Investigation 5:
Hydrogen Power!

We now have almost all the components for actually powering a car. In the electrolyzer 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 20% 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.

In the *Fuel Cell Model Car kit* you have the device to do this. In Investigation 4 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 fuel cell produces an electric current. The hydrogen unites with the oxygen to produce water again, which is the raw material we started with. You could diagram 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 add only water vapor or liquid water to our atmosphere while using pure water and electricity as the source of the hydrogen needed to power the fuel cell.

Astronauts living in space stations already use this technology. 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.

With the *Fuel Cell Model Car* we can use stored hydrogen to produce electricity to power the motor. Because the electric motor spins very quickly it has a gearbox to reduce the speed of the motor shaft and carry power the rear wheels of the car. In this investigation we don't put the car on the floor. Instead we support the car so its wheels can turn without touching anything. This makes it easier to collect some data.

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 * V = P (amperes * volts = watts)

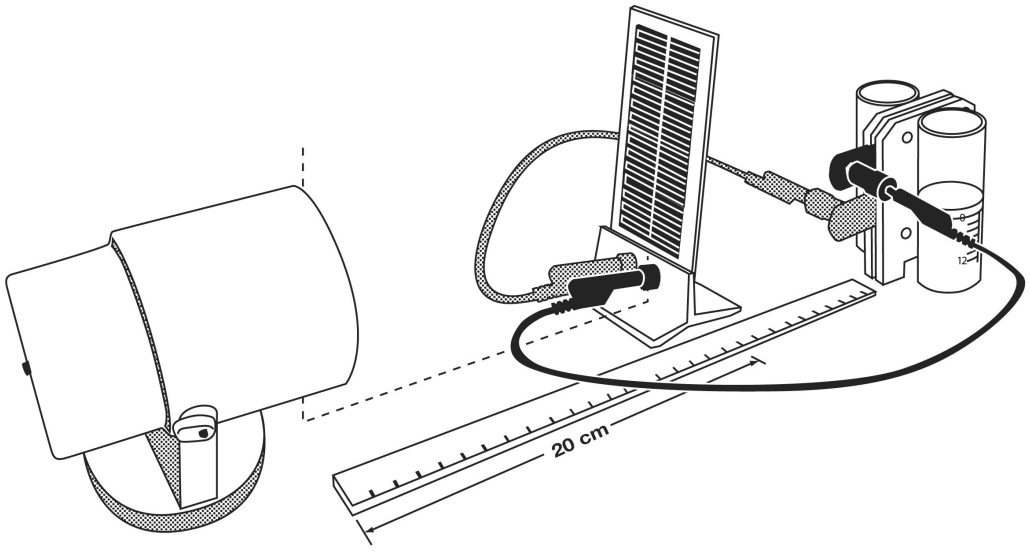
Can we use stored hydrogen to produce electricity?

You will need:

- goggles or eye protection
- solar panel from the *Fuel Cell Model Car Kit*
- three patch cords
- reversible fuel cell and car base from the *Fuel Cell Model Car Kit*
- load box from the *Fuel Cell Model Car Kit*
- distilled water
- 75 watt PAR30 incandescent lamp, or equivalent light source.
- block of wood or other support for the car
- watch with second hand or stopwatch function

Procedure

1. Put on your goggles. Remember that they will only protect you if you wear them properly.
2. The bottom of the fuel cell storage cylinders should be completely filled with distilled water, with no air space or other gas in the cylinders. If you need to add distilled water to the fuel cell, refer to *Filling the electrolyzer* in the section *Using the Fuel Cell Model Car Kit* at the start of this handbook.

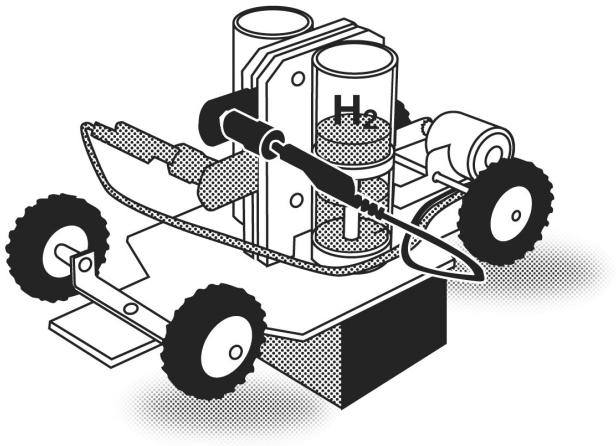


3. With the patch cords, connect the solar module to the reversible fuel cell, which we are using here as an electrolyzer. Red goes to red and black goes to black.

Position the solar panel so it directly faces the light source at the distance your teacher recommends and turn on the light.

