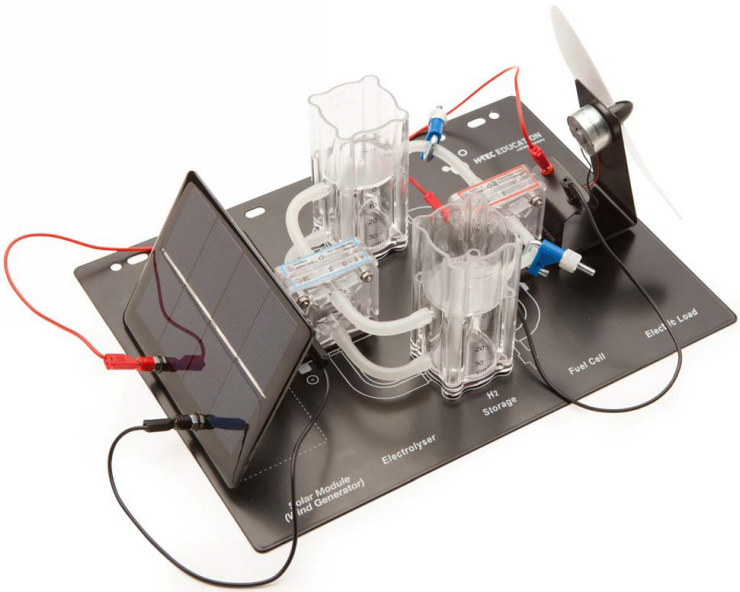
Operating Instructions



T126 - TUTORIAL Basic

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The TUTORIAL Set

The predicted climate change in combination with the worldwide rising energy demand and the decreasing coal, oil and gas resources make the development of new energy sources one of the main tasks of the 21st century. Hydrogen technology plays a special role here. Hydrogen and oxygen can be used to directly generate electricity with the use of fuel cells. The only emission: water. Using electricity (e.g. provided by solar cells), the required hydrogen can be generated directly from water by splitting it into hydrogen and oxygen. The principle behind this is referred to as electrolysis. Together, the two processes form the solar-hydrogen cycle.

All stages of the solar-hydrogen cycle can be clearly explained using simple experiments. This is a simple principle, which works in small and large scale while protecting resources and relieving the strain on the environment. It is not a surprise then that all experts predict excellent future prospects for fuel cell technology.

These instructions explain the assembly, startup and function of the set. Furthermore, you will find numerous experiments and suggestions for using the devices in class.

We hope you conduct exciting experiments and gain interesting insights into the future of energy supply.

About these instructions

- These operating instructions are intended for the supervisor in charge.
- These operating instructions have to be read and observed before use.
- These operating instructions have to be available for reference and have to be stored in a safe place.
- All safety instructions must be observed.
- This product may only be put into operation and operated under the directions of the responsible supervisor.

Safety information

Read and observe the general safety instructions included separately with this product before using the product!

Product-specific safety information

The product may only be used:

- according to the intended use
- in compliance with all safety information

Your Duties as a Supervisor

These Operating Instructions are intended for the responsible supervisor.

- Read the Operating Instructions before using the equipment. Observe the instructions and keep them on hand.
- Pay particular attention to the General Safety Precautions (page 5).
- This product may be set up and operated only under the supervision of the person responsible.

Objective / Introduction

The predicted climate change combined with the worldwide increase in energy requirements and the declining resources of coal, oil and gas make the development of new energy sources one of the main tasks of the 21st century. Hydrogen technology is particularly important in this regard. With the help of fuel cells, electricity can be produced directly from hydrogen and oxygen. The only waste product is water.

With the help of electricity, which is obtained from renewable energy like solar cells or wind power, the required hydrogen can in turn be produced directly from water by splitting into hydrogen and oxygen. The principle on which this is based is called electrolysis. Together, the two processes form the solar hydrogen cycle.

All stages of the solar hydrogen cycle can be clearly explained with simple experiments using this working model. A simple principle, which works on both a small and a large scale, and in doing so conserves resources and unburdens the environment. It is therefore no wonder that all experts in fuel cell technology forecast excellent prospects for the future.

The design, set-up and operation of the TutorialBasic are explained in this manual. You will also find suggestions for using the equipment in tutorials. The team wishes you exciting experiments and an interesting insight into the future of energy supply.

Intended Use

The equipment described in this manual allows the principles of PEM fuel cells (PEM = proton exchange membrane), PEM electrolyzers and solar modules to be demonstrated, and appropriate measurements to be taken. The equipment has been developed for teaching and demonstration purposes only.

