A12: PEM-Fuel Cell

Group:
Supervisors:

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1 Theoretical Background

The PME is the most common fuel cell. It converts enthalpy of the dissoziation of H_2 to electric energy (and heat) with a high efficency. It consists of two electrodes for the conversion of hydrogen and oxygen. The main components are shown in Figure 1. The anode (left) and the cathode (right) serve as catalysts for the dissociation of the H_2 and O_2 molecules. They are usually made of metal or carbon coated with a thin layer of a catalytically active transition metal. The electrodes are surrounded by an electrolyte and separated from each other by a semi-permeable membrane, which is only permeable to protons. The hydrogen is oxidized at the negatively charged anode.

$$2H_2 \rightarrow 4H^+ + 4e^-$$

The resulting protons pass through the membrane to the cathode, while the electrons can only flow to the cathode via an external conductor with load resistance and thus produce electricity. At the same time, the oxygen conducted to the cathode is reduced in a second partial reaction. [1]

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

Full reaction: $2H_2 + O_2 \rightarrow 2H_2O$

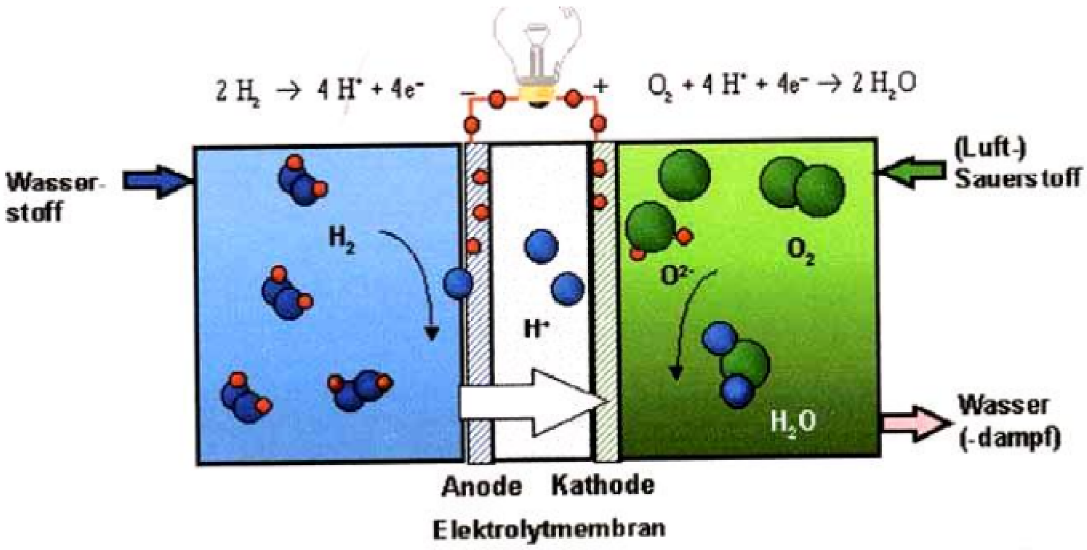


Figure 1: PEM [2]

2 Goal of the experiment

The first goal of the experiment is to identify the optimized characteristics of the fuel cell. Second to define the energetic efficiency of the Fuel cell. And third to determine the Faraday efficiency.

3 Experimental Procedure

Two gas cylinder (oxygen, hydrogen) are connected to each end of the PEM. The hydrogen one is connected to a part, that can divide the volume of a gas in specific parts. This is directly connected to one side of the PEM. There are also three barometer to determine the pressure on the O_2-side, the H_2-side and in the PEM itself.

The electrical flow of the PEM is connected to a computer, which measures U (electric Tension), I (current), t (time) and each p (pressure).

In the first part of the experiment U and I are measured for 10 different resistance (0-1 Ω). This happens three times with different pressures.

