ELECTRICAL ENERGY, CURRENT AND CIRCUITS

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Problem:

The median age for employees in the energy industry is over 50 years old. Most of these employees will be retiring in the next five to ten years – that is over 500,000 employees. Not only will the industry need to replace these workers, but will need to hire even more due to technological advances and demand. That means more power plant construction, more fuel sources being needed, more infrastructure being created and more research to find reliable and efficient renewable energy sources. There are skill sets and educational requirements to be successful in the energy industry, however public perception especially with the younger generations see this pathway as not as lucrative and lower skilled than other careers. This means that qualified workers are not taking the opportunities that the energy field possesses. One solution that many states, universities and companies are looking at is developing curriculum and pathways for high school students.
Abstract:

Globally and locally we are in an energy crisis. This is not just due to the loss of non-renewable fuel sources that have been projected to be depleted in the next 50 – 100 years, but the lack of an upcoming utility workforce. One solution that many states, universities and companies are looking at is developing curriculum and pathways for high school students. GridEd is one such group. We are a collaborative group of universities, educators, industry stakeholders and the Electric Power Research Institute to create energy curriculum for K-12 students in effort to teach and encourage the next generation to enter into the energy sector. We have developed high school level lessons for Unit 1: Introduction to Energy and plan to complete lessons for the other six units in the developed course outline. The lessons have been created to allow schools and educators to pick and choose lessons, PowerPoints and activities to match their framework and timeline. For example, some schools might have a dedicated yearlong Energy class, or have break out programs a couple of times a month, or even yet science and engineer teachers can adopt these items within their classes. We wanted to make the material as flexible as possible to reach as many students as we can. The next steps is to promote these resources, to provide professional development to educators, create curriculum for elementary and middle school age students and monitor and survey schools and students to see how successful this program has been implemented.
National Standards:

As a result of their activities in grades 9-12, all students should develop an understanding of

PS 1a: Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.

PS 2b: Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element. Bonds between atoms are created when electrons are paired up by being transferred or shared.

PS 3a: Chemical reactions occur all around us, for example in health care, cooking, cosmetics, and automobiles. Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light.

PS 3b: A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds.

PS 4c: The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel. The strength of the force is proportional to the charges, and, as with gravitation, inversely proportional to the square of the distance between them.

PS 4d: Between any two charged particles, electric force is vastly greater than the gravitational force. Most observable forces such as those exerted by a coiled spring or friction may be traced to electric forces acting between atoms and molecules.

PS 5a: The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.

PS 5b: All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.

PS 6d: In some materials, such as metals, electrons flow easily, whereas in insulating materials such as glass they can hardly flow at all. Semiconducting materials have intermediate behavior. At low temperatures some materials become superconductors and offer no resistance to the flow of electrons.
GPS STANDARDS FOR PHYSICS

SCSh1. Students will identify and investigate problems scientifically.
   a. Suggest reasonable hypotheses for identified problems.
   b. Develop procedures for solving scientific problems.
   c. Collect, organize and record appropriate data.
   d. Graphically compare and analyze data points and/or summary statistics.
   e. Develop reasonable conclusions based on data collected.
   f. Evaluate whether conclusions are reasonable by reviewing the process and checking against other available information.

SCSh2. Students will use standard safety practices for all classroom laboratory and field investigations.
   1. Follow correct procedures for use of scientific apparatus.
   2. Demonstrate appropriate technique in all laboratory situations.
   3. Follow correct protocol for identifying and reporting safety problems and violations.

SCSh3. Students will identify and investigate problems scientifically.
   g. Suggest reasonable hypotheses for identified problems.
   h. Develop procedures for solving scientific problems.
   i. Collect, organize and record appropriate data.
   j. Graphically compare and analyze data points and/or summary statistics.
   k. Develop reasonable conclusions based on data collected.
   l. Evaluate whether conclusions are reasonable by reviewing the process and checking against other available information.

SCSh4. Students use tools and instruments for observing, measuring, and manipulating scientific equipment and materials.
   a. Develop and use systematic procedures for recording and organizing information.
   b. Use technology to produce tables and graphs.
   c. Use technology to develop, test, and revise experimental or mathematical models.

SCSh6. Students will communicate scientific investigations and information clearly.
   a. Write clear, coherent laboratory reports related to scientific investigations.
   b. Write clear, coherent accounts of current scientific issues, including possible alternative interpretations of the data.
c. Use data as evidence to support scientific arguments and claims in written or oral presentations.
d. Participate in group discussions of scientific investigation and current scientific issues.

SCSh9. Students will enhance reading in all curriculum areas by:
   a. Reading in All Curriculum Areas
      • Read technical texts related to various subject areas
   b. Discussing books
      • Examine author’s purpose in writing.
      • Recognize the features of disciplinary texts.
   c. Building vocabulary knowledge
      • Demonstrate an understanding of contextual vocabulary in various subjects.
      • Use content vocabulary in writing and speaking.
      • Explore understanding of new words found in subject area texts.
   d. Establishing context
      • Explore life experiences related to subject area content.
      • Discuss in both writing and speaking how certain words are subject area related.
      • Determine strategies for finding content and contextual meaning for unknown words.

SP3. Students will evaluate the forms and transformations of energy.
   a. Analyze, evaluate, and apply the principle of conservation of energy and measure the components of work-energy theorem by
      • describing total energy in a closed system.
      • identifying different types of potential energy.
      • relating transformations between potential and kinetic energy.
   b. Explain the relationship between matter and energy.
   g. Analyze and measure power.

SP5. Students will evaluate relationships between electrical and magnetic forces.
   a. Describe the transformation of mechanical energy into electrical energy and the transmission of electrical energy.
   b. Determine the relationship among potential difference, current, and resistance in a direct current circuit.
   c. Determine equivalent resistances in series and parallel circuits.
Objectives:

1) Blur the lines between the fields of science. Physics, chemistry, and biology are not independent of each other. I want to start tying in chemical and biological concepts into my physics class.

2) To tie in more real-world experiences. Sometimes the concepts taught are very abstract to the students and they do not connect to them.

3) To create more inquiry based labs. I want to require my students to use high order thinking skills and to become comfortable with scientific investigations.

4) To vary my teaching techniques. I need to be sure to use many teaching styles to reach the most students.

5) To inspire more students to go into the fields of engineering and applied sciences. This is crucial for the United States to stay competitive in our technology driven world and the great need for young talent to enter the utilities industry.

I want to take the “scariness” out of physics. I want my students to move past their insecurities of math and science and begin to understand the importance and relevance of the physical sciences. I want my students to be excited about coming to class and excited to tell their friends, parent/guardian, etc. about what they have discovered in class. I want my students to become interested in the content discussed and have them research and explore on their own. I want my students to feel comfortable to ask questions and question concepts (this means to actively participate).