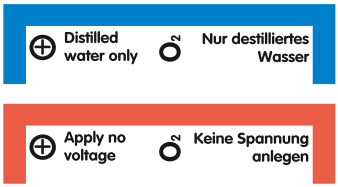
Any other use is prohibited.

WARNING!
Distilled water is required to operate the TutorialBasic. The electrolyzer splits this water into hydrogen and oxygen. In the fuel cell, hydrogen (H2) and oxygen (O2) react again. These gases can be dangerous if handled improperly. In order to avoid any risks you must follow the recommended safety precautions when using the equipment.

H-TEC fuel cells and electrolyzers are clearly color-coded according to their function

blue: electrolyzer

red: fuel cell



Those descriptions show also the electric polarity and their gas connection (O_2 or H_2).

General Safety Precautions

The General Safety Precautions attached separately to the product must be read before using the product and must be observed!

Additional note

Make sure the polarity is always correct (red = “+” , black = “-”)!

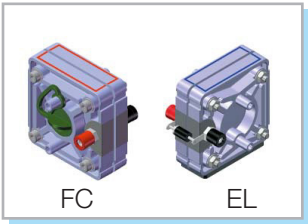
Overview of TUTORIAL Basic (T126)

The TUTORIAL Basic is a working model of the solar hydrogen cycle and it features modular components for flexibility. The solar module generates electricity, which is used to break down the distilled water in the electrolyzer into oxygen and hydrogen gas. The gases are collected in separate gas storage tanks.

Then, in the fuel cell, the two gases react with one another to form water again. This reaction generates electricity, which can be used to operate an electric load.

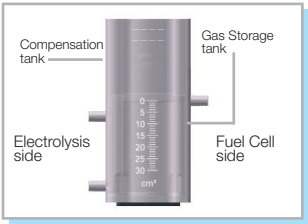
The TUTORIAL Basic allows experiments across the whole range of hydrogen applications.

Contents



1x Fuel Cell - H_2/O_2/Air

1x Electrolyzer - Electrolyzer Cell 5



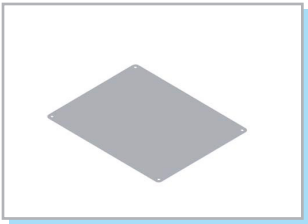
2x Gas Storage Tank - Storage 30

Note: When filling the tanks do this in strict accordance with the assembly instructions of each experiment.

The tanks are provided with a measurement scale on the gas storage tank itself and two fill level marks on the compensation tank.

1x Solar Module

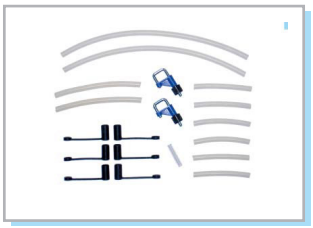
1x Fan



1x Printed baseplate with assembly aid

Contents (continued)

2x Connecting cable - 2mm; black
2x Connecting cable - 2mm; red



1x Tube set

Detailed view of:
Cap for Gas connector
Stopper for sealing air inlet

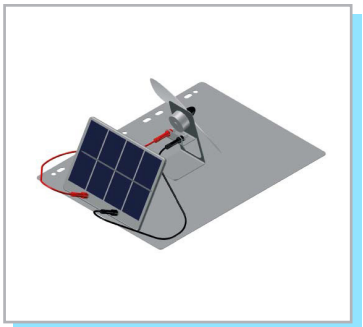
Experiments

Experiment 1: Solar Energy

Overview
The objective of the experiment is to convert light energy into electrical energy using the solar module. The electrical consumer is used for illustration purposes.

Setup time: approx. 1 minute **Length of experiment:** approx. 1 minute

Experiments from the accompanying book: Current-voltage characteristics, power curve and efficiency of the solar module (2.2)



Devices and material

The following is required for the experiment:

- 1x solar module
- 1x suitable light source
- 1x fan
- 2x connecting cable 2 mm
- 1x base plate

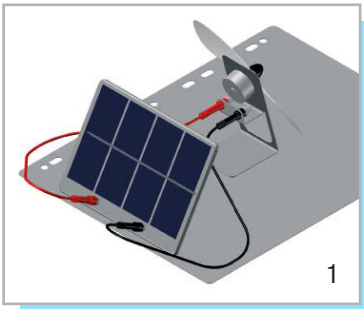
Setting Up:

1. Place the solar cell and the fan on the base plate as shown in sketch (Fig.1).

2. Connect the solar module to the appropriate connectors on the fan, using the connecting cables. When doing so, make sure the polarity is correct (red = "+", black = "-").

