parallel connection will not become clear until characteristic curves have been recorded (see Experiment C4.4.7.2) .

Cleaning and disposal

Once used, the fuel cells should be stored in a moist condition if possible. For this, connect both hydrogen inputs together using a short piece of tubing and store all fuel cells in a water-tight bag.

Unscrew the HydroStik PRO from the valve for storage. It is then sealed and no hydrogen can escape.

Remove the water from the HydroFill PRO and then store it in a dark place.

Remarks

If the fuel cells lose their power, there can be two reasons for this: The cells are either too wet or not wet enough. If the cells are too wet, the hydrogen can no longer reach the catalytically active electrode in sufficient quantities. Therefore the power falls drastically. In this case blow out the cells with air (from a syringe) or with hydrogen from the HydroStik PRO.

If the cells are too dry, the PEM will not function perfectly. The proton-conducting property is only present when the membrane is wet. It can help in this case to wet the cells again.