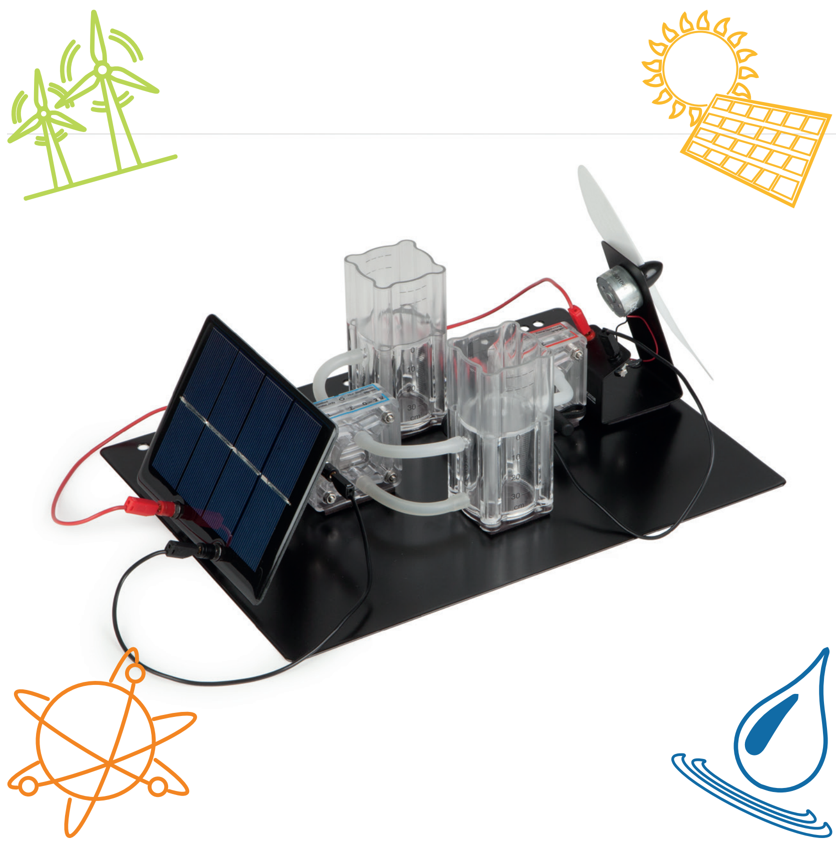
H-TEC EDUCATION

Solar-Hydrogen Cycle Experimentation Book



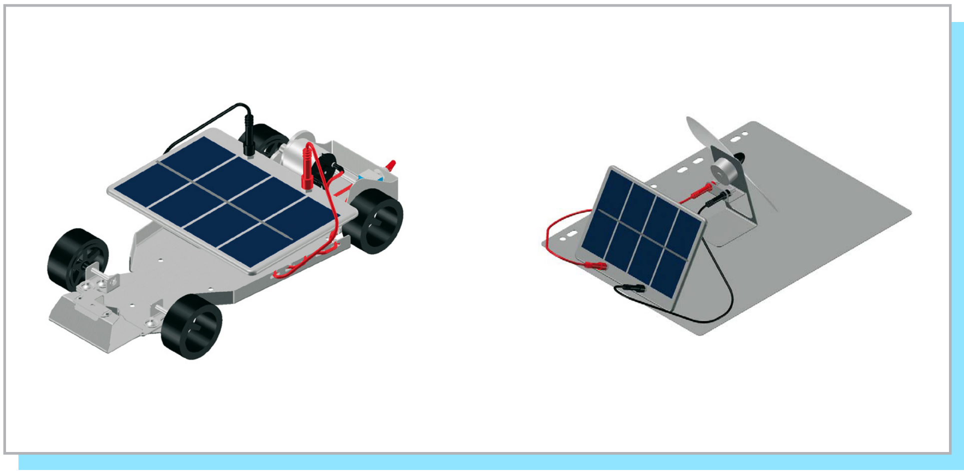
Experiment 1: Solar Energy Demonstration

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

Duration of the experiment: approx. 1 minute



Devices and materials

The following items are required for the experiment:

- 1x solar module
- 1x fan, vehicle plate, or other load
- 1x experimentation plate (optional)
- 1x suitable light source (full sunlight, or solar simulator light)
- 2x banana cables 2 mm (1 red, 1 black)
- Safety adapter 2 mm to 4 mm, if necessary

Setup/assembly

1 . Place the solar module and the fan on the experimentation plate (Fig. 1) or place the solar module on the vehicle plate (Fig. 2) as marked.

2 . Connect the solar module to the corresponding connections on the fan or to the motor cables on the experimentation plate using the connecting cables. Ensure correct polarity (red = "+", black = "-").

⚠ 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, at least, 140 °F / 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.

3 . When the solar module receives enough light, the fan or the motor starts to run.

