Investigation 4:
Understanding Electrolysis

In a previous investigation you saw that electricity flowing through water with a little salt added produced gases at each electrode. Electricity is a flow of electrons and this flow needed to have the salt dissolved in the water in order to have these electrons complete their journey through the wires from the anode to the cathode. An interesting extra effect was that along the way the electron flow broke up water molecules to produce the bubbles of gas. When you look at the formula for water (H_20) you probably have some idea of what these two gases might be. This investigation will introduce you to another way to break up water with electricity by having it flow through a special piece of equipment called an electrolyzer. The electricity to break up water will come from the solar panel as before.

The electrolyzer is quite different from your electrolysis tank in Investigation 3. We must not contaminate its special membrane by letting it contact damaging chemicals such as table salt. If the membrane becomes contaminated it will not work as well and the electrolyzer will not be able to break up water. Even tap water is not pure enough. You must use pure distilled water when you fill the electrolyzer or you could permanently damage the membrane.

In the previous investigation dissolving salt in water created charged particles called ions. Electricity was able to flow through the water using these ions. The electrolyzer can break up water because it contains a special membrane containing a substance that allows hydrogen ions to jump between molecules and flow in one direction through the membrane. This substance is held inside two very thin layers of carbon that have had tiny amounts of the element platinum added to them on one side and tiny amounts of platinum plus another element, iridium on the other side. These microscopic amounts of platinum and iridium allow the water molecules to break apart when the membrane is being used as an electrolyzer.

The platinum and iridium do not change in the electrolysis reaction but remain in place to continue helping with the reaction. Substances that change reaction rates but do not change themselves are called catalysts and are a very important part of fuel cells. You must always use pure distilled water to avoid destroying their properties.

The concept of a catalyst is an important one. A baseball bat is used to propel the ball a long distance but hitting the ball does not materially change the bat. Swim fins allow a swimmer to go faster but do not change while they are being worn. These examples are not usually considered catalysts but perhaps you can see how platinum and iridium allow a reaction to happen much faster than if they weren't there. Pure water is very difficult to break apart so the platinum catalyst is essential.

Now, put on your goggles and take a look at this electrolyzer.

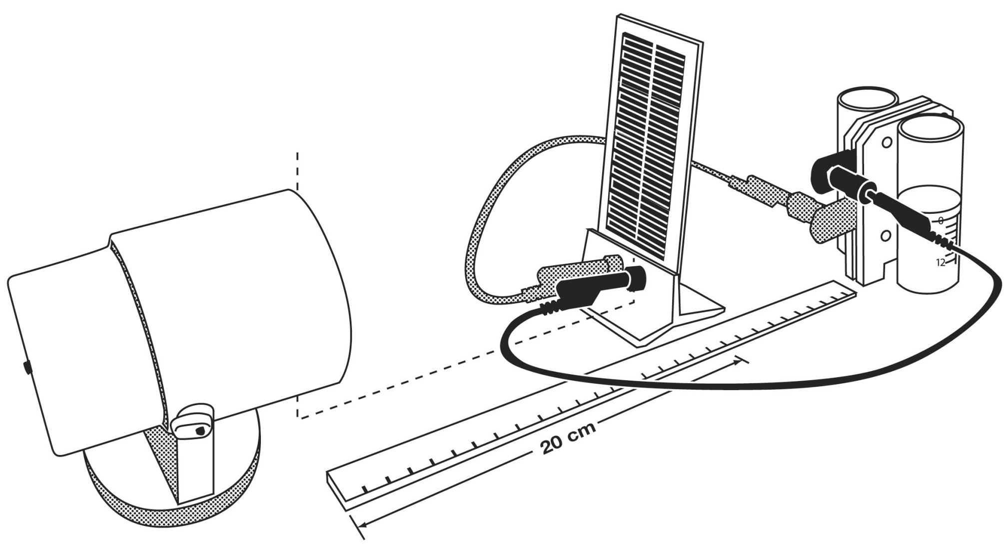
What is an electrolyzer and what does it do?

You will need:

- goggles or eye protection
- solar panel from the *Fuel Cell Model Car Kit*
- two patch cords
- reversible fuel cell from the *Fuel Cell Model Car Kit,* used here as an electrolyzer
- distilled water
- 75 watt PAR30 incandescent lamp, or equivalent light source.
- two small test tubes, 1 cm by 10 cm
- matches
- wooden splints
- tray to place under fuel cell, or paper towels

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. Place the fuel cell on a tray or folded paper towels to catch the water that will overflow in the later steps of this investigation. Watch the top of the small tubes for 30 seconds to see if some water comes out.

