Building Your Prototype Car

Instruction Manual

Kit Parts

- Solar Panel
- Chassis
- Clamps
- Syringe
- Multimeter
- Hose
- Motor
- Banana wires (attaches to motor)
- Motor Mount
- Alligator clips & Battery cap wires
- Hydrogen Fuel Cell
- Extra wires
- Cylinders and Bells
- Tires, axles, gears, T-clips
- Pinon Gears

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Additional Tools

The following items are not included and are needed to assemble the kit:

- Ruler, scissors, 9V battery per fuel cell, and distilled water.

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Preparation of the Chassis

- There are two parts of the chassis: a cylinder plate where the storage containers will fit and the 2 side plates.
- Slide the cylinder plate into the side plates.

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Preparing the Wheels

Place one tire around each of the four wheel hubs provided.

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Preparing the Axles

- Push the middle-size gear onto the center of one of the axles.
- Gears and wheels are difficult to insert into the axles. Take great caution not to bend the axles during this process.
- Steady pressure on a firm surface should work. Patience and care are required to avoid damage to both yourself and the axles.
- ***BE CAREFUL*** when you use bare hands when inserting axles. Be sure to use a book or other hard object to push the gear or wheels on the axles. Don't slip and push an axle through your hand!

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Attaching Wheels to the Car

- After placing the middle-size gear on the back axle. Place 2 wheels and tires on the outside of the side piece.
- Place the 2 wheels and tires on the front axle on the outside of the side piece.
- The cylinders are on the front part of the car.

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Attach Motor to Chassis

- In order to attach the Banana wires to the motor, locate the round indentation on the motor. This is the positive terminal.
- Connect the stripped end of the red wire to the positive side. The black end is connected to the other terminal.
- Attach a pinon gear onto the stem of the motor.
- Put the motor into the motor mount and secure it by pressing both sides of the mount snuggly against the motor.
- Place the plastic fuel cell holder with the motor attached onto the chassis
- The pinon gear should mesh with the axle gear. If not, swap it out for another.

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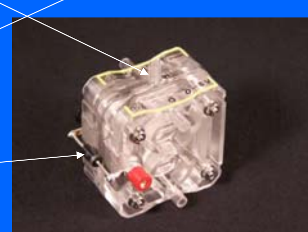
Preparing the Fuel Cell

- There is only one flat side of the fuel cell that you can use as a base while you are attaching the tubing. Lay the fuel cell flat on that bottom side.
- The top of the fuel cell should have a nozzle coming up from the middle.
- The front of the fuel cell has a nozzle extending out from the bottom.
- The back of the fuel cell has a diode connecting the red and black jacks.

Front



Back

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Cutting The Tubing

Cut the tubing into the following pieces:

- Three - 2”pieces
- Three - 4” pieces
- One - 6” pieces

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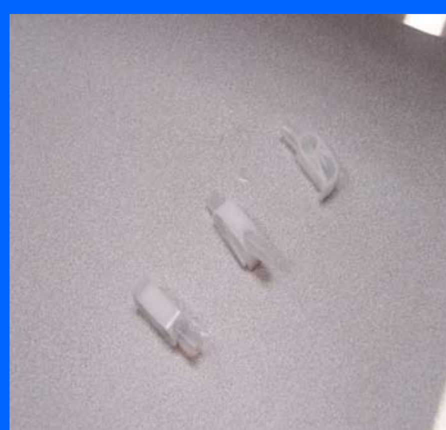
Clamp Tubes

- Attach a white clamp to each of the 2” pieces



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Attach The Tubes

- Attach the clamped tubes to the O2 vent nozzles on each side of the top of the fuel cell. These nozzles release oxygen.
- Attach the third clamped tube to the nozzle on the bottom front of the fuel cell. This is the hydrogen release nozzle.

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Oxygen Tubing

- Attach one of the 4" tubes to the bottom nozzle of each side of the fuel cell. Use a T connector to attach these tubes together above the fuel cell.
- These are the oxygen input valves. You will have oxygen going to each side of the fuel cell from a single cylinder.
- Attach the remaining 4" tube from the T to the top of the bell that inserts into the oxygen cylinder.
- Push the bell into the rim around the bottom of the cylinder being sure to leave the notches open so that water can escape from it.

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Hydrogen Tubes

- Attach the 6” tube from the top nozzle of the fuel cell marked “in” to the top of the bell that inserts into the hydrogen cylinder.
- Push the bell into the rim around the bottom of the cylinder being sure to leave the notches open so that water can escape from it.

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Hydrating the Cell.

- Attach the syringe to a clamped oxygen or hydrogen release valve. Pull the syringe plunger until only water is entering the syringe and there are no air bubbles.
- You might have to disconnect the syringe and release water a few times until you have removed all the air bubbles.
- Close the clamp and repeat on the remaining two.

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Prepare Battery Cap

- Attach Battery cap wires to the 9-volt battery. Before connecting the stripped wire end to the alligator clip, be sure to slide the insulator sheath over the wire.
- Loop the stripped end of the battery wire through the hole at the end of the alligator clip and press the tabs firmly down on top of it.
- Slide insulator sheath over the alligator clip. Repeat process for the second clip.
- Do not let the metal ends of the alligator clips contact each other. This will overheat the battery and could catch on fire.

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Attach Battery Pack

- Attach the black wire and alligator clip to the section of wire on the diode nearest the black banana jack.
- Attach the red wire and alligator clip to the section of wire on the diode nearest the red banana jack.
- You should immediately see hydrogen and oxygen being produced if all systems are connected.

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Insert Fuel Cell

- Place the fuel cell on the chassis. Turn the cell so the diode is facing the motor.
- The hydrogen output nozzle faces the front of the car near the storage cylinders. The diode faces the motor. You might have to adjust the tubing to fit.

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Connect the Power to the Motor

- Insert the black banana plug into the black jack on the fuel cell.
- Insert the red banana plug into the red jack on the fuel cell.
- If your Fuel Cell is hydrated and your car completely connected, you should here the roar of the gears!!!
- You car is ready to fly down the race track.

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Trouble Shooting

If the car does not go, check the following:

- Are all electric connections solid and soldered? If not, reconnect or solder and try again.
- Are the gears meshing freely? If not, reposition the motor on the axle.
- If the car goes backward, reverse the positions of the two alligator clips on the fuel cell.
- If the wheels do not spin freely, reposition them on the axles to provide clearance between the wheel and the side piece of the chassis..
- If the car does not go fast enough, try different gear combinations, wheels, and chassis styles. Try to make a car with front-wheel drive! Experiment and find out what works best!!
- Check your seals to make sure that the gas is not leaking
- Check the connections to the motor
- Make sure that the wheels are straight and the axle is not bent
- If there is not hydrogen or oxygen being produced, add water to the fuel cell and check to see that the battery is fully charged.

Water Management

- Fill chambers infrequently.
- Electrolyze with open venting for 10 minutes with all tubes open the first time you use this fuel cell.
- In subsequent use, electrolyze for a generous amount of time.
- Occasionally open all the clamps and allow drops of water to drip out. You may need to do this more often especially with a close system, i.e. using syringes as your storage containers.

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Care of Fuel Cell

- Use correct voltage – 9 volts
- Store the fuel cell in a baggie with a moist paper towel
- Use only distilled water
- Use clean hands and materials
- Keep hydrogen clean. For example, if you use a balloon the hydrogen may be contaminated with powder.
- Keep your storage cylinders clean especially if you have used packing peanuts to transport your car to the race.

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How to Get Help

- Email: kay@fuelcellstore.com
- Call Fuel Cell Store

  303 237-3834

  Office hours 8:30-5:00 MST Monday-Friday

  Hotline 1-866-562-8457

  Monday-Friday 4-7:00 Pacific Time

  Saturday 10-4:00 Pacific Time

  Sunday 11-2:00 Pacific Time

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renewable energy

SOLAR ENERGY

The amount of energy that the sun produces is staggering (Earth receives only 0.00000001% of it!). But just that little bit is enough to power everything we use. There are a few different ways to harness our little piece of the solar energy pie. Photovoltaic (PV) cells are the most common, converting light directly to usable electricity. However, it can also be used to create tremendous amounts of heat to run an industrial gas turbine, heat a local swimming pool, or even simple baseboard heating for an apartment.

However, there are obstacles to overcome and the price of solar panels is still among the most expensive renewable energies. But there is also a great amount of promise in solar energy. Research has drastically increased the low efficiencies of a few years ago and architects and engineers are beginning to design more dynamic and resourceful structures to utilize the energy power of the sun.

WIND ENERGY

Wind energy is the fastest growing source of energy in the world, and for good reason. Our ancestors harnessed wind energy with the first sailboat. Research in the field of wind technology has resulted in impressive improvements: wind energy is now the cheapest form of renewable energy at around 4 cents per kilowatt hour (much less than 10–15 cents for solar PV cells). With such a competitive advantage, wind power is poised for a very rapid growth. Growth has not just applied to the percentage of energy produced by wind (around 5% of U.S. output in 2004) but also in the output of the machine itself from 1,000 megawatts (MW) in 1985 to over 10,000 MW in 2006. Worldwide installations in 2005 were nearly 59,000 megawatts. Scientists and engineers continue to develop wind power technology, including off-shore wind farms such as the large farm off the coast of Ireland that can power over 16,000 homes.

