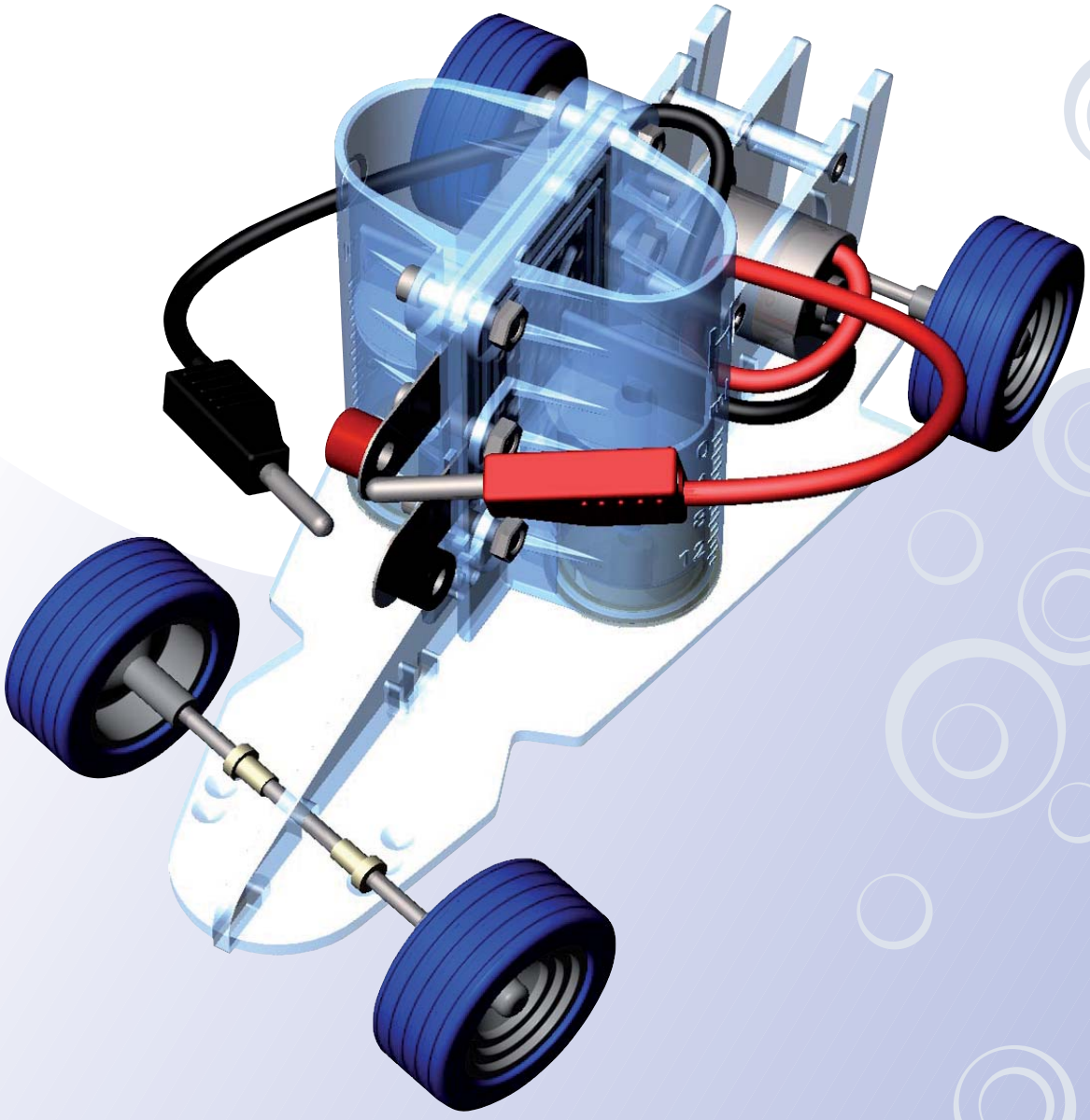
Heliocentris

Dr FuelCell® Model Car

Teacher's Guide



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Content

Preface

This book is intended to bring your students into contact with fuel cell technology. The basic principles of fuel cells are examined in a playful, fun filled manner, encouraging your students to examine this new technology.

Fuel cells use the chemical energy of hydrogen to generate electricity, cleanly and efficiently. Hydrogen fuel cells have the potential to

- Reduce the generation of greenhouse gases, air pollution and global climate changes
- Be an important part of energy security
- Propel hydrogen technology as the energy supply of the future

Teaching your students about this important technology will give them an edge in this developing field.

Curriculum aspects

Many curriculum aspects can be taught with this new technology:

- Concept of molecules
- Structure of atoms
- Chemical reactions
- Conversion of different types of energy
- Performing scientific inquiries
- Design and conduct scientific investigations
- Science and technology in local, national and global challenges

We hope your students will play an important part in making fuel cells part of our sustainable future.

8 Hydrogen Power!

In this investigation the students will explore how to gain electrical energy from combining hydrogen and oxygen.

This investigation is a continuation of the previous ones but it is not essential that the students have actually performed them.

8.1 Teacher's Essentials

8.1.1 Objectives

Qualifications

In order to ensure maximum learning success, your students should already be familiar with:

- Breaking up of chemical compounds
- Redox reaction
- Batteries
- Hydrogen test
- Linearity and extrapolation

Learning objectives

In this investigation your students will learn:

- Gaining electricity from combining hydrogen and oxygen
- Conversion of energy
- Power as the product of current and voltage
- Faraday's first law of electrolysis
- Need for reproducibility of scientific investigations
- Hydrogen is stored chemical energy

Outlook

This investigation may serve as a starting point for a variety of different topics, for example:

- Concept of catalysts
- Concept of electrons, atoms, etc.
- Power industries
- Greenhouse effect
- Avogadro's constant

8.1.2 Time Table

The amounts of time are rough estimates.

Task	Time
Preparation prior to class	20 min
Investigation	90 min
Time students will need to answer questions	35 min

Table 8-1 Schedule

8.1.3 Teaching Method

Method	Suitability
Group work	✓✓✓✓
Chalk and talk	✓
Silent work (student questions)	✓✓
Homework (student questions)	✓✓✓

Table 8-2 Teaching method (✓= poor … ✓✓✓✓=very good)

8.1.4 Background

Powering a car with hydrogen?