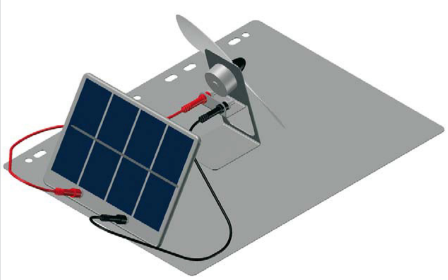


Fig. 1

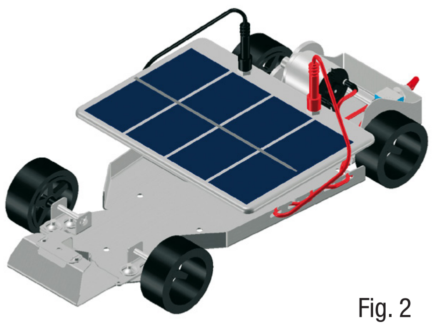


Fig. 2

Conclusion

When photons, or light particles, reach the solar panel, they react with the silicon cell and cause electrons to begin to move. This creates a flow of electric current. Wires in the individual cells on the solar panel (A.K.A. photovoltaic cells) then move that electric current from the solar module out to the fan or car motor.

Experiment 1

Solar Energy Demonstration

Solar module

Consumer

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Experiment 2: Hydrogen generation and storage

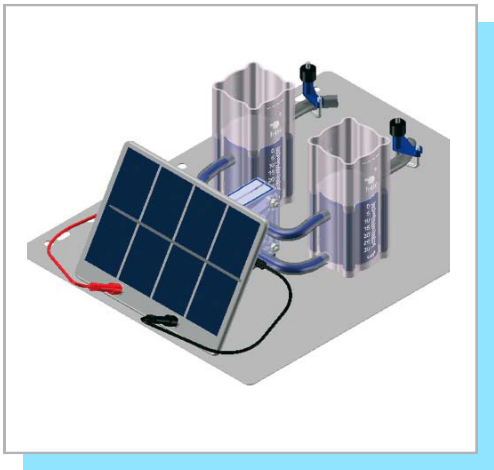
Overview:

The objective of the experiment is to operate the electrolyzer with the energy generated by the solar panel.

The electrolyzer splits water into the gases hydrogen and oxygen which are stored in the respective gas storage tanks.

Setup time: approx. 3 minutes

Duration of the experiment: approx. 5-15 minutes



Devices and materials

The following items are required for the experiment:

- 1x electrolyzer
- 2x gas storage tank
- 1x solar module or power supply
- 1x experimentation plate (optional)
- 1x suitable light source (full sunlight or solar simulator light)
- 1x tube set (4x short, 2x long)
- 2x tube clamp
- 1x bottle with distilled or deionized water - about 100 mL
- 2x banana cables 2 mm (1 red, 1 black)
- Safety adapter 2 mm to 4 mm, if necessary

Setup/assembly

1 . Connect the ports on the "Electrolyzer" side of the storage tanks to the corresponding ports on the electrolyzer, i.e. connect the top ports on the storage tank to the top ports on the electrolyzer. Do this using the short lengths of tube.

⚠ CAUTION

Risk of injury from hydrogen ignition
Damaged tubes or leaking connections can cause hydrogen to leak. Incorrect connection of the tubes can lead to formation of an explosive hydrogen-air mixture. Hydrogen and hydrogen-air mixtures can ignite in proximity to an ignition source. Check tubes and connections for damage before each setup. The tubes have to be connected exactly as described in the instructions.

2 . Place one long tube on the connection of the "Fuel Cell" side of each of the gas storage tanks and close each tube off with a tube clamp (Fig. 1).

3 . Fill both gas storage tanks with distilled water to the top marking on the top half of the gas storage tanks.

4 . Open the tube clamps. This will allow the air to escape from the gas storage tanks and the electrolyzer. The water will move to the bottom of the tank and into the electrolyzer. The process is completed when the water level in the gas storage tanks no longer decreases (Fig. 2). Then close off both tube clamps again.

5 . Connect the solar module to the corresponding connections on the electrolyzer using the connecting cables (Fig. 3). Ensure the correct polarity (red = "**+**", **black** = "**-**")!

⚠ CAUTION

Risk of injury from hot surfaces!
The protection diode on the electrolyzer becomes very hot in case of incorrect polarity. Touching the surface of the diode can cause injuries. Before startup, ensure correct polarity of the connecting cables and the electrical connections (red = "+", black = "-")! Do not touch the diode.

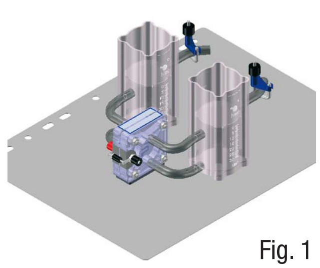


Fig. 1

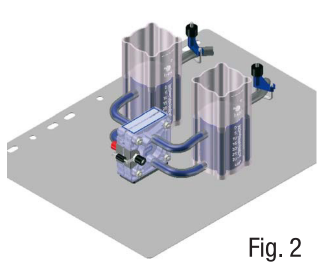


Fig. 2

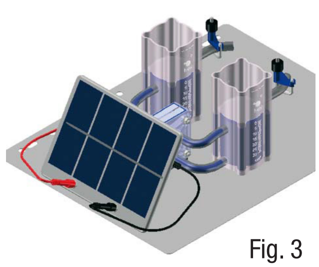


Fig. 3

Gas generation

1 . When the solar module receives enough light, or the power supply is turned on, the electrolyzer will produce hydrogen and oxygen (Fig. 4).