4. When the hydrogen storage cylinder is filled to a little more than 12ml carefully remove the solar panel from the system by disconnecting the patch cords from the reversible fuel cell.

5. On the top side of the car base directly in front of the gears, you will notice a felt-covered upright piece of plastic. Also notice that the bottom of the fuel cell has a slot between the two cylinders. Turn the fuel cell so that the red and black contacts are towards the front of the car. Carefully slide the fuel cell over the black felt and push down gently until the fuel cell is fully seated on the car base. You may need to hold the connecting cables out of the way as you do this. Place the block of wood under the car base, so that the wheels on your car are free to turn. Connect the car motor to the fuel cell as shown.

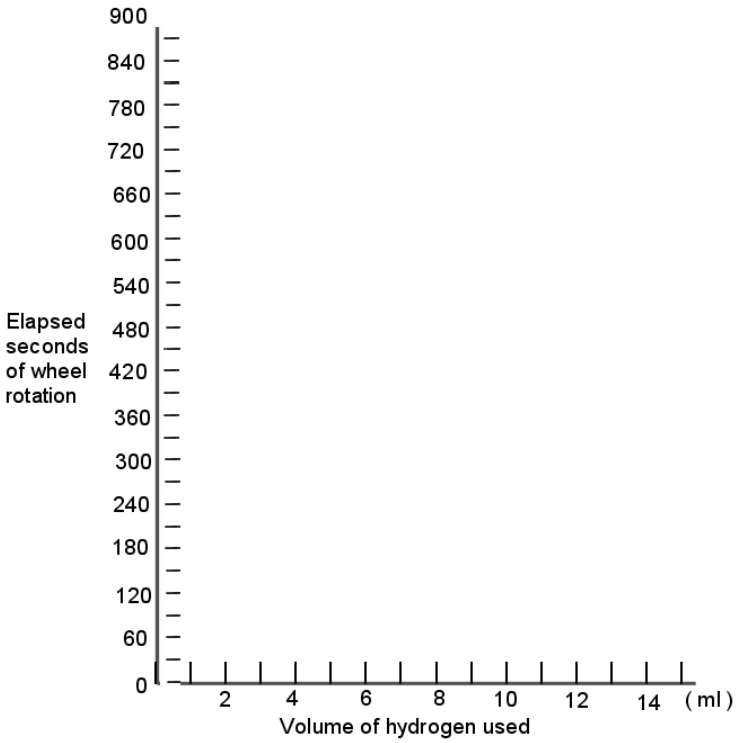


6. Watch the level of gas in the hydrogen storage cylinder, and when the gas level reaches exactly 12ml, start a stopwatch (or record the time to the nearest second). Again record the time on the stop watch (or the current time) when the gas level has been reduced to 11ml and again at 10ml, and so on. Use the table to continue recording the time at each ml until the hydrogen is gone. Record any extra time the wheels turn after the cylinder seems to have no more hydrogen. If you were not using a stopwatch, you will need to do some arithmetic to fill in the “elapsed seconds” column.

7. Set up the light source again, and repeat the steps 3 to 6 as many times as your teacher suggests. Always begin your timing when the gas level is at exactly 12ml. On the axes supplied, plot a graph of your results showing time of wheel rotation against the volume of hydrogen used.