In the electrolyzer we have used in the previous experiments we have a source of hydrogen and a way of storing it in the gas cylinder. We also have a source of oxygen, although we could simply use air, as it contains 21 % oxygen. Now we need a way to change the hydrogen and oxygen back into electricity that will power an electric motor to move the car.

Fuel cell

In the Model Car a device to change hydrogen and oxygen back into water is provided. In investigation *UNDERSTANDING ELECTROLYSIS* we used the main component in this kit – the reversible fuel cell – as an electrolyzer. But if you supply hydrogen on one side of the fuel cell and oxygen on the other, the reversible fuel cell produces an electric current. The hydrogen unites with the oxygen to produce water again, which is the material we started with. You could write this as follows:

Electricity + Water → Hydrogen + Oxygen

Hydrogen + Oxygen → Water + Electricity

This could be a wonderful solution to the air pollution problem as hydrogen fuel cell power would release only water or water vapor into the atmosphere, using water and electricity as the source of the hydrogen needed to power the fuel cell.

Astronauts already use this technology in space stations. With solar cells, electrolyzers, fuel cells, and an initial supply of water, the astronauts have a source of electricity and oxygen as well as an abundant supply of hydrogen. As the hydrogen is used as fuel to produce electricity, it also produces water.

Recall the reaction within a fuel cell:

$2\ H_2 + O_2 \rightarrow 2\ H_2O$

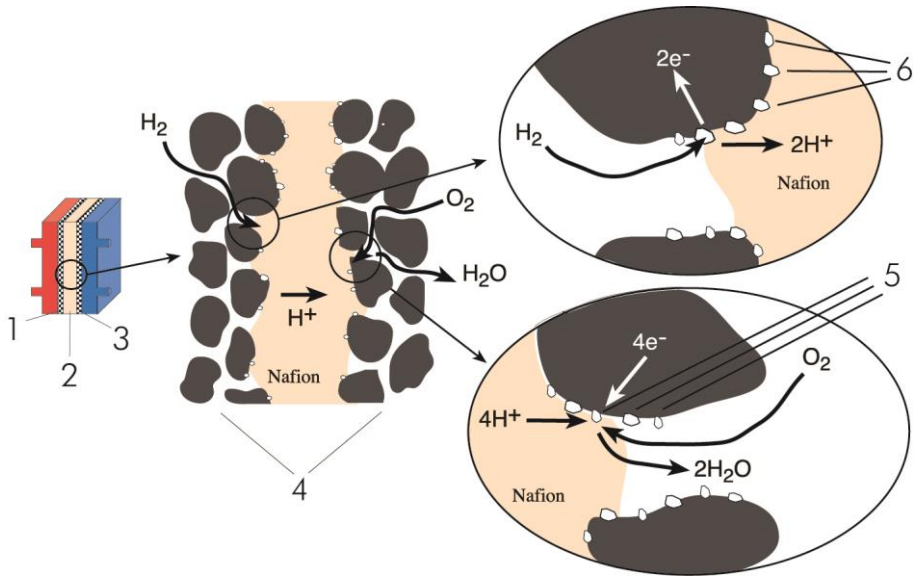

Fig. 8-1 Principle fuel cell

1	Anode	4	Carbon layer
2	Polymer electrolyte membrane (Nafion)	5	Platinum-iridium catalyst
3	Cathode	6	Platinum catalyst

The electron flow can be used by a consumer load.

With the Model Car we can use stored hydrogen to produce electricity to power the motor. Because the electric motor spins very quickly it has gearing to reduce the speed of the motor shaft and carry power the rear wheels of the car

Power

When describing electrical events, the power (in watts) going into or out of a device can be determined by multiplying the current (in amperes) passing through the device by the voltage (in volts) that exists across that device. Power describes the strength of a process. We can write:

$I \times V = P$ (amperes × volts = watt)

Anode / Cathode

When we used the reversible fuel cell as an electrolyzer, we observed the polarity: negative (black) = hydrogen=cathode, and positive (red) = oxygen = anode. Now that we are using the reversible fuel cell as a fuel cell, it is convenient that the polarity is almost the same. The hydrogen side (black) produces a negative voltage; the oxygen side (red) produces a positive voltage. However in keeping with the definition of anode / cathode (electrons are lost at the anode), the hydrogen side is now called the anode and the oxygen side is called the cathode.

8.2 The Investigations – Teachers

8.2.1 Preparation

It is advisable that you try out this investigation before class.

8.2.2 In Class

Depending on your didactic approach and the number of Model Cars at hand, you may either choose group work or chalk and talk teaching.

Safety

- ➔ Always make your students aware of investigating safely and make yourself familiar with the potential hazards.
- ➔ Make sure to provide the students with goggles and to wear goggles yourself.

> ⚠ **CAUTION**
>
> **Overpressure in reversible fuel cell!**
>
> Injuries due to objects shooting out, when the top of the overflow compartments of the storage cylinders is obstructed.
>
> - ➔ Do not block the top of the overflow compartments of the storage cylinders.
> - ➔ Always wear eye protection.

> ⚠ **CAUTION**
>
> **Ignition of hydrogen!**
>
> Skin burns and damage to the fuel cell.
>
> - ➔ No open flames.
> - ➔ No smoking.
> - ➔ Well ventilated workspace.

TIP

Students may observe that the motor stops before all the hydrogen is used up, or conversely, the motor continues to run after the hydrogen appears to be gone. You could offer the following explanations:

- Motor stops before all the hydrogen is used up:
  - This may be the result of air left in the system when it was filled with water. What's left in the hydrogen side is not completely hydrogen.
- Motor continues to run after the hydrogen is gone:
  - Although no hydrogen is visible in the storage cylinder, hydrogen can still be present around the membrane.

8.2.2.2 Group Work

For group work several Model Cars are required.

8.2.2.3 Chalk and Talk

For chalk and talk only one Model Car is required.