The second part determines the time needed for specific volumes of H_2 to completely react, so that the voltage in the PEM falls to zero. For this each ventil of the pipe will be once closed to stop more than the

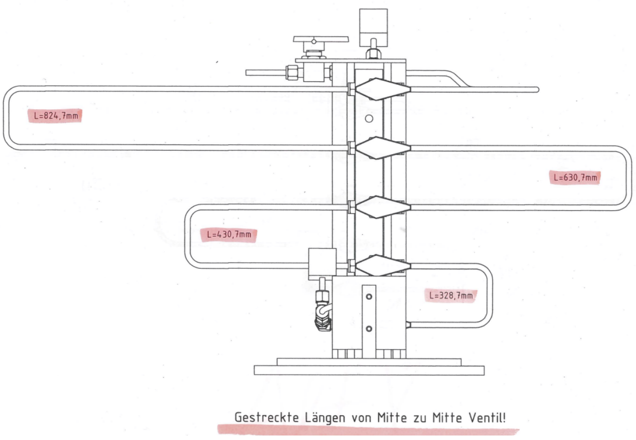
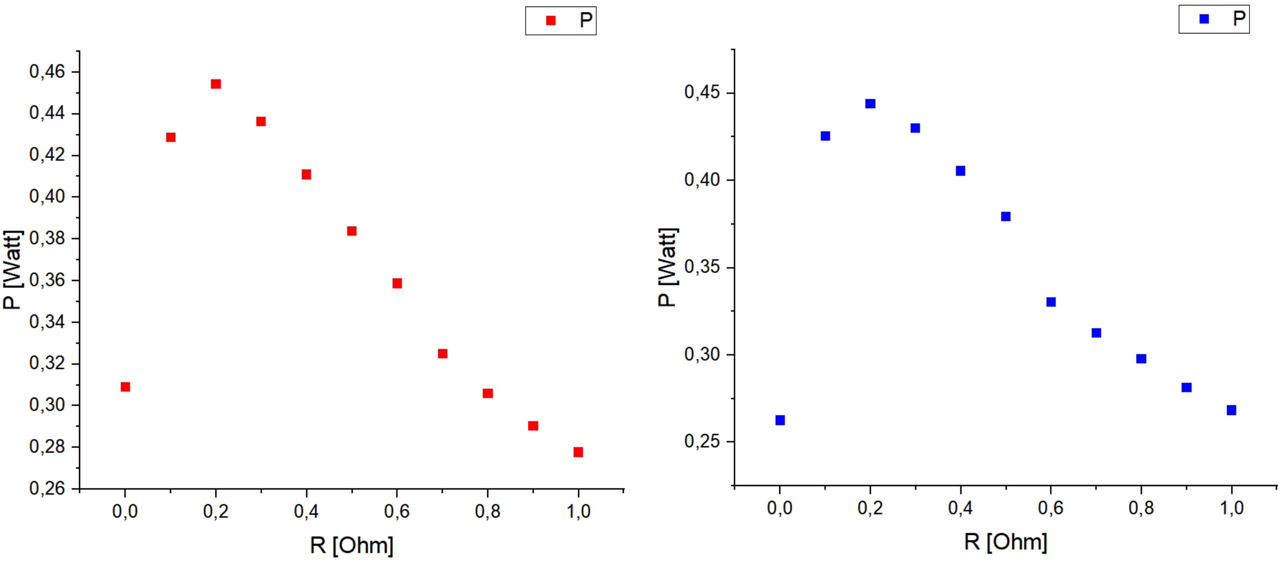


Figure 2: buildup [3]

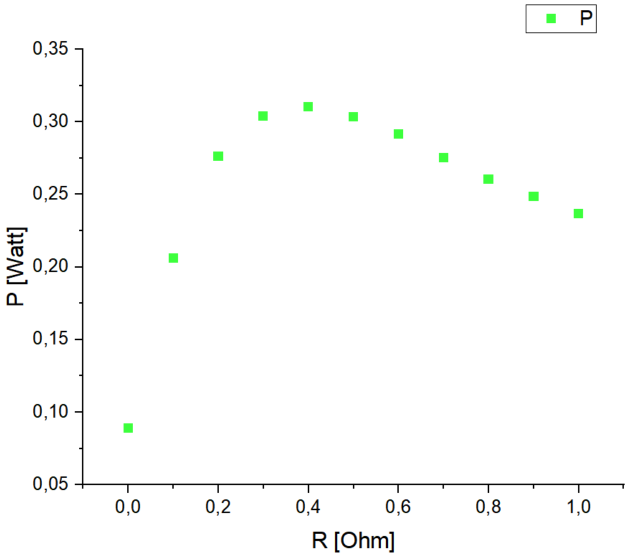
wanted volume to enter the PEM. If the ventil is closed, the voltage of the cell is measured in relation to the time until the voltage drops to zero.

