Aluminum–Air Battery

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In this Activity, students construct a simple battery from aluminum foil, saltwater, and activated charcoal. The battery can power a small motor or light.

Background

Homemade batteries are an inexpensive, practical, and hands-on way to teach oxidation and reduction reactions. A popular battery can be made out of a lemon and two metal electrodes, but a single lemon cell rarely produces enough current to power an actual device *(1)*. Students must construct several cells in series or monitor readings on a multimeter in order to visualize battery performance *(2)*. A simple aluminum–air battery can generate 1 V and 100 mA, which is enough power to run a small electrical device or light. While the voltage is comparable to a traditional lemon cell, the current can be up to 400 times greater than what is generated in a typical classroom activity *(1)*. This battery relies on oxidation of aluminum at the anode and reduction of oxygen at the cathode to generate electrical energy. A diagram of the battery and equations for the half and overall reactions are given below.

Anode: $Al(s) + 3OH^-(aq) \rightarrow Al(OH)_3(s) + 3e^-$

Cathode: $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

Overall: $4Al(s) + 3O_2(g) + 6H_2O(l) \rightarrow 4Al(OH)_3(s)$

Aluminum foil provides an affordable supply of aluminum. Activated charcoal is used at the cathode to increase the amount of oxygen that comes in contact with the battery. Activated charcoal is very porous and has a high surface area to mass ratio. This surface provides a large number of adsorption sites to which oxygen can bind and participate in the cathode reaction.

Pressing the electrode into the activated charcoal generates enough current to illuminate a holiday light.

Integrating the Activity into Your Curriculum

This Activity demonstrates oxidation and reduction reactions, which are integral parts of battery chemistry. The use of atmospheric oxygen as the oxidizing agent has extensions to other redox reactions that occur in corrosion, metabolism, and combustion. In addition, the participation of oxygen as a reactant in the aluminum–air battery can be used to introduce the concepts of fuel cells and alternative energy sources. Photos of the aluminum–air battery procedure are online *(3)*, as well as directions for a homemade saltwater battery *(4)*.

About the Activity

Students use non-toxic, readily available materials to construct a battery that can power an electrical device. Activated charcoal can be found in pet and aquarium supply stores. Small electrical devices such as a 1.5–3 V dc motor (Radio Shack #273-223, *http://www.radioshack.com*) are available at electronic stores. The battery is also strong enough to power a holiday light that has been cut from the string and stripped to reveal its wire leads. Make sure the chosen device will produce a noticeable change when connected to a 1 V power supply. If desired, students can also measure the voltage and current produced by their cell on a multimeter. Comparisons can be made to determine what aspects of the design contribute to improved battery performance.

Answers to Questions

1. In order for current to pass between the electrodes, there must be an electrolyte between them. The salt provides ions that can move through the wet paper towel and transfer charge.
2. Though there is plenty of oxygen in the air, it must be in contact with the carbon in order to react. The increased surface area allows more oxygen to participate in the reaction at the cathode. This improves the overall rate of reaction, which results in a greater number of electrons to flow per unit time and thus increases the current.
3. The oxygen that reacts at the cathode is constantly replenished, just as reactants in a fuel cell are. At the other electrode, aluminum is oxidized and slowly consumed. After enough use, this oxidation can be seen as corrosion of the Al surface.
4. If the foil from one cell is in contact with the foil from the cell above it, the electrons will bypass the paper towel and activated charcoal, moving directly into the second piece of foil, which has a lower resistance than the charcoal layer. This effectively shorts out the lower cell, which no longer contributes to the overall power output. Compare the power from the stacked pile of cells when pieces of foil are touching versus when they are not.

References, Additional Related Activities, and Demonstrations (accessed Sep 2007)

1. Swartling, Daniel J.; Morgan, Charlotte. Lemon Cells Revisited—The Lemon-Powered Calculator. *J. Chem. Educ.* **1998**, *75,* 181–182.
2. Muske, Kenneth R.; Nigh, Christopher W.; Weinstein, Randy D. A Lemon Cell Battery for High-Power Applications. *J. Chem. Educ.* **2007**, *84,* 635–638.
3. Aluminum Air Battery. *http://www.exo.net/~pauld/activities/AlAirBattery/alairbattery.html*
4. Saltwater Battery. *http://www.exo.net/~pauld/summer_institute/summer_day15current/saltwaterbattery.html*

