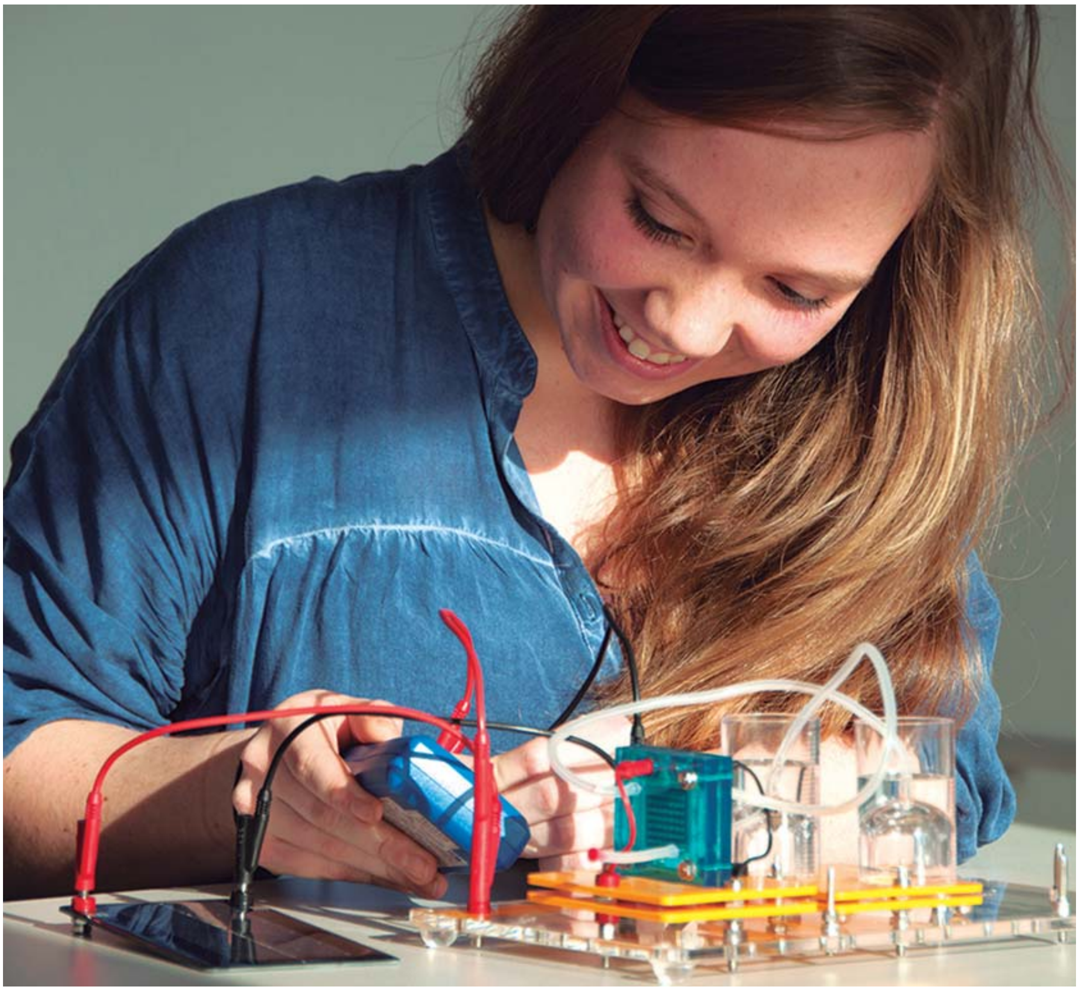
leXsolar-H_2 Large



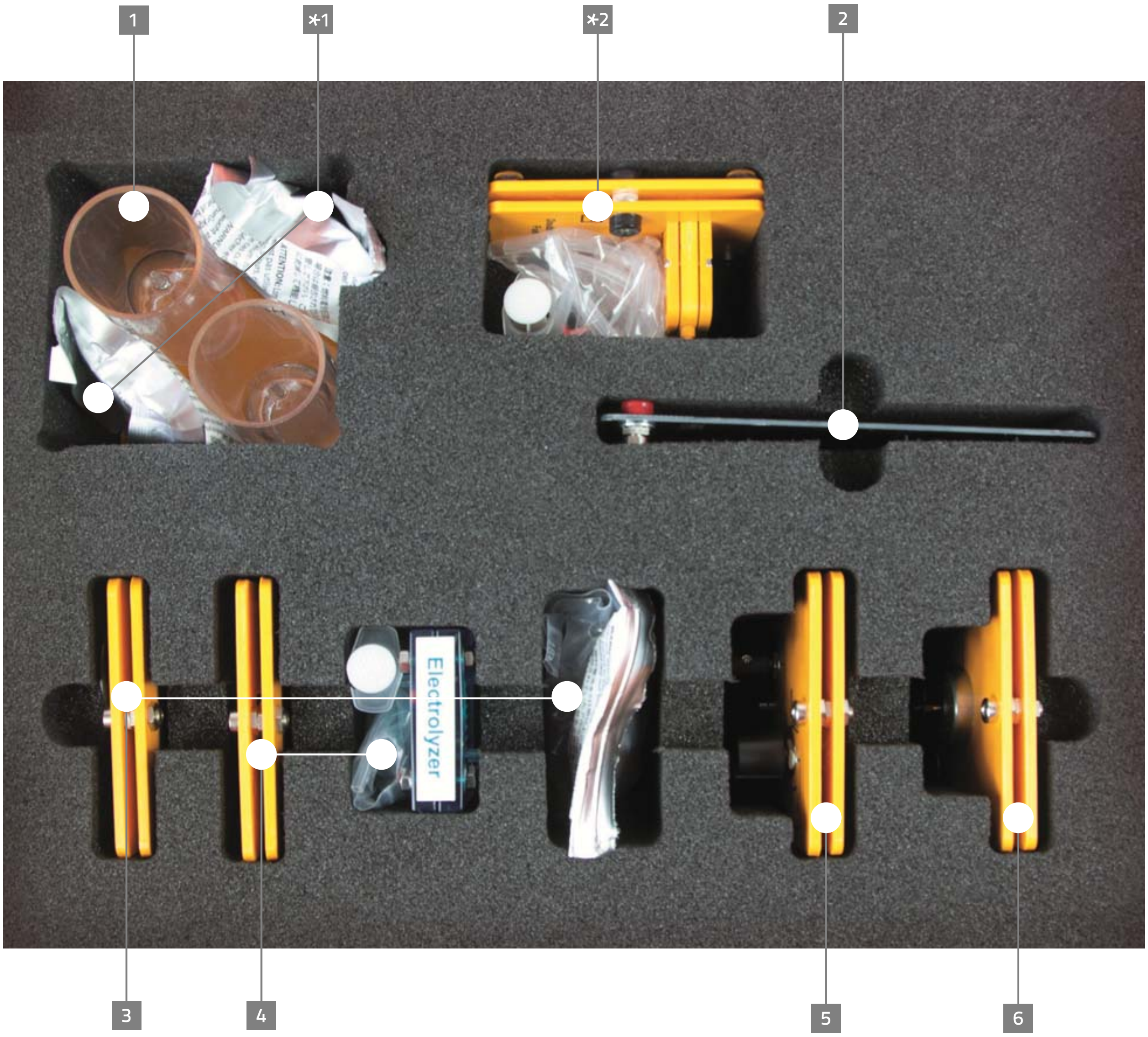
Teacher's Manual

Layout diagram leXsolar-H_2 Large 2.0

Item-No.1218

Bestückungsplan leXsolar-H_2 Large 2.0

Art.-Nr.1218



1	1213-01 Gas storage module 1213-01 Gasspeichermodul
2	1100-31 Solar panel 2.5 V, 420 mA 1100-31 Solarmodul 2.5 V, 420 mA
3	1218-02 PEM-Fuel cell module 1218-02 PEM-Brennstoffzellenmodul
4	1218-03 Electrolyzer module 2.0 1218-03 Elektrolyseurmodul 2.0
5	1100-23 Potentiometer module 1100-23 Potentiometermodul
6	1100-27 Motor module with L2-02-017 Yellow propeller 1100-27 Motormodul ohne Getriebe mit L2-02-017 Luftschraube (Propeller) gelb

Optional expansions
Optionale Erweiterungen

*1	2x1218-02 PEM-Fuel cell module with *3 2x1218-02 PEM-Brennstoffzellenmodul mit *3
*2	1700-01 Ethanol fuel cell module 1700-01 Ethanol-Brennstoffzellenmodul