2 . Generate 30 mL of hydrogen and disconnect the solar panel.

Questions

When you generate 30 mL of hydrogen, how many mL of oxygen did you generate?

Why do you think you generated a different amount of hydrogen and oxygen?

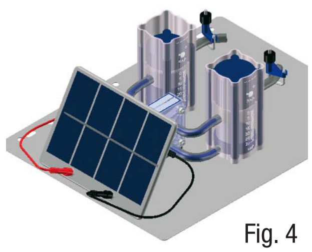


Fig. 4

Definitions

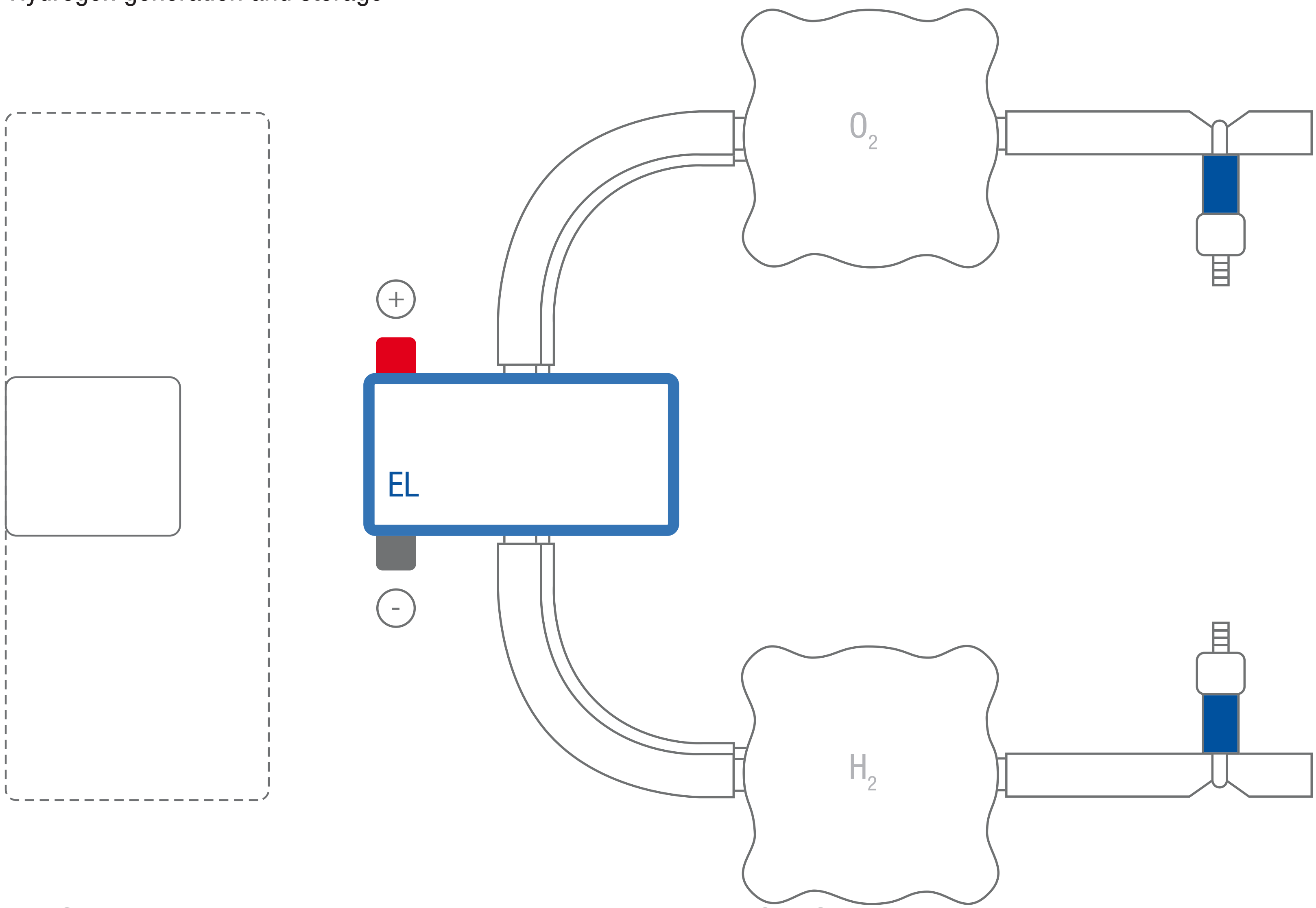
Catalyst: Allows electrolysis to occur at lower energy.
Electrolysis: A chemical change using electricity, i.e. splitting water into hydrogen and oxygen gases.
Membrane: A specialized plastic that allows only protons to move through.
Protons: Ions that are the positively charged part of hydrogen atoms.
Water: A molecule consisting of two hydrogen atoms and one oxygen atom.

