Lemon Battery

Key Knowledge

Vocabulary

energy: the capacity to do work, the potential for causing change

energy transfer: the movement of energy from one place, object, or form to another

chemical energy: energy generated by a chemical reaction

circuit: path through which electrical energy flows

current: flow of electrons through a circuit (abbreviated I)

voltage: force moving electrons (abbreviated V) (standard batteries are 1.5 V)

Concepts

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.

Materials and Equipment

- lemons, limes, potatoes
- multimeters (RadioShack)
- copper pieces (hardware store)
- zinc pieces (hardware store)
- paper clips
- galvanized nails
- pennies
- alligator clips
- l.e.d.s
- lemon battery clock

Script

Prepreparation

Cut small slits in the lemons using a sharp knife for students to insert electrodes in.

Introduction (10 minutes)

Introduce yourself, assistants.

Today we are going to talk about electricity. Where can we get electricity? Ideas they could come up with include batteries, power plants.

Explain that electricity is a kind of energy, that energy can be converted from one form to another. Can they think of a form of energy that electricity can be converted to? Perhaps motors (mechanical), lights (heat), buzzers (vibrational).

> *Main idea, write on board:* energy transfer

Where do they think the electricity energy comes from? Burning coal (chemical), wind turbines (mechanical), dams (mechanical).

What about batteries? What kind of energy does battery electricity come from?

> *Main idea:* batteries use chemical energy to generate electricity. They have two different metals or other materials and an acid.
>
> *Write on board:* chemical energy

Lemon battery introduction (5 minutes)

So we mentioned acid in batteries. People usually call lemons acidic. Do the students predict that a lemon can be used as the acid source for a battery? What else will we need for a battery? *Different metals.* Can the students think of anything that we might be able to use for the metals?

We need an acid and two metals. These can be our variables. What would the students like to test? Options could be:

- different fruits
- different combinations of metals
- spacing of electrodes
- squeezing lemon vs. not squeezing

How will we measure the data? Show the student a multimeter. Explain that it can measure the current (how much

Activity 1: Lemon battery experiments (15 minutes)

Students should choose a question to test. Let them have access to paper and markers so they can note the multimeter values for the variables they test.

Volunteers should visit the groups to measure the current and voltage with the multimeter. As students work, ask questions such as

- What have you tried?
- What happened?
- What happens with different metals?
- Have you tried hooking your lemon up with your neighbors'? What happens to the measurements then?

If students have questions, the leader should try to guide them to a way to figure it out themselves or to another group that has an idea.

Discussion (10 minutes)

Have students come back to the front of the room to report their results and conclusions. All students should be expected to listen to the others presentations.

Challenge (15 minutes)

A typical LED uses 1.8 volt, 20mA. Based on the students' results (including observations about hooking up lemons in series), can they predict how many lemons it might take to light an LED?

Wrap Up (10 minutes)

Ask the students if they have any final questions. Ask them to vote on which fruit you should use to power the clock. Have a student volunteer help hook the clock up. Have them predict how long they think the clock will work. Do they think lemon batteries are a good (environmentally sound, inexpensive) alternative to other batteries? Remind them of the energy needed to grow a lemon, the cost of a lemon.

Lemon Battery procedure

Hypothesis

Certain metals will produce more current in the lemon battery.

Certain fruits/vegetables will produce more current.

Materials

For each group of 4 students:

- one lemon
- other fruit (for second hypothesis)
- copper piece
- zinc piece
- paper clip, penny, galvanized nail (for first hypothesis)
- alligator clips

For volunteers:

- multimeters

Procedure

Insert metal into lemon. Measure current and voltage with multimeter.

Questions for students

What combinations of metals produce current?
Do all fruits/vegetable options produce current?
Does the battery work when the metals are close? Far apart?
What happens if multiple lemon batteries are in a row?
Do they think they could power any of their electronics with it?

Things to watch out for

The electrodes have to be close enough, but not too close. The multimeter should read about 1 V, 0.0001 amps.

Science Background

Analogy: Electricity vs. Water Flow

Since the flow of electricity cannot be seen except in severe circumstances (lightning, metal touch shocks in dry weather), we compare electricity to the flow of water to understand it more easily. This analogy can be used by the demonstration instructor as deemed appropriate.

When an electron moves, it is electricity! We call the flow of electrons or electricity "current". Voltage is what pushes electrons to flow and creates useful current and electricity. Other particles, such as ions (atoms with too many or too few electrons) can also conduct electricity. Here, we focus on electron flow, because electrons conduct a majority of electricity we use in our everyday lives.

Just like water, electrons (current) will not flow down a wire (pipe) from which they cannot return. We say that current requires a closed "loop" or "circuit" in order to flow and conduct electricity. Electricity flowing from the power plant may power our appliances, losing energy along the way, but it always returns to the power plant. When electricity encounters a break in the wire or pipe along which it is flowing, we call this an "open circuit". If electricity encounters no obstacles along its path, we call this a "short circuit". We make the following analogies between electricity and water flow:

Driving force:

- voltage causes current to flow in a circuit
- pressure causes water to flow in pipes

Valves (spigots):

- Fully "turned on" valves are similar to electrically turned on switches
- Fully "turned off" values are similar to electrically turned off switches

Resistors

- A partially "turned on" valve is like a resistor
- The more "turned on" a valve is, the smaller its resistance and the more water that flows.
- The smaller an electrical resistance is, the more current that flows.