4. 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.

5. Watch the top of the small tubes again. What is pushing the water out?

6. Continue observing and every two minutes record the amount of gas collected in each storage chamber in this table.

Time From Start	Cathode Gas Volume (black)	Anode Gas Volume (red)
0 minutes	0 ml	0 ml
2 minutes		
4 minutes		
6 minutes		

7. When 10ml of gas is collected in one cylinder, record the time, and record the amount of gas in the other cylinder. This completes your table.

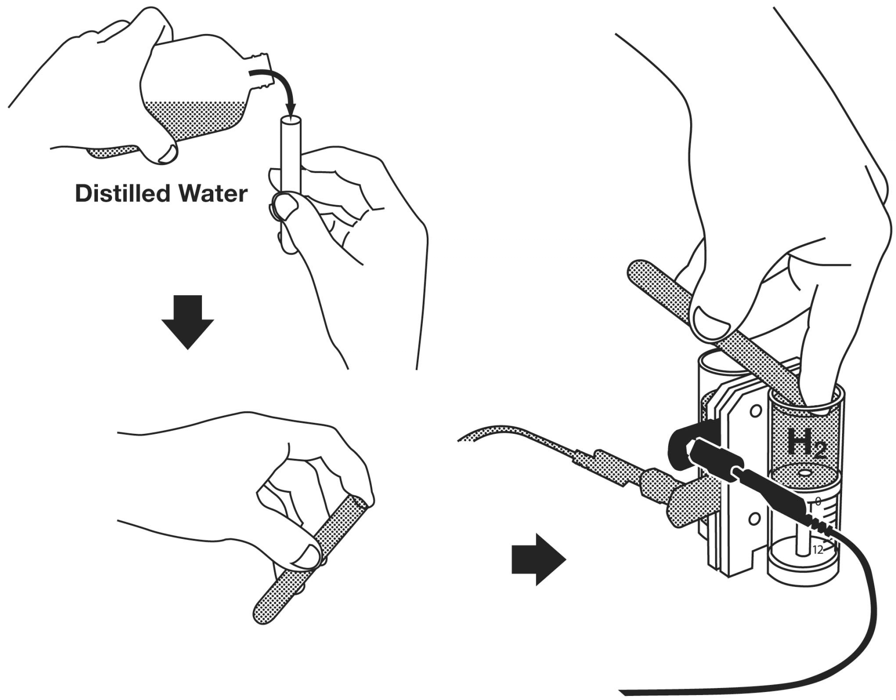
8. Let the electrolyzer continue working until all the water has moved into the upper portion of one of the cylinders. (With optimum lighting, it will take about 10 minutes to displace all the water into the upper hydrogen cylinder.)

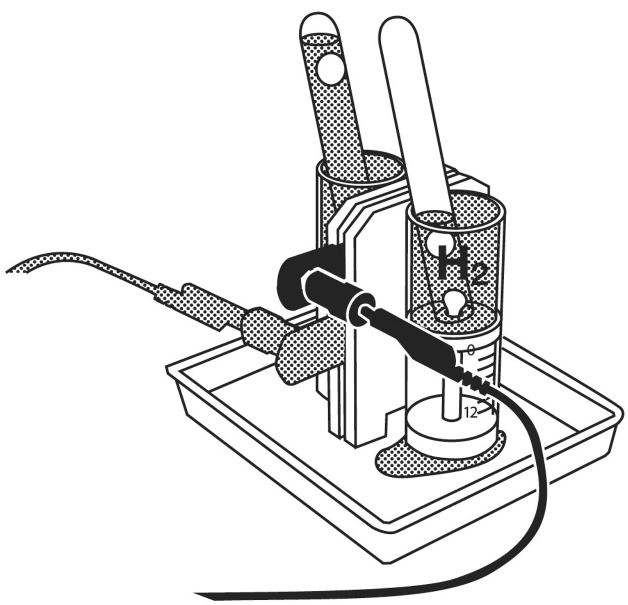
9. As the production of gas continues, you will see bubbles moving up through the water as the gas escapes through the small tube in the center of the cylinder.

10. If necessary, add more distilled water to the upper part of the cylinder so it is overflowing.

11. Wash and rinse your hands carefully to ensure no other chemicals or dirt contaminate the electrolyzer. Avoid using soap that could contaminate the distilled water. Completely fill one of the small test tubes with distilled water. Cover the end of the tube with your finger, turn the tube upside down and keeping it covered

place it under the surface of the water as quickly as you can, trying to prevent any air getting into the tube. (A small amount of air, less than 1 ml in the test tube will not matter. But if there is more you should repeat the procedure, perhaps asking someone with smaller fingers to help!) Then uncover the tube and position it so the bubbles of gas will be collected in the inverted test tube.