To accomplish this I also have to be an active and creative participant. I will need to know my students and their learning styles. Due to time constraints and student personalities this is not always an easy task. Personal reflection and the willingness to try new methods are always crucial to teaching. Also, identifying students with special needs is very important so I can modify lessons and offer additional support.

Another big concern within a science classroom is financial. Public school budgets are usually tight so it is important to be creative when creating activities. Thanks to the internet many demonstrations can be shown to the class without the expense of equipment.
Anticipated Learner Outcomes:

Students should demonstrate mastery in the following tasks:

- Accurate measurement of quantitative and qualitative data to support conclusions.
- Formulate and prove/disprove hypotheses with relevant supporting data collected from experiments or activities.
- Application of quantitative data into graphic representations of data.
- Correlation of learned content to factors involved in electrical storage.
- Creation of a series and parallel circuit.
- Demonstration of mastery of subject through successful completion of various assessments (test, homework check, lab practicums, modeling, reports).

Follow safety and clean-up protocols for laboratory activities.

Students will be using electrical components and should be reminded of the following safety considerations.

- Review of fire drills and placement of fire extinguishers.
- Review of proper lab dress code and rules.
- Electrical Safety Guidelines:
  1. Be sure that equipment is in the “off” position before you plug it in.
  2. Never use an electrical appliance around water or with wet hands or clothing.
  3. Be sure to turn off and unplug electrical equipment when you are finished using it.
  4. Do not work with any batteries, electrical devices, or magnets other than those provided by your teacher.

Use of sharp dissecting tools (razors, knives, and scalpels) may lead to cutting injuries. This can be minimized through supervision of students.
Assessment/Rubrics:

My lesson plans includes the following (hard and electronic copies):

1) Collection of teacher created worksheets
2) Review questions for Team Trivia.
3) Seven Power Points
4) Class Lab and Teacher Guide.
5) Lab Practicum and Teacher Guide
6) Alternative Labs (I took the main lab and divided it into three separate labs to use alone) and Teacher Guide.
7) Journal Project and Rubric
8) Electromagnetism Project and Rubric
Background:

Electrical basics

In an electrical system, increasing either the current or the voltage will result in higher power. Let's say you have a system with a 6-volt light bulb hooked up to a 6-volt battery. The power output of the light bulb is 100 watts. Using the equation above, we can calculate how much current in amps would be required to get 100 watts out of this 6-volt bulb.

You know that \( P = 100 \text{ W} \), and \( V = 6 \text{ V} \). So you can rearrange the equation to solve for \( I \) and substitute in the numbers.

\[
I = \frac{P}{V} = \frac{100 \text{ W}}{6 \text{ V}} = 16.66 \text{ amps}
\]

What would happen if you use a 12-volt battery and a 12-volt light bulb to get 100 watts of power?

\[
100 \text{ W} / 12 \text{ V} = 8.33 \text{ amps}
\]

So this system produces the same power, but with half the current. There is an advantage that comes from using less current to make the same amount of power. The resistance in electrical wires consumes power, and the power consumed increases as the current going through the wires increases. You can see how this happens by doing a little rearranging of the two equations. What you need is an equation for power in terms of resistance and current. Let's rearrange the first equation:

\[
I = \frac{V}{R} \text{ can be restated as } V = IR
\]

Now you can substitute the equation for \( V \) into the other equation:

\[
P = VI \text{ substituting for } V \text{ we get } P = IR I, \text{ or } P = I^2R
\]

What this equation tells you is that the power consumed by the wires increases if the resistance of the wires increases (for instance, if the wires get smaller or are made of a less conductive material). But it increases dramatically if the current going through the wires increases. So using a higher voltage to reduce the current can make electrical systems more efficient. The efficiency of electric motors also improves at higher voltages.

This improvement in efficiency is what is driving the automobile industry to adopt a higher voltage standard. Carmakers are moving toward a 42-volt electrical system from the current 12-volt electrical systems. The electrical demand on cars has been steadily increasing since the first cars were made. The first cars didn't even have electrical headlights; they used oil lanterns. Today cars have thousands of electrical circuits, and future cars will demand even more power. The change to 42 volts will help cars meet the greater electrical demand placed on them without having to increase the size of wires and generators to handle the greater current.
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 electronegativities 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.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Potential, Volts</th>
<th>Metal</th>
<th>Potential, Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>+2.20</td>
<td>Hydrogen</td>
<td>0.000</td>
</tr>
<tr>
<td>Magnesium</td>
<td>+1.87</td>
<td>Antimony</td>
<td>-0.190</td>
</tr>
<tr>
<td>Aluminum</td>
<td>+1.30</td>
<td>Arsenic</td>
<td>-0.320</td>
</tr>
<tr>
<td>Manganese</td>
<td>+1.07</td>
<td>Bismuth</td>
<td>-0.330</td>
</tr>
<tr>
<td>Zinc</td>
<td>+0.758</td>
<td>Copper</td>
<td>-0.345</td>
</tr>
<tr>
<td>Chromium</td>
<td>+0.600</td>
<td>Mercury</td>
<td>-0.799</td>
</tr>
<tr>
<td>Iron</td>
<td>+0.441</td>
<td>Silver</td>
<td>-0.800</td>
</tr>
<tr>
<td>Cadmium</td>
<td>+0.398</td>
<td>Platinum</td>
<td>-0.863</td>
</tr>
<tr>
<td>Nickel</td>
<td>+0.220</td>
<td>Gold</td>
<td>-1.100</td>
</tr>
</tbody>
</table>

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

We've had some students do this project and then try to use the lemon "battery" to light a small flashlight's light bulb. The lemons did not work. Why? The reason is that the lemons produce only a very small current (about one milliamp). This is not enough electric current to light the bulb. Even with multiple lemons, the amount of current flowing through the wire is not enough. Though the voltage is high enough (1.5 volts with two lemons), the current is too weak. But it was a great experiment! Even if an experiment doesn't work, it helps us to understand why.

Oxidation Reduction Reactions

Many definitions can be given to oxidation and reduction reactions. In terms of electrochemistry, the following definition is most appropriate, because it let us see how the electrons perform their roles in the chemistry of batteries.

Loss of electrons is oxidation, and gain of electrons is reduction.

\[
\text{Zn} = \text{Zn}^{2+} + 2e^- \\
\text{Cu}^{2+} + 2e^- = \text{Cu}
\]

1.10 V

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\]

1.10 V

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Copper-Zinc Voltaic Cells
As an introduction to electrochemistry let us take a look of a simple Voltaic cell or a galvanic cell.

When a stick of zinc (Zn) is inserted in a salt solution, there is a tendency for Zn to lose electron according to the reaction,

\[ \text{Zn} = \text{Zn}^{2+} + 2 \text{e}^- \]

The arrangement of a Zn electrode in a solution containing Zn\(^{2+}\) ions is a half cell, which is usually represented by the notation:

\[ \text{Zn} | \text{Zn}^{2+} \]

Zinc metal and Zn\(^{2+}\) ion form a redox couple, Zn\(^{2+}\) being the oxidant, and Zn the reductant. The same notation was used to designate a redox couple earlier.