8. Disassemble the equipment, put it away and then take off your goggles and return them carefully.

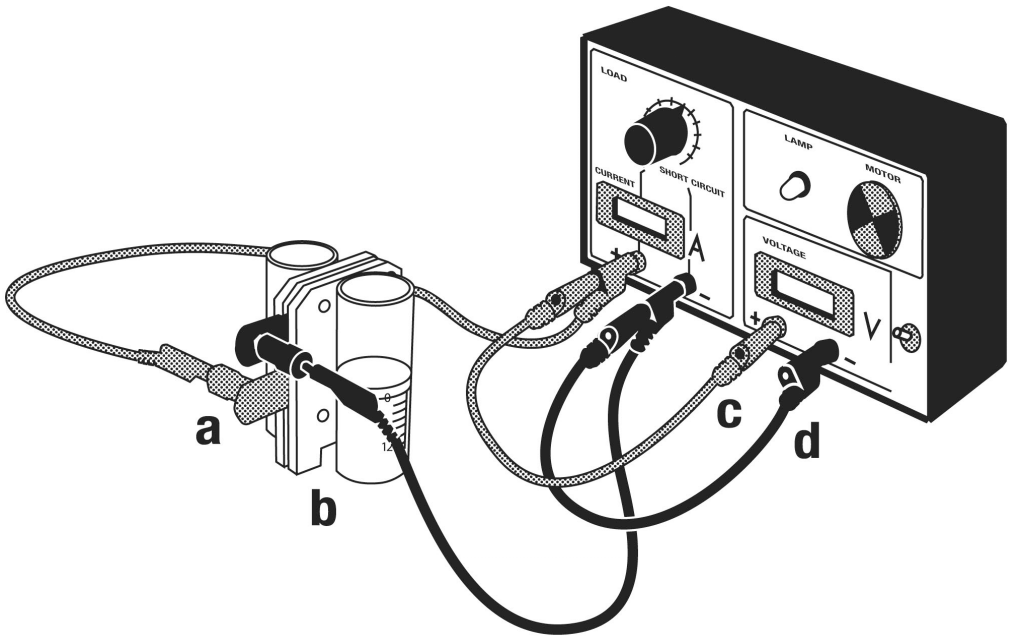
	Trial 1		Trial 2		Trial 3			
	time	elapsed seconds since 12 ml level	time	elapsed seconds since 12 ml level	time	elapsed seconds since 12 ml level	Elapsed seconds of wheel rotation (average of trials)	volume of hydrogen used
Time when 12 ml H_2 left								0 ml
Time when 11 ml H_2 left								1 ml
Time when 10 ml H_2 left								2 ml
Time when 9 ml H_2 left								3 ml
Time when 8 ml H_2 left								4 ml
Time when 7 ml H_2 left								5 ml
Time when 6 ml H_2 left								6 ml
Time when 5 ml H_2 left								7 ml
Time when 4 ml H_2 left								8 ml
Time when 3 ml H_2 left								9 ml
Time when 2 ml H_2 left								10 ml
Time when 1 ml H_2 left								11 ml
Time when no H_2 left								12 ml
Time when wheels stop								

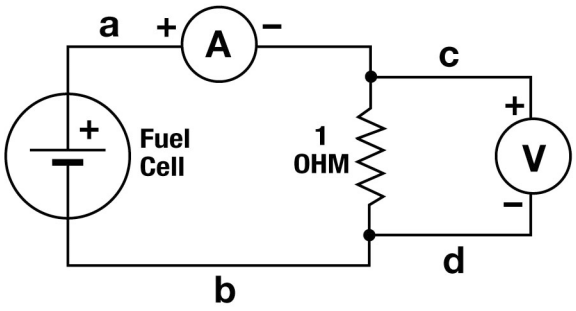


Duration of rotation per given volume of hydrogen

E1. **Extension:** In this investigation you have seen that with the stored hydrogen it is possible to produce electricity in the fuel cell to power the car wheels. If you have time left you can also try the following extension activity to find out how much power the small fuel cell can deliver.

E2. Repeat steps 3 and 4 to load the storage cylinders with gas. Turn the load box ON. Set LOAD to OPEN and connect the patch cords as shown. Then set LOAD to 10Ω.





This schematic diagram is another way of describing the circuit you have made. Notice how the ammeter (A) on the load box measures the current flowing through the load, at the same time the voltmeter (V) measures the voltage across the fuel cell output connectors.

E3. Briefly observe the current, and the voltage and write them in the following table. Also calculate the power output of the fuel cell. Change the load setting to 5Ω, 3Ω and then to 1Ω and again observe and record the current and voltage and calculate the power. Then disconnect the load box from the fuel cell and turn it OFF.

E4. Disassemble the equipment, put it away and then take off your goggles and return them carefully.

Load	Current	Voltage	Power
10 Ω	_____ Amperes	_____Volts	_____Watts
5 Ω	_____ Amperes	_____Volts	_____Watts
3 Ω	_____ Amperes	_____Volts	_____Watts
1 Ω	_____Amperes	_____Volts	_____Watts

Questions

1. Why is it important to have the hydrogen gas cylinder filled with exactly 12ml 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 did you notice as you compared the time the wheels turned as you repeated the experiment?

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

6. Predict how long the wheels would rotate for 24ml of hydrogen gas. Refer to your graph and extrapolate an answer.

7. Why do you think the motor continued to turn after the volume of hydrogen reached 0ml in the storage cylinder?

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

9. (Extension activity) When you decreased the resistance from 10 Ω to 1Ω, what happened to the current? What happened to the voltage? What is the maximum power output from the fuel cell you have determined?

10. (Extension activity) 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.

Teaching supplement for Investigation 5: *Hydrogen Power!*

The expected learning outcome of this investigation is to have students experience that hydrogen fuel can produce an electrical current when used in a fuel cell. The objectives may be written:

- Students will record that electrical energy is produced when hydrogen is used to power a fuel cell.
- Students will note that repeating an experiment will produce similar results.
- Students will use this data to produce a graph that will allow them to predict the duration of rotation for a given volume of hydrogen gas.
- Students will demonstrate correct safety procedures for this investigation.