GEOTHERMAL ENERGY

After the first geothermal power plant in 1904 began powering its local Italian countryside, the flood gates of research were opened. Of course, the ability to use geothermal power had been around for sometime. Over 10,000 years ago, Native Americans used local hot springs to cook their food. Romans used the warmth under Pompeii to heat their houses. Today, the heated water from geothermal reservoirs provide steam to power turbines producing completely clean energy.

In 2003, about 2,800 megawatts of electricity was generated from geothermal sources in the United States. As of 2005, approximately 8,900 megawatts was generated in twenty-four countries worldwide. The amount of viable sites is growing much faster than the power plant building can keep up with. A ten-fold increase in production of energy from geothermal fields is well within sight.

HYDRO ELECTRIC

Without question, water turbine energy has already proved its usefulness throughout the world. In 2004, over 715,000 megawatts of power, an astounding 19 percent of the world's energy was produced from the flow of water through turbines. And we continue to build dams for more hydro-electric power. Another 17,000 megawatts will be produced from the Three Gorges Dam of the Yangtze River, not to mention hundreds of proposed hydroelectric sites that are slated for utilization. This time-tested technology has been amplified with the staggering efficiencies of the turbines themselves (over 90 percent) and its completely renewable power sources; water and gravity.

Despite the fact that this energy has proven its worth, there are still questions with the development of each new site. While entirely renewable, the damming of rivers is far from what could be considered "green" power with the severe interruption of many of the rivers' natural processes.

FUEL CELL ENERGY

Of course, there are people that live where it is always overcast, never windy, in the middle of a tectonic plate, and without any viable dam spots. That quickly limits the ability of solar, wind, geothermal or water turbine energy to become the "energy of the future." However, there is one energy currency that could be tapped to assist those in less desirable environments. Hydrogen can be made using renewable energy sources, stored, and shipped anywhere in the world to power a fuel cell giving a truly renewable source of energy to any location.

While this may be one solution to the energy crisis, there are still kinks to work out. Expensive platinum is currently required for the fuel cell reaction, power density is relatively low and storage of hydrogen is an issue. Nevertheless, giant strides are being made in every facet of the technology with billions of dollars flowing into research and development in both the private and public sector.

the fuel cell timeline

FUEL CELL INFANCY

1800 Nicholson and Carlisle separate water into oxygen and hydrogen in the first experiment of electrolysis.

1838 William Grove creates his “wet cell” battery using platinum, nitric acid, zinc, and sulfur. This is a tremendous step towards the eventual creation of the fuel cell.

1840 Morse creates his famous code and the telecommunications industry, the first mass need for power. Coal becomes the fuel of choice sealing the fate of “green” power for years to come.

1843 Grove continues his research in battery technology and stumbles across a new type. With platinum electrodes, sulfuric acid, hydrogen and oxygen, he creates his “gas battery” a way of reversing electrolysis. History will call it the fuel cell.

FUEL CELLS ON THE BACK BURNER

1859 Edwin Drake drills the first successful oil well in Pennsylvania. The well is only 69 feet deep, but produces yet another cheap competitor that will further deflate fuel cell research.

1860 Hundreds of companies follow the lead of Drake and create wells all across the nation. Over 500,000 barrels of oil are produced and is followed by exponential growth for years to follow. Between coal and oil, energy questions seem answered, further wounding fuel cell research.

1893 Ostwald concludes his paper on the physical chemistry of the reaction inside the fuel cell connecting the various components to their actions. While an important piece in the line, it was hypothesized by Grove fifty years ago. The technology of fuel cells remains stagnant.

1896 Jacques claims to invent “a process of making electricity directly from coal” though it is quickly debunked as a small thermoelectric action.

THE ELECTROLYTE EXPLOSION

1930s Baur and Preis begin to experiment with different electrolytes with growing attention to what would eventually become Solid Oxide Fuel Cells (SOFC). Despite attempting electrolytes using yttrium, cerium, lanthanum and tungsten, unwanted chemical reactions continue.

1937 The Hindenburg explodes on May 6th bringing bad press for hydrogen. It was later proved that the covering of the zeppelin was to blame, not the hydrogen.

1938 Teflon is developed by DuPont which steps toward Nafion, a key component in the development of Proton Exchange Membrane Fuel Cells (PEMFC). At the same time, Francis Bacon begins experimentation with potassium hydroxide as an electrolyte with dramatically increases the power density of the fuel cell.

1940s Davtyan begins serious research into SOFCs using monazite, sodium carbonate and tungsten trioxide. However, problems still occur with unwanted chemical reactions and lifetimes.

ON THE WAY TO NICHE MARKETS

1957 Broers and Ketelaar abandon the SOFC research of Davtyan and others due to its stubbornness with the solvency of unwanted chemical reactions and lifetime issues. They begin the field of Molten Carbonate Fuel Cells (MCFC).

1959 To combat the growing ill will towards SOFCs, a fuel cell symposium involving the Central Technical Institute, Consolidation Coal Company and General Electric is convened. However, it quickly becomes an almost universal agreement that SOFCs are not worth the trouble and begin working on MCFCs as quickly as possible. Staying above the fray, Allis-Chalmers begins to outfit its tractor with 1,008 Alkali

Fuel Cell (AFC) giving it 15,000 watts. They continue their niche market with a golf cart, personal submarine, and fork lift.

THE RENNAISANCE OF THE FUEL CELL

1960 Broers and Ketelaar announce that their new MCFC has been running continuously for six months, drastically besting the lifetime of SOFCs. Materials in the gaskets begin to show trouble, but the improvement over SOFC is large.

1961 Elmore and Tanner publish "Intermediate Temperature Fuel Cells" revolutionizing research in Phosphoric Acid Fuel Cells (PAFC). Their work greatly increased the power density of fuel cells.

1965 The U.S. Army begins testing of a MCFC produced by Texas Instruments which can run off of gasoline via a reformer. Meanwhile, NASA begins using General Electric's breakthrough PEMFC on their Gemini space missions.

1968 G.E.'s PEMFC under-performs on Gemini V prompting NASA to award a new contract to Pratt and Whitney for their Alkali Fuel Cells (AFC). The AFCs remain an integral part of Gemini, Apollo and the Space Shuttle.

BUILDING TOWARDS THE HYDROGEN ECONOMY

1970 The term "hydrogen economy" is first used by John O'M. Bockris when talking about a world without petroleum as a fuel.

1973 The OPEC oil embargo prompts many scientists and policy makers to focus on alternative energy sources, including fuel cells.

1993 The first hydrogen powered bus finally hits the streets in Chicago. Soon after, all of the major automobile manufacturers begin prototypes.

1998 Iceland announces a plan to become the first country to become a true "hydrogen economy" by the year 2030.

2001 Ballard produces the first mass-manufactured PEMFC.

2003 $1.2 billion is earmarked by the United States for the development of hydrogen fuel cells. This is closely tied to both the FreedomCAR (a cooperative agreement to speed the production of fuel cell vehicles) and FutureGen (a planned coal plant designed for the production of hydrogen and sequestering of carbon monoxide and dioxide).

a brief history of element one: hydrogen

Elements are the building blocks that make up the universe. Many elements, such as gold, silver, and lead have been familiar to scientists since ancient times. Other elements were discovered as recently as the 1990s. The Modern Periodic Table of Elements currently lists 114 elements. Of these, 92 are natural elements and 22 are man-made.

Hydrogen was first classified as a distinct element by Henry Cavendish in 1766. It is known as Element 1 because it has one electron and one proton making it the first element listed in the Periodic Table. Hydrogen is the smallest and lightest element in the universe, and it is the most abundant. The word hydrogen comes from the Greek words *hydro* which means "water" and *genes* meaning "forming." It is estimated that hydrogen makes up over 90 percent of the total molecules in the observable universe. An important characteristic of hydrogen is that of all of the elements it has the highest energy content per unit of weight.

Hydrogen was used as an energy source for transportation in the early 1900s in zeppelins. The Hindenburg accident slowed the development of the use of hydrogen in transportation. Although it has been shown that the hydrogen in the Hindenburg did not cause the accident and that hydrogen actually burned safely away from the passengers within 60 seconds, the public still had the perception that hydrogen was unsafe.