Similarly, when a stick of copper (Cu) is inserted in a copper salt solution, there is also a tendency for Cu to loose electron according to the reaction,

\[ \text{Cu} = \text{Cu}^{2+} + 2 \text{e}^- \]

This is another half-cell or redox couple: Cu | Cu\(^{2+}\).

However, the tendency for Zn to loose electron is stronger than that for copper. When the two cells are connected by a salt bridge and an electric conductor as shown to form a closed circuit for electrons and ions to flow, copper ions (Cu\(^{2+}\)) actually gains electron to become copper metal. The reaction and the redox couple are respectively represented below,

\[ \text{Cu}^{2+} + 2 \text{e}^- = \text{Cu}, \quad \text{Cu}^{2+} | \text{Cu} \]

This arrangement is called a galvanic cell or battery as shown here. In a text form, this battery is represented by,

\[ \text{Zn} | \text{Zn}^{2+} \ || \ \text{Cu}^{2+} | \text{Cu} \]
in which the two vertical lines (||) represent a salt bridge, and a single vertical line (|) represents the boundary between the two phases (metal and solution). Electrons flow through the electric conductors connecting the electrodes and ions flow through the salt bridge. When
\[ [Zn^{2+}] = [Cu^{2+}] = 1.0 \text{ M}, \]
the voltage between the two terminals has been measured to be 1.100 V for this battery.

A battery is a package of one or more galvanic cells used for the production and storage of electric energy. The simplest battery consists of two half cells, a reduction half cell and an oxidation half cell.

**Oxidation and Reduction Reactions -- a review**

The overall reaction of the galvanic cell is

\[ \text{Zn} + \text{Cu}^{2+} = \text{Zn}^{2+} + \text{Cu} \]

Note that this redox reaction does not involve oxygen at all. For a review, note the following:

- Oxidant + n e\(^-\) = Reductant
- Example: \( \text{Cu}^{2+} + 2 \text{ e} = \text{Cu} \)
  - \( \text{Cu}^{2+} \) is the oxidizing agent and \( \text{Cu} \) the reducing agent.

- Reductant = n e\(^-\) + Oxidant
- Example: \( \text{Zn} = \text{Zn}^{2+} + 2 \text{ e}^- \)
  - \( \text{Zn} \) is the reducing agent, and \( \text{Zn}^{2+} \) the oxidizing agent.

Theoretically, any redox couple may form a half cell, and any two half cells may combine to give a battery, but we have considerable technical difficulty in making some couples into a half cell.

A simple electrochemical cell can be made from two test tubes connected with a third tube (the crossbar of the “H”), as shown in Figure 1. The hollow apparatus is filled by simultaneously pouring different solutions into the two test tubes, an aqueous solution (aq) of zinc sulfate into the left tube and a copper sulfate solution into the one on the right. Then a strip of zinc metal is dipped into the ZnSO\(_4\) solution, a piece of copper is inserted into the CuSO\(_4\) solution, and the two ends of the metal strips are connected by wires to a voltmeter. The lateral connecting tube allows ionic migration necessary for a closed electrical circuit. The voltmeter will show the electrical potential of 1.10 volts, which leads to the movement of electrons in the wire from the zinc electrode toward the copper electrode.
The electric current is caused by a pair of redox reactions. At the zinc electrode, the metallic zinc is slowly being dissolved by an oxidation reaction:

\[
Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-}
\]

A voltaic cell.

An electrode at which oxidation occurs is called an anode; it strongly attracts negative ions in the solution, and such ions are consequently called anions.

Simultaneously, a reduction reaction at the copper cathode causes Cu\(^{2+}\) cations to be deposited onto the electrode as copper metal:

\[
Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)
\]
Because negatively charged electrons are flowing from the anode, it is the negative electrode. The cathode is the positive electrode.

Adding the reactions at the two electrodes gives

\[
\text{Zn}(s) + \text{Cu}^{2+}(aq) \rightarrow \text{Cu}(s) + \text{Zn}^{2+}(aq),
\]

which is the overall redox reaction in the zinc-copper cell.


**Electrode Potential**

The potential difference, which is measured in *volts* (v), depends upon the particular substances constituting the electrodes. For any electric cell, the total potential is the sum of those produced by the reactions at the two electrodes:

\[
\text{EMF}_{\text{cell}} = \text{EMF}_{\text{oxidation}} + \text{EMF}_{\text{reduction}}
\]

The EMF denotes electromotive force, another name for electrical potential.

Chemists have measured the voltages of a great variety of electrodes by connecting each in a cell with a standard hydrogen electrode, which is hydrogen gas at 1 atmosphere bubbling over a platinum wire immersed in 1 M H\(^+\) (aq). This standard electrode is arbitrarily assigned a potential of 0 volts, and measurement of the EMF of the complete cell allows the potential of the other electrode to be determined. Table 1 lists some standard potentials for electrodes at which reduction is occurring.

**TABLE 1 Standard Electrode Potentials**

<table>
<thead>
<tr>
<th>Volts</th>
<th>Reduction</th>
<th>Half-Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.87</td>
<td>F(_2) (g)</td>
<td>+ 2e(^-) → 2F(^-) (aq)</td>
</tr>
<tr>
<td>1.36</td>
<td>Cl(_2) (g)</td>
<td>+ 2e(^-) → 2Cl(^-) (aq)</td>
</tr>
</tbody>
</table>
Near the middle of the list, you will see 0 volts arbitrarily assigned to the standard hydrogen electrode; all other potentials are relative to the hydrogen half-reaction. The voltages are given signs appropriate for a reduction reaction. For oxidation, the sign is reversed; thus, the oxidation half-reaction,

\[ \text{Pt(s)} \rightarrow \text{Pt}^{2+} (aq) + 2e^- \]

has an EMF of −1.20 volts, the opposite given in the Table 1. Look this up in the chart to be sure that you understand.

Consider how these standard potentials are used to determine the voltage of an electric cell. In the zinc-copper cell described earlier, the two half-reactions must be added to determine the cell EMF. (See Table 2.)