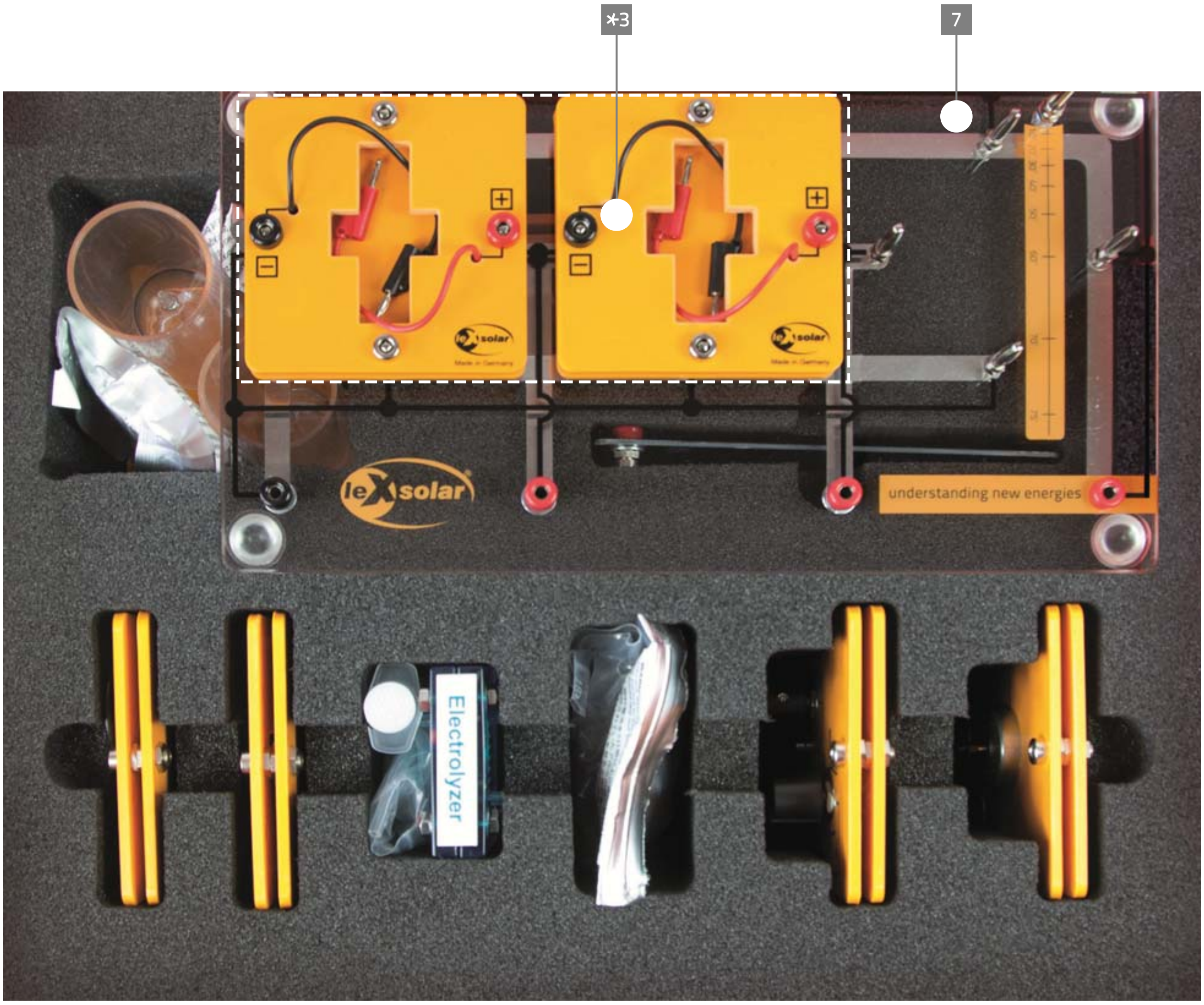
Version number
Versionsnummer

L3-03-164_16.03.2017

CE RoHS2

Layout diagram leXsolar-H_2 Large 2.0
Item-No.1218

Bestückungsplan leXsolar-H_2 Large 2.0
Art.-Nr.1218



7 1100-19 Base unit large
1100-19 Grundeinheit groß

Optional expansions
Optionale Erweiterungen

*3 2x1218-02 PEM-Fuel cell module with *1
2x1218-02 PEM-Brennstoffzellenmodul mit *1

CE RoHS2

leXsolar-H_2 Large

Teacher's manual

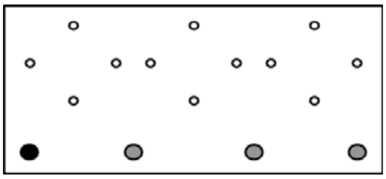
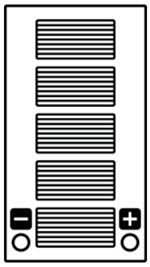
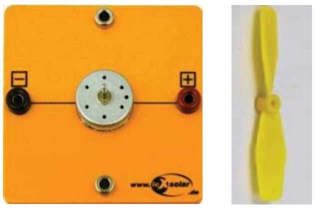
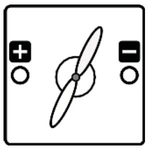
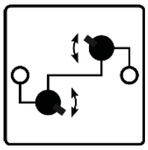
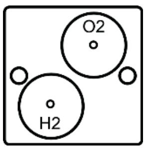
I Introduction