4 Data

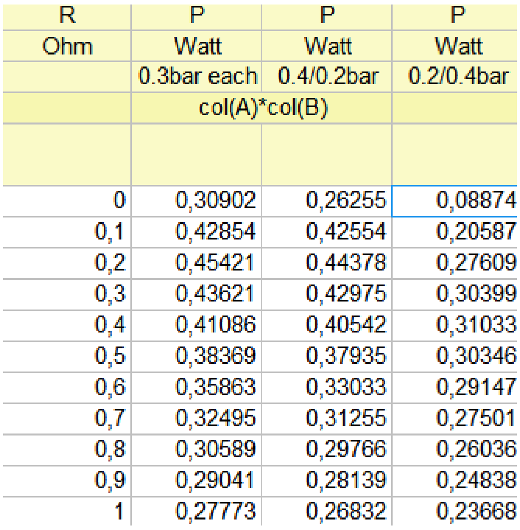


(a) 0.3bar O_2 and H_2

(b) 0.4bar O_2 and 0.2bar H_2



(c) 0.2bar O_2 and 0.4bar H_2

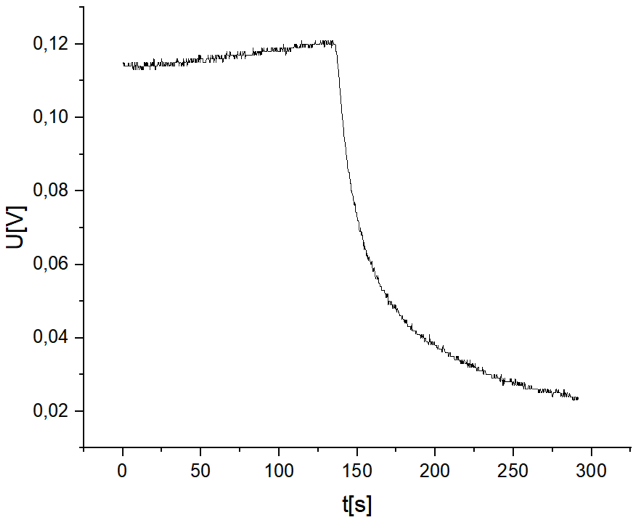


R	P	P	P
Ohm	Watt	Watt	Watt
	0.3bar each	0.4/0.2bar	0.2/0.4bar
	col(A)*col(B)		
0	0,30902	0,26255	0,08874
0,1	0,42854	0,42554	0,20587
0,2	0,45421	0,44378	0,27609
0,3	0,43621	0,42975	0,30399
0,4	0,41086	0,40542	0,31033
0,5	0,38369	0,37935	0,30346
0,6	0,35863	0,33033	0,29147
0,7	0,32495	0,31255	0,27501
0,8	0,30589	0,29766	0,26036
0,9	0,29041	0,28139	0,24838
1	0,27773	0,26832	0,23668