To present the investigation you will need the following:

Investigation

- ✓ Goggles or eye protection
- ✓ Solar panel or hand generator

TIP

As an alternative to the solar panel you may also use the hand generator as a source for electrical energy (see Instruction Manual).

- ✓ 2 or 5 patch cords (5 if you wish to investigate how much power the fuel cell can deliver)
- ✓ Reversible fuel
- ✓ Car with motor
- ✓ Load measurement box (if you wish to investigate how much power the fuel cell can deliver)
- ✓ Distilled water
- ✓ 100–120 watts PAR lamp, or equivalent light source
- ✓ Block of wood or other support for the car

✓ Watch with second hand or stopwatch function

1. Put on your goggles.

Filling the reversible fuel cell with distilled water

2. Place the fuel cell upside down (numbers facing down) on the flat surface.
3. Remove the stoppers.

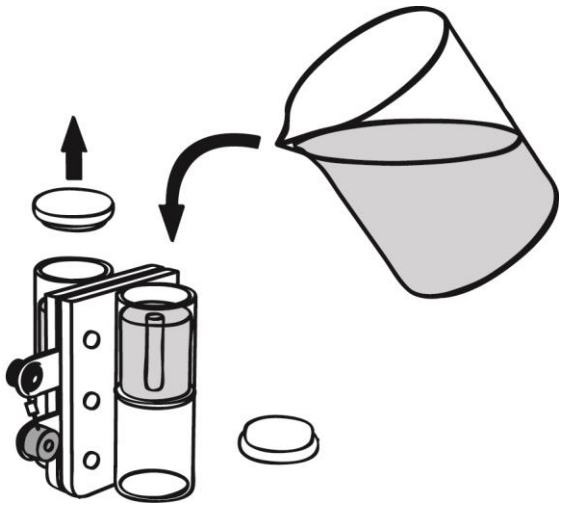

Fig. 8-2 Filling the reversible fuel cell with distilled water

NOTICE

Only use distilled water!

Tap water and other liquids will permanently damage the membrane of the reversible fuel cell.

4. Pour distilled water into both storage cylinders until the water reaches the tops of the small tubes in the center of the cylinders.
5. Tap the fuel cell lightly to help water flow into the area surrounding the membrane and metal current-collecting plates.
6. Add more water until it starts to overflow into the tubes in the cylinders.
7. Place the stoppers back onto the cylinders. Make sure no air is trapped inside the cylinder.

TIP

A small air bubble in the order of 0.5 mL will not cause problems and can be ignored.

8. If the reversible fuel cell has not been used for a while, leave it to rest for 20 min; if has been used recently, turn it right side up.

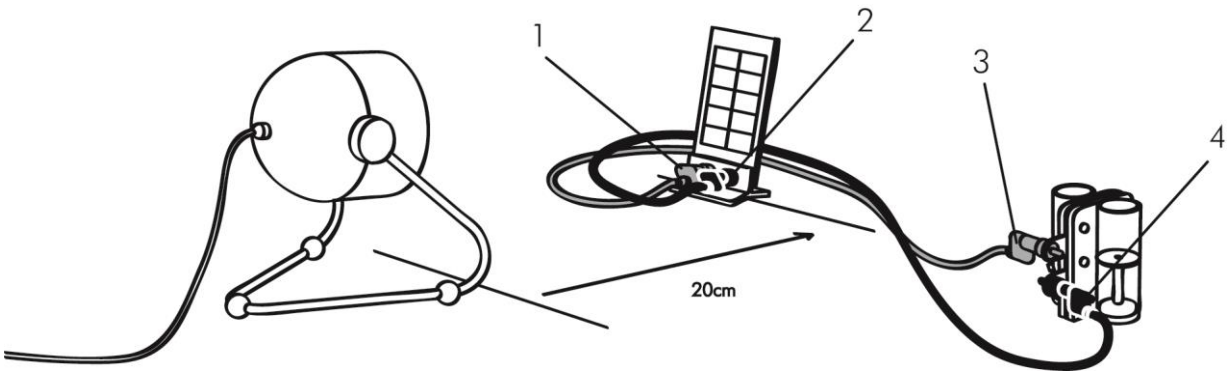

Fig. 8-3 Connecting solar panel and fuel cell

Producing hydrogen

9. Plug the red banana jacks of the red patch cord into the red (positive) banana jack terminals of the solar panel (1) and the fuel cell (3).

> **NOTICE**
>
> **Short circuit of reversible fuel cell!**
>
> Hot spots in the membrane, leading to deterioration of the membrane.
>
> ➔ Do not short circuit the reversible fuel cell.

10. Repeat step 9 with the black patch cord and the negative terminals (2, 4).

> **NOTICE**
>
> **Overheating of the solar panel!**
>
> Malfunctioning of or permanent damage to the solar cells.
>
> ➔ Only use light sources with a maximum power of 120 W.
>
> ➔ Keep a minimum distance of 20 cm (8 inches) between light source and solar panel.
>
> ➔ Do not concentrate light.

11. Align the solar panel with the light source, keeping a minimum distance of 20 cm (8 inches).

> ⚠ **CAUTION**
>
> **Hot surface of solar panel and lamp!**
>
> Skin burns.
>
> ➔ Do not touch the hot surface of the solar panel or lamp.
>
> ➔ Allow solar panel / lamp to cool down before touching it.

12. Turn on the light.

The fuel cell starts producing hydrogen.

13. When the hydrogen storage cylinder is filled to a little more than 12 ml:
    - Turn off the light.
    - Unplug the patch cords from the reversible fuel cell.