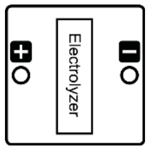
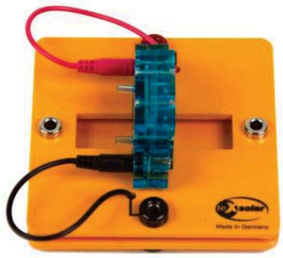
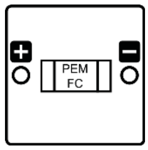
II Experiments

** This experiment is only possible with 2 x expansion "1218-02 PEM fuel cell"*
*** This experiment is only possible with 1 x expansion "1700-01 Ethanol fuel cell"*

L3-03-061_21.04.2017

1 Designation of components

Standard equipment of leXsolar-H_2 Large		
Designation	**Component**	**Symbol in the Experimental Setup**
	leXsolar main board	
	Solar module (2.5V, 420mA)	
	Motor module without gear	
	Potentiometer module	
	Gas storage module	

	Electrolyzer module	
	PEM fuel cell module	

2 Handling suggestions

When conducting experiments with the leXsolar-H_2 Large, some advice concerning the handling of the components and devices should be considered.

2.1 Operation of the electrolyzer

Specifications:

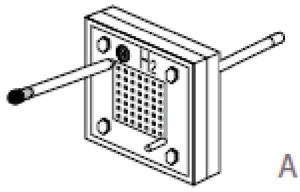
- Input voltage: 1.8 V ~ 3 V (D.C.)
- Input current: 0.7 A
- Hydrogen production rate: 7 ml per minute at 1 A
- Oxygen production rate: 3,5 ml per minute at 1 A

Important handling guidelines:

- Whenever not in use, the electrolyzer should be stored in an air-tight plastic bag, to keep it from drying out.
- Positive and negative pin of the electrolyzer must always be connected to correctly to the voltage source, to avoid damages to the electrolyzer.
- The electrolyzer must only be used with moistened membranes. The distilled water must be filled in on the O_2-side and should be allowed to soak for about 3 minutes. Connecting the dry electrolyzer to the voltage source can lead to irreparable damages.

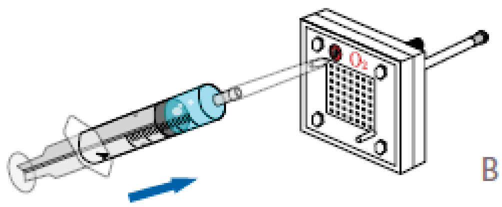
User instructions:

1. The electrolyzer should be placed on a flat surface. The short piece of tube must be connected to the upper port on the H_2-side (black port) and be sealed with the black pin (see A).



A

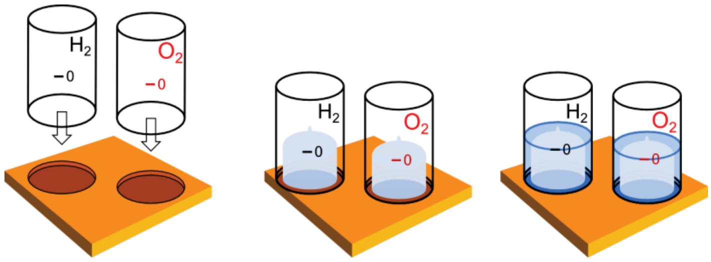
2. The syringe must be filled with distilled water and another short piece of tube should be fitted to it. The other end of the tube must be connected to the upper port on the O_2-side (red port) (see B).



B

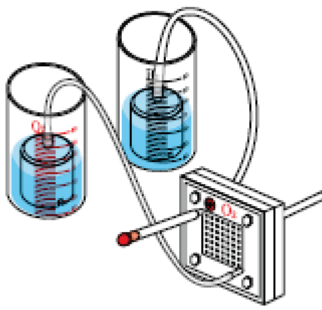
Now, using the syringe, the water should slowly be pumped into the electrolyzer until it leaks out of the lower port. The syringe can now be pulled off the tube, which can be sealed with the red pin. At this point the electrolyzer should sit for 3 minutes.

3. Now, the water barrels should be filled with distilled water up to their respective markings.



4. Each gas storage tank should be pinned onto the ring mount at the bottom of each water barrel, so that the grooves on the bottom of the gas tanks are aligned with the grooves of the ring mounts. Excess water can be removed using the syringe.

5. At this point, the gas storage tanks can be connected to the lower ports of the electrolyzer using the long pieces of tube. The black port of the H_2-side must be connected to the H_2- storage tank and the same goes for the red O_2-side and the O_2 tank (see C).



C

6. The electrolyzer can now be placed onto the module plate and be connected to it using the respective cables (red for O_2, black for H_2).

7. Now, the unit can be connected to the solar module or an external voltage source to start the electrolytic process.

<u>NOTE</u>: If the hydrogen gas shall later be used for a fuel cell experiment, it is recommended to put a clamp on the tube connecting the H_2-side of the electrolyzer with the H_2 tank. It can be closed after the gas production, so that the hydrogen can be stored in its tank for later experiments.