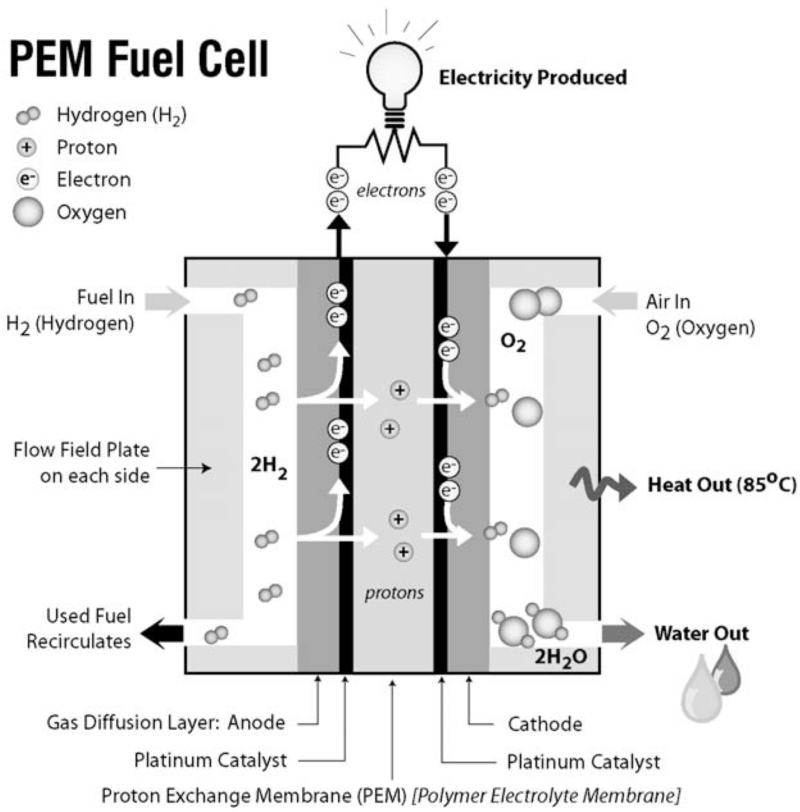
Today, major utility and car companies recognize the potential of safely using hydrogen for energy. Car companies including General Motors, Ford, Honda, and Toyota have developed hydrogen fuel cell cars. BMW has developed a hydrogen combustion engine. Oil companies like Shell Oil and Chevron-Texaco are beginning to build hydrogen refueling stations so that fuel cell cars can be refueled in gas stations.

PEM fuel cells

HOW A PEM FUEL CELL WORKS

A PEM Fuel Cell converts the chemical energy of hydrogen and oxygen into electrical energy. The fuel cell itself has no moving parts. The heart of a PEM Fuel Cell is a polymer (perflorinated sulfonic acid polymer) called a Proton Exchange Membrane (also known as Polymer Electrolyte Membrane) which acts as an electrolyte. Platinum is attached to the membrane as a catalyst.

When a hydrogen molecule with one negative electron and one positive proton is introduced to the membrane, the platinum along with the membrane, creates an environment that allows the positive proton to pass through the membrane, but the negative electron does not pass through. The electrons begin to move along a path creating electricity that is captured as the electron moves around the circuit through a current collector to the other side of the fuel cell. The electron re-joins a proton and the newly formed hydrogen atoms join oxygen to produce water. This reaction also generates heat. So, **the output of a hydrogen PEM fuel cell includes 1) electricity, 2) heat, and 3) pure, clean water.**

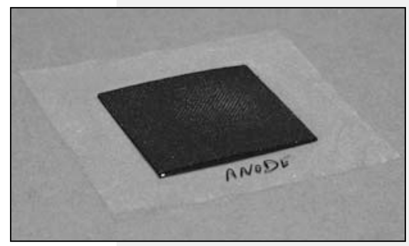


Source: *HYDROGEN - Hot Stuff Cool Science book*

The amount of current produced in a fuel cell is dependent on the active area of the MEA (membrane electrode assembly—or the polymer plus the platinum). The amount of voltage produced is usually around .85 volts (at best—1.23 volts). So, in order to increase the amount of power required, the size of the MEA is increased. To increase the voltage, fuel cells are joined together in series to create fuel cell stacks.

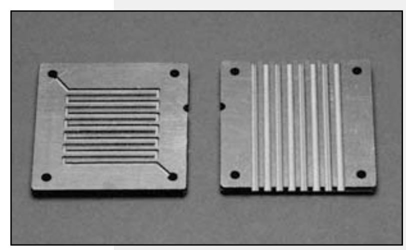
COMPONENTS OF A PEM FUEL CELL

The **Membrane Electrode Assembly (MEA)** consists of the perflorinated sulfonic acid polymer membrane (PEM) and the platinum catalyst. Protons can pass through the membrane, electrons are directed around an electrical circuit. Nafion® by Dupont has been the leading membrane in the market, although companies such as GEFC and GORE are now producing popular polymer membranes as well. Research is being conducted to find materials to combine with or take the place of platinum as the catalyst to decrease the cost of the fuel cell.



Membrane Electrode Assembly (MEA)

Graphite plates are used on both the hydrogen (anode) and oxygen (cathode) side of the fuel cell. Channels are usually machined into the graphite so hydrogen and oxygen are distributed evenly across the MEA.



The two sides of a graphite plate with serpentine flow channels

Fuel Cell Stack A single cell of a fuel cell consists of an MEA and graphite plate. Each cell produces about .85 volts regardless of the size of the MEA or the amount of catalyst. The wattage produced by a fuel cell depends on the amount of platinum catalyst on the active area of the fuel cell. So, individual cells are layered into fuel cell stacks to produce the voltage and wattage required.

5-cell PEM Fuel Cell Stack

electrolysis

A PROCESS FOR PRODUCING HYDROGEN

Electrolysis is the process of converting electrical energy into chemical, potential energy. In the 1780s, scientist Antoine Lavoisier discovered a way to split water molecules into hydrogen and oxygen and then recombine the them to make water again. When a chemical charge is applied to water, the charge breaks the chemical bond between the hydrogen and oxygen and splits apart the atomic components, creating charged particles called ions.

An electrolyser has two electrodes where the ions form. One electrode, called the anode, is positively charged. The other electrode, called the cathode, is negatively charged. Hydrogen gathers at the negative cathode, and the positively charged anode attracts oxygen. A voltage of about 1.6 is required for electrolysis to take place. This voltage requirement increases or decreases with changes in temperature and pressure. Adding an electrolyte such as salt to water increases the rate at which hydrogen and oxygen are produced.

Reversible fuel cells can be used to perform electrolysis. In a fuel cell, the electrolyte is a polymer that looks like clear plastic and is part of the fuel cell membrane assembly. When you apply current to a fuel cell, it will electrolyze water giving you hydrogen on the cathode side and oxygen on the anode side.

$$2H_2O + \text{Energy} = 4H + 4e- + O_2$$

PLEASE NOTE: The Following experiments show the old fuel cell. Please use the experiments as guides for science concepts.

experiment 1: electrolysis

INTRODUCTION

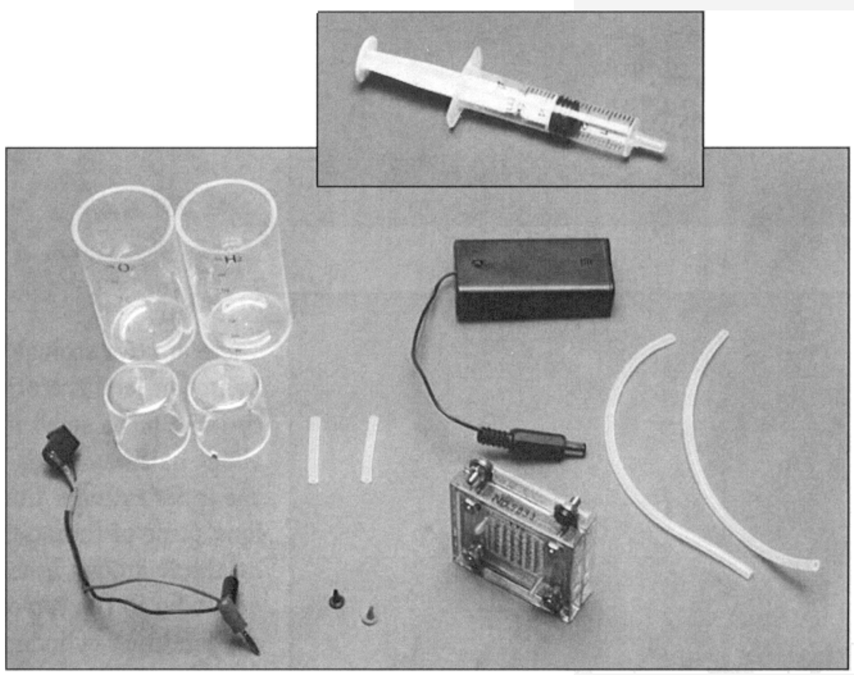
In this experiment you will produce hydrogen and oxygen using a reversible fuel cell. You will observe the volume of hydrogen produced compared to the volume of oxygen produced.

PREPARATION

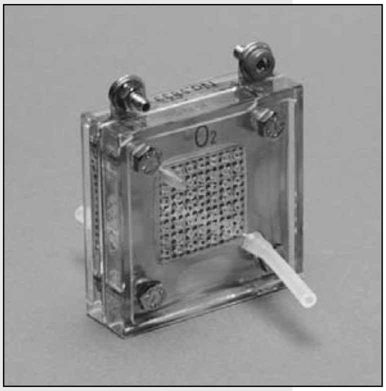
Prepare the lab documentation sheet on page 23. Answer questions 1-3.

PREPARE YOUR EQUIPMENT

- **Distilled water 100 rnl**
- **PEM reversible fuel cell**
- **Oxygen storage cylinder**
- **Hydrogen storage cylinder** 0 **Power supply**
- **Silicon tubing-**
- 2 **pieces 11/2" long,**
- 2 **pieces 8" long**
- **Red and black plugs**
- **Electric cables/wires**
- **Syringe**



Items Needed

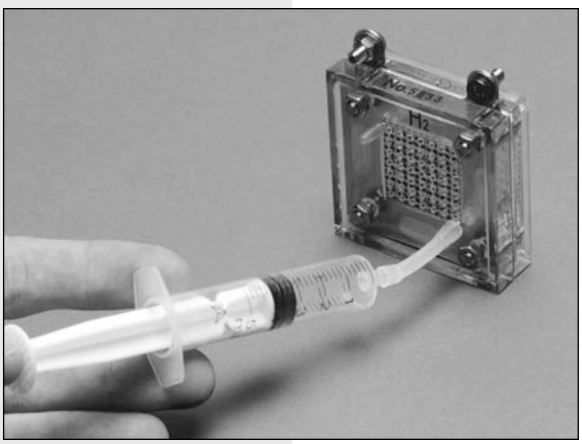


STEP 1

EXPERIMENT SET-UP

STEP 1

Attach a short section of tubing to the top nozzle on the Hydrogen (H_2-black) side of the fuel cell. Repeat on the Oxygen (O_2-red) side. Do not plug the tubing yet.