**TABLE 2 Zinc-Copper Cell**

<table>
<thead>
<tr>
<th>Half-reaction</th>
<th>Type</th>
<th>Electrode</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \text{Pt}^{2+} (aq) \rightarrow \text{Pt} (s) ]</td>
<td></td>
<td></td>
<td>1.20</td>
</tr>
<tr>
<td>[ \text{Hg}^2+ (aq) \rightarrow \text{Hg} (l) ]</td>
<td></td>
<td></td>
<td>0.92</td>
</tr>
<tr>
<td>[ Ag^+ (aq) \rightarrow \text{Ag} (s) ]</td>
<td></td>
<td></td>
<td>0.80</td>
</tr>
<tr>
<td>[ I_2 (s) \rightarrow 2I^- (aq) ]</td>
<td></td>
<td></td>
<td>0.53</td>
</tr>
<tr>
<td>[ \text{Cu}^{2+} (aq) \rightarrow \text{Cu} (s) ]</td>
<td></td>
<td></td>
<td>0.34</td>
</tr>
<tr>
<td>[ 2\text{H}^+ (aq) \rightarrow \text{H}_2 (g) ]</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>[ \text{Pb}^2+ (aq) \rightarrow \text{Pb} (s) ]</td>
<td></td>
<td></td>
<td>−0.13</td>
</tr>
<tr>
<td>[ \text{Ni}^{2+} (aq) \rightarrow \text{Ni} (s) ]</td>
<td></td>
<td></td>
<td>−0.26</td>
</tr>
<tr>
<td>[ \text{Fe}^{2+} (aq) \rightarrow \text{Fe} (s) ]</td>
<td></td>
<td></td>
<td>−0.44</td>
</tr>
<tr>
<td>[ \text{Zn}^{2+} (aq) \rightarrow \text{Zn} (s) ]</td>
<td></td>
<td></td>
<td>−0.76</td>
</tr>
<tr>
<td>[ \text{Al}^{3+} (aq) \rightarrow \text{Al} (s) ]</td>
<td></td>
<td></td>
<td>−1.66</td>
</tr>
<tr>
<td>[ \text{Na}^+ (aq) \rightarrow \text{Na} (s) ]</td>
<td></td>
<td></td>
<td>−2.71</td>
</tr>
<tr>
<td>[ \text{Ca}^{2+} (aq) \rightarrow \text{Ca} (s) ]</td>
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<tr>
<td>[ \text{K}^+ (aq) \rightarrow \text{K} (s) ]</td>
<td></td>
<td></td>
<td>−2.91</td>
</tr>
<tr>
<td>[ \text{Li}^+ (aq) \rightarrow \text{Li} (s) ]</td>
<td></td>
<td></td>
<td>−3.04</td>
</tr>
</tbody>
</table>
\[
\text{Zn} (s) \rightarrow \text{Zn}^{2+} (aq) + 2e^- \quad \text{Oxidation Anode} \quad 0.76 \text{ volts} \\
\text{Cu}^{2+} (aq) + 2e^- \rightarrow \text{Cu} (s) \quad \text{Reduction Cathode} \quad 0.34 \text{ volts} 
\]

The complete zinc-copper cell has a total potential of 1.10 volts (the sum of 0.76v and 0.34v). Notice that the sign of the potential of the zinc anode is the reverse of the sign given in the chart of standard electrode potentials because the reaction at the anode is oxidation.

In the chart of standard electrode potentials (Table 1), reactions are arranged in order of their tendency to occur. Reactions with a positive EMF occur more readily than those with a negative EMF. The zinc-copper cell has an overall EMF of +1.10 volts, so the solution of zinc and deposition of copper can proceed.

Calculate the total potential of a similar cell with zinc and aluminum electrodes. Table 3 shows the two pertinent half-reactions.

**TABLE 3 Aluminum-Zinc Cell**

<table>
<thead>
<tr>
<th>Half-reaction</th>
<th>Type</th>
<th>Electrode</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2\text{Al} (s) \rightarrow 2\text{Al}^{3+} (aq) + 6e^-)</td>
<td>Oxidation</td>
<td>Anode</td>
<td>1.66 volts</td>
</tr>
<tr>
<td>(3\text{Zn}^{2+} (aq) + 6e^- \rightarrow 3\text{Zn} (s))</td>
<td>Reduction</td>
<td>Cathode</td>
<td>-0.76 volts</td>
</tr>
</tbody>
</table>

Such a cell with zinc and aluminum electrodes would have an overall potential of +0.90 volts, with aluminum being dissolved and zinc metal being deposited out of solution.

If you select any two half-reactions from the chart of standard electrode potentials, the half-reaction higher on the list will proceed as a reduction, and the one lower on the list will proceed in the reverse direction, as an oxidation. **Beware:** Some references give standard electrode potentials for oxidation half-reactions, so you have to switch “higher” and “lower” in the rule stated in the preceding sentence, though this is not common.

The oxidation number rules for identifying the oxidant and reductant in a redox reaction seem complex at first but become quite simple with a small amount of practice and are an excellent tool for understanding the chemical reactions that occur all around us. Oxidation numbers are not charges even though many times they can be the same as ionic charges. They are an invented system for keeping track of electron loss and gain. We do not need to know anything about the bonding within the chemicals in order to be able to use these numbers effectively.

For each element or molecule that is involved in a reaction we need to follow these simple rules.

**Rule 1.** All pure substances have an oxidation number of zero. This applies to any pure substance whether it is a diatomic gas like O₂ or a piece of pure metal like Iron (Fe). Examples of
Rule 2. In compounds, elements that usually have an ionic charge imparted by their position in a particular group have that same oxidation number. An example is Cl which is usually in the form Cl\(^-\) in compounds; this will have an oxidation number of -1 in compounds.

Rule 3. When two or more usually negatively charged ions are involved in a compound, the one with the highest electronegativity value is given its ionic charge as the oxidation number; the others are worked out normally. An example is OF\(_2\). F is more electronegative, and so it is assigned the value of -1. Here is a good table of electronegativity values.

Rule 4. Oxygen in a compound always has an oxidation number of -2

Rule 5. Hydrogen in compounds always has an oxidation number of +1 except in the rare case of Metal Hydrides where it has a value of -1.

Rule 6. The oxidation numbers in the compound or molecule must total to the overall charge of that compound or molecule. For example CO\(_2\) has no overall charge and so the oxidation numbers must tally to zero. The sulfate ion, SO\(_4^{2-}\), has an overall charge of -2, so the oxidation numbers must tally to -2

Examples of Applying Oxidation Number Rules

These oxidation number rules only make sense when we start to use them. It is easiest to get the correct values if we break up molecules into their component atoms and line them up next to each other.

Example 1: Carbon Dioxide

Let's start with the very familiar Carbon Dioxide, CO\(_2\).

Carbon Dioxide contains one carbon atom and two oxygen atoms bound together in a discreet molecule. It is an uncharged molecule, meaning its overall charge value is zero.

First we draw each atom involved. Since there are two oxygen atoms in CO\(_2\), we put two of them in the drawing. We then make that collection of atoms equal to the overall charge which in this case is zero.

Next we go through the rules from 1 to 6, skipping any that are not relevant.

Rule 1: not relevant: CO\(_2\) is a compound and not a pure substance.

Rule 2: Oxygen is the most electronegative element and so it gets its standard charge of -2 for each oxygen atom.

Rule 3: not relevant: Carbon never forms negatively charged ions and even if it did it it is less electronegative than oxygen so what we have done is still good.
Rule 4: this has already been taken care of in Rule 2.

Rule 5: not relevant: there are no Hydrogen atoms involved.