2.2 Operation of the PEM fuel cell

Specifications:

- Output power: 270 mW
- Output voltage: 0,6 V (DC)
- Output current: 0,45 A

Important handling guidelines:

- Whenever not in use, the fuel cell should be stored in an air-tight plastic bag, to keep it from drying out.

User instructions:

1. To operate the fuel cell, hydrogen gas is needed. This can be obtained from the H_2-Storage or from the H_2 tank from a previous experiment.

2. If the hydrogen is taken from the gas tank, the tube must be clamped to avoid hydrogen gas to leak.

3. The tube of the H_2 tank must be connected to the lower port of the fuel cell. The O_2 supply for this model is ensured by the ambient air.

4. The upper port of the fuel cell must be sealed, using a short piece of tube and a pin.

5. The fuel cell can now be placed onto the module plate and be connected to it using the respective cables (red for O_2, black for H_2).

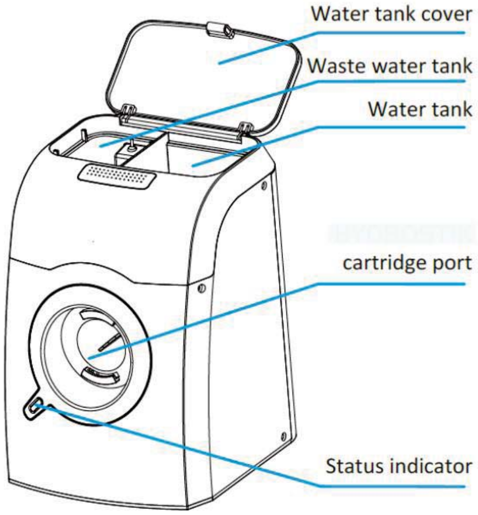
6. Now, the unit can be connected to an electrical load. (Mind the polarity!).

7. By opening the tube clamp the experiment can be started.

NOTE: For quantitative experiments like taking a characteristic curve, we recommend flushing the fuel cell with hydrogen gas by initiation the gas supply (opening the tube clamp on the tank or opening the valve on the H_2 storage) and removing the pin on the short tube for only 1-2 seconds.

2.3 Operation of the H_2-Charger and H_2-Storage (not included in H_2 Large)

Designation of the parts:



Specifications H_2-Charger:

- Power: 23 W
- Input voltage: 10 V-19 V (DC)
- Use: De-ionized or distilled water (10-40°C)
- Water consumption: ca. 20 ml/h
- Hydrogen pressure: 0-3 MPa
- Hydrogen production rate: ca. 3 l/h
- Hydrogen purity: 99.99%
- Refill time per cartridge: about 4 h

Specifications H_2-Storage:

- Capacity: 10 l hydrogen
- Storage material: AB5 metal hydride
- Load pressure: 3 MPa
- Working temperature: 0-55°C

Important handling guidelines:

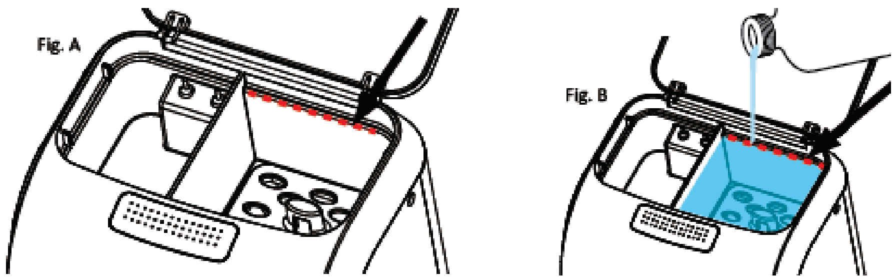
- The H_2-Charger must not be disassembled.
- Both the H_2-Charger and the H_2-Storage must be kept away from heat or flames.
- The H_2-Charger should be operated in an upright position.
- Operations should be done in a well-vented room.
- All electric connections should be kept away from water.

Status light:

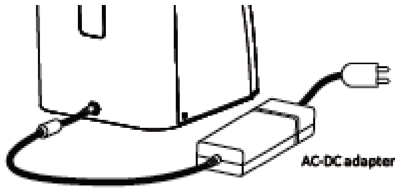
green	red	System status
on		H_2-Storage full
1 second on, 1 second off		Filling of H_2-Storage is halted
	on	H_2-Storage is being filled
	1 second on, 1 second off	Add water or empty the waste water container

Usage instructions:

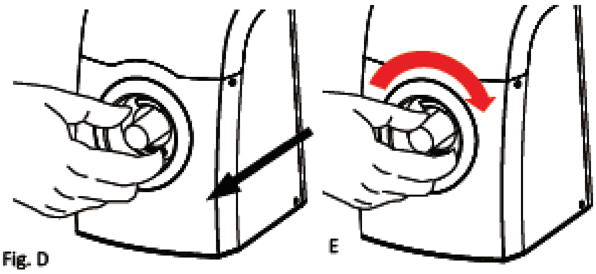
1. Firstly, fill distilled or deionized water up to the mark (see red line and arrow in the figure).



