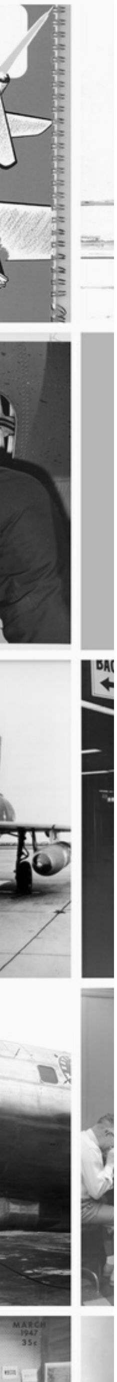
NATIONAL ELECTRONICS MUSEUM

Lesson Plan:

How Batteries Work



Grades 6th-8th

NGSS Standards:

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Objective: Students will examine the different components of batteries and the chemical reaction that takes place in a battery. Students will construct a battery using lemons in order to further understand the necessary components.

Overview

Section I

Lesson Introduction: The Voltaic Pile (~15-20 minutes)

- Students will complete the reading on Section #1 about the Voltaic Pile, in order to understand the components of batteries and how electrons flow through them as part of a complete circuit.
- Have students complete Quiz #1 questions

Section II

- Students will read Section #2 called "Chemistry of a Battery and "Intro to Chemical Reactions in a Battery"

Section III

- Students will read the section "What Happens Inside a Battery? Even More on Chemical Reactions" and the watch the "Be A Battery" video clip.
- Student will complete Quiz #2

Lab: Lemon Battery (~30 minutes)

- Students will follow along with the video clip and/or the written instructions to conduct the lemon battery experiment.

Post Activity Quiz Questions (~5-10 minutes)

- After students have successfully created their lemon battery, answer the reflection questions (Quiz #3)

Student Learning Goal:

- By the end of the lesson, students should be able to name the three major elements of a battery, the direction of electron flow, the oxidation-reduction reaction, and be able to build and explain the parts of their lemon battery.

Outline

Section I
The Voltaic Pile

In 1800 Italian physicist Alessandro Volta invented an electrical battery. This was the first device that continuously provided an electric current to a circuit. In electronics, a circuit is a path between two or more points along which an electrical current can be carried. Volta's invention was significant because it became one of the first reliable sources of electricity.

A **battery** is a device that converts stored chemical energy into electrical energy in a process known as electrochemistry. The best way to understand how a battery works is to study the **electrochemical cell**. A battery can be made up of one or several electrochemical cells, such as Volta's pile. Electrochemical cells are made up of two electrodes- Volta used zinc and silver pieces- and are separated by an electrolyte solution- Volta used saltwater.

Let's explore how Volta created his electrical battery. Electric current flows when electrons pass through a conductor. Volta found he could create this electron flow with just three components, or parts. Using one silver disc and one zinc disc separated by paper or cloth soaked in saltwater he was able to detect a small potential, what we'll refer to as voltage. This is when electrons flow from one metal to the other. These three materials combined make up a single cell as seen in Fig. 1.

Single Cell
Fig. 1

Section I, continued

The voltage created by Volta's single cell was quite low. To increase the voltage, he stacked or piled many single cells on top of each other creating the the Voltaic Pile. This was the first device that could deliver continous electric current in a circuit. The continous electric current was produced due to an electrochemical reaction, which will be discussed in the next section. In Fig. 2 you can see how Volta piled up many cells to create his Voltaic Pile. You also see two wires, one connected to the top and one connected to the bottom of the pile. These wires allowed for connection to the Voltaic Pile. Fig. 3 shows a representation of a four-cell pile.