3. When the illumination of the solar module is adequate, the fan will start to run.

Note: If the lighting is not sufficient, you can use a powerful halogen spotlight.



1

⚠ CAUTION

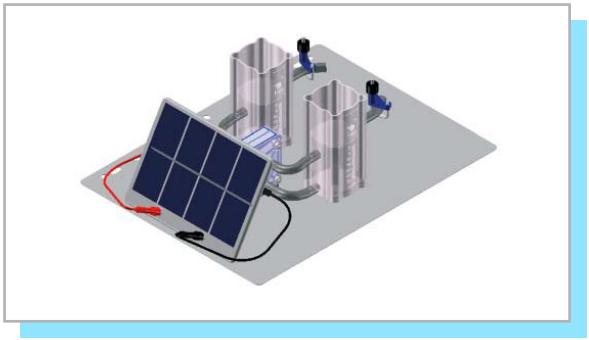
Risk of injury from hot surfaces!
The surface of solar modules can become very hot during operation. Touching the surface of solar modules may cause injuries. Do not touch the surface of solar modules during operation. Let the surface of the solar modules cool to 60 °C before removing.

Experiment 2: Solar hydrogen production and storage

Overview
The object of the experiment is to use the electrical energy obtained from the solar module to power the electrolyzer. The electrolyzer breaks down water into hydrogen and oxygen gases, which are stored in their respective gas storage tanks.

Setup time: approx. 3 minutes **Length of experiment:** approx. 5-15 minutes

Experiments from the accompanying book:
Decomposition of water with regard to the resulting volume of hydrogen and oxygen gas (2.1.)
Current-voltage characteristics, power curve and efficiency of the solar module (2.2.)
Current-voltage characteristics of the PEM electrolyzer (2.3.)
Energy efficiency and Faraday efficiency of the PEM electrolyzer (2.4.)



Devices and material

The following is required for the experiment:

- 1x Electrolyzer
- 2x Gas Storage Tanks
- 1x Solar module
- 1x Base plate
- 1x Tube set (4x short, 2x long)
- 2x Hose clamps
- 1x Protective goggles
- 2x Connecting cable (2mm)
- 1x Water bottle with distilled water
- Sufficient sunlight or halogen lamp

Setting Up:

1. Place the two gas storage tanks and the electrolyzer on the baseplate as shown in the sketch (Fig. 1).

2. Connect the bottom and top connectors of the electrolyzer to the corresponding connectors on the electrolyzer side of the storage tanks using four short hoses.

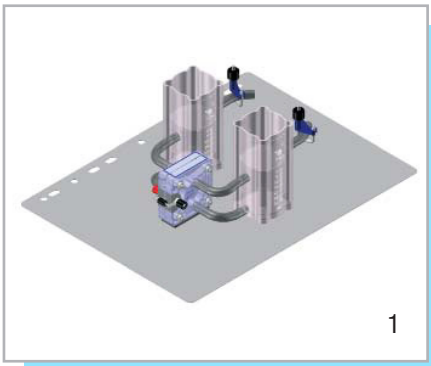
3. Fit long hoses to the connectors on the fuel cell side of the gas storage tanks and seal these with hose clamps (Fig. 1).

4. Fill both storage tanks with distilled water up to the top mark of the compensation tank.

5. Open the hose clamps on the hoses on the fuel cell side of the gas storage tanks one after the other. Air will escape from the gas storage tanks and the electrolyzer. The process is complete when the water level in the storage tanks stops falling (Fig. 2). After this, reseal the hose clamps.