2. Connect the power adaptor to the H_2-Charger. The status light should flash green.



3. Insert the H_2-Storage into the opening on the front side of the H_2-Charger. For this, the stick should be turned clockwise until it locks in place. Don't apply too much force!



4. While the status light is flashing red, the H_2-Storage is being filled. Only when the status light flashes green, the cartridge is completely filled. The stick may now be removed by turning it counter clockwise.

5. Now remove the power adaptor and empty the water tank, in case the H_2-Charger will not be used within the following week. If further cartridges must be filled, revisit this procedure, starting at point 3.

NOTE: Distinct noises (gargling and whistling) are normal during the charging process and are being produced by the self-cleaning of the device.

I. Sample solution of the experiments

The filled out forms of the students' notebook depict the expected experimental results and show possible answers to the questions asked in the evaluation. Those answers are to be understood as guidelines. Every teacher should decide for themselves which answers to expect from their students.

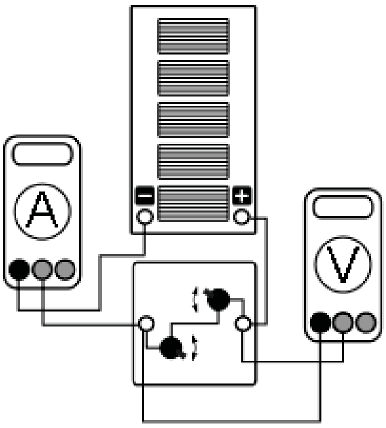
The association of each experiment with a specific grade varies with each curriculum. For some experiments there are variations accommodating different age groups. The more phenomenological experiments are better suited for younger students. Whereas experiments containing power measurements are recommended for older students, since fundamental knowledge in physics and mathematics are required. All manuals are provided as a Microsoft Word document, so they can be altered at your own discretion.

1. I-V curve of a solar module

Goals

Take the I-V curve of a solar module and interpret ist behavior.

Setup



Equipment needed

- Solar module
- Lamp
- Cables
- Ammeter
- Voltmeter
- Potentiometer module

Procedure

1. Set up the experiment in accordance with the drawing.
2. Place the lamp in front of the solar module (distance ca. 30 cm) and switch on the lamp.
3. Set sensible values for the voltage and measure the resulting current. For this, first adjust the 1kΩ resistor and then the 100Ω resistor for better control.
4. Enter your measurements into the table.

Measurements

V in V	I in mA	P in mW
0.13	38.4	4.99
0.60	38.4	23.04
0.75	38.3	28.73
1.00	38.5	38.50
1.25	38.6	48.25
1.50	38.2	57.30
1.75	38.2	66.85
2.00	36.0	72.00
2.25	25.7	57.83
2.50	6.0	15
2.55	0	0