Parallel ("One or both"):

- Valves in two different pipes are in parallel; if one is turned off, water still flows in the other pipe.
- If one of two parallel, electrical switches is turned off, current still flows through the other switch.

Series ("Both or none"):

- Valves in the same pipe are in series; if one is turned off, water will not flow.
- If one of two series, electrical switches is turned off, current stops flowing in the wire.

Generation of Force:

- A pump generates pressure to cause water flow.
- A battery or wall outlet generates voltage to cause current flow.

One-Way flow:

- A check valve allows water to flow only one way in a pipe (e.g. sprinkler systems)
- A diode allows current to flow only one way in a wire.

Electrochemical Cells

Oxidation and reduction reactions are used to provide useful electrical energy in batteries. A simple electrochemical cell can be made from copper and zinc metals with solutions of their sulfates. In the process of the reaction, electrons can be transferred from the zinc to the copper through an electrically conducting path as a useful electric current.

An electrochemical cell can be created by placing metallic electrodes into an electrolyte where a chemical reaction either uses or generates an electric current. Electrochemical cells which generate an electric current are called voltaic cells or galvanic cells, and common batteries consist of one or more such cells. In other electrochemical cells an externally supplied electric current is used to drive a chemical reaction which would not occur spontaneously. Such cells are called electrolytic cells.

The metals used in a dry-cell battery are usually copper and zinc. These materials are called the electrodes. The current is generated because a chemical reaction causes the copper electrode to develop a shortage of electrons. At the same time the zinc electrode develops an over-supply of electrons. When the two are connected, a flow of electrons from the zinc to the copper electrode results.

Over a period of time, the zinc electrode will dissolve and increase the concentration of the zinc ion solution. The copper ion will plate onto the copper electrode and thus the concentration of the copper ion in solution will decrease. As this happens, the reaction slows down and the voltage decreases.

Electropotential Table

Understanding how batteries actually work requires a knowledge of chemistry. The most important factor in battery design is the electrical relationship between the two metals used in the battery. Some metals give electrons away while other metals accept extra electrons. This difference is exploited in a battery to create a flow of electrons.

Electronegativity is a measure of the magnitude of the force by which an atom or molecule is able to acquire an extra electron, thereby becoming a negatively-charged ion. Differing electronegativies is a major reason why different substances must be used as the electrodes in an electrochemical cell. For example, consider Substance A, which has a higher electronegativity than Substance B: If these are used as electrode materials, then electrons will flow from B to A, because A has the greater greed for extra electrons. This means that B will be the anode and A will be the cathode of that particular cell.

From the preceding we may conclude that if we want to use copper as an electrode, and we want it to be the anode, then we must select a substance for the second electrode that has a higher electronegativity than copper. Now it is widely known that if copper and zinc are inserted into a lemon, the citric acid of the lemon will work as an electrolyte, and a small voltage and current can be produced for a short time. However, it happens that zinc has a lower electronegativity than copper; this means that in a 'lemon' cell the copper electrode is the cathode, and the zinc electrode is the anode.

The lemon cell is peculiar in that both oxidation and reduction take place at the same electrode. The anode metals become oxidized (Zn to Zn^{+2}, Mg to Mg^{+2}) and the hydrogen ions in the lemon are reduced to hydrogen gas, in part, at the zinc and magnesium electrodes. In fact, hydrogen gas can be seen vigorously bubbling out from around the magnesium electrode. The copper electrode is simply an auxiliary electrode; it merely acts as an electron shunt, where reduction of hydrogen ions to hydrogen gas also takes place.

The table can be used to calculate theoretical voltages for various metal combinations.

Metal	**Potential,Volts**	**Metal**	**Potential,Volts**
Calcium	+2.20	Hydrogen	0.000
Magnesium	+1.87	Antimony	-0.190
Aluminum	+1.30	Arsenic	-0.320
Manganese	+1.07	Bismuth	-0.330
Zinc	+0.758	Copper	-0.345
Chromium	+0.600	Mercury	-0.799

Iron	+0.441	Silver	-0.800
Cadmium	+0.398	Platinum	-0.863
Nickel	+0.220	Gold	-1.100

Source: http://hilaroad.com/camp/projects/lemon/electric_potential.html

Battery History

A professor of physics at the University of Padua in Spain, Alessandro Volta (1745-1827) is credited with the invention of the electric cell. It was on March 20, 1800 that he sent a letter to the Royal Society of London describing a revolutionary discovery. He had stacked a zinc disk and a copper disk, with a leather disk in between. The leather disk had been soaked in a mild acid solution of lemon juice. Volta found that a small flow of electrical current between the copper and zinc resulted. Thus was born the “voltaic pile” of electrical storage battery.

There are different kinds of batteries, but they all work on the same general principle. Several different acid solutions are used. These solutions are called electrolytes. They allow current to flow through them because they contain many charged atoms, known as ions. In a dry-cell battery, like the one used in a flashlight, the electrolyte is not really dry but mixed with a paste of absorbent material.

Volta discovered that, when two dissimilar metals are separated by a conducting liquid, electrons flow from one metal to the other through the liquid. The metal less acted upon accumulates electrons. Even though Volta did not know why his discovery worked, his contribution is one of the most important in the history of electrical science. This discovery in 1800 was the forerunner of the primary cell, which delivers an electrical current as the result of an electrochemical reaction.