6. Connect the solar module to the appropriate connectors on the electrolyzer using the connecting cables (Fig. 3).

When doing so, make sure that the polarity is correct (red = “+”, black = “-”).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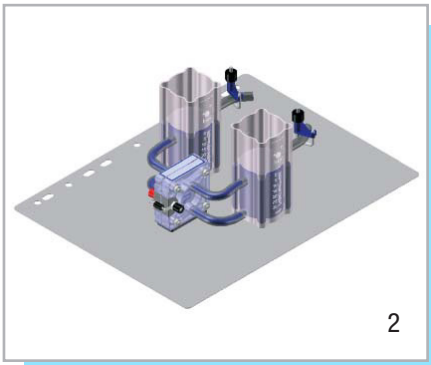
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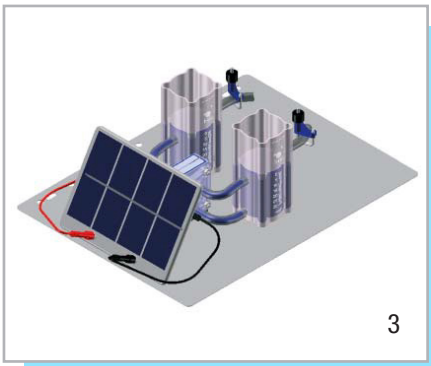
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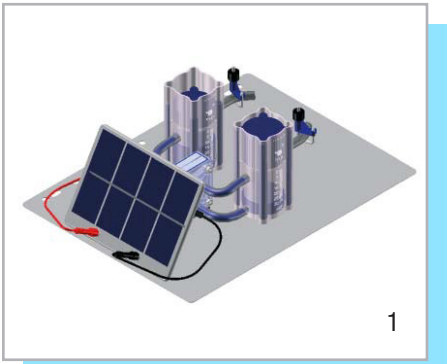
Gas production

1. When the illumination of the solar module is adequate, the electrolyzer will begin to produce hydrogen and oxygen in a ratio of 2:1 (Fig. 4).

Note:

If the lighting is not sufficient, you can use a powerful halogen spotlight.

2. When the gas storage tanks are full, excess gas will escape in the form of bubbles.



1

⚠ CAUTION

Risk of injury from hot surfaces!
The surface of solar modules can become very hot during operation. Touching the surface of solar modules may cause injuries. Do not touch the surface of solar modules during operation. Let the surface of the solar modules cool to 60 °C before removing.

CAUTION

Risk of damage through insufficient distance to lamps
The solar module can become excessively hot or sustain irreparable damage if it is too close to the lamp. Observe the minimum distance defined by the manufacturer when operating solar modules with lamps.

Emptying the storage tanks

1. To empty the storage tanks disconnect the electrolyzer from the solar module.

2. Take the storage tanks together with the electrolyzer from the baseplate and pour the water into a collecting tray.

⚠ CAUTION

Risk of injury from hydrogen ignition
Escaping hydrogen can ignite in proximity to an ignition source. Prevent hydrogen from escaping. Completely use up all hydrogen at the end of experiments, before dismantling.

Experiment 3: Solar hydrogen production and storage

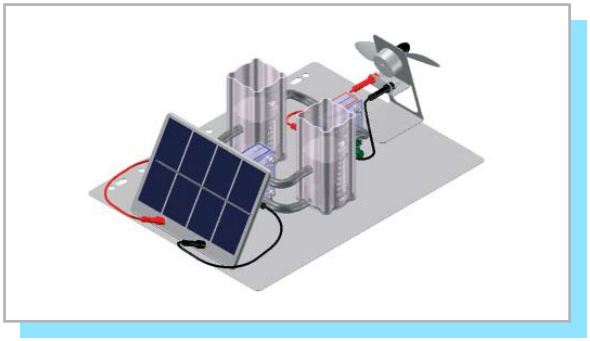
Overview

The object of the experiment is to use the stored gases to produce electrical energy. The gases are fed to the fuel cell, which converts the chemical energy into electricity and heat. An electrical load is used for illustration purposes.

Setup time: approx. 5 minutes **Length of experiment:** approx. 10 minutes

Experiments from the accompanying book:

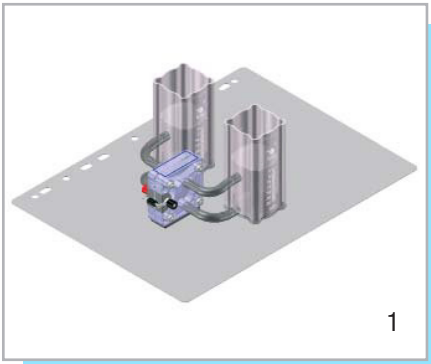
Decomposition of water with regard to the resulting volume of hydrogen and oxygen gas (2.1)
Current-voltage characteristics, power curve and efficiency of the solar module (2.2)
Current-voltage characteristics of the PEM electrolyzer (2.3)
Energy efficiency and Faraday efficiency of the PEM electrolyzer (2.4)
Current-voltage characteristics and power curve of the PEM fuel cell (2.5)
Energy efficiency and Faraday efficiency of the PEM fuel cell (2.6)