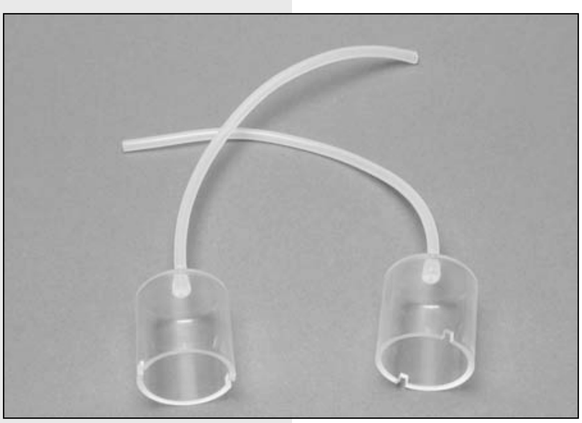
STEP 2

STEP 2

Using the syringe, push water into the hydrogen side of the fuel cell through the tube until you can see that the reservoir is full. Plug the tube.

Repeat on the oxygen side.

Note: The syringe is slightly too big to fit into the tubing, and some water may drip out.



STEP 3

STEP 3

There are two storage cylinders. One is for hydrogen, and the other is for oxygen. Each cylinder has a small inner cylinder that reaches about half way up each storage cylinder. Remove the inner cylinder from the outer cylinder. Attach a long piece of tubing to the top of the inner cylinder on the hydrogen inner cylinder. Attach a long piece of tubing to the top of the inner cylinder on the oxygen inner cylinder.

continued

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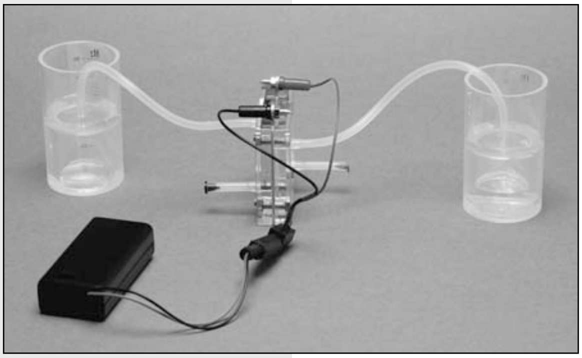


STEP 6

STEP 6

Insert 2 AA batteries into the power supply. Attach your power source to the fuel cell. Connect the red wire to the red jack on the fuel cell and the black wire to the black jack on the fuel cell. Turn on the battery pack.

STEP 7

You will immediately see water in the cylinder being displaced to the top of the cylinder. Hydrogen and oxygen are being captured in the inner cylinders. Hydrogen and oxygen are invisible, so you will be recording what looks like empty space as water is pushed by hydrogen from the inner cylinder to the outer cylinder.

STEP 8

Begin your measurements. Record the amount of hydrogen and oxygen produced every 30 seconds for 5 minutes.

STEP 9

Disconnect the battery pack from the fuel cell. Turn off the battery pack.

STEP 10

Complete Lab Sheet

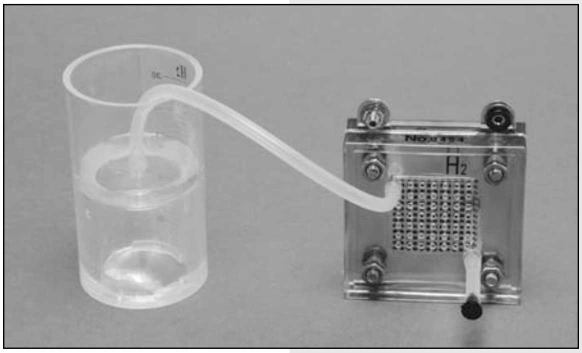
STEP 4

Pour distilled water into the outer cylinder up to the 0ml mark. Fit the inner cylinder snuggly into the outer cylinder capturing water in the inner cylinder. Push down on the inner cylinder to be sure the cylinder fits tightly onto the rim at the bottom of the outer cylinder. There is a small gas outlet on the edge of the inner cylinder. Be sure to allow the gas to escape from the inner cylinder into the outer cylinder. Do not block the outlet with the plastic rim on the bottom of the outer cylinder.

STEP 4

STEP 5

Attach the tubing from the hydrogen cylinder to the top inlet on the hydrogen side of the fuel cell. Repeat on the oxygen side of the cylinder.



STEP 5

continued

lab documentation: electrolysis

In this experiment you will produce hydrogen and oxygen using a reversible fuel cell. You will observe the volume of hydrogen produced compared to the volume of oxygen produced.

1. What is the chemical symbol for hydrogen?

2. What is the chemical symbol for oxygen?

3. When you use electrolysis to separate water, what do you predict the ratio of hydrogen to oxygen will be?

Time Elapsed	Hydrogen (*ml*)	Oxygen (*ml*)	Ratio of Hydrogen to Oxygen
0.5 minute			
1.0 minute			
1.5 minutes			
2.0 minutes			
2.5 minutes			
3.0 minutes			
3.5 minutes			
4.0 minutes			
4.5 minutes			
5.0 minutes			

4. Which gas was produced more quickly?

5. What is the ratio of hydrogen to oxygen in water?

6. What is the chemical symbol for water?
   What does that symbol mean?

experiment 2: efficiency

DOES OXYGEN INCREASE THE EFFICIENCY OF A PEM FUEL CELL?

INTRODUCTION

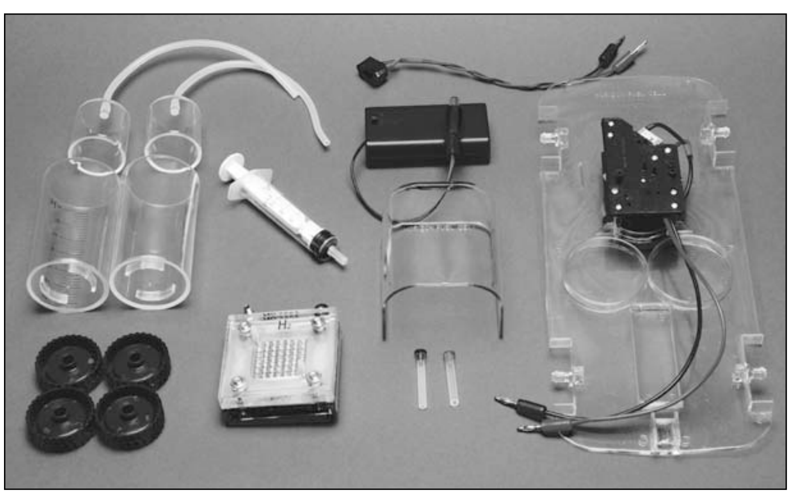
In this experiment you will evaluate the use of oxygen in a reversible fuel cell. You will compare the productivity of the fuel cell with oxygen compared to the productivity of the fuel cell when oxygen is not used.

PREPARATION

Prepare the lab documentation sheet on page 27.
Answer questions 1-3.

PREPARE YOUR EQUIPMENT

- ❍ Distilled water 100 ml
- ❍ Intelligent Fuel Cell Car parts
- ❍ Syringe
- ❍ Two books to hold the car in the air.

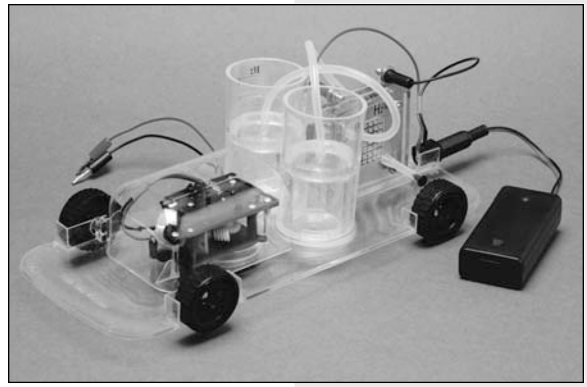


Items Needed

EXPERIMENT 2 SET-UP

STEP 1

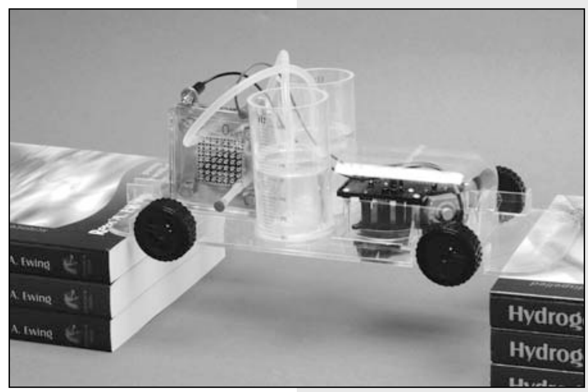
Follow steps 1–10 on pages 5 – 8 to assemble the Intelligent Fuel Cell Car.



