Battery Power

Student Objective
The student:
- can explain current battery technology
- can explain the different types of batteries
- can explain how Volta invented the first battery
- will build a simple battery and describe how it works.

Key Words:
anode
capacity
cathode
dry cell
efficiency
electrolyte
fuel cell
galvanic cell
lead acid battery
lithium-ion battery
oxidation
reduction
volt
voltaic pile

Materials:
- copper pennies (before 1982) – if unavailable, see substitution suggestions below
- 3/4" outside diameter zinc discs or zinc washers
- mat board (or thick construction paper)
- wires, 4 - 6" long with 1/2" stripped on each end
- white vinegar
- salt
- scissors
- LED bulbs (red and blue)
- multimeter
- paper cup
- paper towels
- electrical tape

Time:
1 class period

Note: If pre-1982 pennies are not available in enough quantity for your lab, you can use post 1983 pennies (that are 95% zinc) for the zinc discs, and nickels (that are 75% copper) for the copper discs. However, this may be confusing to the students who relate pennies with copper, and it will change the anode and cathode in your stack. Alternatively, you can sand the copper off one side of the post 1982 pennies so that they have a zinc side and a copper side, however, this doesn't "pile" as nicely for students to see the individual "cells" in their battery, and it defaces coins.

Background Information

A battery is one kind of galvanic cell, a device that can change chemical energy into electrical energy through oxidation-reduction reactions. Galvanic cells that we use as "batteries" include dry cells, lead-acid batteries and fuel cells. In these cells, an electrolyte is placed in between the anode and the cathode. A chemical reaction occurs where the electrolyte creates an unbalance of charge on the anode (too many electrons giving it a negative charge) and on the cathode (too few electrons giving it a positive charge). When the battery is connected to an external electric circuit, the circuit provides a path for the electrons to flow from the anode back to the cathode, which returns the metals to their original balanced state, and "drains" the battery.

The energy source that we commonly call a "regular" battery is more technically a **dry cell**. Moreover, there are three major types of dry cells–acidic, alkaline and lithium. All three types are "dry"–they use a moist electrolyte paste inside the battery instead of a liquid solution. The **acidic** cell uses a carbon rod (the battery's positive terminal) that connects with a wet paste of carbon, ammonium chloride (NH_4Cl), manganese oxide (MnO_2), starch and water. On the outside, the zinc case serves as the negative terminal of the battery.

The **alkaline** cell is a newer version of the dry cell battery. The parts of the alkaline cell are similar to the acidic cell, but the carbon cathode has been replaced by a piece of brass and the ammonium chloride has been replaced by potassium hydroxide (this strong base chemical gives the cell its alkaline name). A sturdy steel shell is needed on these batteries to prevent the caustic contents from leaking. This extra encasement is the reason that these batteries are more expensive to produce than the older, acidic versions.

Lithium batteries have lithium as an anode but can have many different cathodes and electrolytes. The most common type of lithium cell for consumer applications uses metallic lithium as the anode and manganese dioxide as the cathode, with a salt of lithium dissolved in an organic solvent. They have a high charge density, long life, and some types (lithium-ion and lithium-polymer) are rechargeable.

Lead acid batteries, like those in a gasoline car, use an aqueous solution of electrolytes, so they should be held in an upright position. These batteries are made up of a stack of alternating lead and lead oxide plates isolated from each other by thin porous separators, with the stacks sitting in a concentrated solution of sulfuric acid. This type of battery is easily recharged by applying electricity in the opposite direction so that the internal reactions are reversed and the cell is eventually restored to its charged state.

In a **fuel cell**, the oxidizing and reducing chemicals (usually gases) are brought in from outside the cell. Unlike a dry cell, a fuel cell can theoretically work forever if the two agents are continuously supplied. Because fuel cells directly change chemical energy into electrical energy they are very efficient and are cleaner than the combustion of fuels in a power plant to generate electricity.

Procedure

1. **Engage:** Show the short Ted-Ed video *How Batteries Work* (link is in the Internet Sites section).
2. Tell the students that they are going to be making an oxidation/reduction device similar to the voltaic stack that Alessandro Volta made in 1799.

3. **Explore:** Divide the students into lab groups and have them follow the steps in their Laboratory Manual. The groups should start out with red LEDs; they will be prompted to switch colors during the lab. *(Note: different colors of LEDs produce different wavelengths--and frequencies–(their color) at differing voltage)*
4. If the students are unfamiliar with a multi-meter or it has been awhile since they have worked with one, demonstrate its use with your particular multi-meter:
   - Put the black lead in the common plug.
   - Show the students where to plug the red lead in for voltage readings.
   - Show students which setting to use for voltage (the voltage in this experiment will be in the range of 0 to 5V).
5. Help the students as needed. Don't clue them in, but the red LED light should work with a three penny stack.

   Note: the main problems that will be encountered are not layering their stacks correctly (penny, paper, washer, penny, paper, washer, etc), not connecting the LED up properly (the long leg–positive--goes to the copper and the short leg–negative--to the zinc washer), not cutting out the paper carefully (something is touching that shouldn't be, causing an open circuit), liquid dripping from one paper to another (the students may be squeezing their stack), and not having a good connection between the wires and the top and bottom of their stacks.