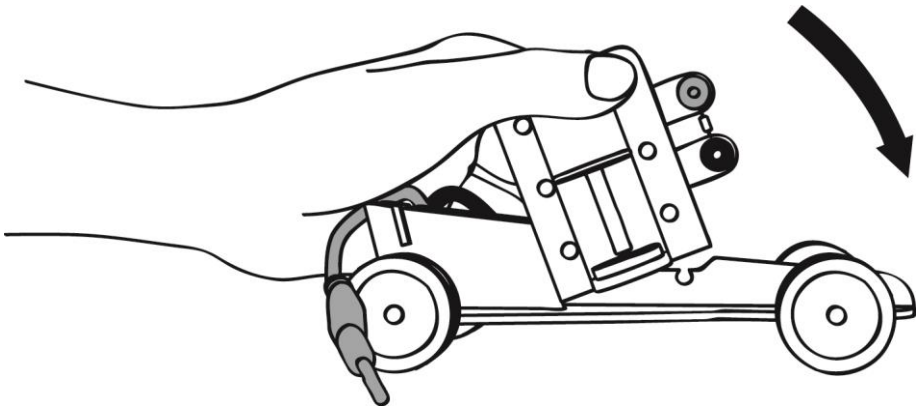

Fig. 8-4 Placing reversible fuel cell onto Model Car

Running the car

14. With the red and black terminals facing towards the front of the car, place the reversible fuel cell into the notches on the model car until it audibly clicks into place.

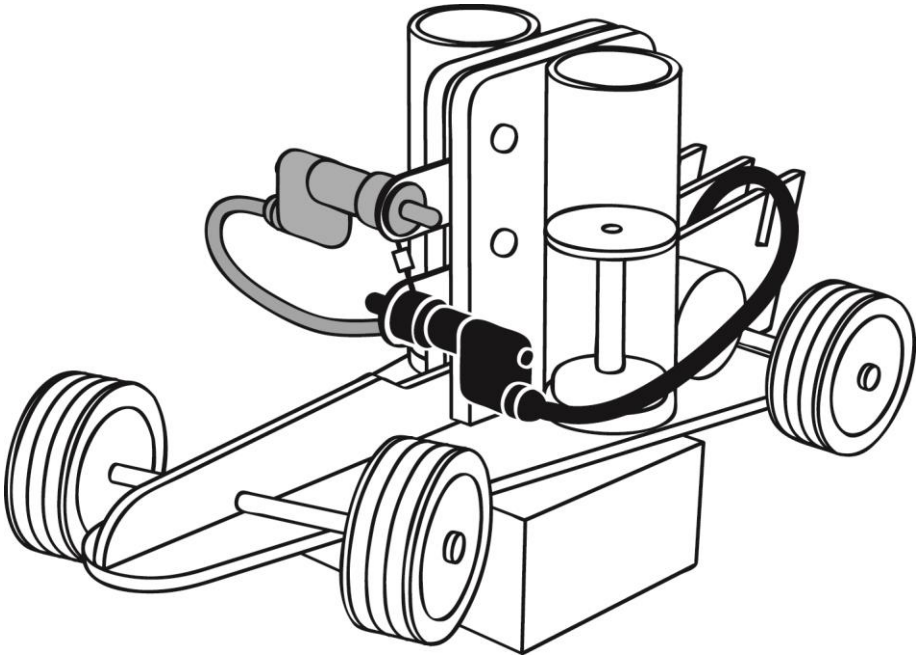

Fig. 8-5 Placing Model Car on block

15. Place the block of wood under the car base, so that the wheels on the car are free to turn.
16. Connect the red (positive) banana jack with the red (positive) terminal and the black (negative) banana jack with the black (negative) terminal.

Student participation

17. Have the students watch the level of gas in the hydrogen storage cylinder and when the gas level reaches exactly 12 mL, have them start a stopwatch (or record the time to the nearest second).
18. Have them record the time after each milliliter that has been consumed.
19. Have a student keep record in a table (on chalk board).

Hydrogen consumed [mL]	Elapsed time [s] Trial 1	Elapsed time [s] Trial 2	Elapsed time [s] Trial 3	Average elapsed time of all trials
0	0	0	0	0
1	60	60	60	60
2	120	110	120	117
3	170	160	170	167
4	220	210	210	213
5	270	260	260	263
6	320	310	300	310
7	370	360	350	360
8	420	410	400	410
9	470	460	450	460
10	520	510	490	507
11	570	550	550	557
12	–	–	–	–
When wheels stop	580	550	550	560

Table 8-3 Example for hydrogen consumption (values are examples and can vary)

20. Continue until the motor stops.
21. Disconnect fuel cell and car and connect the fuel cell to the solar panel to produce hydrogen again.
22. Turn on the light.
23. Repeat production of hydrogen and consumption by the car as many times as you think it makes sense (at least once).
24. Have one student draw a graph onto the chalk board, resulting in a graph showing the volume of hydrogen used as a function of the duration of time the wheels turn.

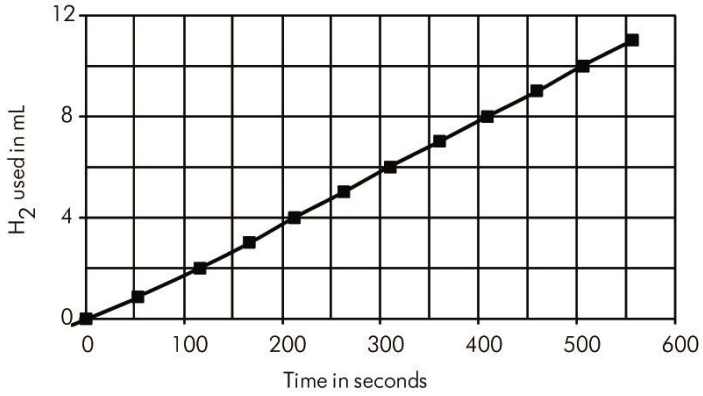

Fig. 8-6 Hydrogen volume as function of time wheels run (values are examples and can vary)

How much power can the fuel cell deliver

You can stop the investigation at this point, if you do not have any time left or if you wish to continue differently. You may however, continue with the investigation on how much power a fuel cell can deliver:

1. Fill the reversible fuel cell with distilled water (if necessary) and produce hydrogen, see steps 2.–13. on pages 95–96.