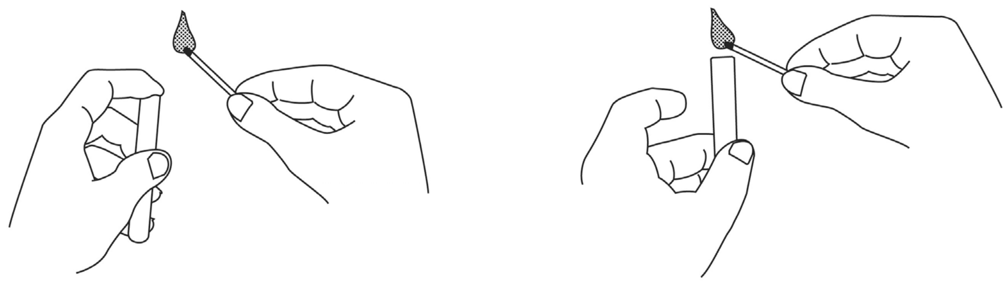




12. When bubbles of gas start to escape in the other cylinder, repeat steps 10 and 11 for that cylinder.

Your instructor may wish to supervise the following gas tests.

13. When the test tube above the cathode is filled with gas, again cover the end with your finger before you remove the tube from the water, trapping the collected gas.



14. Still keeping the tube closed, hold it right side up. Bring the flame of a lighted splint to the top of the tube and release your finger. There will be a visible and audible reaction. Also look carefully at the inside of the mouth of the tube immediately after. Use all your senses for observations. Write your observations here.

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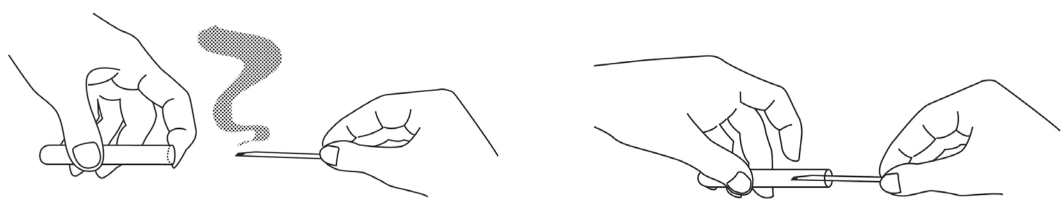
15. When the test tube above the anode is filled with gas, cover the end with your finger before you remove the tube from the water, trapping the collected gas.



16. Still keeping the tube closed, hold it horizontally. Light a wooden splint and then blow it out to leave a glowing ember on the end of the splint. Release you finger and insert the glowing splint half way into the tube. Write your observations here.

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17. Take apart the equipment, put it away and then take off your goggles and return them carefully.

Questions

1. Why is it important to ensure there are no large bubbles of air remaining when we fill the gas storage cylinders with water?

2. Using the information provided by the labels on the gas storage cylinders, which electrode is attached to which cylinder?

3. Is gas produced at similar rates at each electrode? What evidence do you have of this?

4. What simple ratio can you use for this gas production?

5. Why do we test the gas from the cathode first?

6. Do you have any evidence that the labels on the cylinders are placed on the correct cylinder?

7. Looking at the scientific formula for water, H_2O, what do you think happened in this investigation?

8. Looking back at investigation 3 can you make any inferences about the gases you saw being produced at each electrode? Did you observe any differences when you watched the gases being produced by simple electrolysis and by the electrolyzer?

9. Use the data from your table to create a simple graph. How much gas would be produced if you ran your electrolyzer for one hour? How long would it take you to collect a litre of Cathode gas? Of Anode gas?