STEP 1

STEP 2

To achieve more consistent results, prop the car chassis between two books so the drive wheel is in the air and the car will not move. Plug the red and black wires from the car chassis into the banana jacks on the fuel cell.



STEP 2

STEP 3

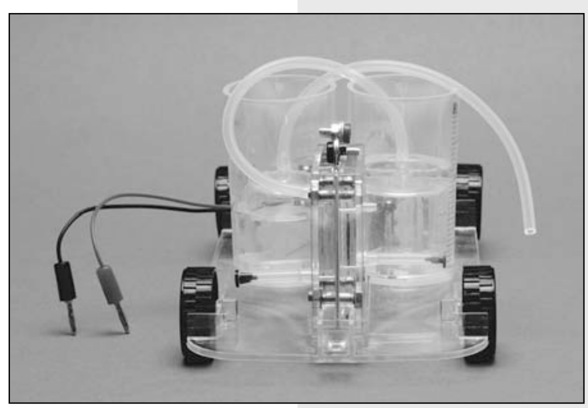
Begin a stop watch. Note the amount of time it takes for the motor to stop moving. Unplug the wires from the chassis to the fuel cell.

STEP 4

Release any remaining hydrogen and oxygen in the inner cylinders by disconnecting the long, upper tubes from the fuel cell. When all of the water in the upper gas cylinders has moved back to the bottom of the cylinders, reattach the tubes to the top of the inner cylinders.

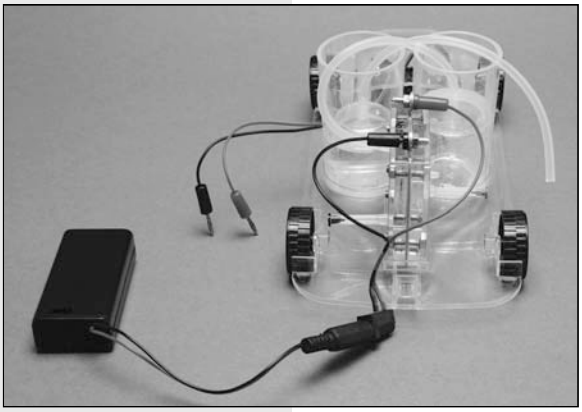
STEP 5

Reattach only the hydrogen side tubing to the fuel cell, leaving the upper nozzle on the oxygen side of the fuel cell open. Remove the small tube on the lower nozzle of the oxygen side of the fuel cell.

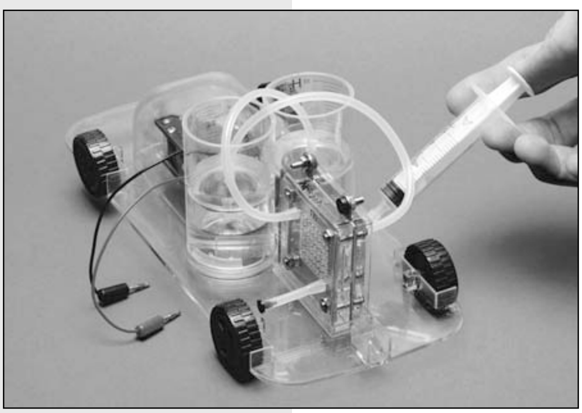


STEP 5

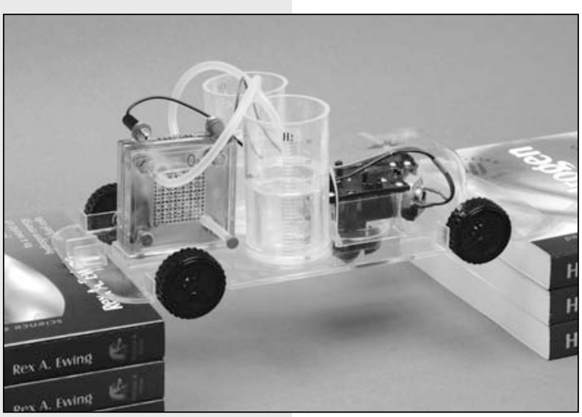
continued



STEP 6



STEP 8



STEP 9

STEP 6

Attach the power supply to the fuel cell. Insert the red wire into the red banana jack and the black wire into the black banana jack. You will see hydrogen being produced. The oxygen is being released into the air.

STEP 7

When you begin to see hydrogen bubbles released through water in the upper chamber, turn the power supply off and remove the power supply from the fuel cell. Attach the wires from the chassis to the fuel cell.

STEP 8

Attach the upper tube from the oxygen cylinder to the top of the oxygen side of the fuel cell. Using your syringe, pull the plunger of the syringe up filling the syringe with air. Connect the syringe to lower inlet on the O_2 side and push the air through the bottom tube of the fuel cell through the fuel cell and into the inner oxygen cylinder until the inner oxygen cylinder is full of air.

STEP 9

Attach wires from the car motor to the fuel cell. Prop the car between two books so the motor can turn freely. Note the amount of time it takes before the motor stops running.

STEP 10

Complete Lab Sheet

lab documentation: efficiency

In this experiment, you will examine the role of oxygen in a PEM Fuel Cell. If you have not already done so, read pages 16 – 17: How a PEM Fuel Cell Works.

1. What is the purpose of hydrogen in a PEM fuel cell?

2. What is the purpose of oxygen in a PEM fuel cell?

3. In the explanation How a PEM Fuel Cell Works, three types of fuel cells are discussed. One is H_2/O_2, one is H_2/Air and one is H_2/Forced Air. Since a fuel cell can operate without oxygen, what do you think will happen when we disconnect the oxygen from this fuel cell?

4. How long did your fuel cell run with the oxygen attached?

5. How long did your fuel cell run using air?

6. How would you explain the difference in the times.

7. How would you design this fuel cell differently to have it work better using ambient air without forced oxygen?

experiment 3: resistance

DOES RESISTANCE CHANGE THE AMOUNT OF TIME THE PEM FUEL CELL WILL RUN THE CAR?

INTRODUCTION

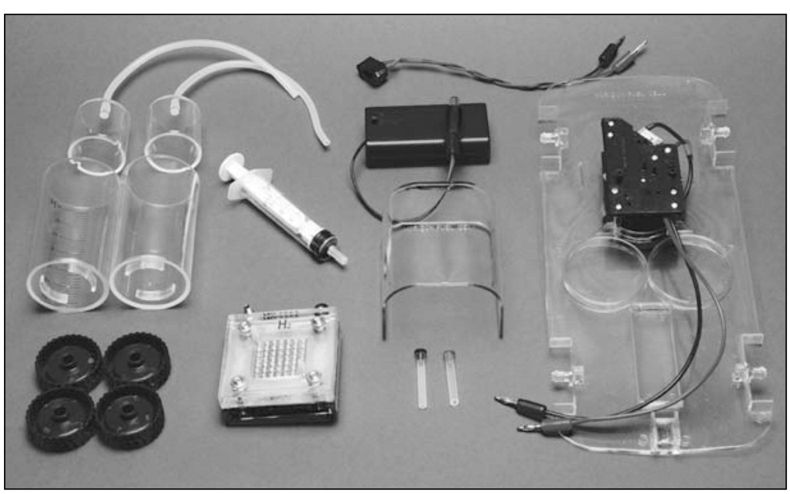
In this experiment you will evaluate the effect of resistance on the reversible fuel cell. You will compare the amount of time the fuel cell will power the car with no resistance to the amount of time the fuel cell will power the car when resistance is added.

PREPARATION

Prepare the lab documentation sheet on page 31.
Answer questions 1–3.

PREPARE YOUR EQUIPMENT

- ❍ Distilled water 100 ml
- ❍ Intelligent Fuel Cell Car parts
- ❍ Syringe
- ❍ Two books to hold the car in the air.



Items Needed

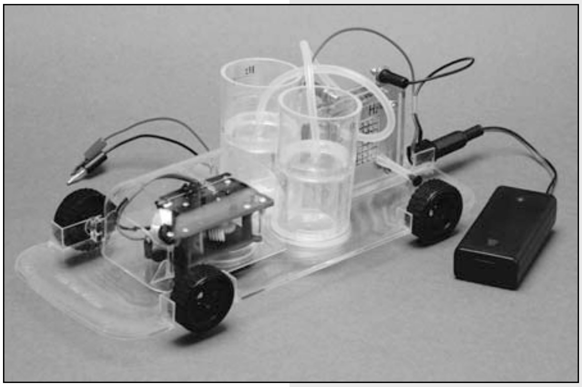
PLEASE NOTE: The folowing experiments show the old fuel cell. Please use the experimentsas guides for science concepts.

EXPERIMENT 3 SET-UP:

STEP 1

Write your prediction on the lab sheet.

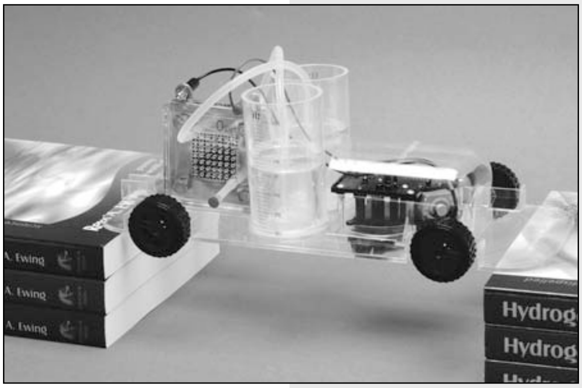
Follow steps 1–10 on pages 5 – 8 to assemble the Intelligent Fuel Cell Car.