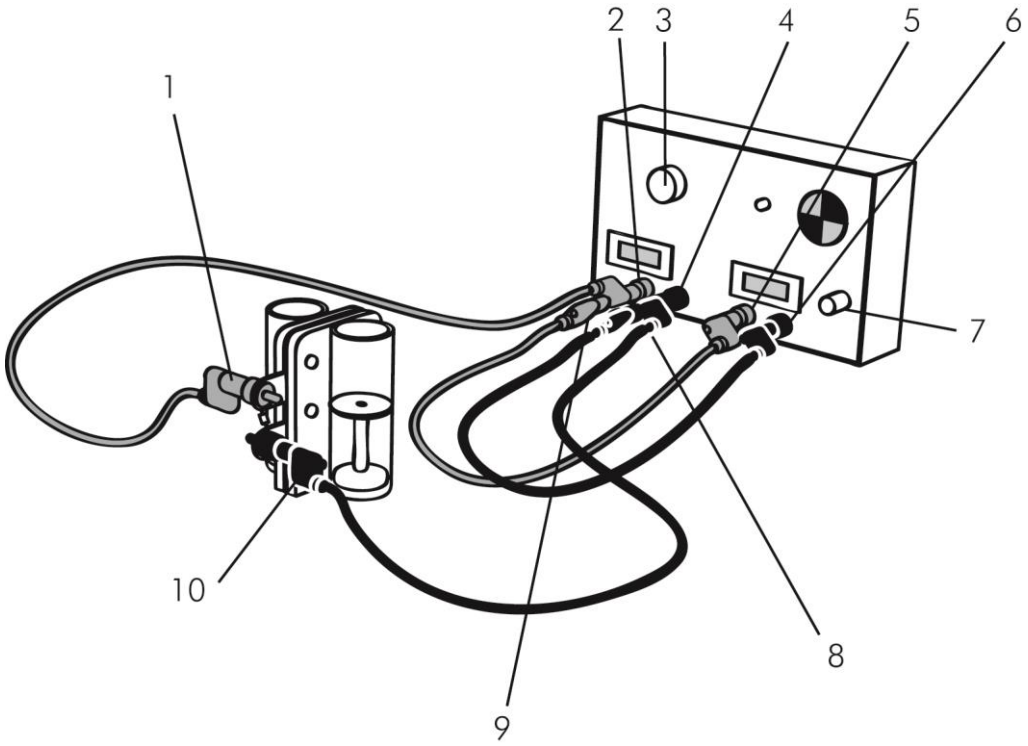

Fig. 8-7 Connecting reversible fuel cell and load measurement box

2. Set the *LOAD* knob (3) to *OPEN*.

3. Connect the red (positive) terminal of the reversible fuel cell (1) to the red (positive) terminal of the ammeter at the load measurement box (2).
4. Connect the black (negative) terminal of the reversible fuel cell (10) to the black (negative) terminal of the ammeter at the load measurement box (4).
5. Connect the red (positive) terminal of the ammeter at the load measurement box (9) with the red (positive) terminal of the voltmeter (5) at the load measurement box.
6. Connect the black (negative) terminal of ammeter at the load measurement box (8) with the black (negative) terminal of the voltmeter at the load measurement box (6).
7. Push the *ON / OFF* button (7).
8. Set the *LOAD* knob (3) to 10 Ω.

Measuring current and voltage

9. Observe the current and the voltage for a few seconds.

TIP

You might see the voltage start at a value even higher than 1.23 V (theory says this is the maximum possible voltage of a hydrogen-oxygen fuel cell) and then slowly fall. This happens because of surface layers left on the catalyst after electrolysis.

Student participation

10. When current and voltage appear to have settled, encourage the students to write them in the following table (here with typical results).

Load [Ω]	Current [A]	Voltage [V]	Power [W] (calculated)
10	0.080	0.840	0.067
5	0.145	0.780	0.113
3	0.237	0.750	0.178
1	0.497	0.640	0.318

Table 8-4 Typical results power output of fuel cell (values are examples and can vary)

11. Change the load setting to 5 Ω, 3 Ω and then to 1 Ω and at each point have the students record the current and voltage.
12. Have students calculate the power output of the fuel cell.
13. Disconnect the load measurement box and turn it off.
14. Disassemble the equipment and put it away.

8.2.2.4 Silent Work

The students can be encouraged to answer the questions in *QUESTIONS – STUDENTS* on page 112 in silent work or partner work. This depends on the students' abilities and the didactic approach.

8.2.2.5 Homework

The questions provided in section *QUESTIONS – STUDENTS* on page 112 can be used for homework as well, if your students do not need teacher's assistance to answer them.

8.2.3 Questions and Answers

1. Why is it important to have the hydrogen gas cylinder filled with the same amount each time we start to measure the length of time the wheels turn for each mL of gas?

   If we want to compare the duration of the wheels turning for each mL of hydrogen gas used it is important to begin our timing with the same amount of hydrogen each time.

2. What happens to the level of gas in the hydrogen storage cylinder as the wheels turn? Why does this occur?

   The volume of gas in the hydrogen storage cylinder decreases because as the wheels turn they use electricity to power the electric motor and this electricity comes from the hydrogen gas combining with the oxygen gas to form water and produce electricity.

3. Could you power the electric motor with electricity produced by the solar panel? What is the advantage of powering a car with hydrogen fuel rather than a solar panel connected directly to the electric motor?

   Yes, I think you could power the electric motor with electricity produced by the solar panel. Powering a car with hydrogen fuel rather than a solar panel would mean that you could drive the car in the dark when there is not enough light to allow a solar panel to work.

4. What is the advantage of having hydrogen combine with oxygen in this way rather than having it burn and explode as it does in the hydrogen test?

   The advantage of having the hydrogen combine with oxygen in this way rather than having it burn and explode is that it produces a much more controlled energy flow in the form of electricity. This electricity can be turned on and off so you can use it a little at a time. With an explosion a lot of the energy is released in the form of heat and cannot easily be used to power the car.

5. Predict how long the wheels would rotate for 20 mL of hydrogen gas. Refer to your graph and extrapolate an answer.

[individual results will vary]

Because the wheels rotated 507 seconds for 10 mL of hydrogen, I predict they will rotate two times 507 seconds (1014 seconds or 17 minutes) for 20 mL of hydrogen. The relation between hydrogen consumption and wheel rotation is linear.

6. What is the answer to the question at the start of the investigation: Can we use stored hydrogen to produce electricity? Explain.

   Yes, we can use stored hydrogen to produce electricity. We have seen the fuel cell use hydrogen while making electrical energy.