Rule 6: In order to tally to zero, we MUST assign Carbon the oxidation number of +4. Therefore we can confidently state that after following the oxidation number rules, Carbon has an oxidation number of +4 in this compound.

Example 2: DichloroMethane

This unfamiliar chemical is also a discreet molecule that contains one Carbon atom, two Hydrogen atoms and two Chlorine atoms. Like Carbon Dioxide, it has an overall charge of zero.

Again, we go through the rules from 1 to 6:

Rule 1: not relevant: it is a compound.

Rule 2: Chlorine is the most electronegative element and so it gets its standard charge of -1 for each Chlorine atom.

Rule 3: not relevant: Carbon never forms negatively charged ions and even if it did it is less electronegative than Chlorine so what we have done is still good.

Rule 4: not relevant: there are no Oxygen atoms involved.

Rule 5: both Hydrogen atoms are given an oxidation number of +1.

Rule 6: In order to tally to zero, we MUST assign Carbon the oxidation number of 0. Therefore we can confidently state that after following the oxidation number rules, Carbon has an oxidation number of 0 in this compound.

The steps taken to achieve this result are also shown in picture form below.
Example 3 + 4: More Challenging

Lastly, let's look at a couple of more challenging examples. The unnecessary steps have been omitted. See if you can follow the six rules to get the same result as those given here:
Galvanic cell (also called voltaic cell) uses chemical reaction to produce electrical energy (flow of electrons).

When zinc metal placed in CuSO₄ solution, following reaction take place:

\[
\text{Zn}_\text{(s)} + \text{CuSO}_4^{\text{(aq)}} \rightarrow \text{ZnSO}_4^{\text{(aq)}} + \text{Cu}_\text{(s)}
\]

Oxidation: \( \text{Zn}_\text{(s)} \rightarrow \text{Zn}^{+2} + 2e^- \)

Reduction: \( \text{Cu}^{+2} + 2e^- \rightarrow \text{Cu} \)

Overall: \( \text{Zn}_\text{(s)} + \text{Cu}^{+2} \rightarrow \text{Zn}^{+2} + \text{Cu}_\text{(s)} \)

Electrons will not flow in the following apparatus:

But if reaction carried out in the apparatus shown in Figure 21.2 (Cu/Ag system), electrons are transferred from Zn\textsuperscript{0} to Cu\textsuperscript{+2} through a wire producing electrical energy.

The salt bridge is necessary to complete the circuit and maintain charge neutrality.

\[
\text{Zn} | \text{Zn}^{+2} || \text{Cu}^{+2} | \text{Cu}
\]

\[
\text{SO}_4^{+2} \quad \text{anode} \quad \uparrow \quad \text{salt bridge} \quad \text{Zn}^{+2} \quad \text{cathode}
\]
<table>
<thead>
<tr>
<th>Anode</th>
<th>Cathode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation occurs</td>
<td>Reduction occurs</td>
</tr>
<tr>
<td>Electrons produced</td>
<td>Electrons are consumed</td>
</tr>
<tr>
<td>Anions migrate toward</td>
<td>Cations migrate toward</td>
</tr>
<tr>
<td>Has negative sign</td>
<td>Has positive sign</td>
</tr>
</tbody>
</table>

#### Shorthand Notation for:

\[
Zn^0 + Cu^{+2} \rightarrow Zn^{+2} + Cu^0
\]

Write shorthand notation for:

\[
Fe(s) + 2Fe^{+3}_{(aq)} \rightarrow 3Fe^{+2}_{(aq)}
\]

\[
Fe^0 Fe^{+2} Fe^{+3} Fe^{+2}
\]

Write shorthand notation for:

\[
2Ag^{+1}_{(aq)} + Ni(s) \rightarrow 2Ag(s) + Ni^{+2}_{(aq)}
\]

\[
Ni^0 Ni^{+2} Ag^{+1} Ag^0
\]

#### Capacitors

In a way, a capacitor is a little like a battery. Although they work in completely different ways, capacitors and batteries both store electrical energy. If you have read How Batteries Work, then you know that a battery has two terminals. Inside the battery, chemical reactions produce electrons on one terminal and absorb electrons on the other terminal. A capacitor is much simpler than a battery, as it can't produce new electrons -- it only stores them.

In this article, we'll learn exactly what a capacitor is, what it does and how it's used in electronics. We'll also look at the history of the capacitor and how several people helped shape its progress.

Inside the capacitor, the terminals connect to two metal plates separated by a non-conducting substance, or dielectric. You can easily make a capacitor from two pieces of aluminum foil and a piece of paper. It won't be a particularly good capacitor in terms of its storage capacity, but it will work.
In theory, the dielectric can be any non-conductive substance. However, for practical applications, specific materials are used that best suit the capacitor's function. Mica, ceramic, cellulose, porcelain, Mylar, Teflon and even air are some of the non-conductive materials used. The dielectric dictates what kind of capacitor it is and for what it is best suited. Depending on the size and type of dielectric, some capacitors are better for high frequency uses, while some are better for high voltage applications. Capacitors can be manufactured to serve any purpose, from the smallest plastic capacitor in your calculator, to an ultra capacitor that can power a commuter bus. NASA uses glass capacitors to help wake up the space shuttle's circuitry and help deploy space probes. Here are some of the various types of capacitors and how they are used.

- Air - Often used in radio tuning circuits
- Mylar - Most commonly used for timer circuits like clocks, alarms and counters
- Glass - Good for high voltage applications
- Ceramic - Used for high frequency purposes like antennas, X-ray and MRI machines
- Super capacitor - Powers electric and hybrid cars

Capacitor Circuit

When you connect a capacitor to a battery, here's what happens:

- The plate on the capacitor that attaches to the negative terminal of the battery accepts electrons that the battery is producing.
- The plate on the capacitor that attaches to the positive terminal of the battery loses electrons to the battery.

Once it's charged, the capacitor has the same voltage as the battery (1.5 volts on the battery means 1.5 volts on the capacitor). For a small capacitor, the capacity is small. But large capacitors can hold quite a bit of charge. You can find capacitors as big as soda cans that hold enough charge to light a flashlight bulb for a minute or more.

Even nature shows the capacitor at work in the form of lightning. One plate is the cloud, the other plate is the ground and the lightning is the charge releasing between these two "plates."

Obviously, in a capacitor that large, you can hold a huge amount of charge!

Let's say you hook up a capacitor like this:
Here you have a battery, a light bulb and a capacitor. If the capacitor is pretty big, what you will notice is that, when you connect the battery, the light bulb will light up as current flows from the battery to the capacitor to charge it up. The bulb will get progressively dimmer and finally go out once the capacitor reaches its capacity. If you then remove the battery and replace it with a wire, current will flow from one plate of the capacitor to the other. The bulb will light initially and then dim as the capacitor discharges, until it is completely out.