STEP 1

STEP 2

To achieve more consistent results, prop the car chassis between two books so the drive wheel is in the air and the car will not move. Plug the red and black wires from the car chassis into the banana jacks on the fuel cell.



STEP 2

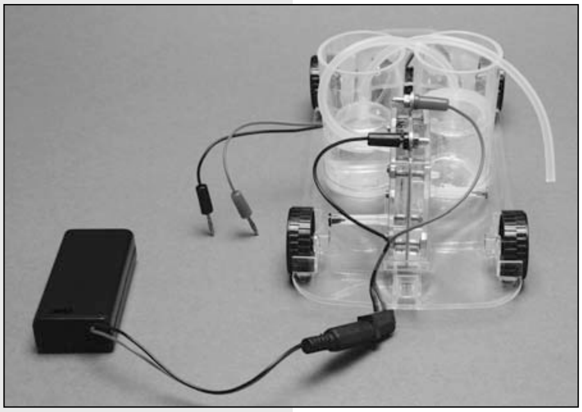
STEP 3

Begin a stop watch. Note the amount of time it takes for the motor to stop moving. Unplug the wires from the chassis to the fuel cell.

STEP 4

Release any remaining hydrogen and oxygen by disconnecting the long, upper tubes from the fuel cell. When all of the water in the upper gas cylinders has moved back to the bottom of the cylinders, reattach the tubes.

continued

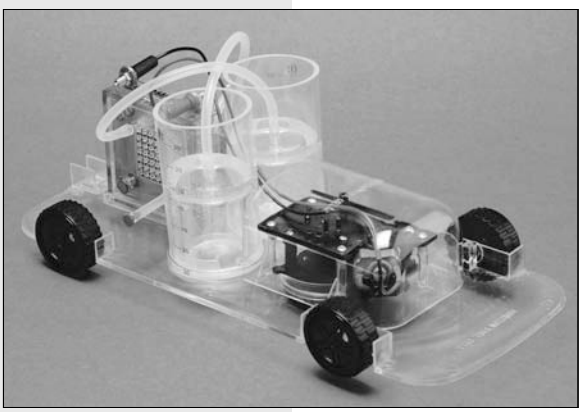


STEP 5

STEP 5

Attach the power supply to the fuel cell. Insert the red wire into the red banana jack and the black wire into the black banana jack. You will see hydrogen being produced again.

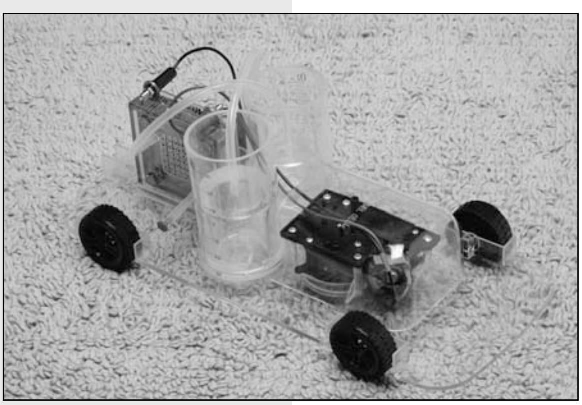
Note: if you have used the fuel cell 2 or 3 times without adding additional water, you might need to add a small amount of water to the fuel cell on both the hydrogen and oxygen sides.



STEP 6

STEP 6

When you begin to see hydrogen bubbles released through water in the upper chamber, turn the power supply off and remove the power supply from the fuel cell. Attach the wires from the chassis to the fuel cell.



STEP 7

STEP 7

Put the car on a flat surface and note the amount of time it runs. For additional experiments, count the amount of time the car has to turn. Compare how long the car runs when it turns just a few times to how long it runs when it has to make many turns. Also, compare how long the car runs on a smooth surface such as a wooden floor to how long it runs on a rough surface such as carpeting.

STEP 8

Complete Lab Sheet

lab documentation: resistance

In this experiment you will evaluate the effect of resistance on the reversible fuel cell. You will compare the amount of time the fuel cell will power the car with no resistance to the amount of time the fuel cell will power the car when resistance is added.

1. Make a prediction: Will the car fun for a longer period of time when it is hanging in the air or when it is running on a surface? Why?

2. How long did your car motor run when it was hanging in the air without any resistance?

3 How long did your car motor run when it was running on a surface?

4. What do you think an ideal surface would be to allow the car to run longer?

5. Why do you think the car runs for less time when it has to make more turns?

6. What adjustments could you make to the design of the car to make it run longer on a surface that offers resistance?

Ohm’s Law

Georg Simon Ohm was a Bavarian physicist who is credited for developing the mathematical formulas for electrical current. Ohm’s law recognizes the relationship between Voltage (V), Current (I), and Resistance (R).

The basic equation formed by Ohm’s Law is: V=IR. When we measure electricity we usually denote current as amperes (amps) and resistance as ohms.

Working from Ohm’s Law we can also define the amount of electric power being produced. The equation for finding power is: P=VI. Power is measured as Watts. Using the equations below you can find the watts, amps, and voltage of your fuel cell.

- Watts divided by Volts = Amps $P \div V = I$
- Watts divided by Amps = Volts $P \div I = V$
- Volts divided by Amps = Ohms $V \div I = R$
- Volts times Amps = Watts $V \times I = P$

Single slices of fuel cells can produce only about .85 volts. The amount of current (or amps) produced by the fuel cell depends primarily on the area and amount of catalyst on the Proton Exchange Membrane (PEM). Fuel cell manufacturers design fuel cells based on the user’s requirements for volts, watts, and amps by varying the size of the fuel cell and the number of fuel cell slices in a fuel cell stack.

P = watts
I = current (amps)
R = resistance (ohms)
V = volts

experiment 4: Ohm's Law

INTRODUCTION

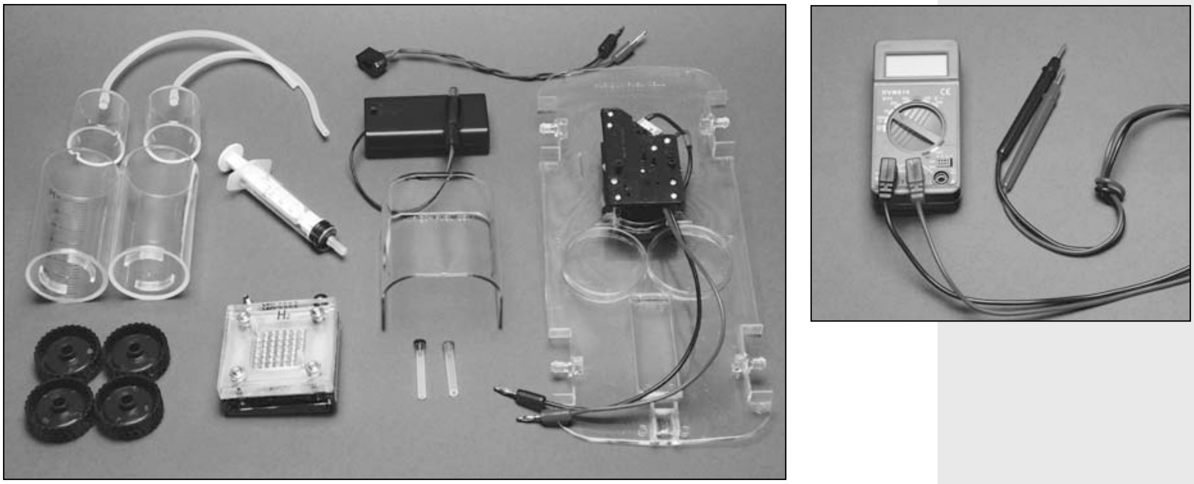
In this experiment you will calculate the number of watts being produced by your fuel cell using equations derived from Ohm's Law.

PREPARATION

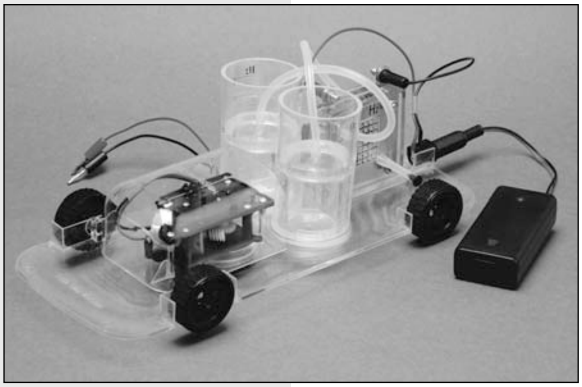
Prepare the lab documentation sheet on page 36.
Answer questions 1 and 2.

PREPARE YOUR EQUIPMENT

- ❍ Multimeter (not included in kit)
- ❍ Distilled water 100 ml
- ❍ Intelligent Fuel Cell Car parts
- ❍ Syringe
- ❍ Two books to hold the car in the air.