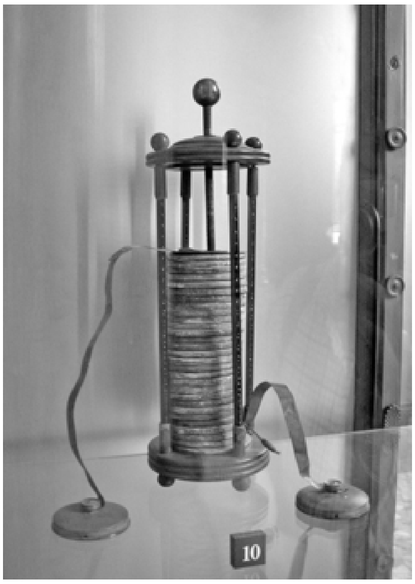
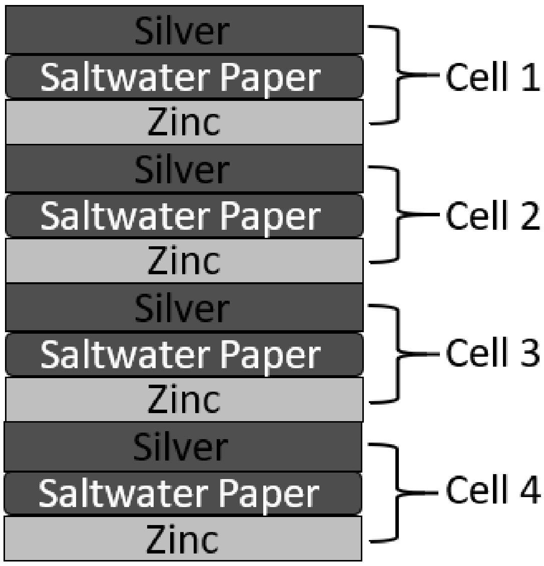


Fig. 2



4 Cell Pile
Fig. 3

Fig. 2 Image Source:
https://en.wikipedia.org/wiki/History_of_the_battery#/media/File:VoltaBattery.JPG

Quiz #1

Directions: Use the reading above to answer the following questions.

1. Which metals did Volta use to construct the voltaic cell?
2. What are the three components of an electrochemical cell?
3. We measure the amount of energy a battery can produce in:
    a. Meters
    b. Volts
    c. Watts
    d. Kilowatts
4. Volta created a voltaic pile which is an early form of what we know today as a ____________.

Answer Key:
1. Copper and zinc
2. Two electrodes and one electrolyte solution
3. B
4. Battery

Section II
Chemistry of a Battery

How does an electrochemical cell such as what Volta created produce electricity? Briefly defined, electricity is the flow of electrons. What occurs in the electrochemical cell is a **chemical reaction** that occurs at one electrode, and that reaction produces electrons at one of the electrodes, and then those electrons travel to the other electrode, and this completes the chemical reaction.

But what are **electrodes**? In order to have a flow of electrons, you have to have a place for the electrons to flow to and from. Electrons flow from the **anode** (the negative electrode) to the **cathode** (the positive electrode) The electrodes are made up of different metals which have opposite attractions.

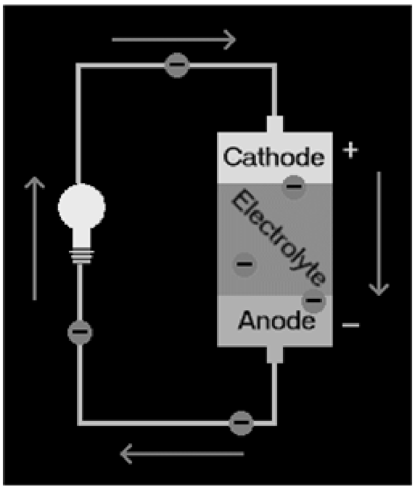


Image source: http://www.qrg.northwestern.edu/projects/vss/docs/power/2-how-do-batteries-work.html

Section II, continued
Intro to Chemical Reactions in a Battery

Now we know some of the elements of a battery, but why do the electrons flow from the anode to the cathode? We have to take a look at the **chemical reaction** occurring in the cell.

First, let's look at the anode. The anode reacts with the electrolyte in the cell which produces electrons. The electrons collect at the anode, and at the same time, at the cathode, a reaction is occurring at the cathode that allows it to accept the electrons.

This reaction, which is an exchange of electrons, is called a **oxidation-reduction reaction**, or a redox reaction. Two reactions are occurring at the same time, one at the anode and the other at the cathode. Oxidation is the loss of electrons, and that occurs at the anode, therefore the anode is oxidized. Reduction is the gain of electrons, and that is what occurs at the cathode, so the cathode is reduced.

You can use the helpful mnemonic device and think of the phrase "OIL RIG", which stands for oxidation is losing, and reduction is gaining, to remember what occurs during the reaction.

This oxidation reduction cycle creates a flow of electrons between the two electrodes.

Another part of the battery that facilitates the reaction is the **electrolyte**. In Volta's pile, the **electrolyte** was the pieces of cloth soaked in saltwater. An electrolyte can be a gel, liquid, or solid substance. More importantly, the electrolyte is either an acid or a base and it is a conductive chemical, which means it allows the movement of charged ions.