   Let the students work out the logistics of stacking and measuring within their group–it's a good teamwork exercise! However, if they get really stuck, you can suggest that they tape their negative lead to the bottom of their pile (on the bottom of the zinc), and tape their positive lead to the top of their pile (on the top of their last penny). The tape needs to be only on one side of the zinc or the copper–if they wrap it around it will disturb the flow of voltage. The other ends of the wires can be wrapped around or taped to the probes on the multi-meter. This set-up will make it a little easier to handle the pile and take measurements.
6. After a group finishes, have them clean up their area.
7. **Explain:** Have a few of the groups explain their process and results.
8. Lead a discussion. Questions to ask the class could be:
   - Why did it take more cells (layers) in your battery (voltaic stack) to light the blue LED *(different color LEDs produce different frequencies of light by using different chemicals that need differing amounts of electricity to produce the reaction)*
   - What is happening in the solution in the mat layer? *(The solution is allowing electrons to flow from the zinc to the copper)*
   - What happens when materials from one layer, like the mat board, touches the mat board from another layer *(It creates a "short" circuit–effectively, the electrons are not forced to take the long way around through the wire, so the load (LED, motor) doesn't get powered).*
   - Have the students tell you how their battery works. Keep prompting and asking questions until they can explain the chemical and electrical processes. *(The oxidation/reduction cycle creates a flow of electrons between two substances. The zinc oxidizes--loses electrons–which are gained by the ions in the water (reduction) producing hydrogen gas. When you connect a wire from one end of*

the stack to the other end and put a load like an LED bulb in the middle of the circuit, you give it power.)

Answer Key - Laboratory Manual

1. Answers will vary slightly, but the voltage should increase directly as a result of how many cells are measured. The red LED should light with three or four stacks in the pile.
2. Yes
3. Zinc, Copper
4. The LED doesn't light. *(Note: the students may not get this answer correct if they had more than 4 cells stacked with their red LED–this could be caused by bright classroom lights making it hard for them to see when their light was first dimly lit.)*
   Depending on the LED lights you use in your lab, the blue should take 1 - 2 more stacks
5. The students should be able to hypothesize that it takes more voltage to light the blue LED even if they don't yet know why.

Answer Key - Problem Set

1. In a rechargeable battery the oxidation/reduction cycle is reversible. When electricity is put back into the battery, it drives the reaction in the opposite way to regenerate the metal which makes electrons available for oxidation once again.
2. Over time the recharging process causes imperfection and irregularities in the metal surface that prevent it from oxidizing properly.

3 - 7 Answers will vary. See Background Information section for general information that they should list. Students should show effort in researching the different terms and writing a coherent answer.

Key Words & Definitions

- **anode –** the electrode on whose surface oxidation takes place; anions migrate toward the anode, and electrons leave the system from the anode
- **capacity –** the maximum amount that something can contain
- **cathode –** the electrode on whose surface reduction takes place
- **dry cell** – a galvanic cell (battery) that has a moist electrolyte paste in its core instead of a liquid core
- **efficiency** – the ratio of useable energy coming out of a process to the total energy being input in a process
- **electrolyte** – a liquid or gel that contains ions and can be decomposed by electrolysis
- **fuel cell –** a device that produces an electric current directly from a chemical reaction
- **galvanic cell –** a device that can change chemical energy into electrical energy
- **lead acid battery –** a device that uses plates of lead and lead oxide in a sulfuric acid solution using a chemical reaction to produce electricity. A lead acid battery can also be rechargeable.
- **lithium-ion battery –** a device that uses metallic lithium, manganese dioxide and a lithium salt in an organic solvent to produce electricity. A lithium-ion battery has a high

charge density, long life, and is rechargeable.

- **oxidation –** any chemical reaction in which a material gives up electrons, as when the material combines with oxygen
- **reduction –** any chemical reaction in which the atoms in a material take on electrons
- **volt** – unit of electricity that represents the amount of work needed to move an electric charge between two points
- **voltaic pile –** a series of electrochemical cells, a battery, which is named alfter Alessandro Volta

Related Research

1. Research quantum batteries to find out what they are, how they theoretically would work, and the reasons why we are still a long way from developing them.
2. Although batteries of all types have chemicals in them that should not be thrown in the garbage, most people do throw their small batteries away. Research how harmful it is (or isn't) for batteries to end up in the landfill. If there is a problem, what can we do to mitigate it?
3. Battery technology is frequently in the news with researchers trying to reach the goal (as stated by the Department of Energy) of a battery that is "economical, safe, compact, and energy dense enough to store energy at a cost of less than $100. a kilowatt-hour". Research the recent battery breakthroughs in the news to find out how close researchers are getting to this goal.
4. Excess electricity produced by photovoltaics can easily be stored in batteries to be used during the night or when there isn't sufficient sunlight. Research other ways electricity from photovoltaics could be stored, both currently in use, and possible future methods of storage.