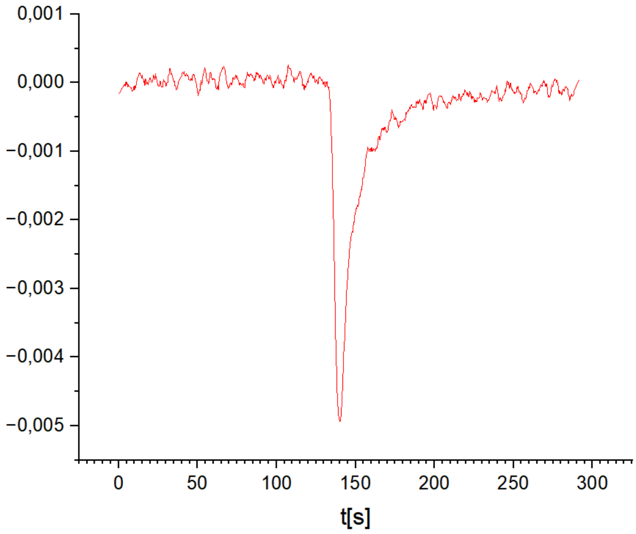
(d) Measurements

Figure 3: Power Curves

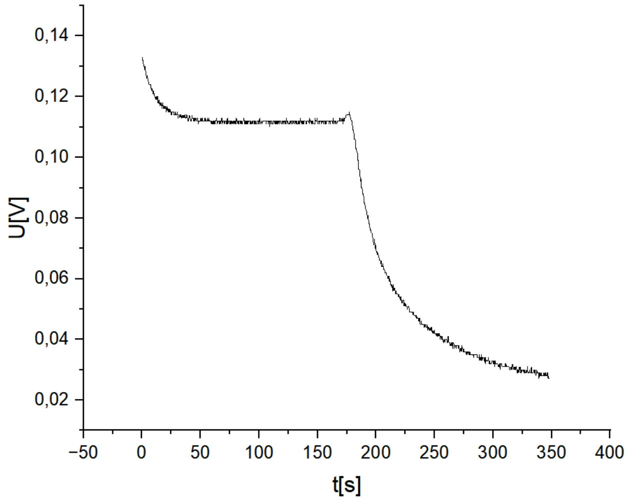
You can get from these graphs that R = 0.2. This measured value is used in the following calculations. Also the maximal power you can get from the PEM is 0.454 W.
In the following graphs are the results of the second experiment shown. By using the derivatives of the t-U-diagramms the time until the H_2 fully reacted is determined (global minimum). The chosen times - shown in the table on the next page - are used to calculate the dead volume and η_E and $\eta_{Faraday}$.