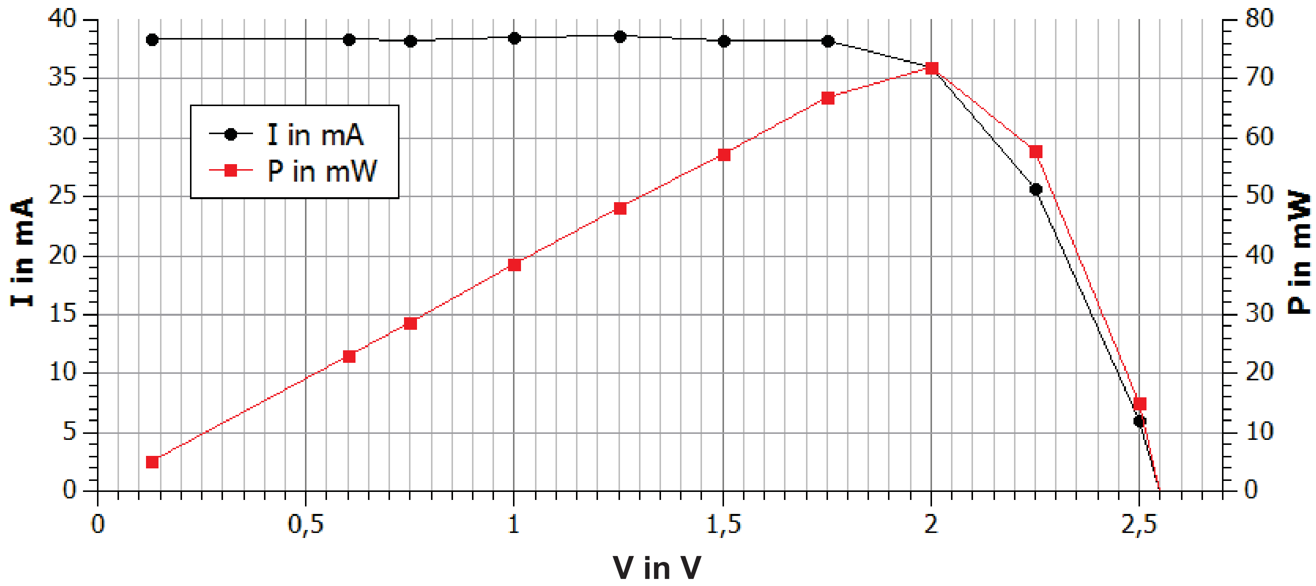
1. I-V curve of a solar module

Evaluation

1. Calculate the power for every pair of voltage and current values and enter your results into the table.
2. Plot the respective value in the given diagram.
3. Describe the behavior of the current and the power in dependence of the voltage.

Diagrams

2.



3.

The I-V curve matches that of a single solar cell. In the first segment the current remains nearly constant with increasing voltage. Starting at a voltage of about 1.7 V the current decreases rapidly.

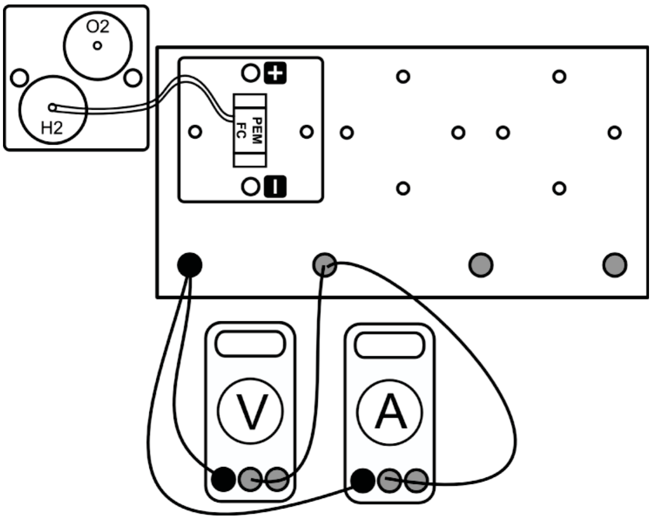
The power of the solar module strongly increases with the voltage and peaks at around 2 V. This particular point is called the "MPP – Maximum Power Point". Solar cells should be operated at that point to achieve maximum power efficiency.

3.3 FARADAY- and energy efficiency of a PEM fuel cell

Goals

Measure the FARADAY- and energy efficiency of a PEM fuel cell.

Setup



Equipment needed

- leXsolar main board
- PEM fuel cell module
- Potentiometer module
- Voltmeter
- Ammeter
- Cables
- Tubes
- Distilled water
- Gas storage (full)

Procedure

1. Set up the experiment in accordance with the drawing. The gas storage has to be filled prior to the experiment. You can find notes on how to set up and use the electrolyzer in chapter “Operation of the electrolyzer” on page 7.
2. Quickly flush the fuel cell with hydrogen. You can find hints on how to do this on page 9.
3. Measure the volume of hydrogen V_H at the beginning of the experiment and after 5 minutes. Write down the amount of used hydrogen
4. Also after 5 minutes, measure current and voltage of the fuel cell.

Measurements

t = 5 min

V = 0.41 V

I = 74.3 mA

V_H = 3 ml

Evaluation

1. Calculate the FARADAY-efficiency of the PEM fuel cell.
2. What influences the FARADAY efficiency of the fuel cell?
3. Calculate the energy efficiency of the PEM fuel cell.

3.3 FARADAY- and energy efficiency of a PEM fuel cell

Goals

1. To calculate the FARADAY-efficiency we use the following formula:

$$\eta = V_{H2theoretical} / V_{H2}$$

$$V_{H2theoretical} = I \cdot t \cdot V_m / Q_m$$

V_m = 24 l mol^{-1} (molar volume H_2 at 20 °C, standard pressure)
Q_m= 192 968 C mol-1 (material specific charge)

Solution: $\eta = V_{H2theoretical} / V_{H2}$

$V_{H2theoretical} = I \cdot t \cdot V_m / Q_m$
$= 74.3\ mA \cdot 300\ s \cdot 24\ l\ mol^{-1} / 192\ 968\ C\ mol^{-1}$
$= 2.8$ ml

V_{H2} = 3 ml

η = 2.8 ml/3 ml
≈ 0.93

2.