10. From your careful reading of the introduction and the results you obtained from this investigation, what is the answer to the question at the start of the investigation: *What is an electrolyzer and what does it do?*

11. Is hydrogen a good name for the gas collected over the cathode?

Teaching supplement for Investigation 4: *Understanding Electrolysis*

The objective of this investigation is to introduce students to the reversible fuel cell as it is used as an *electrolyzer* to break water into hydrogen gas and oxygen gas through electrolysis. The students will move from qualitative observations as done in Investigation 3 through quantitative observations of the 2:1 ratio when water is broken down into hydrogen and oxygen. The learning objectives may be written:

- Students will set up the *electrolyzer* according to instructions and will observe, make quantitative observations and answer questions on the construction and function of a reversible fuel cell used as an *electrolyzer*.
- Students will observe that in electrolysis twice as much gas is produced at the cathode than is produced at the anode.
- Students will make inferences as to the identity of the two gases.
- Students will demonstrate correct safety procedures for this investigation.
- Students will observe that the gas collected above the cathode can be ignited in air to produce a mild explosion complete with heat, light, sound and the production of water and that this is a test for the presence of hydrogen gas.
- Students will observe that the gas collected above the anode will support rapid combustion when a glowing splint is thrust into it and that this is a test for the presence of oxygen.

Teacher Notes

Although the device that produces the gases in this investigation is more complex than the simple aluminum electrodes of investigation 3, the polarity is exactly the same. Specifically, the positive (red) side of the electrolyzer releases oxygen, and is the *anode*. The negative (black) side releases hydrogen and is the *cathode*.

You should consider whether you want students to do this investigation, or you will do it as a demonstration. The last part of the procedure, steps 14 to 17 involve open flames, and a small explosion as the hydrogen ignites. There may also be a popping sound as the lighted splint is placed within the oxygen tube. If students do perform the investigation they may be startled and drop the test tube so close supervision may be advisable. In any case, use small test tubes.

Try out the procedure steps yourself to ensure you have allowed enough time to collect gas and perform the demonstrations. The entire gas storage cylinder needs to fill before any bubbles of hydrogen collect in the test tube. Even with bright light, it will take at least 10 minutes to fill the storage cylinder with hydrogen and then another 5 minutes to collect the first tube of hydrogen. Additional tubes could be obtained at 5-minute intervals. For oxygen, all the times are doubled. For this reason, you may want to start the electrolyzer before class begins.

Practice placing the water filled test tubes over the gas bubbles before you have students arrive as this is a little tricky and requires you use your index finger to cap the tube as you reach inside the reservoir. A small student hand may help here if you have the student practice before attempting it.

Your students should understand the importance of using only distilled water for this investigation. It might be a good idea to put tape or a sign on the water taps to prevent mistakes. There is no need for any tap water when using the fuel cell. Wash and rinse your hands carefully to ensure no other chemicals enter the system. Avoid using soap that could contaminate the distilled water.

With the students, examine the markings used on the gas collection cylinders so that all students can read them correctly. Some students will not be familiar with scales that have "missing" numbers.

Place the *electrolyzer* on a tray or absorbent towels to catch the considerable overflow. Water in the test tube is displaced and runs over the edge of the reservoir.

You should stop measuring the gas levels when the H_2 gas cylinder is reading 10 ml. When the hydrogen begins to escape into the upper reservoir, the ratio of stored hydrogen to stored oxygen becomes meaningless.

If you are doing this as a demonstration, when you remove the tube filled with hydrogen from the reservoir, hold it as close to the bottom as you can so that your index finger is extended and when pulled away will allow the students to see the reaction easily. As the reaction is instantaneous you will need to prepare the students to watch carefully. With the hydrogen it may help to darken the room so the light blue explosion from the combustion may be seen. Do not point the tube at yourself or a student. As soon as the hydrogen burns take the tube to the students to allow them to observe the water droplets that have been produced just inside the top edge of the tube. They will be small but they will be there.

When performing the oxygen test considerable heat may be produced. Hold the tube in such a way that you will not be burned. As soon as the splint ignites and burns brightly remove it from the tube to show the students that it has reignited. After the splint reignites, do not insert it a second time into the tube of oxygen. Gases produced by the volatilization of the wood resins, with a lesser concentration of oxygen could result in a large 'pop'. Although not dangerous, it may cause you to drop the tube.

Answers to the student questions

1. *Why is it important to ensure there are no large bubbles of air remaining when we fill the gas storage cylinders with water?*

   It is important to ensure there are no large bubbles of air remaining when we fill the gas storage cylinders so we can get an accurate measure of the gas collected.

2. *Using the information provided by the labels on the gas storage cylinders, which electrode is attached to which cylinder?*

   The H_2 gas-collecting cylinder is attached to the cathode (black, negative) and the O_2 gas collecting cylinder is attached to the anode (red, positive).

3. *Is gas produced at similar rates at each electrode? What evidence do you have of this?*

   The gases are not produced at similar rates at each electrode. Our table shows that in four minutes we collected x ml at the anode and 2x ml of gas at the cathode.