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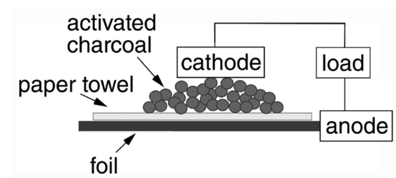
Batteries are devices that convert chemical energy into electrical energy. They have two electrodes (electrical conductors) where chemical reactions that use or produce electrons take place. The electrodes are connected by a solution, called an electrolyte, through which ions can move, completing an electrical circuit. Electrons are produced at the anode and can flow through an external circuit to the cathode. This movement of electrons is an electric current that can be used to power simple devices. One particular battery can be formed using these two reactions: (1) a reaction with aluminum that generates electrons at one electrode, and (2) a reaction with oxygen that uses electrons at the other electrode. To help the electrons in the battery get access to the oxygen in the air, you can make the second electrode out of something that can conduct electricity but is non-reactive, like charcoal, which is mostly made of carbon. Activated charcoal is highly porous, and these pores result in a large surface area that is exposed to the atmosphere. One gram of activated charcoal can have more surface area than an entire basketball court! In this Activity, you will construct a battery that uses these two reactions to produce current. Do you think that a homemade battery will be able to power a small motor or light?

Try This



You will need: aluminum foil, scissors, ruler, activated charcoal, metal spoon, paper towels, salt, small cup, water, two electrical leads with clips on the ends, and a small electrical device, such as a battery-powered dc motor or holiday light.

__1. Cut a piece of aluminum foil that is approximately 15 cm × 15 cm.

__2. Prepare a saturated saltwater solution: mix salt in a small cup of water until some undissolved salt remains on the bottom of the cup. Fold a paper towel into fourths, dampen it with the saltwater solution, and place the towel on the foil.

__3. Add a heaping spoonful of activated charcoal on top of the paper towel, and gently crush it into fine bits using the back of the spoon. Pour some of the saltwater solution on the charcoal to moisten it. Be sure that the charcoal is wet throughout, but does not touch the foil directly. You should have three layers, like a sandwich.

__4. Prepare your electrical device for use. If you are using a dc motor, attach a small piece of tape to the end of the motor shaft to serve as a "flag" so that you can easily see when the motor is working. If you are using a holiday light, strip the ends of the wires so that you can attach the leads.

__5. Clip one end of each electrical lead to each lead of the motor or holiday light. Clip the other end of one of the leads to the aluminum foil. Firmly press the final clip on the pile of charcoal, and watch what happens! If the battery doesn't seem to be working after a few seconds, you may need to reduce its internal resistance. Try increasing the contact area between the clip and the charcoal by folding the entire battery over the clip (like a taco) and pressing down hard. Make sure that the clip stays buried in the charcoal. If you are using a motor, you can also try giving it a "kick start" by briefly spinning the flag.

__6. The first modern electric battery was made of a series of electrochemical cells, called a voltaic pile. Repeat steps 1–3 to construct additional aluminum–air cells. Stack two or three aluminum–air cells on top of each other to see if you can make a more powerful battery. Clip one lead to the bottom piece of foil, and place the other lead in the top charcoal pile. Press down firmly on the pile to reduce the internal resistance of the battery, but make sure that the foil pieces don't touch each other. You can compare the power qualitatively by looking at the intensity of a holiday light or quantitatively by taking measurements on a multimeter.

More Things To Try

Use a multimeter to measure the voltage and current generated by your battery. What changes in the battery design result in a larger voltage or current? Calculate the power output from your battery by calculating the product of its voltage and current. Try to power other devices that require higher voltage or current, such as a string of LEDs (make sure they're connected in the right orientation), a piezo buzzer, or a more powerful light. What happens when you swap the leads clipped onto your device to change the direction of electron flow?

Questions

1. Why must salt be added to the water for the battery to work?
2. This battery works much better with activated charcoal than the lump charcoal you use in your grill. Explain. Does the battery work better due to a higher voltage or greater current?
3. Fuel cells are devices that create electrical energy from chemical reactions with reactants that are constantly replenished. How is the battery you made like or unlike a fuel cell?
4. When constructing a voltaic pile out of several aluminum–air cells, why is it important to make sure the foil pieces don't touch?

Information from the World Wide Web (accessed Sep 2007)

Fuel Cells 2000. *http://www.fuelcells.org/*