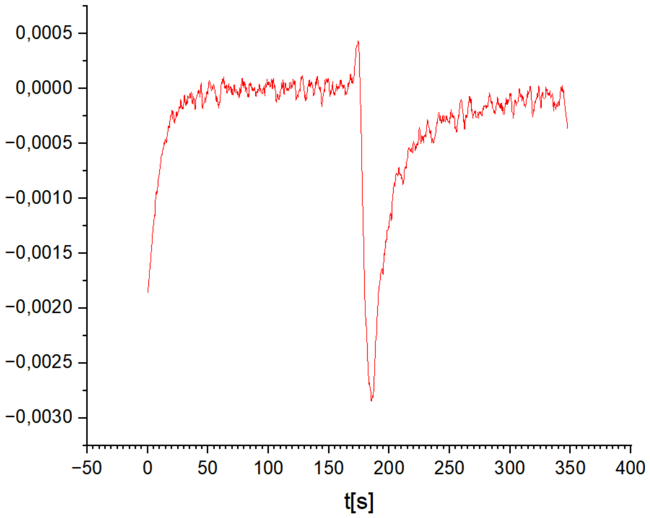
(a) dead volume



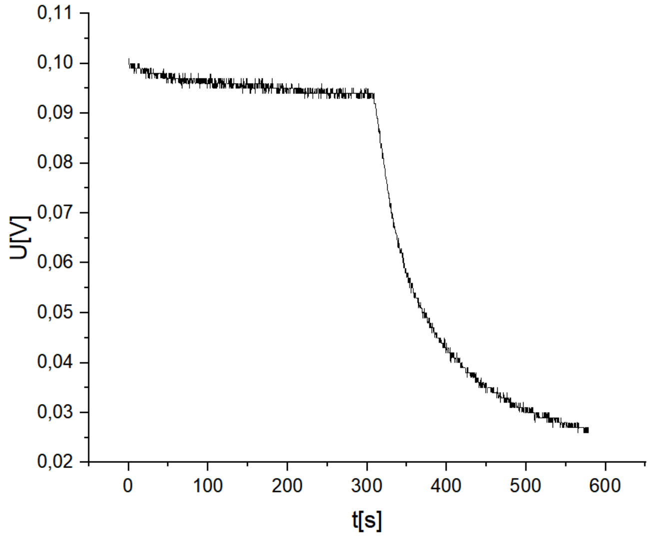
(b) derivative of dead volume



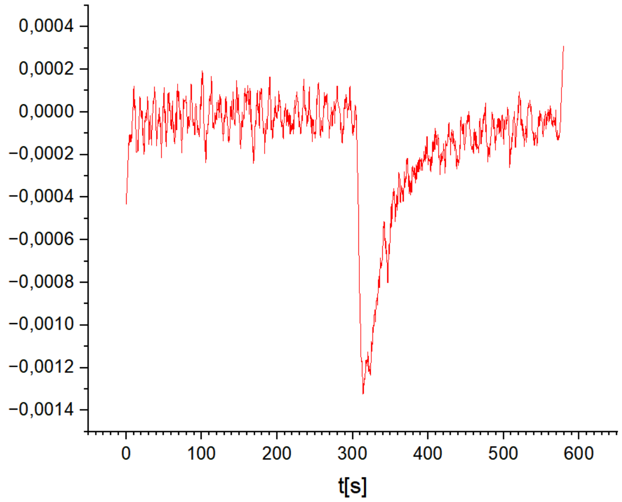
(c) volume 1



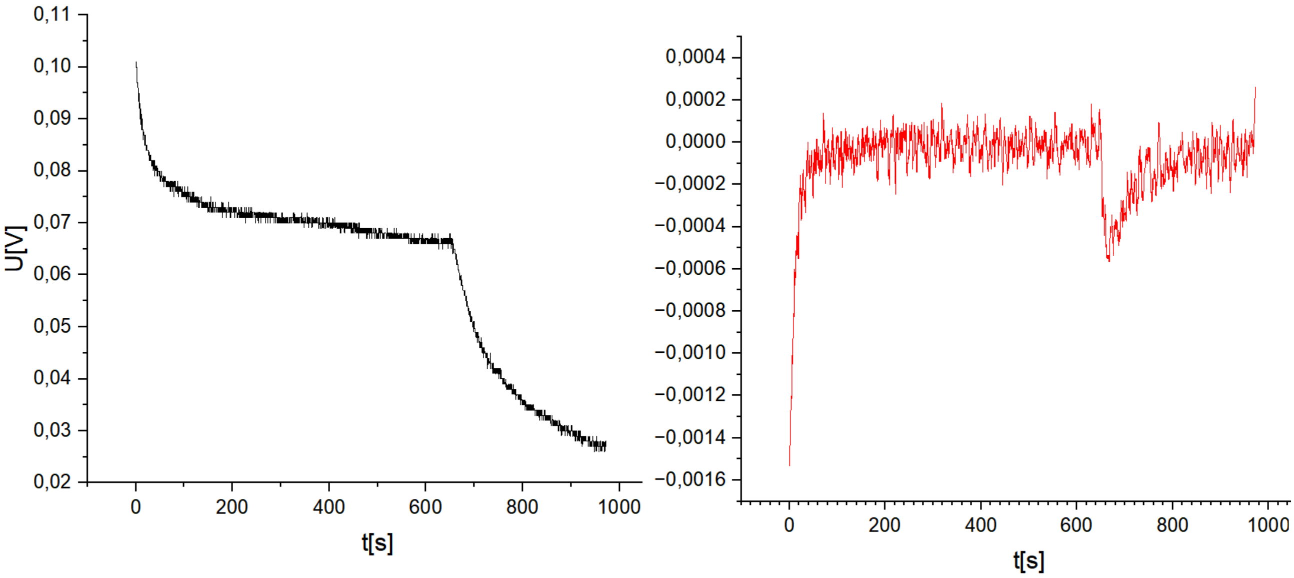
(d) derivative of volume 1



(e) volume 2

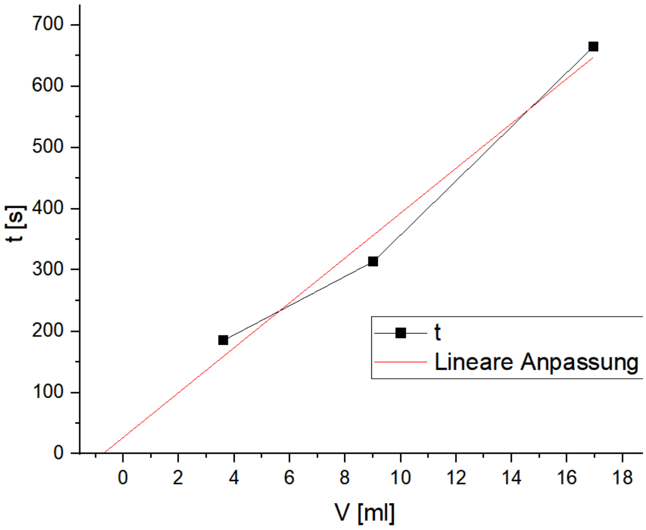


(f) derivative of volume 2

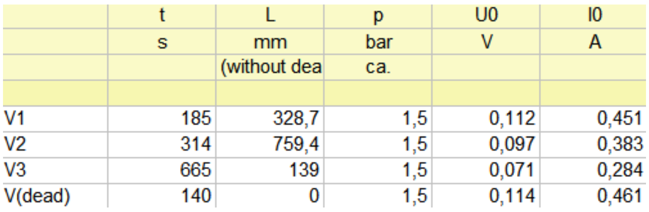


(g) volume 3

(h) derivative of volume 3



(i) linear fit



	t	L	p	U0	I0
	s	mm	bar	V	A
		(without dea	ca.		
V1	185	328,7	1,5	0,112	0,451
V2	314	759,4	1,5	0,097	0,383
V3	665	139	1,5	0,071	0,284
V(dead)	140	0	1,5	0,114	0,461

(j) table

The linear equation of the linearfit is

$$f(x) = 12,55 + 3,35x.$$

Because there was a big error rate we used a more convenient y-axis intercept.

5 Evaluation

The dead volume is identified by a linear fit:

$$0 = 12,55 + 3,35xx = 3,75$$

In the following we use 3,75 mL for the dead volume. For calculating the efficiency the formular is

$\eta = \frac{U_0 \cdot V_0 \cdot t \cdot R \cdot T}{p \cdot (V_{dead} + \frac{\pi \cdot d^2 \cdot L}{4}) \Delta_r H}$