Devices and material

The following is required for the experiment:

- 1x Electrolyzer
- 1x Fuel cell
- 2x Gas Storage Tanks
- 1x Solar module
- 1x Fan
- 1x Base plate
- 1x Tube set (6x short)
- 1x Stopper
- 2x Cap
- 1x Protective goggles
- 4x Connecting cable (2mm)
- 1x Water bottle with distilled water
- Sufficient sunlight or halogen lamp



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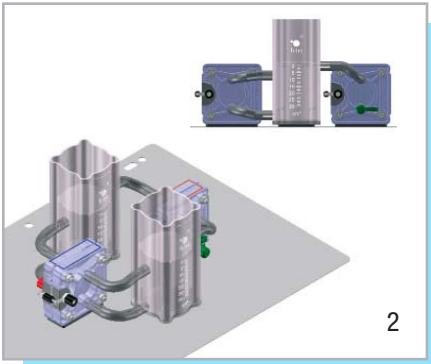

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3

Setting Up:

1. Place the two gas storage tanks and the electrolyzer on the baseplate as shown in the sketch (Fig. 1).

2. Connect the bottom and top connectors of the electrolyzer to the corresponding connectors on the electrolyzer side of the storage tanks using four short hoses (Fig. 1).

3. Place the fuel cell on the baseplate and connect the connectors on the fuel cell side of the hydrogen storage tank to the top connector on the hydrogen side of the fuel cell using a short hose (Fig. 2)

4. Fit caps to the bottom connectors of the fuel cell (Fig. 2).

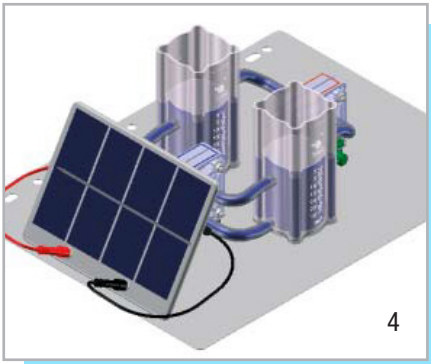
5. Fill both storage tanks with distilled water up to the lower mark on the compensation tank.

6. Open the caps on both sides of the fuel cell one after the other. Air will escape from the gas storage tanks, electrolyzer and fuel cell. The process is complete when the water level in the storage tanks stops falling (Fig. 3). After this, re-seal the bottom connectors of the fuel cell.

Note:
Make sure no water runs into the fuel cell.

7. Place the solar module on the baseplate and connect it to the appropriate connectors on the electrolyzer using the connecting cables (Fig. 4). When doing so, make sure that the polarity is correct (red = “+”, black = “-”).

8. Place the fan on the baseplate and connect it to the appropriate connectors on the fuel cell using the connecting cables. When doing so, make sure that the polarity is correct (red = “+”, black = “-”).



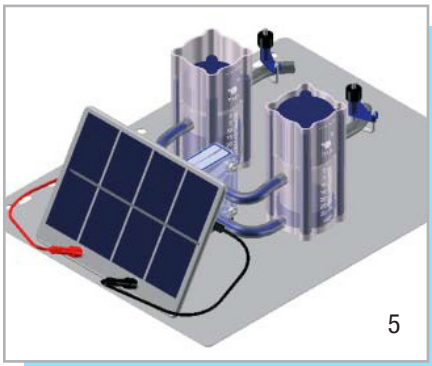
4

⚠ CAUTION

Risk of injury from hot surfaces!
The surface of solar modules can become very hot during operation. Touching the surface of solar modules may cause injuries. Do not touch the surface of solar modules during operation. Let the surface of the solar modules cool to 60 °C before removing.

CAUTION

Risk of damage through insufficient distance to lamps
The solar module can become excessively hot or sustain irreparable damage if it is too close to the lamp. Observe the minimum distance defined by the manufacturer when operating solar modules with lamps.



5

Gas production

1. When the illumination of the solar module is adequate, the electrolyzer will begin to produce hydrogen and oxygen in a ratio of 2:1 (Fig. 5).

Note:
If the lighting is not sufficient, you can use a powerful halogen spotlight.

2. When the gas storage tanks are full, excess gas will escape in the form of bubbles.

⚠ CAUTION

Risk of injury from hydrogen ignition
Escaping hydrogen can ignite in proximity to an ignition source. Prevent hydrogen from escaping. Stopping hydrogen production.