7. When you decreased the resistance from 10 to 1 Ω, what happened to the current? What happened to the voltage? What is the maximum power output from the fuel cell you determined?

   [individual results will vary]

   When I decreased the resistance, the current increased but the voltage decreased. The maximum power I measured was 0.318 watts with the 1 Ω resistor.

8. The dependence of current and voltage you have determined is typical for batteries too. Can we say the fuel cell is a battery? Please discuss this.

   Yes we can say that a fuel cell is a battery because it makes electricity out of a chemical reaction, which is separated in two half-cells having a minus pole anode and a plus pole cathode.

   Batteries show a similar behavior. They have a no-load voltage, which decreases with increasing current. For example the no-load voltage for a NiCd battery is 1.2 volts.

8.3 Student's Section

In this investigation you will examine if you can use hydrogen as a fuel.

8.3.1 Can We Use Stored Hydrogen to Produce Electricity?

Safety

➔ Wear goggles when experimenting.

> **CAUTION**
>
> **Ignition of hydrogen!**
>
> Skin burns and damage to the fuel cell.
>
> ➔ No open flames.
>
> ➔ No smoking.
>
> ➔ Well ventilated workspace.

> **CAUTION**
>
> **Overpressure in reversible fuel cell!**
>
> Injuries due to objects shooting out, when the top of the overflow compartments of the storage cylinders is obstructed.
>
> ➔ Do not block the top of the overflow compartments of the storage cylinders.
>
> ➔ Always wear eye protection.

✓ Goggles or eye protection

✓ Solar panel or hand generator

> **TIP**
>
> As an alternative to the solar panel your teacher may also ask you to use the hand generator as a source for electrical energy (see Instruction Manual).

✓ 2 or 4 patch cords

✓ Reversible fuel cell

- ✓ Car with motor
- ✓ Load measurement box
- ✓ Distilled water
- ✓ 100–120 watts PAR lamp, or equivalent light source
- ✓ Block of wood or other support for the car
- ✓ Watch with second hand or stopwatch function

1. Put on your goggles.
2. Place the fuel cell upside down (numbers facing down) on the flat surface.
3. Remove the stoppers.

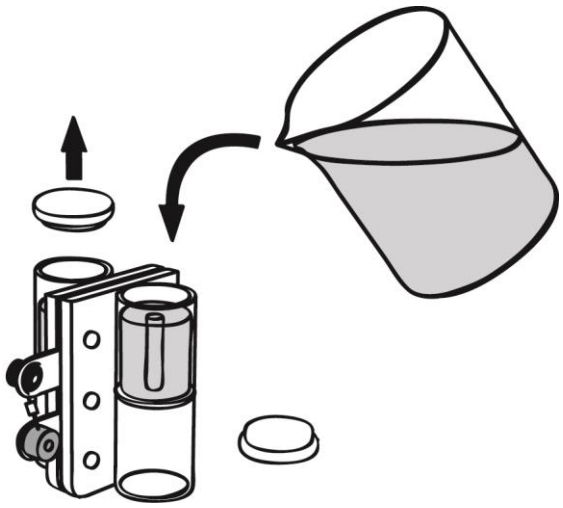

Fig. 8-8 Filling the reversible fuel cell with distilled water

NOTICE

Only use distilled water!

Tap water and other liquids will permanently damage the membrane of the reversible fuel cell.

4. Pour distilled water into both storage cylinders until the water reaches the tops of the small tubes in the center of the cylinders.
5. Tap the fuel cell lightly to help water flow into the area surrounding the membrane and metal current-collecting plates.
6. Add more water until it starts to overflow into the tubes in the cylinders.
7. Place the stoppers back onto the cylinders. Make sure no air is trapped inside the cylinder.

TIP

A small air bubble in the order of 0.5 mL will not cause problems and can be ignored.

8. Turn the reversible fuel cell right side up.

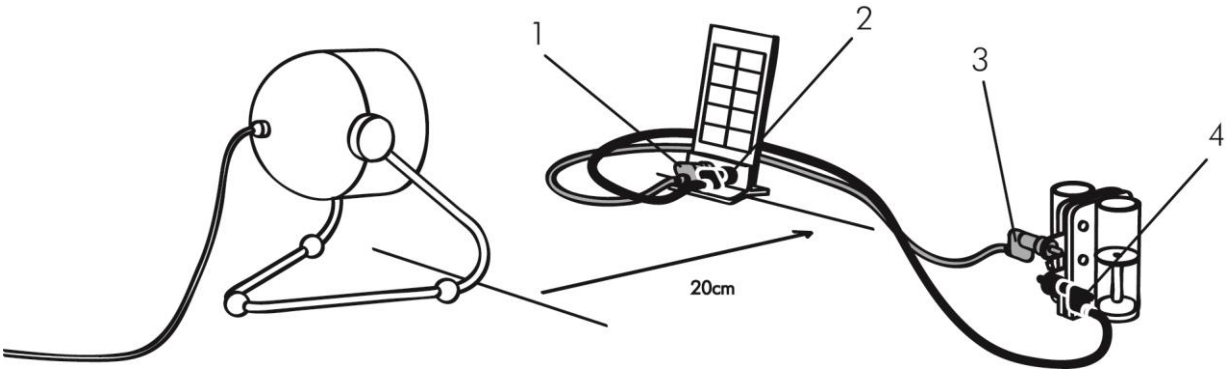

Fig. 8-9 Connecting solar panel and fuel cell

9. Plug the red banana jacks of the red patch cord into the red (positive) banana jack terminals of the solar panel (1) and the fuel cell (3).

NOTICE

Short circuit of reversible fuel cell!

Hot spots in the membrane, leading to deterioration of the membrane.

➔ Do not short circuit the reversible fuel cell.

10. Repeat step 9 with the black patch cord and the negative terminals (2, 4).

NOTICE

Overheating of the solar panel!

Malfunctioning of or permanent damage to the solar cells.

- ➔ Only use light sources with a maximum power of 120 W.
- ➔ Keep a minimum distance of 20 cm (8 inches) between light source and solar panel.
- ➔ Do not concentrate light.

