

Aluminum air battery activity

Overview:

Students design and build the simplest possible battery with aluminum foil, salt water and copper wire.

Essential Question:

How can we capture the energy released from a chemical reaction to deliver useful electrical power?

Background:

This battery uses the **oxidation** of aluminum at the **anode** and the **reduction** of oxygen at the **cathode** to form a **galvanic cell**. This is also known as a **primary cell** because the cell ingredients are consumed and it can't be recharged. The aluminum is completely reacted to produce aluminum hydroxide. Copper or graphite are used as current collectors but are not consumed in the reaction. Carbon is also a **catalyst** and activated charcoal greatly increases the **surface area** where the reactions can occur. The salt water electrolyte carries charge and provides a medium for the reaction. The reaction rate can be increased by adding additional hydroxide ion using washing soda or caustic soda (NaOH or KOH).

The metal air battery has a very attractive **energy density** because part of the reactants come from the air. They have been developed for long range power supplies for electric vehicles. For example rechargeable Li-ion batteries could be used for around town but aluminum air batteries could be used for 1000 mile range. The battery is then replaced and the aluminum hydroxide is re-processed to produce reduced aluminum metal. In a sense the energy for this battery comes from electricity consumed in the aluminum refining process.

The anode oxidation half-reaction is $\text{Al} + 3\text{OH}^- \rightarrow \text{Al}(\text{OH})_3 + 3\text{e}^- -2.31 \text{ V}$.

The cathode reduction half-reaction is $\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^- +0.40 \text{ V}$.

The balanced equation is $4\text{Al} + 3\text{O}_2 + 6\text{H}_2\text{O} \rightarrow 4\text{Al}(\text{OH})_3 + 2.71 \text{ V}$.

(The reaction improves if it is done in a basic solution that supplies excess OH^- ions. With potassium hydroxide electrolyte the 1.2 volts is produced with salt .7 volts per cell. Be very cautious if experimenting with KOH or NaOH electrolytes, use gloves and eye protection)

Research Connection:

Researchers are trying to find new chemistries for batteries that use earth abundant materials, are safe and reliable, and have a high energy density. While this cell is not rechargeable it could play a role in electric vehicles. Some progress has been made in creating rechargeable metal air batteries.

NGSS Standards:

Standard Number	Standard text
MS-PS1-5	Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.
MS-PS1-2	Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.
HS-PS3-3.	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
SEP	Defining problems, Designing solutions

Grades: 7-12

Time: 1 hour

Materials:

- Aluminum sheet- pie plate or foil
- Paper towel-or water color paper
- Charcoal Briquette or activated charcoal ground to a powder
- .5" Copper foil tape with conductive adhesive, unvarnished copper wire, or graphite rod
- Salt water (saturated) with a little sodium carbonate (washing soda)
- Styrofoam container, cups or plastic pill bottles
- Clip leads
- multimeter
- Wear goggles and gloves especially if using NaOH in the electrolyte

Procedure:

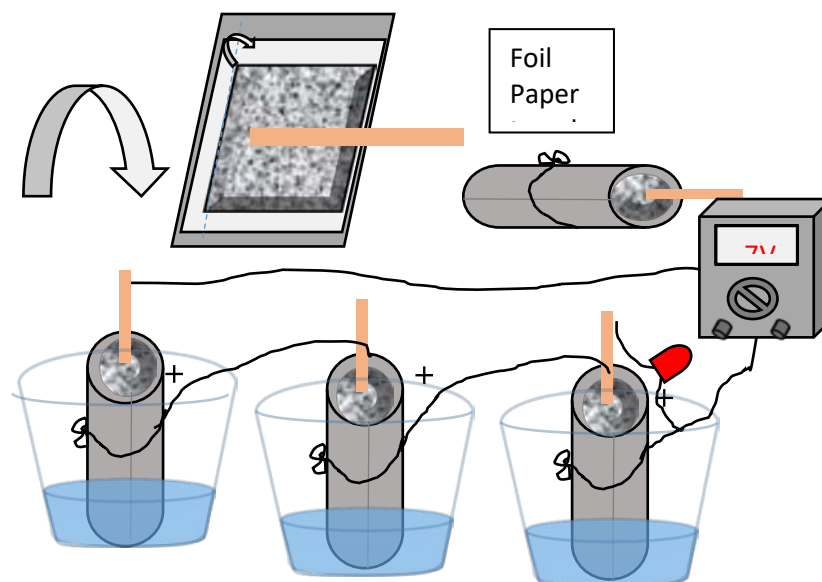
Introduction

Review the reactions that are occurring. Have students list the inputs and outputs of the system. What factors (design requirements) must be considered In designing a battery that uses these reactions? (Supply of oxygen, evaporation of electrolyte, how to maintain, surface area considerations, copper connections between cells, inclusion of charcoal or graphite as a catalyst or conductor.) You could have students perform free form experiments with aluminum foil, copper wire and electrolytes and measure the output with multimeter. Any part of this system can be experimented with before actually building the complete cell in order to optimize the components.(ie The best concentration/ composition of electrolyte, the role of carbon or graphite, different current collectors) Students can also consider the practical **form factor**, will the battery be a tube, or pouch, what voltage and current is needed for your application. Be sure to point out the interplay of science and engineering in different steps of the process.

Cup cell design

This format uses aluminum roll shaped cells that sits in individual cups containing electrolyte reservoirs. The electrolyte wicks up into the charcoal in the center and evaporates slowly and allowing air to penetrate the interior.

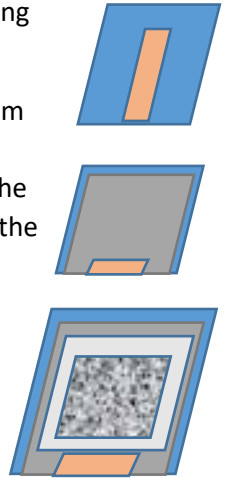
1. Cut a 6" square of aluminum foil, plate or aluminum can. Sand the can to remove paint and plastic barrier on the inside.
2. Place the aluminum on a soft surface and poke holes all over it to allow air to penetrate.
3. Add a 6" square of paper towel on top of the aluminum.
4. Add a ½" thick mound of ground briquette or activated charcoal about the texture of course corn meal. You can wrap the charcoal in paper and pound with a hammer to shatter the lumps.
5. Place copper strip in the center of the mound so that it doesn't touch the bottom and 2" sticks out above.
6. Fold the paper towel over the charcoal pile at the bottom to prevent it from fall out later.
7. Roll the aluminum around so that the copper electrode is in the center of the mound of charcoal and does not touch the aluminum. Tie the tube with a twisty tie or a piece of wire. The top of the tube should be open with the charcoal and copper wire exposed.
8. Place the battery in a plastic cup.
9. Pour saturated salt electrolyte into the charcoal core until you have about 1" at the bottom of the cup.
10. Connect clip leads to the center copper lead and to the top of aluminum tube, and then to an electric meter.
11. Connect several cup cells together going the copper lead of one to the aluminum lead of the next. Measure the voltage at the end of the chain as each cell in inserted. When you reach 2-3 volts you may be able to light the LED.
12. Note you could also reverse the design by rolling the aluminum into a central tube, and surrounding this with the paper towel and wire.