V_1	V_2	V_3	V_{dead}
$0,215\eta$	$0,508\eta$	$0,365\eta$	$0,113\eta$

$\eta_{ges} = \frac{V_1 + V_2 + V_3 + V_{dead}}{4} = 0,300$

For calculating $\eta_{Faraday}$ the formual is

$\eta_{Faraday} = \frac{V_{calculated}}{V_{real}}$ with $V_{calculated} = \frac{R \cdot I \cdot t \cdot T}{F \cdot p \cdot z}$

V_1	V_2	V_3	V_{dead}
$2.24 \cdot 10^-6m^3$	$1,03 \cdot 10^-5m^3$	$1,61 \cdot 10^-5m^3$	$5,51 \cdot 10^-6m^3$

The values of V_3 and V_{dead} are not realistic and will not be included in the calculation of $\eta_{Faraday}$.
For $V_1 \eta_{Faraday} = 0,62$ and for $V_2 \eta_{Faraday} = 0,69$.
With $\eta_{Faraday} = \frac{V_1 + V_2}{2} = 0,655$

6 Discussion

I	R	V_{tot}	η_E	$\eta_{Faraday}$
1.4A	0.2Ω	3.75ml	0,300q	0,655

One of the sources of error will be the fluctuation in pressure, which sometimes varied by ± 0.5 bar. This could have falsified the measurement results and led to subsequent errors. Another source of error could be calculating errors. Because we have one less measurement than needed, the linear fit will have more errors.