As the electrons move through a closed circuit, the electrolyte is the medium through which the charge balancing ions can flow. The **electrolyte** helps make the battery conductive by promoting the movement of **ions** from the **anode** to the **cathode**. Moreover, the anode and the cathode have to be separated from each other. If they come in contact, this would create a short circuit and the battery wouldn't work properly.

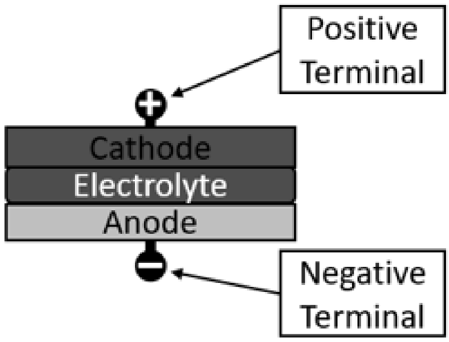
Since Volta's pile, scientists have improved the design of batteries. They replaced the wet, saltwater solution with dry cells that are filled with a chemical paste. More on this in the next section.

Section III
What Happens Inside a Battery?
Even More on Chemical Reactions

There are basically two types of batteries; wet cell and dry cell. Wet cell batteries often use sulfuric acid in liquid or gel form for the electrolyte. In this lesson we'll stick with dry cell batteries where the electrolyte is typically a paste, which is a partially moist mixture of chemicals.

Fig. 5 shows the batteries we're most familiar with today which are the D, C, AA and AAA cells. We don't typically talk about the internal electrodes of the battery, but we do talk about the Positive and Negative Terminals so in Fig. 6 we add them to our single cell representation. The positive terminal is always connected to the cathode and the negative terminal to the anode.

Fig. 5



Single Cell with Terminals
Fig. 6

An insulator prevents electrons from flowing when placed between two conductive materials, like copper wires. Electrolyte is actually an insulator, if it wasn't it would short circuit the battery. Electrons cannot move between the cathode and electrolyte or between the electrolyte and anode by themselves, however ions can!

Section III, continued
What Happens Inside a Battery?
Even More on Chemical Reactions

Let's briefly talk about ions. Atoms are made of electrons and protons. If the atom is balanced, it has the same number of electrons and protons. If the electrons outnumber the protons or the protons outnumber the electrons, the atom is called an ion.

If the ion has more electrons it is a negative ion, and if it has more protons, it's a positive ion.

The chemicals used in the electrolyte react with the chemicals of the cathode and anode to transfer negative ions, which we know have an excess of electrons. It is the electrolyte that allows the movement of charged ions.

The anode releases electrons to the negative terminal to supply the circuit and, at the same time, the cathode is accepting electrons at the positive terminal connection of the circuit. This completes the flow of electrons through the circuit.

So how do we get electron flow from our battery? Chemistry! Chemical reactions take place only when the battery is connected to a circuit. This chemical reaction, which is an exchange of electrons, is called a reduction - oxidation reaction, or redox reaction. We have talked about this reaction in the previous section, but let's take a look again.

The redox reaction performs two jobs at the same time in our battery. The reduction reaction uses electrons it gets at the positive (cathode) terminal. Those electrons are coming from the negative (anode) terminal where the oxidation reaction is producing electrons. The oxidation reaction always happens along with the reduction reaction because the oxidation reaction produces the electrons needed by the reduction reaction.

Section III, continued
What Happens Inside a Battery?
Even More on Chemical Reactions

In Fig. 7 you see the reduction and oxidation reactions identified to the left of the single cell battery.