**Farad**

A capacitor's storage potential, or capacitance, is measured in units called farads. A 1-farad capacitor can store one coulomb (coo-lomb) of charge at 1 volt. A coulomb is $6.25 \times 10^{18}$ electrons. One amp represents a rate of electron flow of 1 coulomb of electrons per second, so a 1-farad capacitor can hold 1 amp-second of electrons at 1 volt.

A 1-farad capacitor would typically be pretty big. It might be as big as a can of tuna or a 1-liter soda bottle, depending on the voltage it can handle. For this reason, capacitors are typically measured in microfarads (millionths of a farad).

To get some perspective on how big a farad is, think about this:

- A standard alkaline AA battery holds about 2.8 amp-hours.
- That means that a AA battery can produce 2.8 amps for an hour at 1.5 volts (about 4.2 watt-hours -- a AA battery can light a 4-watt bulb for a little more than an hour).
- Let's call it 1 volt to make the math easier. To store one AA battery's energy in a capacitor, you would need $3,600 \times 2.8 = 10,080$ farads to hold it, because an amp-hour is 3,600 amp-seconds.

If it takes something the size of a can of tuna to hold a farad, then 10,080 farads is going to take up a LOT more space than a single AA battery! Obviously, it's impractical to use capacitors to store any significant amount of power unless you do it at a high voltage.

**Applications**
The difference between a capacitor and a battery is that a capacitor can dump its entire charge in a tiny fraction of a second, where a battery would take minutes to completely discharge. That's why the electronic flash on a camera uses a capacitor -- the battery charges up the flash's
capacitor over several seconds, and then the capacitor dumps the full charge into the flash tube almost instantly. This can make a large, charged capacitor extremely dangerous – flash units and TVs have warnings about opening them up for this reason. They contain big capacitors that can, potentially, kill you with the charge they contain.

Capacitors are used in several different ways in electronic circuits:

- Sometimes, capacitors are used to store charge for high-speed use. That's what a flash does. Big lasers use this technique as well to get very bright, instantaneous flashes.
- Capacitors can also eliminate ripples. If a line carrying DC voltage has ripples or spikes in it, a big capacitor can even out the voltage by absorbing the peaks and filling in the valleys.
- A capacitor can block DC voltage. If you hook a small capacitor to a battery, then no current will flow between the poles of the battery once the capacitor charges. However, any alternating current (AC) signal flows through a capacitor unimpeded. That's because the capacitor will charge and discharge as the alternating current fluctuates, making it appear that the alternating current is flowing.

Capacitive Touch Screens

One of the more futuristic applications of capacitors is the capacitive touch screen. These are glass screens that have a very thin, transparent metallic coating. A built-in electrode pattern charges the screen so when touched, a current is drawn to the finger and creates a voltage drop. This exact location of the voltage drop is picked up by a controller and transmitted to a computer. These touch screens are commonly found in interactive building directories and more recently in Apple's iPhone.

History of the Capacitor

The invention of the capacitor varies somewhat depending on who you ask. There are records that indicate a German scientist named Ewald Georg von Kleist invented the capacitor in November 1745. Several months later Pieter van Musschenbroek, a Dutch professor at the University of Leyden came up with a very similar device in the form of the Leyden jar, which is typically credited as the first capacitor. Since Kleist didn't have detailed records and notes, nor the notoriety of his Dutch counterpart, he's often overlooked as a contributor to the capacitor's evolution. However, over the years, both have been given equal credit as it was established that their research was independent of each other and merely a scientific coincidence [source: Williams].

The Leyden jar was a very simple device. It consisted of a glass jar, half filled with water and lined inside and out with metal foil. The glass acted as the dielectric, although it was thought for a time that water was the key ingredient. There was usually a metal wire or chain driven through a cork in the top of the jar. The chain was then hooked to something that would deliver a charge, most likely a hand-cranked static generator. Once delivered, the jar would hold two equal but opposite charges in equilibrium until they were connected with a wire, producing a slight spark or shock [source: Williams].
Benjamin Franklin worked with the Leyden jar in his experiments with electricity and soon found that a flat piece of glass worked as well as the jar model, prompting him to develop the flat capacitor, or Franklin square. Years later, English chemist Michael Faraday would pioneer the first practical applications for the capacitor in trying to store unused electrons from his experiments. This led to the first usable capacitor, made from large oil barrels. Faraday's progress with capacitors is what eventually enabled us to deliver electric power over great distances. As a result of Faraday's achievements in the field of electricity, the unit of measurement for capacitors, or capacitance, became known as the farad [source: Ramasamy].


http://www.forevergeek.com/2005/04/instructions_for_making_a_film_canister_leyden_jar/

I wrote these plans after building the project pictured at Lenny R’s Web Page. This is a guide on how to make a Leyden Jar that makes awesome blue sparks with materials mostly just lying around your house. It’s cheap, it’s basically harmless, and it’s fun! First, here’s a list of the materials you will need:

- An empty film canister with its lid
- Multistrand insulated wire
- Single conductor/solid uninsulated wire, about 1.5mm in diameter
- Some aluminum or copper foil (NOTE: Any conductive foil will work. Copper foil is thicker and easier to work with than aluminum foil, but aluminum foil works if that’s all you have.)
- A screw with a round head that is shorter than the film canister’s height
- Two nuts that fit on the screw
- Scotch tape
- optional. A PVC Pipe, 3/4” wide and about 3 or 4 feet long.
- optional. Fur, wool, or cotton fabric
Now that you have all of the parts, let’s get to work. First, drill (or poke) a hole in the center of the lid of the **film canister**. The hole should be just wide enough to allow the screw to fit snugly inside it. Next, cut a rectangle of foil large enough to wrap around the outside of the canister, and about 2/3 of the height of the canister. Tape the foil to the canister, being sure to leave an open section for a loop of **wire** to go around the canister over the foil (you should just need to tape the foil’s edges to the outside of the canister.) This is roughly what your canister should look like with the top on (sorry for the horrible **MS Paint** art.)

Make another piece of foil the same size as the first piece, and fasten it inside the canister. If you’re using heavy foil, you shouldn’t need to use tape; the tension of the foil being rolled up should be enough to keep it plastered to the inside of the canister. If you are using lighter foil, you’ll need to tape the edges of the foil to the inside of the canister in a similar fashion. It is very important that the foil touches the container all the way around the inside of the canister.

Now, it gets a little more complicated. Secure the multistrand **wire** to the top of the lid using the screw and a nut (see image below.) The multistrand **wire** should be about 1î or 2 cm long, and should have about 1/4î or .75 cm of insulation stripped off both ends. Make a hook on one end of the **wire**, and secure it in between a nut and the outside of the lid. Fan/spread out the conductors on the other end of the **wire**. Secure the solid **wire** to the bottom of the **film canister** in a similar fashion. Bend the **wire** as shown below, making it poke out wider than the canister lid. This way, the **wire** is guaranteed to touch the foil on the inside of the **film canister** when the lid is put on. Make a loop at the end of the **wire** so that it won’t tear through the foil on the inside of the canister and to make better a electrical contact. If this is confusing, look at the drawing below (again, sorry about **MS Paint**.)
Place the lid on the container, ensuring that the wire loop touches the foil on the inside. If the loop doesn’t touch the foil on the inside, bend the loop farther outwards until it does.