Conclusion

Electrolyzers are filled with pure water and the catalyst is submerged. When electricity is applied, the combination of the catalyst and electricity allow the water to be split into two separate protons and a single oxygen atom. The single oxygen atom needs something to bond to, and automatically bonds to another oxygen atom, creating an oxygen molecule, or O_2.

At the same time as the oxygen atoms are joining, protons travel across the membrane, join with electrons from the power supply, and bond together to generate a hydrogen molecule or H_2. Because there is twice as much hydrogen in water hydrogen gas is created twice as fast as oxygen gas.

Experiment 2
Hydrogen generation and storage



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Experiment 3: Solar - hydrogen system using pure oxygen

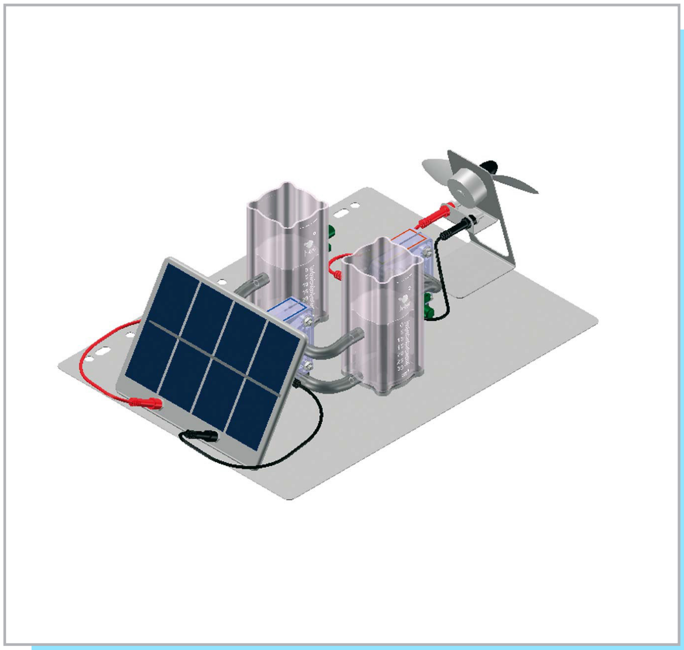
Overview

The objective of the experiment is to generate electrical energy from the stored gases.

The gases are fed to the fuel cell. The fuel cell converts the chemical energy into electricity and heat. The electrical consumer is used for illustration purposes.

Setup time: approx. 5 minutes

Duration of the experiment: approx. 10 minutes



Devices and material

The following is required for the experiment:

- 1x electrolyzer
- 1x fuel cell in H_2/O_2 configuration
- 2x gas storage tank
- 1x solar module or power supply
- 1x experimentation plate (optional)
- 1x suitable light source (full sunlight or solar simulator light)
- 1x load
- 1x tube set (6x short)
- 2x caps
- 1x bottle with distilled or deionized water - about 100 mL
- 2x banana cables 2 mm (1 red, 1 black)
- Safety adapter 2 mm to 4 mm, if necessary

Setup/assembly

1 . Connect the ports on the "Electrolyzer" side of the storage tanks to the corresponding ports on the electrolyzer, i.e. connect the top ports on the storage tank to the top ports on the electrolyzer. Do this using the short lengths of tube.

2 . Connect the top ports on the "Fuel Cell" side of the storage tanks to the top ports on the fuel cell. Do this using the short lengths of tube. The stopper of the fuel cell must be in place.

3 . Close each of the two lower connections of the fuel cell with a cap (Fig. 1).

4 . Fill both gas storage tanks with distilled water to the lower marking on the top half of the gas storage tanks.

5 . Open the caps on both sides of the fuel cell so that the air escapes from gas storage tanks, electrolyzer and fuel cell. The process is completed when the water level in the gas storage tanks no longer decreases (Fig. 2). Then close the lower connections of the fuel cell with the caps again.

NOTE

Water in the fuel cell
Ensure that no water runs into the fuel cell. A water film on the electrode surface can suppress the reaction of hydrogen and oxygen in the fuel cell. The fuel cell then does not have sufficient power.

6 . Connect the solar module to the connections on the electrolyzer using the banana cables (Fig. 3). Ensure the correct polarity (**red** = "**+**", **black** = "**-**")!

7 . Connect the fan to the connections on the fuel cell using the banana cables. Ensure correct polarity (**red** = "**+**", **black** = "**-**").