Teacher Notes

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*.

This investigation requires that the electrolyzers are hydrated and able to produce bubbles of hydrogen quite soon after the class begins. To ensure that the hydrogen is pure and not mixed with air, the electrolyzer cylinders must be filled with distilled water before gas is produced and accumulated. To save class time, you could generate some hydrogen before the class, and leave it in the storage cylinder. If several groups are doing this investigation in a succession of classes, there is no need to empty the electrolyzer each time.

Teachers should specify the minimum distance from the solar panel to the light source to avoid damaging the solar panel through overheating by the light source.

Try out the system beforehand to see how many times students may repeat this experiment within your block of time. Generally, the more data the more accurate the results will be.

Remind your students to measure the volumes carefully to ensure reproducible results.

If you wish to demonstrate powering the car by the solar panel alone you should be aware that the amount of power needed to turn the wheels is considerably more the power needed to run the electrolyzer. To make the wheels turn, the light source must be placed very close to the solar panel. Take care if you demonstrate this, as you will overheat and damage the solar panel if you keep it this close to the light for any length of time.

Answers to the student questions

1. *Why is it important to have the hydrogen gas cylinder filled with exactly 12ml 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 exactly at the 12ml mark 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 did you notice as you compared the time the wheels turned as you repeated the experiment?*

As we repeated the experiment the duration of the wheels turning for each 4ml of hydrogen gas used became more regular. At first there was a shorter duration.

5 *What is the advantage of having hydrogen combine with oxygen in this way rather than having it burn and explode as it did in Investigation 4?*

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 be used to power the car.

6. *Predict how long the wheels would rotate for 24ml of hydrogen gas. Refer to your graph and extrapolate an answer.*

Answers may vary depending upon the individual car and the graph results.

7. *Why do you think the motor continued to turn after the volume of hydrogen reached 0ml in the storage cylinder?*

I think the wheels keep on turning after the volume of gas in the hydrogen gas storage cylinder reaches 0ml because of the extra hydrogen gas that is in the cell itself and surrounds the membrane.

8. *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.

9. *(Extension activity) When you decreased the resistance from 10 Ω to 1Ω, what happened to the current? What happened to the voltage? What is the maximum power output from the fuel cell you have determined?*

When I decreased the resistance, the current increased but the voltage decreases with increasing current. The maximum power I have measured was for the 1 Ω resistor and is _____ watts.

10. *(Extension activity) 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.*

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

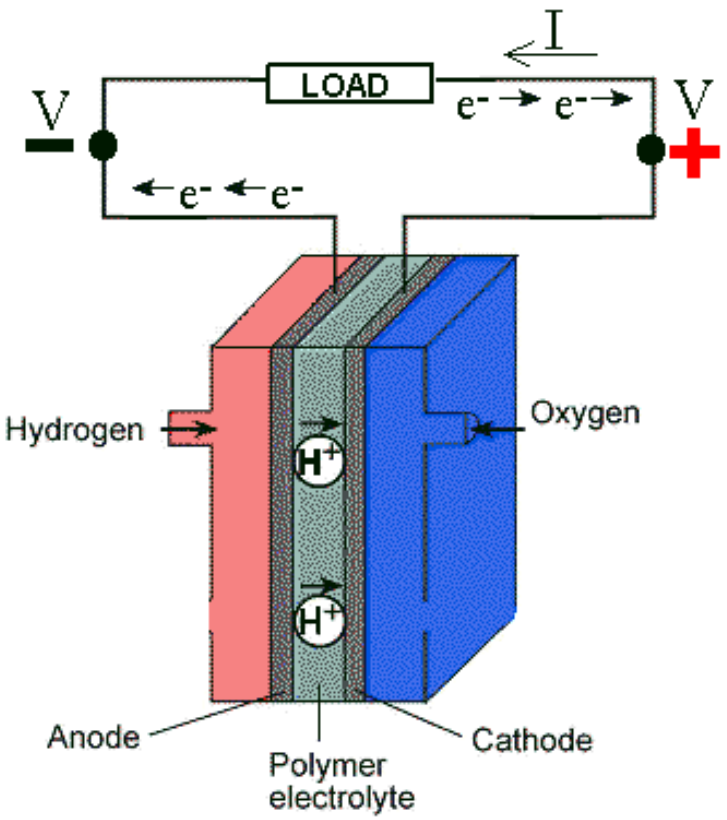
Fuel Cell

Negative Pole

Hydrogen consumed

Oxidation

Anode



Positive Pole

Oxygen consumed

Reduction

Cathode