Last, bend another piece of wire into the shape above, and insert it over the bottom of the canister onto the ‘open section’ of foil, so that it looks similar to the finished Leyden Jar below. Make sure the top of the wire is at a MAXIMUM of 1/4 of an inch away from the screw head. After the wire is in the correct position, cover the outside of the canister with scotch or electrical tape so that you don’t shock yourself while handling it (the canister below is covered with scotch tape, although it’s kind of hard to see.)
You’re done! You have just built something called a Leyden Jar; in effect, it’s a very simple capacitor. To use it, simply wave the canister over the surface of a CRT TV screen or monitor, or anything that makes static electricity (the multistrand wire ‘receives’ the static electricity and should therefore be closest to the static source.) Then gently push down the solid wire on the outside so it reaches a little closer to the screw head (without touching) and ZAP! There’s your spark. Most of the time, the Jar will discharge itself with no extra help. If you’re having trouble charging the Jar, you can use the last two materials on the material list to build a simple but excellent static generator. Take the fabric and rub it along the pipe all the way up, then all the way down. Have someone else hold the Leyden jar; pressing the multistrand pickup wires to the pipe, and discharge the Jar after a few seconds of rubbing.

Please note that the finished Leyden Jar holds high voltage, low current electricity, which is normally harmless. However, don’t take any chances! If you’re not sure if it’s charged or not and you think it’s not safe, simply press the press on the outside wire against the screw to completely discharge it. Keep your finger away from the screw head area as much as possible while it’s charged. You don’t want an ‘accident’ (you’ll just get a static shock. No one likes getting a static shock.)

I would like to give special thanks to Lenny R for his ideas. As far as I know, the original “Film Can Leyden Jar” was his design, and although I’ve made some changes to the design and written this guide, I don’t want to risk getting sued or something for taking credit for the original design (editor’s note: smart thinking)
Cabinet knob or other round metal ball

Metal Foil

Bead Chain

http://micro.magnet.fsu.edu/electromag/java/capacitor/index.html

http://blog.makezine.com/archive/2009/02/make_presents_the_capacitor.html
Materials and Supplies:

Ordered Materials to create seven lab kits for Lab Practicum. Each kit should contain (white vinegar, lemon, aluminum foil, text books and distilled water provided in class)

a) plastic storage container
b) multi-meter (with leads)
c) 5 film-canisters
d) caliper
e) ruler
f) 2 D batteries with holder
g) 2 low current LED bulbs
h) 2 miniature bulbs and holders
i) 7 leads with alligator clips
j) Squeeze bottle (containing lemon juice)
k) 6 galvanized nails
l) 7 pieces of copper wire (10-14 gauge) cut to ~ 8 mm
m) 1 pre-1982 penny
n) 1 post-1965 nickel, dime, or quarter
Summary:

The purpose of my summer research was to investigate possible hands-on applications for teaching concepts of electrochemical energy and current to my students. The majority of my research was dedicated to creating electrochemical cells from household materials. I wanted to create a unit around a lab practicum pertaining to electrical energy storage. I had researched citrus and film canister electrochemical cells but I had found most of the resources were inaccurate, the labs did not work, or were too basic for an Advanced Physics class. My goal was to complete an in-depth and meaningful lab and to determine the best approach to take during its construction. My research was divided into five main parts.

1) Chemical Reactions: I wanted to find a demonstration that showed the students about chemical reactions so we could then discuss chemical energy. I want to start breaking down some of the walls between chemistry and physics classes and show the relationship between both. The Cleaning Pennies lab is simple to demonstrate and opens up dialogue about chemical energy and reactions.

2) Citrus Electrochemical Cells: This was the starting point of my research. Professor Alamgir was very interested for me to expand on a very simple electrochemical cell that really grabs the interest of the student. I experimented with various fruits (lemons, limes, oranges, and grapefruits) and with various electrodes (galvanized nails, pre and post 1982 pennies (cleaned and un-cleaned, sanded and un-sanded), copper wire, nickels, dimes, and quarters). For the greatest voltage, best wow factor, and the most cost-efficient my findings were to use a lemon with galvanized nail and pre-1982 penny (un-cleaned and un-sanded). I also determined that two lemon cells in series could power a calculator and four would power a low-current LED.

3) Film Canister Electrochemical Cells: For cost and re-usability purposes I also wanted to explore creating electrochemical cells using a solution within a film canister. I measured the voltage of many different solutions: white vinegar, cola, diet cola, lemon-lime soda, salt water (iodized and non-iodized), bottled water, Gatorade, distilled water, purified water, lime juice from concentrate, lemon juice, and water and baking soda. For the electrodes I tested various gauges of copper wire. For the greatest voltage, best wow factor, and the most cost-efficient my findings were to use white vinegar, a galvanized nail, and 10-14 gauge copper wire. I also determined that two film canister cells in series could power a calculator and four would power a low-current LED.

4) Resistors (Series and Parallel Circuits): I explored using various resistors in series and parallel circuits that would give the closest measurement to the label and calculated total resistance. I found that using too small of a resistance would give too much error especially when calculating equivalent resistance in parallel circuits.
5) Capacitors: I explored the most efficient way for the students to create a parallel capacitor and obtain results that demonstrated an inverse relationship between capacitance and plate distance.

The main goal of any program like STEP-UP is to provide experience for teachers that can be brought back into the classroom. If the action plan does not meet the standards or is too extensive and/or expensive it will not be done in the classroom and the students will not benefit from the teacher’s experience. I understand this and have created a 4 ½ week unit on two very crucial chapters: Electrical Energy and Current and Circuits and Circuit Elements. I am using my research on Energy and Utilities to produce meaningful activities, demonstrations, Power Points, and labs for my students. From these items and my experience I hope for the students to:

1) Use critical thinking skills to analyze data and make relevant real-world connections.

2) Complete activities that require inquiry and high order thinking skills.

3) Encourage thought on the environmental impact of the concepts.

4) Increase knowledge of scientific concepts.

5) Encourage further exploration of concepts.
CHEMICAL REACTIONS AND ELECTRICAL ENERGY

CLASS ACTIVITY

PART A: Demonstrating a Chemical Reaction: “Cleaning” Pennies

Objective: To demonstrate a chemical reaction and observe chemical changes.

1) Describe the appearance of the pennies before placed in the solution.

2) When pennies appear “dirty” they are actually covered with copper oxide (CuO). How does the copper oxide form on the penny?

3) What is the penny’s material composition?

4) What type of solution is the vinegar? What type of compound is table salt?