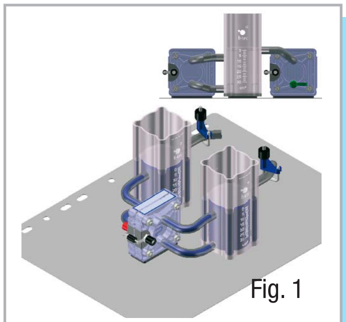


Fig. 1

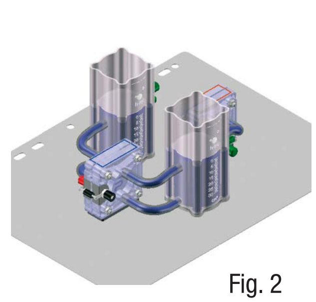


Fig. 2

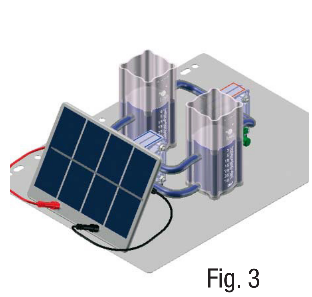


Fig. 3

Gas generation

1 . When the solar module receives enough light, or the power supply is turned on, the electrolyzer will produce hydrogen and oxygen (Fig. 4).

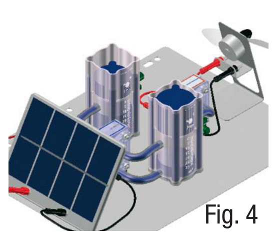


Fig. 4

Starting up the fuel cell

Carry out the following steps to purge the remaining ambient air from the tubes and the fuel cell:

1 . Briefly open the caps at both sides of the fuel cell one after the other so that 10 mL of the stored gases can flow through the fuel cell.

2 . Close the respective cap again. The fan should begin rotating.

3 . Continue operating the fuel cell until the load (e.g. the fan) stops independently after the power source has been removed. This allows some water to remain in the fuel cell, moistening the PEM. The experiment can now be disassembled and stored.

Questions

How long does it take the electrolyzer to produce 30mL of hydrogen?

How long does it take the fuel cell to consume 30mL of hydrogen?

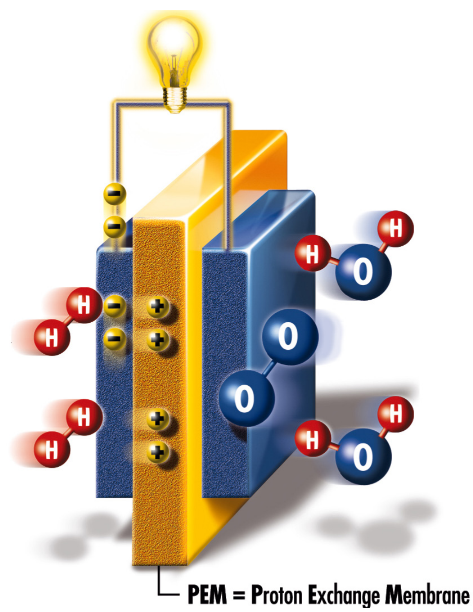
What can you infer from this?

Definitions

Catalyst: Allows electrolysis to occur at lower energy.
Electrolysis: A chemical change using electricity, i.e. splitting water into hydrogen and hxygen gases.
Membrane: A specialized plastic that allows only protons to move through.
Protons: Ions that are the positively charged part of hydrogen atoms.
Water: A molecule consisting of two hydrogen atoms and one oxygen atom.