11. Align the solar panel with the light source keeping a minimum distance of 20 cm (8 inches).

CAUTION

Hot surface of solar panel and lamp!

Skin burns.

- ➔ Do not touch the hot surface of the solar panel or lamp.
- ➔ Allow solar panel / lamp to cool down before touching it.

12. Turn on the light.
13. When the hydrogen storage cylinder is filled to a little more than 12ml:
    - Turn off the light.
    - Unplug the patch cords from the reversible fuel cell.

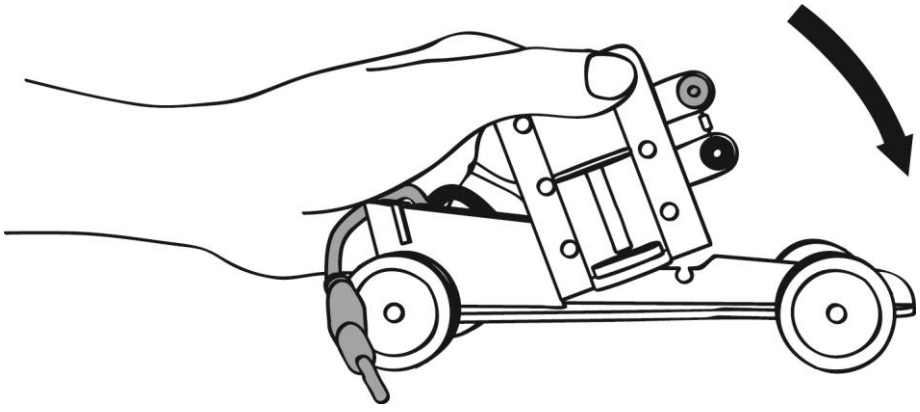

Fig. 8-10 Placing reversible fuel cell onto Model Car

14. With the red and black terminals facing towards the front of the car, place the reversible fuel cell into the notches on the model car until it audibly clicks into place.

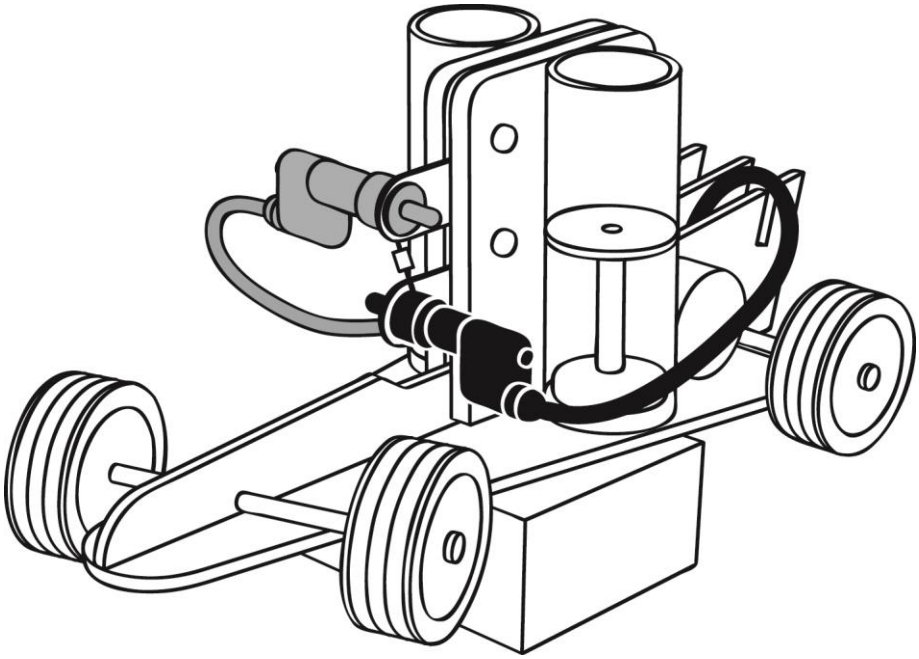

Fig. 8-11 Car on block

15. Place the block of wood under the car base, so that the wheels on your car are free to turn.
16. Connect the red (positive) banana jack with the red (positive) terminal and the black (negative) banana jack with the black (negative) terminal.
17. Watch the level of gas in the hydrogen storage cylinder, and when the gas level reaches exactly 12 mL, start a stopwatch (or record the time to the nearest second).
18. Record the time after each milliliter that has been consumed, keeping record in the table below.

Hydrogen consumed [mL]	Elapsed time [s] Trial 1	Elapsed time [s] Trial 2	Elapsed time [s] Trial 3	Average elapsed time of all trials [s]
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
When wheels stop				

Table 8-5 Hydrogen volume and time the car runs

19. Continue until the motor stops.
20. Disconnect fuel cell and car and connect the fuel cell to the solar panel.

To produce hydrogen again:

21. Turn on the light
22. Repeat production of hydrogen and consumption by the car as many times as you think it makes sense (at least once).
23. Draw a graph into the chart below, resulting in a graph showing the volume of hydrogen used as a function of the duration of time the wheels turn.

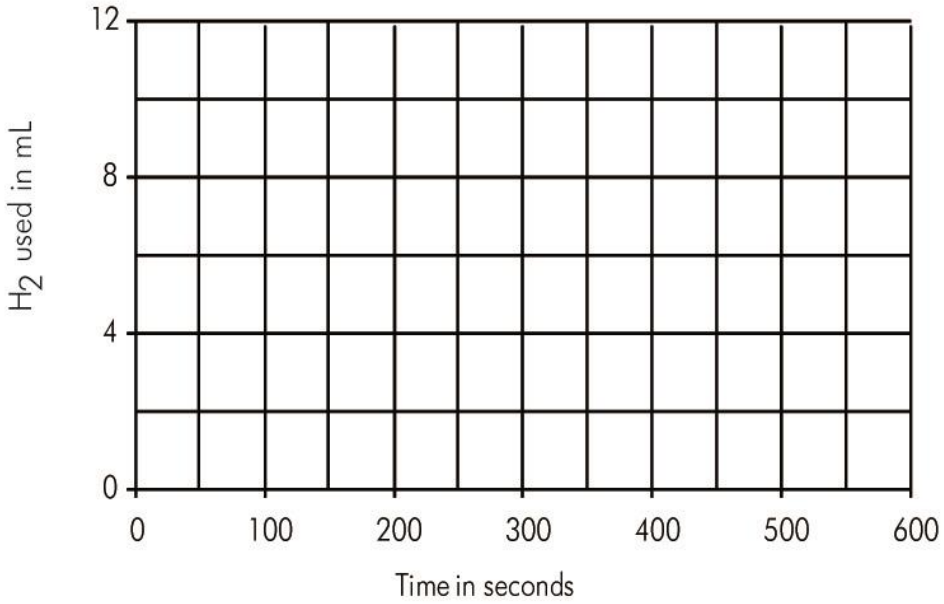

Fig. 8-12 Hydrogen volume as function of time wheels run

The first part of the investigation is finished. Check with your teacher whether you may continue or not.