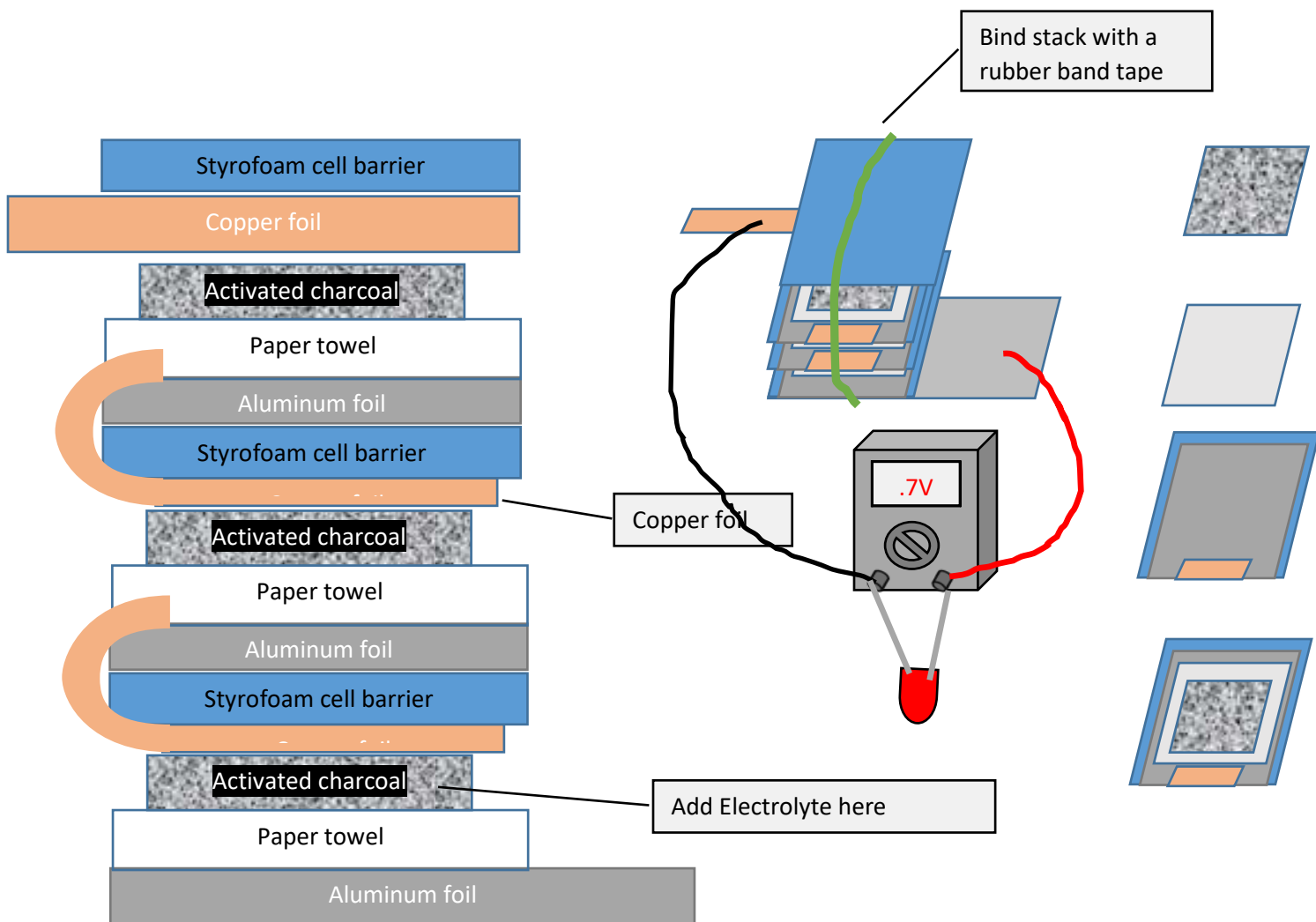


Thin battery sandwich design

This format looks more like a pouch battery but is a little more fussy to build and will not run as long because the electrolyte dries out and aluminum hydroxide clogs the paper. It offers some interesting design challenges to consider how to make the technology practical.

1. Cut 1" squares of Styrofoam from meat trays, 1" squares aluminum foil, plates or aluminum cans that have been sanded. Position the aluminum square on top of the foam square.
2. Cut 1.4" x.5" long strip of copper foil or tape. Wrap this around the Styrofoam square so the sticky side wraps across the bottom of the Styrofoam and makes contact with the edge of the aluminum square on the top
3. Cut 1" filter paper or paper towel and position this in the middle of the aluminum square being careful not to have it stick out beyond the edge of.
4. Grind up the charcoal to make medium grain powder like cornmeal. Sprinkle a thin layer on to the top of the paper towel. This constitutes one cell which should produce about .7 volts with saltwater electrolyte.
5. Stack several cells together. On the bottom have a long aluminum strip that sticks out as a contact. On the top have a square of foam and a long copper strip as a conductor. Carefully bind the stack with a rubber band.
6. Connect the copper foil on the top and the aluminum foil on the bottom with clip leads to an LED and/or electric meter. Wet the exposed paper towel on each cell with the salt electrolyte solution until it will not absorb more.





Design Questions to Explore

- What voltage and amperage can you achieve?
- What is the minimum voltage it takes to light an LED?
- How can you increase the availability of oxygen to the cell?
- Is there a limit to the series voltage a chain of these batteries can achieve?
- How does the pH and concentration of the electrolyte solution affect the current?
- Is it possible to “wake up” a cell after a few days if it stops producing?
- What would be the advantage to using a flowing or circulating electrolyte?

Extensions

Try other electrolytes. Vinegar is conductive and helps keep remove the oxide from the copper during the reaction possibly making it last longer. Bleach provides a different source of oxidizer instead of air. This

Resources

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4. **Aluminum—Air Battery**
 - a. Modesto Tamez and Julie H. Yu
 - b. *Journal of Chemical Education* **2007** 84 (12), 1936A
5. **The Salty Science of the Aluminum-Air Battery**
http://sciencegeekgirl.com/documents/TPT_Salty_Science.pdf
6. Phinergy Battery with Arconic
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