Operating the fuel cell

1. Open the caps on both sides of the fuel cell so that approximately 10cm³ of the stored gases can flow through the fuel cell. Residual air remaining in the hoses and in the fuel cell will escape. After this, replace the caps.

2. The cell will use the stored gas to generate electricity, along with water and a small amount of heat. The fan will start to run.

Note:
If gas production is stopped by removing the voltage source, the fuel cell will continue to produce current until there is no more gas left in the storage tanks. However, if gas production continues, the fuel cell will produce current continuously.

Emptying the storage tanks

1. To empty the storage tanks disconnect the electrolyzer from the solar module.

2. Take the storage tanks together with the electrolyzer from the baseplate and pour the water into a collecting tray.

⚠ CAUTION

Risk of injury from hydrogen ignition
Escaping hydrogen can ignite in proximity to an ignition source. Prevent hydrogen from escaping. Completely use up all hydrogen at the end of experiments, before dismantling.

Experiment 4: Solar hydrogen system - H_2/Air

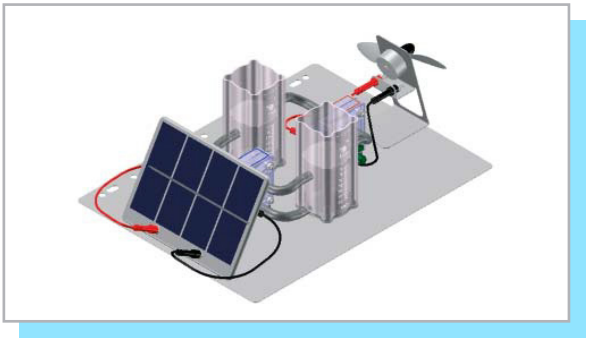
Overview

The object of the experiment is to produce electrical energy by using the stored hydrogen and oxygen in the air. The hydrogen is fed to the fuel cell, which converts the chemical energy into electricity, water and heat. An electrical load is used for illustration purposes.

Setup time: approx. 5 minutes **Length of experiment:** approx. 10 minutes

Experiments from the accompanying book:

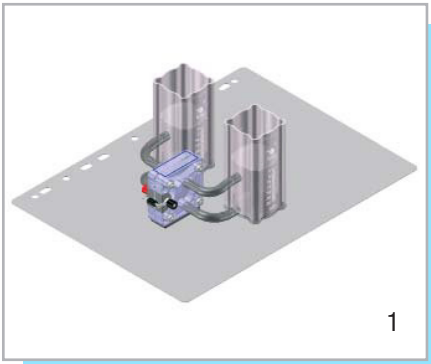
Decomposition of water with regard to the resulting volume of hydrogen and oxygen gas (2.1)
Current-voltage characteristics, power curve and efficiency of the solar module (2.2)
Current-voltage characteristics of the PEM electrolyzer (2.3)
Energy efficiency and Faraday efficiency of the PEM electrolyzer (2.4)
Current-voltage characteristics and power curve of the PEM fuel cell (2.5)
Energy efficiency and Faraday efficiency of the PEM fuel cell (2.6)



Devices and material

The following is required for the experiment:

- 1x Electrolyzer
- 1x Fuel cell
- 2x Gas Storage Tanks
- 1x Solar module
- 1x Fan
- 1x Base plate
- 1x Tube set (6x short)
- 1x Stopper
- 2x Cap
- 1x Protective goggles
- 4x Connecting cable (2mm)
- 1x Water bottle with distilled water
- Sufficient sunlight or halogen lamp



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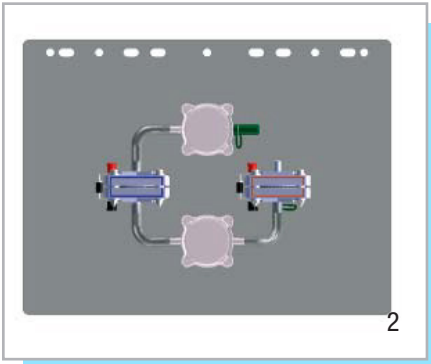


2

3

Setting Up:

1. Place the two gas storage tanks and the electrolyzer on the baseplate as shown in the sketch (Fig. 1).

2. Connect the bottom and top connectors of the electrolyzer to the corresponding connectors on the electrolyzer side of the storage tanks using four short hoses (Fig. 1).