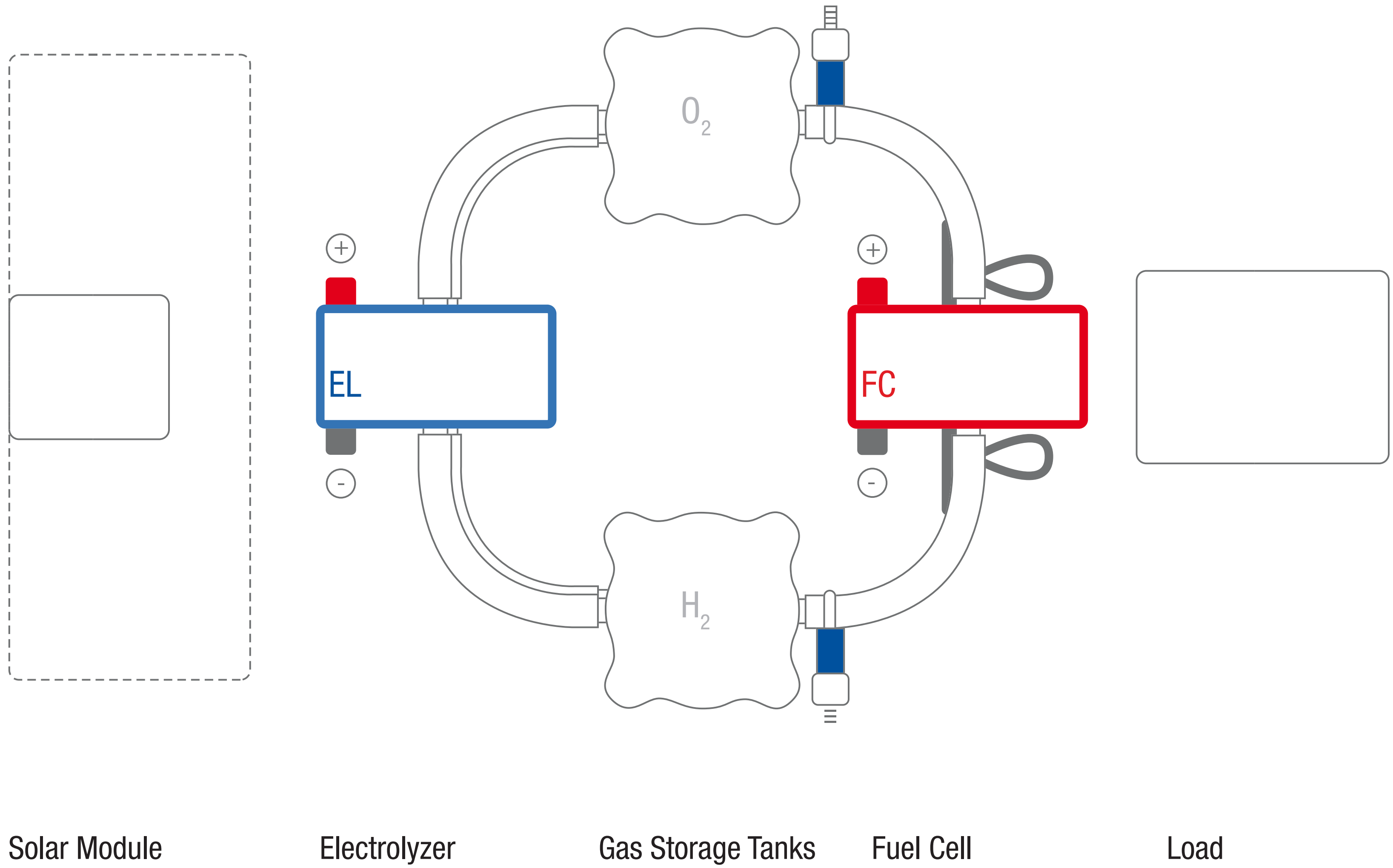
Conclusion

Hydrogen and oxygen gases are supplied to the fuel cell. When the hydrogen molecules (H_2) hit the catalyst they are broken into two protons and two electrons. The protons then move across the membrane to the oxygen side. As this is happening, the electrons move into the electric circuit, and do work on the load (in this case the fan). As the electrons flow through the circuit they end up on the oxygen side as well. At this time, oxygen molecules (O_2) are being split into single oxygen atoms (O). The oxygen atom then joins with two protons and two electrons and create water (H_2O).



Experiment 3

Solar hydrogen generation system - H_2/O_2



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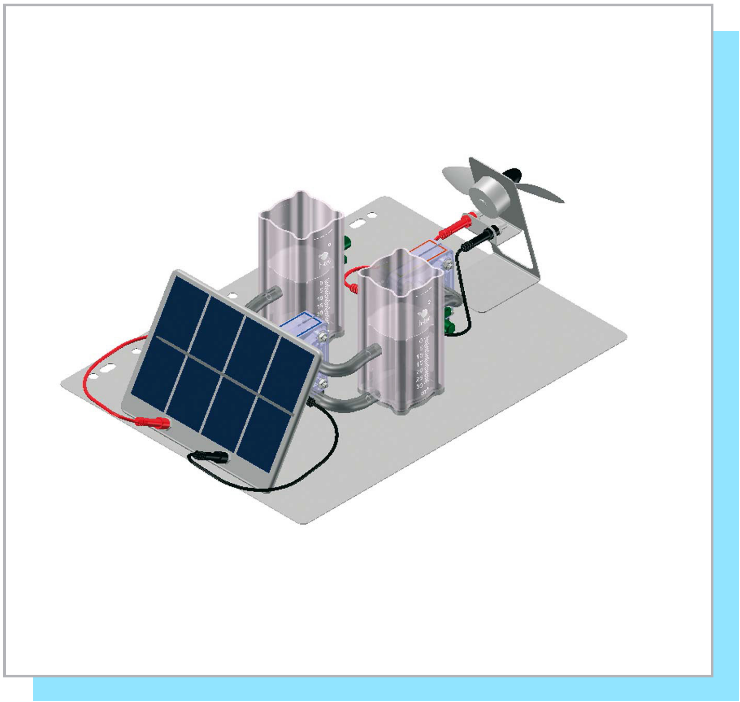
Experiment 4: Solar - hydrogen system - H_2/Air

Overview

The objective of the experiment is to generate electrical energy from the stored hydrogen and atmospheric oxygen. The hydrogen is fed to the fuel cell. The fuel cell converts the chemical energy into electricity and heat. The electrical consumer is used for illustration purposes.