Items Needed

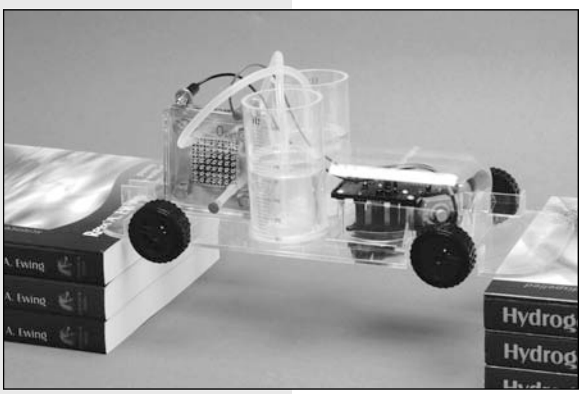


STEP 1

EXPERIMENT 4 SET-UP:

STEP 1

Follow steps 1–10 on pages 5 – 8 to assemble the Intelligent Fuel Cell Car and to produce hydrogen and oxygen.



STEPS 2 & 3

STEP 2

Prop the Intelligent Car chassis between two books so the motor is able to turn freely without the car moving. You are going to be taking measurements, so the car must remain stationary.

STEP 3

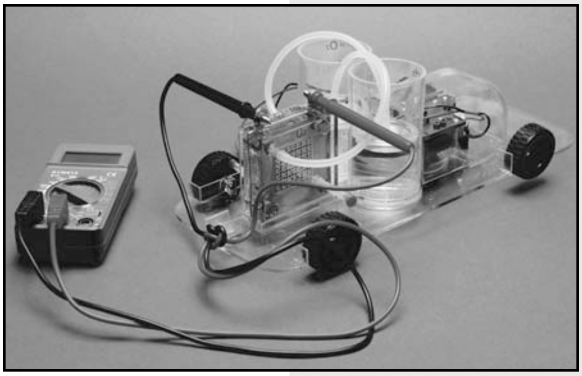
Attach the wires from the car chassis to the fuel cell. Insert the red wire into the red banana jack and the black wire into the black banana jack.

NOTE: It is important that you follow these instructions carefully. If you accidently reverse the red and black wires, you will destroy the fuel cell.

continued

STEP 4 — TO MEASURE AMPS

Turn the multimeter dial to measure amps in the 200 mA range. Touch the red lead from the multimeter to the screw at the back of the red banana jack on the fuel cell. At the same time, touch the black lead from the multimeter to the screw at the back of the black banana jack on the fuel cell. Note the number of mA being produced by the fuel cell on Question 3 on your Lab Sheet.



STEP 4

STEP 5 — TO MEASURE VOLTS

Turn the dial on your multimeter to measure volts in the .200 range. Touch the red lead from the multimeter to the screw at the back of the red banana jack on the fuel cell. At the same time, touch the black lead from the multimeter to the screw at the back of the black banana jack on the fuel cell. Note the number of volts being produced by the fuel cell on Question 4 of your Lab Sheet.

Additional multimeter instructions can be found on pages 37 – 38.

STEP 6

Disconnect the multimeter leads from the fuel cell. Turn the multimeter off. Disconnect the car motor from the fuel cell.

STEP 7

Complete Lab Sheet

lab documentation: Ohm's Law

In this experiment you will calculate the number of watts being produced by your fuel cell using equations derived from Ohm's Law.

1. What is Ohm's Law?

2. What equation will you use to calculate watts if you have measurements for volts and amps?

3. How many amps is your fuel cell producing? (Note that the amps you measured on your multimeter are reported on the digital display as milliamps, so be careful with your decimal point when making your calculations.)

4. How many volts is your fuel cell producing?

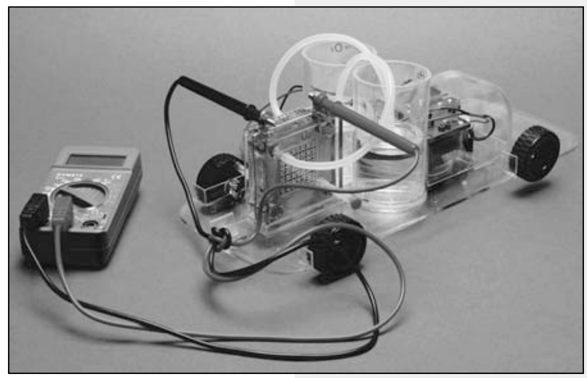
5. Calculate the watts being produced by your fuel cell.

6. If you have a fuel cell that produces .85 volts at 2 watts, how many amps is the fuel cell producing?

7. A single fuel cell usually produces about .85 volts, how many fuel cells would you need to stack together to run a radio that requires 6 volts?

using a multimeter with demonstration fuel cells

Multimeters are used to measure voltage, current, and resistance by measuring electricity between two different points. The red and black wires inserted into plugs on the multimeter create the two points.



Before measuring amps and volts, your fuel cell should provide power to an electrical load, such as the motor on the car.

It helps when you are first using a multimeter to know approximately the range of volts and amps of the fuel cell you are going to measure. Most small, demonstration fuel cells operate at about .75 volts and between 200mA and 400mA.

Before measuring the volts and amps from your fuel cell, your fuel cell should be providing power to some electrical load. This might be a small propeller or a motor on a model car.

VOLTAGE

Voltage is measured in units of volts. To measure volts on your multimeter, first plug the black wire into the COM (left) outlet. The black wire will be in this plug no matter what you are measuring. Plug the red wire into the middle outlet. We use this plug for measuring voltage and to measure Amps that are lower than 10 Amps. Since we know our fuel cell is well below 10 Amps, we can use this plug safely.

To measure volts for this fuel cell, set the dial at the 20 position.

Turn the dial on the multimeter to the left (counterclockwise) to the 20 position. This means we expect our voltage to be closer to 20 volts than to the next two positions which would be 200 volts above and 2000mVolts below. We expect our voltage to be about .75 so the 20 position will be closest for us. Touch the metal probe at the end of the red wire to the positive terminal on your load. Touch the metal probe at the end of the black wire to the negative terminal on your load. Read the digital display to see what the voltage is coming from your fuel cell. It is not unusual for the voltage to be above 1 volt when you first provide power to your load from your fuel cell. The voltage will probably gradually drop and become steady at some point between .60 volts and .95 volts.

To measure amps for this fuel cell, set the dial at the 200m position.

CURRENT

Current is measured in units of amps. To measure current on your multimeter, first plug the black wire into the COM (left) outlet. Plug the red wire into the center outlet.

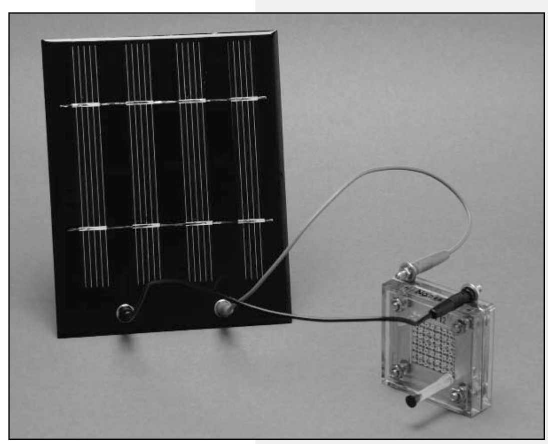
Turn the dial on the multimeter to the right (clockwise) to the 200m position. This means we expect our current to be close to 200mA. Touch the metal probe at the end of the red wire to the positive terminal on your load. Touch the metal probe at the end of the black wire to the positive terminal on your load. Read the digital display to see what the current is coming from your fuel cell. You should expect the current on a small fuel cell to be between 100mA and 400mA.

using solar cells with fuel cells

One of the barriers to developing a hydrogen economy is the production of hydrogen. It is estimated that more than 90 percent of all hydrogen used in industry today is produced from natural gas. When we convert natural gas into hydrogen we lose about 50 percent of the energy in the conversion. Until we produce more of our hydrogen using renewable energy, hydrogen fuel cells might not be an advantage environmentally.

An advantage of using solar cells to produce hydrogen is that solar energy is completely renewable. If we lose some solar energy today, it does not affect the amount of solar energy we can harvest from the sun tomorrow. The loss of energy in the production process is offset by the advantages we gain in being able to store and transport energy in the form of hydrogen.

When choosing a solar cell to provide the electricity for electrolysis in a reversible fuel cell, the most important consideration is matching the ouput capabilities of the solar cell to the maximum allowable input for the fuel cell. Most single cell reversible fuel cells require between 1.8 and 2.2 volts for electrolysis. If more than 2.2 volts are used, the fuel cell can be damaged or the life of the PEM membrane in the fuel cell can be reduced. A general rule of thumb is that for every cell in a fuel cell stack, approximately 2 volts are required for electrolysis.



CONNECTING A SOLAR CELL TO A FUEL CELL IS SIMPLE

To provide electricity to the fuel cell for producing hydrogen, attach the negative output of the solar panel (usually a black connection or indicated by –) to the negative input point (again, usually black or indicated by –) on the fuel cell. Attach the positive output of the solar panel (usually red or indicated by +) to the positive input (again, usually red or indicated by +) on the fuel cell.

Solar cells and fuel cells as renewable energy producers have much in common. They are both silent. Neither has any moving parts that wear out. They both are clean, renewable resources.