- Parallel electrochemical reactions, which provide fewer electrons per used hydrogen
- Chemical reactions of oxygen and hydrogen at the catalysts (catalytic burning)
- recombination of hydrogen and oxygen through diffusion or leakage

3. To calculate the energy efficiency we use the following formula:

$$\eta = U \cdot I \cdot t / (H_{0H2} \cdot V_{H2})$$

H_{0H2} = 11920 kJ m-3.

Solution: η = energy content of hydrogen / electric energy

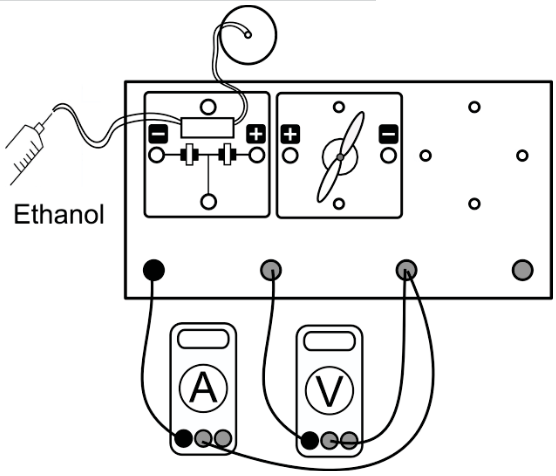
$\eta = U \cdot I \cdot t / (H_{0H2} \cdot V_{H2})$
$= 0.41\ V \cdot 74.3\ mA \cdot 300\ s / 11920\ kJ\ m^{-3} \cdot 3\ ml$
= 0.26

4.3 Temperature dependence of an ethanol fuel cell

Goals

Investigate the fact that the motor runs faster at higher temperatures.

Setup



Equipment needed

- leXsolar main board
- Ethanol fuel cell
- Motor module
- 2 tubes
- Ethanol solution (15%)
- Ammeter
- Voltmeter
- Beaker

Procedure

1. Set up the experiment in accordance with the drawing
2. Use the tubes and the syringe to fill the fuel cell with ethanol.
3. First, measure voltage and current at room temperature. Enter your measurements as well as observations on the motor's movement into the table.
4. To achieve higher or lower temperatures, fill a test tube with ethanol and chill or heat it using a beaker filled with either ice water or hot tap water.
5. Measure current and voltage for each temperature value. Enter your measurements into the table.

Measurements

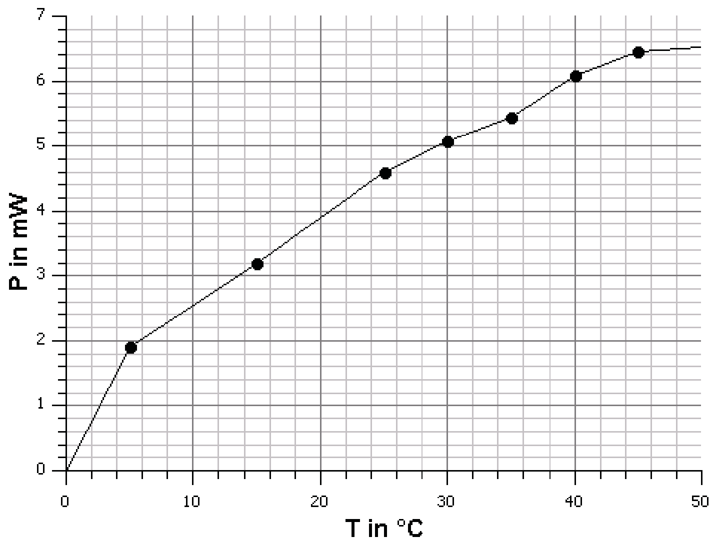
T in °C	Motor movement	V in mV	I in mA	P in mW
0	motor slowly starts to turn, but then stalls	53	0	0
5	motor turns very slowly	204	9.30	1.90
15	motor turns faster	339	9.39	3.18
25	motor turns faster	406	9.45	4.60
30	motor turns faster	479	9.50	5.07
35	motor turns very fast	562	9.70	5.45
40	rotation speed of the motor does not allow distinguishing individual rotor blades	620	9.80	6.08
45	see 40°C	644	10.01	6.45
50	see 40°C	646	10.08	6.51

4.3 Temperature dependence of an ethanol fuel cell

Evaluation

1. Calculate the cell's power output for each value and enter your results into the table.
2. Plot the temperature dependency of the power in the diagram.
3. At which point does the motor start to move? What can you further deduce from the diagram?

Diagramm



Evaluation

3.

At a temperature of about 3°C the motor starts to turn. When raising the temperature, the motor speeds up.
After 45°C the power shows no further increase. On the whole, the curve shows the temperature dependence of the cell's power output.

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