Setup time: approx. 5 minutes

Duration of the experiment: approx. 10 minutes



Devices and material

The following is required for the experiment:

- 1x electrolyzer
- 1x fuel cell in H_2/O_2 configuration
- 2x gas storage tank
- 1x solar module or power supply
- 1x experimentation plate (optional)
- 1x suitable light source (full sunlight or solar simulator light)
- 1x load
- 1x tube set (5 x short)
- 2x caps
- 1x bottle with distilled or deionized water - about 100 mL
- 2x banana cables 2 mm (1 red, 1 black)
- Safety adapter 2 mm to 4 mm, if necessary

Setup/assembly

1 . Connect the ports on the "Electrolyzer" side of the storage tanks to the corresponding ports on the electrolyzer, i.e. connect the top ports on the storage tank to the top ports on the electrolyzer. Do this using the short lengths of tube.

2 . Connect the top port of the hydrogen side (negative connection) of the fuel cell to the top port of the corresponding storage tank. Do this using the short lengths of tube. Remove the stopper from its place.

3 . Close the lower connection of the hydrogen side (negative connection) of the fuel cell with a cap. Close the connections on the "Fuel Cell" side of the oxygen storage tank (Fig. 1).

4 . Fill both gas storage tanks with distilled water to the lower marking on the top half of the gas storage tanks.

5 . Open the caps on both sides of the fuel cell so that the air escapes from gas storage tanks, electrolyzer and fuel cell. The process is completed when the water level in the gas storage tanks no longer decreases (Fig. 2). Then close the lower connections of the fuel cell with the caps again.

NOTE

Water in the fuel cell
Ensure that no water runs into the fuel cell. A water film on the electrode surface can suppress the reaction of hydrogen and oxygen in the fuel cell. The fuel cell then does not have sufficient power.

6 . Connect the solar module to the connections on the electrolyzer using the banana cables (Fig. 3). Ensure the correct polarity (red = "+", **black** = "-")!

7 . Connect the fan to the connections on the fuel cell using the banana cables. Ensure correct polarity (red = "+", **black** = "-").

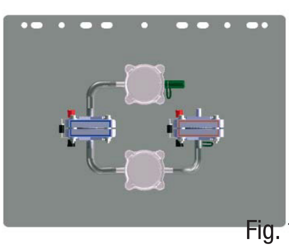


Fig. 1

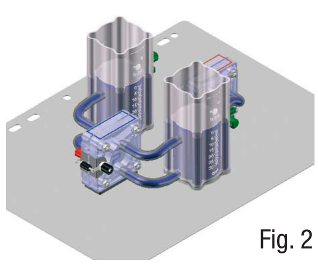


Fig. 2

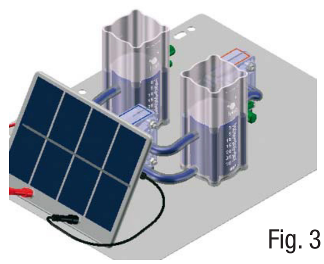


Fig. 3

Gas generation

1 . When the solar module receives enough light, or the power supply is turned on, the electrolyzer will produce hydrogen and oxygen (Fig. 4).

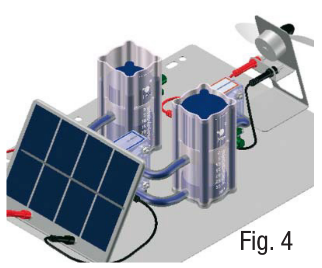


Fig. 4

Starting up the fuel cell

Carry out the following steps to purge the remaining ambient air from the tubes and the fuel cell:

1 . Briefly open the caps on the fuel cell and the storage tank one after the other so that 10 mL of the stored gases can flow through the fuel cell.

2 . Close the respective cap again. The fan should begin rotating.

3 . Continue operating the fuel cell until the load (e.g. the fan) stops independently after the power source has been removed. This allows some water to remain in the fuel cell, moistening the PEM. The experiment can now be disassembled and stored.

Questions

Does the fan run longer in H_2/O_2 mode or in H_2/Air mode?

Does the fan run faster in H_2/O_2 mode or in H_2/Air mode?

What can you infer from this?

What could be the benefits of operating a fuel cell in H_2/Air mode over H_2/O_2 mode?

Definitions
Catalyst: Allows electrolysis to occur at lower energy.
Electrolysis: A chemical change using electricity, i.e. splitting water into hydrogen and oxygen gases.
Membrane: A specialized plastic that allows only protons to move through.
Protons: Ions that are the positively charged part of hydrogen atoms.
Water: A molecule consisting of two hydrogen atoms and one oxygen atom.

Conclusion
Hydrogen and oxygen gases are supplied to the fuel cell. When the hydrogen molecules (H_2) hit the catalyst they are broken into two protons and two electrons. The protons then move across the membrane to the oxygen side. As this is happening, the electrons move into the electric circuit, and do work on the load (in this case the fan). As the electrons flow through the circuit they end up on the oxygen side as well. At this time, oxygen molecules (O_2) are being split into single oxygen atoms (O). The oxygen atom then joins with two protons and two electrons and create water (H_2O).

When using the fuel cell in H_2/Air mode, the fuel cell will put out much less power than it will in H_2/O_2 mode. This is because ambient air contains only about 21% oxygen. When using the pure oxygen generated by the electrolyzer the fuel cell is able to create more power.