4. *What simple ratio can you use for this gas production?*

   Our table shows us that for every two millilitres of gas collected at the cathode there is one millilitre collected at the anode. The ratio is 2:1.

5. *Why do we test the gas from the cathode first?*

   We test the gas collected at the cathode first because it is the gas that is produced more quickly and the test tube will be filled first.

6. *Do you have any evidence that the labels on the cylinders are placed on the correct cylinder?*

I think the labels are placed correctly because there is twice as much gas in the hydrogen storage cylinder. The formula for water, H_2O shows that there is twice as much hydrogen as oxygen.

7. *Looking at the scientific formula for water, H_2O, what do you think happened in this investigation?*

When I look at the formula for water, H_2O, I think that water is being broken up into hydrogen and oxygen with twice as much hydrogen being produced as oxygen.

8. *Looking back at investigation 3 can you make any inferences about the gases you saw being produced at each electrode? Did you observe any differences when you watched the gases being produced by simple electrolysis and by the* electrolyzer*?*

I think that in the other electrolysis investigation that hydrogen gas was being produced at the cathode and oxygen gas was being produced at the anode. The bubbles of hydrogen gas appeared smaller in size.

9. *Use the data from your table to create a simple graph. How much gas would be produced if you ran your* electrolyzer *for one hour? How long would it take you to collect a litre of Cathode gas? Of Anode gas?*

The graphs will be straightforward and the amount of gas produced in one hour should be easily extrapolated from the amount collected in ten or twenty minutes (i.e. 6 times or 3 times). The time needed to collect a litre of Cathode gas would be 100 x the time for 10ml and the time for the collection of Anode gas should be double that of the Cathode gas.

10. *From your careful reading of the introduction and the results you obtained from this investigation, what is the answer to the question at the start of the investigation:* What is an electrolyzer and what does it do?

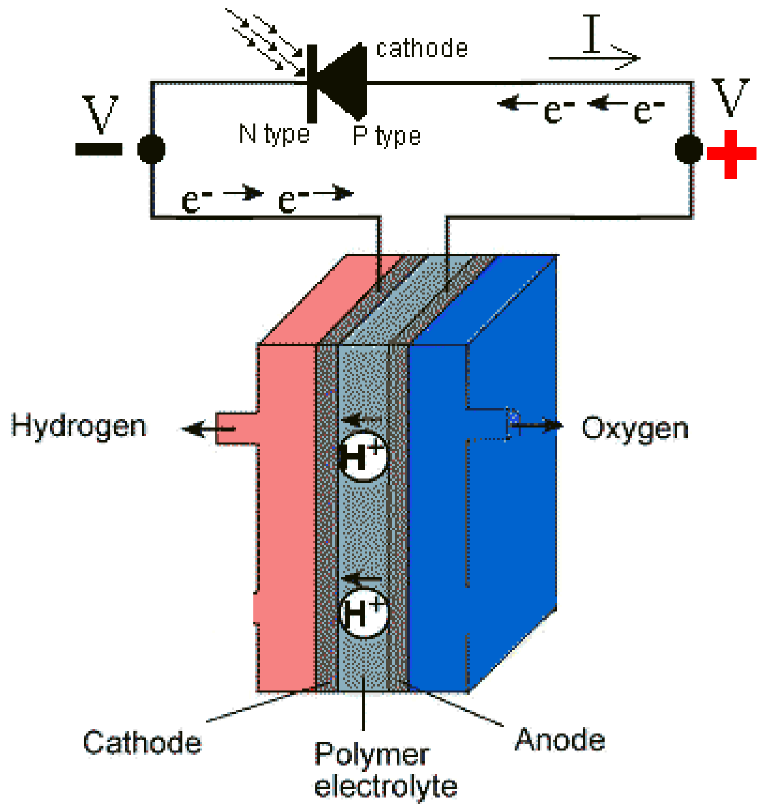
An electrolyzer is a device that allows us to break water into hydrogen and oxygen using electricity. Its solid electrolyte in the membrane between the electrodes makes it work like the simple electrolysis process that used a dissolved-salt electrolyte.

11. *Is hydrogen a good name for the gas collected over the cathode?*

As hydrogen means *water former* it is a good name for this gas which produces water when burned with oxygen.

Electrolysis

Negative Pole	Positive Pole
Hydrogen evolution	Oxygen evolution
Reduction	Oxidation
Cathode	Anode



The current produced by the P-N junction of a solar cell is in the opposite direction to the forward-bias current of an ordinary diode. Therefore the "P" side of the solar cell is its cathode. (The "N" side of an ordinary diode is its cathode.)