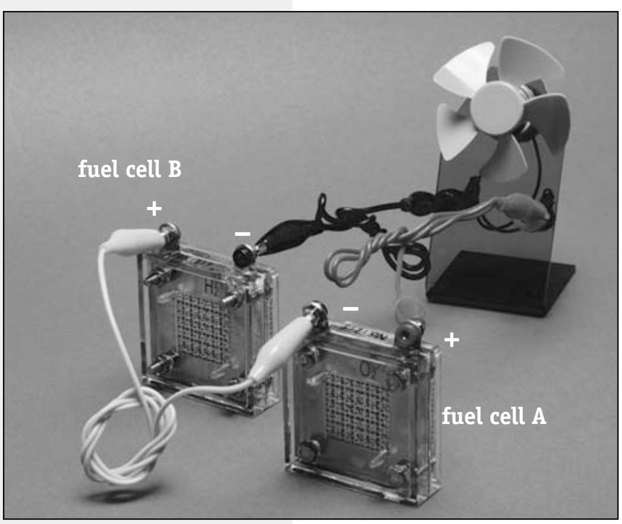
putting fuel cells in series

To increase the voltage, additional fuel cells are stacked in series

A single cell of a fuel cell can theoretically produce a maximum of 1.23 volts. The voltage at which water can be separated into hydrogen and oxygen is the maximum you could expect to receive in the reverse process, the process inside a fuel cell. In practical applications, fuel cell manufacturers expect to receive within the range of .7 to .85 volts per cell. So, to increase the voltage, additional cells must be added to a fuel cell stack in series.

When connecting two or more fuel cells in series, it is helpful to picture putting batteries into a flashlight. The negative end of the first battery (usually a flat metal base) is connected to the bottom of the battery case. The negative end of the second battery touches the top or positive end of the first battery. The positive end of the second battery touches the positive point in the battery case (often a wire spring attached to the light).

In this photo, we use red, black and yellow wires to put two fuel cells in series. Attach one end of the red wire (red usually indicates positive) to the positive connection on fuel cell A. Attach the other end of the red wire to the positive connection on your load (a fan, in this case).



Next, attach one end of the black wire (black usually indicates negative) to the negative connection on fuel cell B and the other end to the negative connection of your load (fan).

Now connect the two fuel cells together by attaching one end of the yellow wire to the negative connection of fuel cell A and the other end to the positive connection on fuel cell B.

glossary of terms

Alkaline Fuel Cell
Fuel Cell that uses an alkaline solution (the opposite of acidic) as the electrolyte. Common alkaline solutions used include salt and KOH.

Alternating Current
A current which periodically changes or reverses it direction of flow.

Amperage
A measure of electrical potential named after the 19th century French physicist Andre Marie Ampere. It is commonly represented with the symbol A or amp.

Anode
The point where electrons exit from a device to the external electric circuit. In a fuel cell the anode is the hydrogen side. When the fuel cell is used as an electrolyser, the anode is the oxygen side.

Atom
The basic building blocks of matter. They cannot be chemically subdivided by ordinary means. Atoms are composed of protons, neutrons, and electrons.

Catalyst
A substance that begins or increases the speed of a chemical reaction. In PEM fuel cells, the catalyst is usually platinum.

Cathode
The point where electrons enter a device In a fuel cell the anode is the oxygen side. When the fuel cell is used as an electrolyser, the cathode is the oxygen side.

Charge
Charge is the imbalance of positive and negative electricity flowing through matter.

Circuit
A complete pathway for electricity to flow.

Current
Flow of electricity between two points. Measured in amps.

Diode
A device having two terminals with a low resistance to current in one direction and a high resistance in the other direction. Diodes can be used on fuel cells to protect against current flowing the wrong way if leads are attached incorrectly.

Direct Current
A current that flows steadily in one direction Fuel cells produce direct current.

Distilled Water
Water that has been heated until it becomes steam, leaving impurities behind, then cooled again from steam to liquid.

Efficiency
The ratio or percentage of the amount energy used compared to the amount of energy created. Efficiency can be represented by the equation: % efficiency = useful energy produced x 100 divided by total energy used.

Electrode
A conductor used to make electrical contact with some part of a circuit Fuel Cells use MEA's—membrane electrode assemblies which are usually a polymer membrane with a platinum catalyst.

Electrolysis
The breaking down of water into hydrogen and oxygen.

Electron
An elementary particle with a negative charge In fuel cells, the electron travels around the electric circuit.

Energy
Energy is the ability to do work. Fuel cells transform chemical potential energy into electrical energy.

Fossil Fuel
Any combustible organic material, such as coal, oil, or natural gas which is derived from the remains of former life held in the earth's crust.

Fuel Cell
A battery-like device that transfers chemical potential energy into electricity using hydrogen as the fuel and oxygen and other elements as catalysts.

Hydrogen
The simplest and lightest and most abundant element. Element one in the Periodic Table of Elements. It contains one proton and one electron.

Ion
An atom or group of atoms in which the number of electrons is different from the number of protons. In a fuel cell, the proton is the hydrogen ion which passes through the Proton Exchange Membrane.

MEA
Membrane Electrode Assembly. The polymer membrane plus the platinum catalyst in a fuel cell.

Methanol
A colorless, toxic, flammable liquid rich in hydrogen (CH_3OH) used as a fuel in methanol fuel cells.

Molecule
The smallest particle of a pure chemical substance that still retains its chemical composition and properties.

Multimeter
Electronic test equipment used to make various measurements such as voltage, current, and resistance.

Ohm's Law
Defines the relationship between voltage and current in an ideal conductor. Ohm's Law states that: The potential difference (voltage) across an ideal conductor is proportional to the current through it. The constant of proportionality is called the resistance, RI is the current flowing through the resistance So, Ohm's Law is given by the equation: V=IR.

Oxygen
An odorless, colorless gaseous element with the atomic number 8.

PEM
Proton Exchange Membrane or Polymer Electrolyte Membrane. It is the polymer in the heart of a fuel cell through which the hydrogen proton passes.

Polymer
A compound derived either by the addition of smaller molecules, or by the condensation of smaller molecules through dehydration. The polymer used in fuel cells is usually formed by eliminating alcohol from a solution.

Power
The product of voltage and current.

Proton
A subatomic particle that has a positive electric charge. In a PEM fuel cell, the proton from a hydrogen atom passes through a polymer leaving the electron to go around a circuit.

Renewable Energy
Naturally occurring, theoretically inexhaustible source of energy, such as hydrogen, biomass, solar, wind, tidal, wave, and hydroelectric power, that is not derived from fossil or nuclear fuel.

Resistance
A material's opposition to the flow of electric current. Resistance is measured in ohms. It can be found using the equation R =V÷I where V represent voltage and I represents current (amperes).

SOFC
Solid Oxide Fuel Cell. A fuel cell that operates at extremely high temperatures.

Voltage
A measure of electrical potential.

Wattage
A measure of the amount of electrical power provided by the circuit. The product of voltage and amps. Watts = Volts x Amps.

reference Web sites

content to come

suggested answers

EXPERIMENT 1 — ELECTROLYSIS

1. H
2. 0
3. Prediction—answers will vary
4. Hydrogen
5. 2:1
6. $H_2 0$; there are two hydrogen atoms and one oxygen atom in a water molecule.

EXPERIMENT 2—OXYGEN IN A FUEL CELL

1. Hydrogen is the fuel; it provides the electrons that create electricity.
2. Oxygen helps the process by joining the hydrogen to make water.
3. Prediction—answers will vary.
4. Answers will vary—the range should be between 3 and 5 minutes.
5. Answers will vary—the range should be between 30 seconds and 2 minutes.
6. There is more oxygen to attract the hydrogen molecules, when air is used, there are elements other than oxygen present that do not help the process.
7. Answers will vary—the design should make it easier for air to pass through the fuel cell.

EXPERIMENT 3—RESISTANCE

1. Prediction—answers will vary.
2. Answers will vary—the range should be between 3 and 5 minutes.
3. Answers will vary—the range should be between 1 and 4 minutes.
4. Answers will vary— Suggested answer: smooth surface.
5. It requires more energy to turn than to go straight because turning increases the amount of resistance.
6. Answers will vary—Suggested answer: change the gear ratio; change the size or material of the wheels; reduce the weight of the fuel cell.

EXPERIMENT 4—OHM'S LAW

1. V = I x R (or V = IR)
2. V x I = P
3. Answers will vary—the range should be between 250 and 400mA
4. Answers will vary—the range should be between .75 and .95 volts
5. Answers will vary—the range should be between .25 and .35 watts
6. 2.35 Amps
7. 7 single cells

NSTA Standards addressed by these experiments

NSTA:

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K-4

- Science and technology have been practiced by people for a long time.
- Men and women have made a variety of contributions throughout the history of science and technology.
- Materials can exist in different states—solid, liquid, and gas. Some common materials, such as water, can be changed from one state to another by heating or cooling.
- Some resources are basic materials, such as air, water, and soil; some are produced from basic resources, such as food, fuel, and building materials; and some resources are nonmaterial, such as quiet places, beauty, security, and safety.

5-8

- Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties.
- In chemical reactions, the total mass is conserved. Substances often are placed in categories or groups if they react in similar ways; metals is an example of such a group.
- Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical.
- Energy is transferred in many ways.
- Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.
- Many individuals have contributed to the traditions of science. Studying some of these individuals provides further understanding of scientific inquiry, science as a human endeavor, the nature of science, and the relationships between science and society.

9-12

- Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.
- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.
- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force be tween the nucleus and electrons holds the atom together.
- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.
- A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions.
- Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.