3. Place the fuel cell on the baseplate and

connect the connectors on the fuel cell side of the gas storage tanks to the top connectors on the fuel cell using two short hoses. Make sure that the hydrogen side is connected with the hydrogen storage tank and the oxygen side is connected with the oxygen storage tank. Check that the stopper is fitted.

4. Fit a cap to the bottom connector on the hydrogen side of the fuel cell and to the connector on the fuel cell side of the oxygen storage tank.

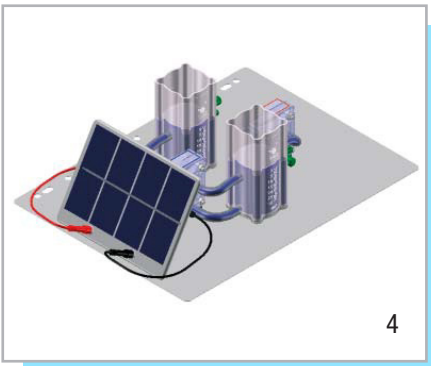
5. Fill both storage tanks with distilled water up to the lower mark on the compensation tank.

6. Open the cap on the bottom connector of the fuel cell and on the fuel cell side of the oxygen storage tank. Air will escape from the storage tanks, electrolyzer and fuel cell. The process is complete when the water level in the storage tanks stops falling (Fig. 3). After this, re-seal the bottom connector of the fuel cell and the connector on the oxygen storage tank.

Note:
Make sure that no water runs into the fuel cell.

7. Place the solar module on the baseplate and connect it to the appropriate connectors on the electrolyzer using the connecting cables (Fig. 4). When doing so, make sure that the polarity is correct (red = “+”, black = “-”).

8. Place the fan on the baseplate and connect it to the appropriate connectors on the fuel cell using the connecting cables. When doing so, make sure that the polarity is correct (red = “+”, black = “-”).



4

⚠ CAUTION

Risk of injury from hot surfaces!
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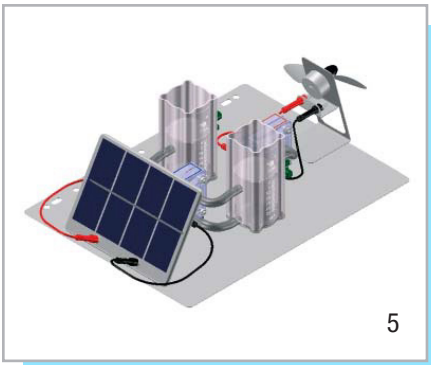
CAUTION

Risk of damage through insufficient distance to lamps
The solar module can become excessively hot or sustain irreparable damage if it is too close to the lamp. Observe the minimum distance defined by the manufacturer when operating solar modules with lamps.



5

Gas production

1. When the illumination of the solar module is adequate, the electrolyzer will begin to produce hydrogen and oxygen in a ratio of 2:1 (Fig. 5).

Note:

If the lighting is not sufficient, you can use a powerful halogen spotlight.

2. When the gas storage tanks are full, excess gas will escape in the form of bubbles.

⚠ CAUTION

Risk of injury from hydrogen ignition
Escaping hydrogen can ignite in proximity to an ignition source. Prevent hydrogen from escaping. Stopping hydrogen production.

Operating the fuel cell

1. Open the stopper on the oxygen side of the fuel cell.

2. Open the cap on the hydrogen side of the fuel cell so that approximately 10 cm^3 of the stored hydrogen can flow through the fuel cell. Residual air remaining in the hoses and in the fuel cell will ex-cape.

3. Replace the cap.

4. The fuel cell will use the stored hydrogen and atmospheric oxygen to generate electricity along with water and a small amount of heat. The fan will start to run.

Note:
If gas production is stopped by removing the voltage source, the fuel cell will continue to produce current until there is no more gas left in the storage tanks. However, if gas production continues, the fuel cell will produce current continuously.

Emptying the storage tanks

1. To empty the storage tanks disconnect the electrolyzer from the solar module and the fuel cell from the storage tanks.

2. Take the storage tanks together with the electrolyzer from the baseplate and pour the water into a collecting tray.

⚠ CAUTION

Risk of injury from hydrogen ignition
Escaping hydrogen can ignite in proximity to an ignition source. Prevent hydrogen from escaping. Completely use up all hydrogen at the end of experiments, before dismantling.