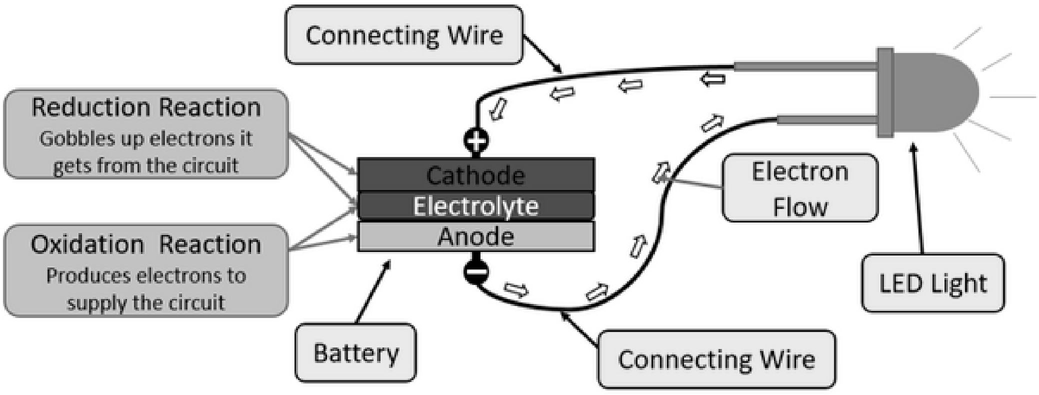


Fig. 7

Fig. 7 shows a complete circuit containing the battery, LED (Light Emitting Diode) and connecting wires. Electrons flow through the wires and the arrows show the direction of the electron flow. If we disconnect one of the wires the circuit will be broken, the LED will go out and the redox reaction will stop within the battery.

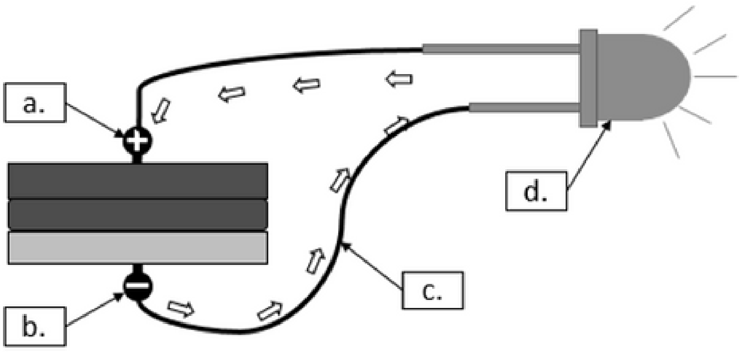
Click here to watch the “Be A Battery” video demonstration.

An ammeter measures the flow of electrons in units of Amps. You can’t see it, but the ammeter’s positive side is connected to the copper plate and its negative side is connected to the zinc plate.

When our presenter put her hands on the copper and zinc plates the ammeter moved in the positive direction. If she swapped her hands the meter would still move in the same direction. Only swapping the connections of the plates to the ammeter would cause the meter to move in the negative direction. From this, we can conclude that our presenter is acting as the electrolyte between the zinc and copper plates of the human battery.

Quiz #2

1. Name the two basic types of batteries __________ and __________.
2. What does the electrolyte do in a battery?
    a. Separates the cathode from the anode
    b. Stores all of the electrons in the battery
    c. Provides chemicals for the Redox Reaction
    d. A and C only
    e. All of the above
3. Electrons in a battery move from the ____________ to the ______________.
4. The battery operates through an electrochemical reaction called an oxidation-reduction reaction. Oxidation is the _________ of electrons, while reduction is the ________ of electrons.
5. Referring to the figure below, match the letter to the correct part name.



____LED

____Negative Terminal

____Wire

____Positive Terminal

Answer Key:
1) Wet and Dry 2) D. 3) Anode, Cathode or negative, positive 4) loss, gain 5) d, b, c, a)

Lab: Build a Battery

At the end of this lab you will be able to:

1) Construct a lemon battery;
2) Demonstrate how a lemon battery can light an LED,
3) Sketch a lemon battery circuit to show a friend and
4) Explain to your friend how the lemon battery works.

Click here to watch the "Lemon Light" video demonstration. If you are unable to view the video, you can follow the full instructions below.

Materials

If you don't have these materials at home, many can be found online!

4 Lemons
4 Galvanized Nails
4 Copper Wires
1 LED (Light Emitting Diode)
5 Alligator Clip Leads: to connect the lemon batteries
Wire Cutters: to cut the copper wire to length
Pliers: to bend the wire
Sandpaper (if needed)

Prepare Your Materials

Lemon Electrolyte: Lemons are filled with citric acid which makes a great electrolyte; however, the acid is captured in the tiny segments within the lemon so firmly roll the lemons on the table to break up the segments releasing the acid within the lemon. Don't press too hard and break the skin of the lemon!

Galvanized Nails, Anode Electrodes: These are nails made of iron or steel. In the video, you will see the nails were lightly sanded to remove any excess dirt or dust.