7 Extra Questions

7.1 What are EMF and electrode potentials in an electrochemical cell?

EMF is the electomotoric force, which describes the ideal voltage of ideal fuel cells. Electrode potentials are the potentials of cells in comparison to the standardhydrogencell. [4]

7.2 Give the Nernst equation for the EMF of a fuel cell.

$\Delta E = EMF = E_2 - E_1$ and $E = E^0 - \frac{RT}{nF} \cdot ln \frac{a_{Red}}{a_{Ox}}$

7.3 Discuss the progression of the U-I curves measured here under different working conditions at the fuel cell.

The power of the fuel cell decreases if the pressures are different. This phenomenon can be explained with the Nernst equation. The equation contians the activities of the oxidation and reduction parts of the reaction. If you differ the concentration of the chemicals, which happens by changing the pressures (pV=nRT), the activities change and so does U. Therefor the progression of the U-I-curves cannot be the same under different conditions.

7.4 Calculate the value of the ideal energy efficiency.

$\eta_{ideal} = \frac{\Delta G}{\Delta H} = \frac{\Delta H - T\cdot\Delta S}{\Delta H} = \frac{-286000\frac{J}{mol} - 298,15K\cdot(-325\frac{J}{mol\cdot K})}{-286000\frac{J}{mol}} = 0.66$
(Calculated with values for H_2O because the water in the PEM seemed to be liquid and not gas.) [5]

7.5 Why is $\eta_{Faraday} < \eta_{ideal}$?

Because η_{ideal} is 1, no real η can ever be 1, because they consider more variabels.

7.6 What physical mechanisms can explain the $\eta_{Faraday} < 1$ relation?

$\eta_{Faraday}$ is calculated by $\eta_{Faraday} = \frac{V_{calculated}}{V_{real}}$. And since energy is always lost as heat in V_{real}, it always needs more than the calculated Volume to get the same amount of power out of the cell, therefor V_{real} is always bigger than $V_{calculated}$ and $\eta_{Faraday}$ always <1.

7.7 Calculate the maximum value of the electromotive force, EMF, that should be achievable with a PEM fuel cell, 1.23 V (open-circuit voltage vs standard electrode potential).

$E(H^+/H_2) + E(O_2/H_2O) = 0V + 1.23V = 1.23V$

7.8 Describe the microscopic structure of the electrode and membrane material.

The membrane consists of a plastic film or a gelatinous material. It is hydrophobic an at the sides there hydrophile sulfonic acid groups. The electrodes are Platinumgrids which are porous.

7.9 Describe the dependence of the electromotive force U on $p(O_2)$ and $p(H_2)$ using the Nernst equation.

$E = E^0 - \frac{RT}{nF} \cdot ln\frac{c_{Red}}{c_{Ox}}$
R, T, n, F and E^0 are constant, and therefor not dependent on p. The concentration is not directly dependent on the pressure, but on Volume. In the formula $pV = nRT$ it is the only variable which is not constant. When the pressure drops the concentration drops as well, and the EMF changes.

7.10 Compare the efficiency of a PEM fuel cell with the efficiency of the Carnot process.

A carnot machien has the best efficiency we can get in the real world $\eta_{Carnot} = 1$, and therefor is more efficient than the PEM fuel cell which has a maximum of usually $\eta = 0,37$.

8 Good scientific practice

Scientific integrity is the basis for the public's trust in research. At KIT, the statutes for safeguarding good scientific practice oblige all members to comply with the basic principles of good scientific practice. This includes the disclosure of all resources used. In addition to the sources listed in the bibliography, the following resources were used in the preparation of this report (please mark with a cross if used):
☐ ChatGPT or equivalent programs:
☑ Legacy protocols: for understanding and formating purpose
☑ (Lecture) scripts: PC1 Scripts of WS23/24 by Prof. Dr. Kappes and Prof. Dr. Schuster
☐ Internet sources that cannot be cited scientifically
☑ Correction and other aids: deepL for translations

9. Literature

(1) Muster-Protokoll_PCA12 `https://ilias.studium.kit.edu/goto.php?target=file_2346921_download&client_id=produktiv`.

(2) A12_2020_english `https://ilias.studium.kit.edu/goto.php?target=file_2324159_download&client_id=produktiv`.

(3) A12_Aufbau `https://ilias.studium.kit.edu/goto.php?target=file_2324157_download&client_id=produktiv`.

(4) R. A. Gaggioli, W. R. D. *J. Energy Resour. Technol.* **Jun 1993**, p.100-104.

(5) `https://webbook.nist.gov/chemistry/` accesed March 2024.