Technical data

Box:

H x W x D:	380 x 250 x 120 mm
Weight:	0.85 kg

Electrolyzer:

H_2 Production:	10 mL/min
O_2 Production:	5 mL/min
Permissible Current:	0 - 1.5 A
Permissible operating voltage:	0 - 2.0 VDC
Electrode Area:	3.6 cm^2
Guide value for distilled water:	<2 µS/cm
Permitted operating pressure:	0 - 20 mbar
H x W x D:	51 x 51 x 41 mm
Weight:	58 g

Fuel Cell:

H_2/ O_2 Power Range:	580 - 640 mW @ 1.5 A
H_2/ Air Power Range:	180 - 200 mW @ 375 mA
Electrode Area:	3.6 cm^2
Permissible Voltage:	0.45 - 0.96 V DC
Permitted operating pressure:	0 - 20 mbar
H x W x D:	51 x 51 x 41 mm
Weight:	58 g

Solar Module:

Active solar area:	approx. 60 cm^2
Open-circuit voltage:	approx. 2 V DC
Operating current:	approx. 350 mA

Gas Storage Tank:

Water Fill Volume - H_2 Side:	approx. 40 mL
Water Fill Volume - O_2 Side:	approx. 40 mL
Gas Storage Volume H_2:	30 mL
Gas Storage Volume O_2:	30 mL

Fan:

Permissible operating voltage:	0.18 - 6 V DC
Starting current:	approx. 10 mA
Rated power consumption:	approx. 10 mW

Troubleshooting

The fuel cell has very little power.

Possible Cause:

- The fuel cell was stored too dry or for too long. A fuel cell with a dry polymer electrolyte membrane (PEM) loses power.

Solution:

- Continue operation. The fuel cell moistens itself during operation which slowly allows it to reach its full capacity again.

Despite hydrogen being present, the load connected to the fuel cell (e.g. the fan) is not working.

Possible Cause:

- Water has entered the fuel cell during operation (e.g. through the gas storage tanks). Drops of water in the fuel cell can block the gas feed and lead to rapid loss of power.

Solution:

- Dry the fuel cell by opening and blowing out the connections.

CAUTION

Risk of damage from compressed air
The use of compressed air for drying the fuel cell can cause irreparable damage to the fuel cell.
Only blow out the fuel cell for drying without technical tools.

With the solar module connected, no hydrogen is produced in the electrolyzer.

Possible Cause:

- The light intensity is insufficient.

Solution:

- In order to operate solar modules, either adequate direct sunlight or concentrated light from a powerful electrical light source is required. Energy-saving light bulbs, fluorescent tubes etc. are unsuitable for the operation of solar modules.

Despite correct setup, the electrolyzer or the fuel cell is not working.

Possible Cause:

- No distilled water was used. The electrolyzer and/or the fuel cell has/have sustained irreparable damage.

Should the above-mentioned solutions not remedy the cause of error, please contact H-TEC EDUCATION.

Shutting down

- Continue operating the fuel cells until the consumer (e.g. the motor) stops independently. This allows some water to remain in the fuel cell, moistening the PEM. This procedure also prevents unnecessary discharge of hydrogen.
- Draining the gas storage tanks:

1 . All gas has to be consumed before draining the storage tanks.

⚠ CAUTION

Risk of injury from hydrogen ignition
Escaping hydrogen can ignite in proximity to an ignition source. Prevent hydrogen from escaping. Completely use up all hydrogen at the end of experiments, before dismantling.

2 . Remove the components from the experimentation plate or vehicle plate as one unit.

3 . Pour water into a collecting vessel.

- Disassembly is carried out in reverse order to assembly.

Before putting the product into storage, observe the following points:

- Close the connections of fuel cells and electrolyzers with caps. This prevents the PEM from drying out. The same applies to stoppers on fuel cells.
- Remove any water droplets from the experimentation plate or vehicle plate with a soft, lint-free cloth. This prevents the formation of water stains.

Maintenance

The components of the product do not require maintenance. The following points should be observed, though:

- Use freshly distilled water for each operation.
- After operation, remove the water from the gas storage tanks.

Disposal

Do not dispose of fuel cells and electrolyzers as general household waste.

⚠ WARNING

Fire hazard from catalytic substances
The catalysts for the electrodes of fuel cells and electrolyzers promote burning when they come into contact with flammable substances. Avoid contact with hydrogen, alcohol fumes or other organic fumes. Ensure correct disposal.

According to European regulations, used electric and electronic devices may no longer be disposed of as unsorted household waste. The symbol of the crossed-out wheelie bin indicates the requirement for separate disposal.

Your local waste management company can provide you with additional information about disposal options.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