Copper Wires, Cathode Electrodes: You are going to cut the copper wire into four, 3-inch pieces and bend one end so it is easier to attach your alligator clips. Sand your pieces of copper wire to remove the outer coating

LED: Did you notice in Fig. 7 one lead of the LED is longer than the other? LED's allow current to flow in one direction. The + (positive) connection is the longer lead and the – (negative) connection is the shorter lead.

Instructions

1. Insert a nail into each lemon without poking all the way through.
2. Insert a copper wire into each lemon without poking all the way through and be sure the wire doesn't touch the nail inside the lemon. Space the wire and nail about 1-2 inches apart.
3. Arrange the lemons in a row and have it so there is a copper to zinc pattern, as you can see in the image below.
4. Connect a set of test leads between each lemon. You will have a wire on each end, one connected to the copper wire, the other connected to the zinc nail. In the center are three more wires with alligator clips, with one clip on the nail and the other on the copper wire.
5. Connect a test lead from last nail to the short lead of the LED.
6. Connect a test lead from the copper wire at the other end of your battery to the long lead of the LED.
7. Your LED should now light up.

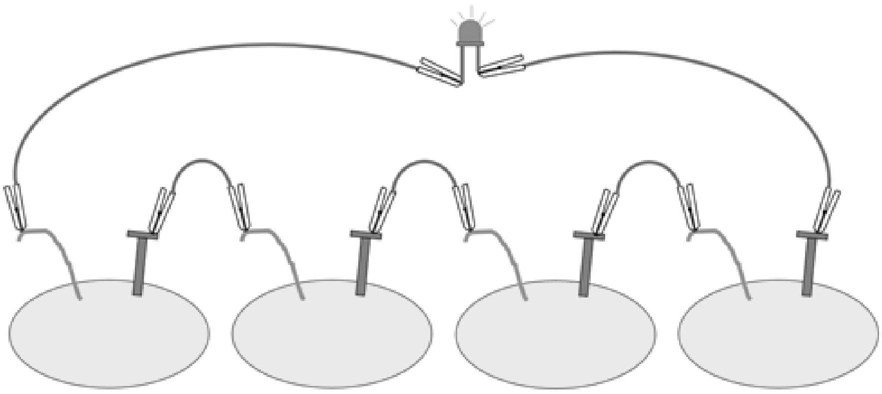


Fig. 8

If your LED doesn't light, try the following:

- Make sure the long lead of the LED's is connected to last copper wire of your lemon battery.
- Be sure none of the nails are touching the copper wires in the lemons.
- You may need to add another lemon cell to your lemon battery.
- Your electrodes might not be making good contact with your electrolyte, do the following for each cell:
  - Disconnect the connections to the cell
  - Remove the copper wire
  - Wiggle the Nail to break any segments preventing the electrolyte from reaching both electrodes.
  - Return the copper wire to the same hole it was in before you removed it.
  - Reconnect the test leads.

Quiz #3

Directions:
After completing your lemon battery, answer the following questions.

1. The galvanized nails in our lemon battery represent a:
   a. Negative Battery Terminal
   b. Cathode Electrode
   c. Positive Battery Terminal
   d. Anode Electrode
   e. a. & b.
   f. a. & d.
   g. b. & c.
2. Our lemon battery has how many cells?
   a. 1
   b. 2
   c. 4
3. True or False: There is no limit to how many lemon cells we can connect to increase the voltage produced by our lemon battery.
4. When our lemon is connected and the LED is lit, how many redox reactions are taking place?

Answer Key: 1) f., 2) 4, 3) true, 4) 4

Glossary

Anode- the negatively charged electrode that has an excess of electrons, giving it a negative charge.

Battery- a device that converts stored chemical energy into electrical energy.

Cathode- the positively charged electrode that has a shortage of electrons, giving it a positive charge.

Circuit- The complete path through which electric current can flow.

Chemical reaction- A process where one or more substances are converted to different substances.

Current- The movement of electrons along a conductor in a circuit.

Electrochemical- chemical changes produced by electricity and the production of electricity by chemical changes.

Electrolyte- a chemical medium that allows charged ions to flow. An electrolyte can be a liquid, gel, or a solid substance.

Ion- An atom or group of atoms that has an unbalanced number of electrons, so they have a positive or negative charge.

Redox Reaction- short for Reduction-Oxidation Reaction where electrons are used during the reaction process and electrons are produced during the oxidation process.

Voltage- the difference of electrical potential between two points in an electric circuit. It is measured in volts.

Volt- A unit of electric potential difference or electromotive force.

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