A few benefits of using a fuel cell in H_2/Air mode are:

- fewer components needed
- safety (no need to store oxygen)
- fuel cell will not flood as easily
- less expensive

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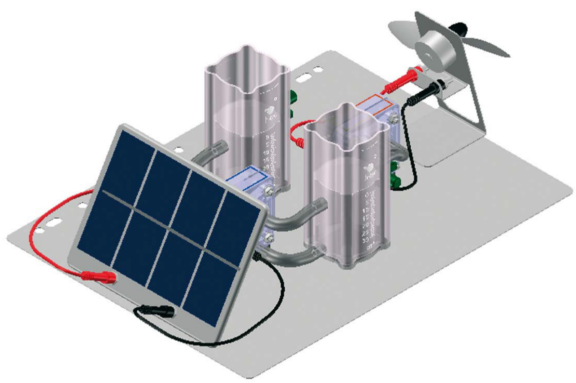
Experiment 5: Current and voltage characteristics and Power curve of a fuel cell

Overview

The objective of the experiment is to see the relationship between current, voltage and power, and see the effects changing each variable has on the production of electricity in the fuel cell.

Setup time: approx. 5 minutes

Duration of the experiment: approx. 30 minutes



Devices and material

The following is required for the experiment:

- 1x electrolyzer
- 1x H_2/O_2/Air fuel cell
- 2x gas storage tank
- 1x solar module or power supply
- 1x experimentation plate (optional)
- 1x suitable light source (full sunlight or solar simulator light)
- 1x decade resistor or various resistors
- 2x multimeters
- 1x tube set (5 x short)
- 2x caps
- 1x bottle with distilled or deionized water
- - about 100 mL
- 6x banana cables 2 mm (3 red, 3 black)
- Safety adapter 2 mm to 4 mm, if necessary

Setup/assembly

1 . Connect the fuel cell, electrolyzer, power source, and storage tanks as in Experiment 3. Instead of connecting the load, connect the fuel cell to the decade resistor, and multimeters as shown in Fig. 1. The multimeters should be set up as shown in Fig. 2.

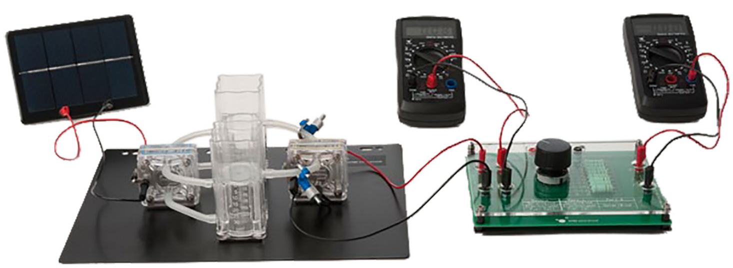


Fig. 1

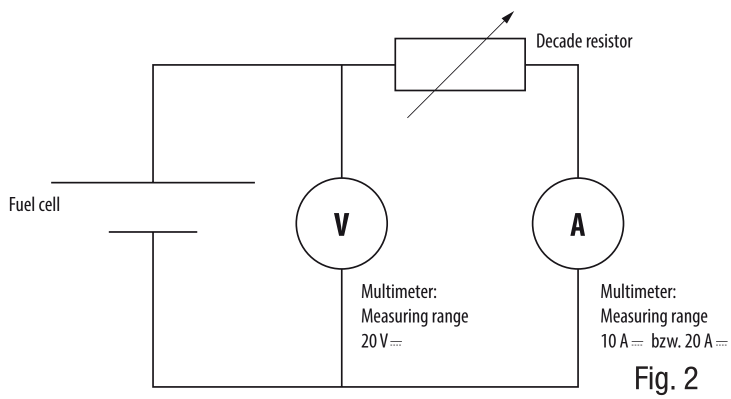


Fig. 2

Procedure

1 . Begin gas production and fuel cell operation as explained in Experiment 3. After fuel cell is purged, you may begin taking readings from the multimeters.

2. Start recording the current and voltage using open circuit voltage (R = ∞), and work your way to lower resistances. After changing the resistance, wait about 20 seconds to obtain accurate results.

3. Repeat the experiment in H_2/Air mode.

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Data

Power = Voltage • Current

Resistance R (Ω)	Voltage U (V)		Current I (A)		Power P (W)	
	H_2/O_2	H_2/Air	H_2/O_2	H_2/Air	H_2/O_2	H_2/Air

Analysis

1. Plot a graph of current (x-axis) vs. voltage (y-axis) using the recorded values.

2. Plot a graph of power (x-axis) vs. current (y-axis), marking the maximum power.

Questions

1. Was your max power at the max current point, max voltage point, or somewhere in between?

2. Why do you think this is?

3. What was the max power in H_2/O_2 mode? What was the max power in H_2/Air mode?

4. Is this difference proportional to the difference in 100% oxygen content of pure oxygen vs. the 21% oxygen content in atmospheric oxygen?

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