Related Reading

- ***Car Wars: The Rise, the Fall, and the Resurgence of the Electric Car*** by John J. Fialka (Thomas Dunne Books, 2015)
  Award-winning former Wall Street Journal energy and environmental reporter, John Fialka documents the history of the electric car and battery technology from the M.I.T./Caltech race between prototypes in 1968, through the U.S. initial rejection of electric cars until today's growing obsession with the technology.

Internet sites:

https://ed.ted.com/lessons/why-batteries-die-adam-jacobson
How Batteries Work, Ted Ed lesson, includes multiple choice questions and discussion points.

https://www.youtube.com/watch?v=RW1Xugey8j0
Fully Charged video, *Batteries to the Future*, visits University of Oxford's professor Peter Bruce to discuss current battery technology and research and the way battery technology is evolving.

https://www.youtube.com/watch?v=TfUEx4VwyqM

CNN Money report, *When the Road Charges Your Electric Car*, explores the idea of a road that recharges your car's battery as your drive.

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Florida NGSS Standards & Related Subject Common Core

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Nature of Science																					
Standard 1	**SC.912.N.1.**	X																			
Physical Science																					
Standard 8	**SC.912.P.8.**								X		X										
Standard 10	**SC.912.P.10.**	X																			
Social Studies Standards		SS.912.A.1.5																			

Science–Standard 1: The Practice of Science
- SC.912.N.1.1 - Define a problem based on a specific body of knowledge, and do the following: 2) conduct systematic observations; 6) use tools to gather, analyze, and interpret data; 7) pose answers, explanations, or descriptions of events; 8) generate explanations that explicate or describe natural phenomena; 9) use appropriate evidence and reasoning to justify these explanations to others; 10) communicate results of scientific investigations; and 11) evaluate the merits of the explanations produced by others.

Science–Standard 8: Matter
- SC.912.P.8.8 - Characterize types of chemical reactions.
- SC.912.P.8.10 - Describe oxidation-reduction reactions in living and non-living systems.

Science–Standard 10: Energy
- SC.912.P.10.1 - Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.

Social Studies–American History
- SS.912.A.1.5 - Evaluate the validity, reliability, bias, and authenticity of current events and internet resources.

National Next Generation Science Standards
Energy
- HS-PS3-2 - Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles and energy associated with the relative position of particles.
- 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.

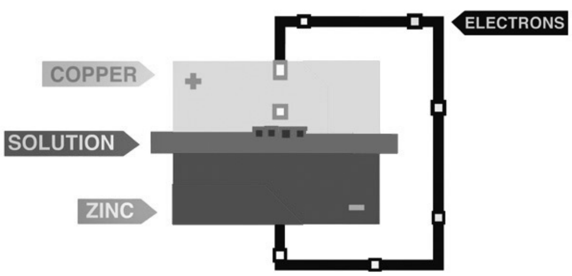
Battery Power

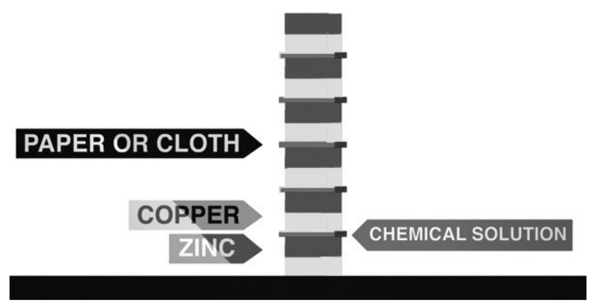
You are going to be making a voltaic pile using copper, zinc, and a salt water solution as the electrolyte, and then use this battery to light LED bulbs and power a motor.

Before you begin, you will need to prepare your materials:

- Cut circles of mat board the same size as the pennies and soak them in a solution of 60mL H_2O and 15g NaCl. When you are ready to use these circles, pat off the excess liquid with a paper towel.
- Clean the impurities off of the copper pennies using vinegar and salt. You can rub the pennies between your fingers and thumb with a paste of salt and vinegar. Rinse the pennies thoroughly and dry them.

1. Your goal is to illuminate an LED lightbulb. Study the two diagrams below and construct a voltaic stack. Record your trials below and the voltage output of each trial stack. (Hint: LED lights have a polarity. The long leg of the LED connects to the positive and the short leg the negative)





Trial #	Number of copper/solution/zinc layers	Voltage output of stack	LED lit?

2. Does increasing the voltaic layers directly increase the electricity (for example, does doubling the number of coin stacks double the electricity produced?)

3. Which coin is acting as the positive terminal, the cathode? _________________________

   Which coin is acting as the negative terminal, the anode? __________________________

4. Exchange your red LED bulb for a blue one and put it in your battery circuit. What happens?

   How many layers (cells) are needed to light the blue LED? _________________________

5. Why do you think it takes more layers to power the blue LED?

Battery Power

1. How do rechargeable batteries work?

2. Why do rechargeable batteries eventually lose their ability to be recharged?

Using the internet and trusted sites, write a brief description of the terms below and the characteristics that make them different. List your source(s) in ( ) after your answer:

3. Dry cell (battery) -

4. Alkaline battery -

5. Lead acid battery -

6. Lithium-Ion battery -

7. Galvanic cell -