How much power can a fuel cell deliver

1. Fill the reversible fuel cell with distilled water (if necessary) and produce hydrogen, see steps 2.–13. on pages 105–107.

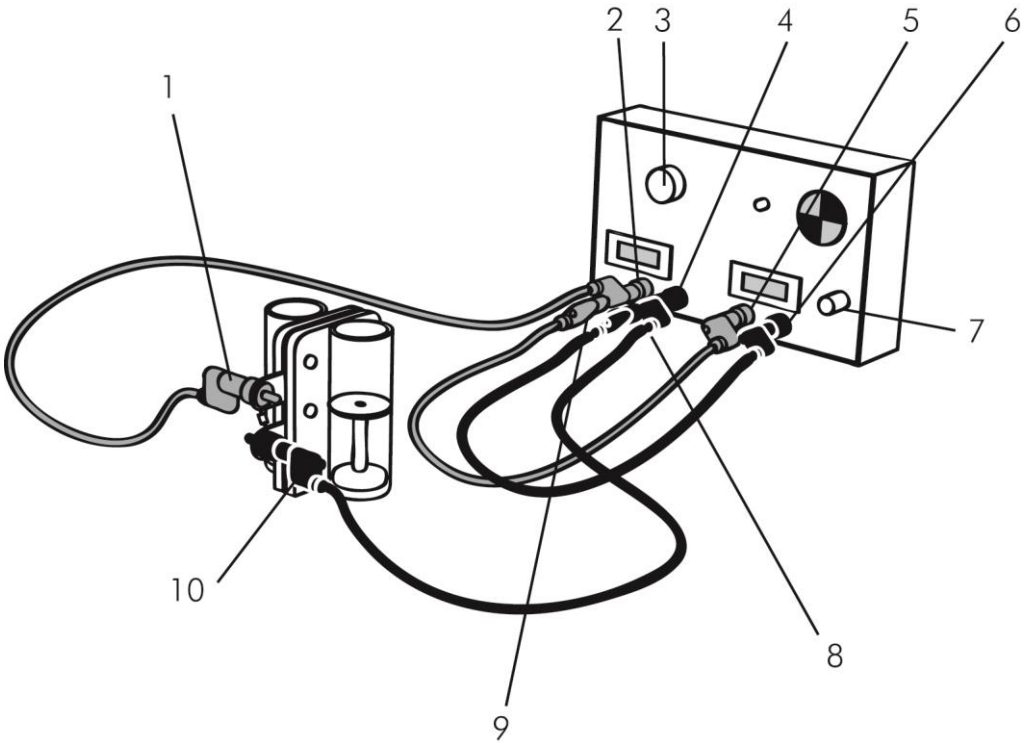

Fig. 8-13 Connecting reversible fuel cell and load measurement box

2. Set the *LOAD* knob (3) to *OPEN*.
3. Connect the red (positive) terminal of the reversible fuel cell (1) to the red (positive) terminal of the ammeter at the load measurement box (2).
4. Connect the black (negative) terminal of the reversible fuel cell (10) to the black (negative) terminal of the ammeter at the load measurement box (4).
5. Connect the red (positive) terminal of the ammeter at the load measurement box (9) with the red (positive) terminal of the voltmeter (5) at the load measurement box.
6. Connect the black (negative) terminal of ammeter at the load measurement box (8) with the black (negative) terminal of the voltmeter at the load measurement box (6).
7. Push the *ON / OFF* button (7).
8. Set the *LOAD* knob (3) to 10 Ω.

TIP

You might see the voltage start at a value even higher than 1.23 V (theory says this is the maximum possible voltage of a hydrogen-oxygen fuel cell) and then slowly fall. This happens because of surface layers left on the catalyst after electrolysis.

9. When current and voltage appear to have settled, write them into the following table.

Load [Ω]	Current [A]	Voltage [V]	Power [W]
10			
5			
3			
1			

Table 8-6 Determination of power output of fuel cell

10. Change the load setting to 5 Ω, 3 Ω and then to 1 Ω and at each point record the current and voltage.
11. Calculate the power output of the fuel cell.
12. Disconnect the load measurement box and turn it off.
13. Disassemble the equipment, put it away and then take off your goggles and return them carefully.

8.3.2 Questions – Students

Use an extra sheet to answer the question.

1. Why is it important to have the hydrogen gas cylinder filled with the same amount each time we start to measure the length of time the wheels turn for each mL of gas?

2. What happens to the level of gas in the hydrogen storage cylinder as the wheels turn? Why does this occur?

3. Could you power the electric motor with electricity produced by the solar panel? What is the advantage of powering a car with hydrogen fuel rather than a solar panel connected directly to the electric motor?

4. What is the advantage of having hydrogen combine with oxygen in this way rather than having it burn and explode as it does in the hydrogen test?

5. Predict how long the wheels would rotate for 20 mL of hydrogen gas. Refer to your graph and extrapolate an answer.

6. What is the answer to the question at the start of the investigation: Can we use stored hydrogen to produce electricity? Explain.

7. When you decreased the resistance from 10 to 1 Ω, what happened to the current? What happened to the voltage? What is the maximum power output from the fuel cell you determined?

8. The dependence of current and voltage you have determined is typical for batteries too. Can we say the fuel cell is a battery? Please discuss this.