5) Describe the appearance of the pennies after placed in the solution.
6) Predict any change in appearance of the pennies as they dry. (Rinsed vs. Un-rinsed)

7) Describe the appearance of the pennies once they had a chance to dry.

8) Explain why the pennies may have changed in appearance.

9) Describe the paperclip before placed in the solution. Predict changes in appearance (if any) after it has been in the solution.

10) Describe the appearance of the paperclip after it has been removed from the solution.
PART B: Changing Chemical Energy into Electrical Energy

Objective: To create an electrochemical battery from a lemon that produces enough voltage and current to light a LED.

1) Describe the components of the lemon cell?

2) What is occurring for each of the lemon cells to produce a voltage?

3) Record the individual voltages of each of the lemons in Data Table 1.

4) When each lemon cell is placed in series the voltages add up. Record in Data Table 2 the calculated values of the following combinations: A + B, A + B + C, and A + B + C + D (you may have to do more combinations if this does not produce enough electrical energy for the LED).

5) Record in Data Table 2 the measured voltages for the combinations. Is there any difference? If so, explain why.

6) Based on your calculated voltages predict how many lemons will be needed for the LED bulb to work.
7) How many lemon cells were needed to light the LED? How did this compare to your prediction?

DATA TABLE 1: Individual Voltage Readings

<table>
<thead>
<tr>
<th>LEMON</th>
<th>_VOLTAGE READING (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>

DATA TABLE 2: Combination Voltage Readings

<table>
<thead>
<tr>
<th>COMBINATION</th>
<th>PREDICTED VOLTAGE (V)</th>
<th>MEASURED VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A + B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A + B + C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A + B + C + D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Combinations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PART A: Demonstrating a Chemical Reaction: “Cleaning” Pennies

Objective: To demonstrate a chemical reaction and observe chemical changes.

Materials:
- Glass/Plastic Container (do not use a metal container because it will react with the vinegar)
- White Vinegar (4-5% acetic acid)
- Table Salt
- Plastic spoon (glass stirrers would work – just not metal)
- 20 “dirty” pennies (“dirty” meaning tarnished; a month prior to this experiment you may want to start a collection within your classroom or school)
- 3 steel paperclips
- Paper Towels
- Marker/Pen
- Water Source
**Procedure and Observations:**

1) Carefully pour the white vinegar into the container (usually you need about a $\frac{1}{4} - \frac{1}{2}$ cup but depending on your containers you need enough to cover the pennies when they are added).

2) Add about a teaspoon of salt to the vinegar and stir until the salt dissolves.

3) Pass the dirty pennies around so the students can observe them.

4) Place the pennies in the solution and leave them in for about 10 minutes.

5) During this time mark two paper towels as A and B. Also, unbend one of the paperclips.

6) Remove ten pennies from the vinegar and salt solution and place on towel B. Then remove the other pennies, rinse them thoroughly under water and place them on towel A. DO NOT discard the solution.

7) Set the towels aside to let the pennies dry till the next day.

8) Place the unbent paperclip in the container so half of it is in the solution and the other half is out. Also place one of the bent paperclips into the solution. Leave overnight and remove the paperclips and place them on a towel. Pass them around so the students may observe them.

11) Describe the appearance of the pennies before placed in the solution.

   **Dull and dingy looking**
12) When pennies appear “dirty” they are actually covered with copper oxide (CuO). How does the copper oxide form on the penny?

The dullness of pennies occurs when the copper in the pennies reacts with the oxygen in the air and forms copper oxide (CuO).

13) What is the penny’s material composition?

Pennies prior to 1982 were made almost completely out of copper. However, post 1982 pennies are copper plated around a zinc core (97.5% Zn/2.5% Cu).

14) What type of solution is the vinegar? What type of compound is table salt?

Acidic solution; ionic compound

15) Describe the appearance of the pennies after placed in the solution.

The students should notice that the pennies are shiny and most of the tarnish was removed; placing the pennies in a salt and vinegar solution allows for the acetic acid from the vinegar to dissolve the CuO. The copper from the CuO remains in the solution.

16) Predict any change in appearance of the pennies as they dry. (Rinsed vs. Un-rinsed)

Predictions may vary.

17) Describe the appearance of the pennies once they had a chance to dry.

The students should notice that the pennies on A (rinsed) remained shiny and the pennies on B (un-rinsed) turned a blue-green color.

18) Explain why the pennies may have changed in appearance.

The vinegar and salt dissolve the CuO layer making it easier for the copper atoms to join oxygen from the air and chlorine from the salt to make blue-green compounds.
called copper carbonate, and copper chloride (verdigris). The vinegar can also cause copper acetate to form. The students may not know these particular compounds but they should observe that leaving the vinegar and salt solution on the pennies causes a reaction in air).

Statue of Liberty, copper pots, other copper (brass, bronze) materials; The Statue of Liberty was not always green but the copper clad would have oxidized quickly being surrounded by water. Unfortunately, there was not color photography in the mid 1880’s to see the difference. There is a same-size replica of the face shown as part of the exhibit in one of the corridors of the Statue's pedestal. The patina (oxidized layer) on the statue acts as a barrier protecting the underlying copper from any further oxidation.

19) Describe the paperclip before placed in the solution. Predict changes in appearance (if any) after it has been in the solution.

They are stainless steel so they appear shiny and silvery.

20) Describe the appearance of the paperclip after it has been removed from the solution.

The students should note a color change to the paperclip. When the pennies are removed the copper from the CuO remains in the solution. The copper in the solution are positively charged copper ions. The paperclip is made of steel (an alloy of iron and carbon) and the salt and vinegar solution dissolves some of the iron and its oxides on the surface of the paperclip leaving its surface negatively charged. The positive copper ions are attracted to the negatively charged surface of the paperclip which will coat the paperclip.
PART B: Changing Chemical Energy into Electrical Energy

Materials:
- At least 4 lemons (limes may be used instead; other citrus fruit can be used but usually are less acidic and will produce a smaller voltage)
- 4 pre-1982 pennies (these pennies are almost 100% Copper and work better than the post-1982 pennies; if post-1982 pennies must be used more lemon cells may be needed; copper wire (10-14 gauge is another alternative)
- 4 galvanized nails (this means they are zinc coated; they are easily found at building supply or hardware stores)
- 7 connecting wires with alligator clips (pieces of thin copper or insulated wire can be used instead)
- multi-meter (or voltmeter)
- 1 LED light (clear bulbs with red or pink glow are usually the easiest to detect; Recommended: 5mm Red LED (clear-color lens; typical voltage 1.7 V, with a max voltage of 2.4 V; 20 mA max); these can be purchased through an electronics store or on-line; To view LED better in a classroom setting the room should be darken)
- marker
- knife/razor blade

Procedure and Observations:

1. Using the marker label each lemon as A, B, C, and D.

2. Puncture on one side of each lemon with the galvanized nails. (See Figure 1.)
3. With the knife/razor blade make a small incision (large enough to fit a penny) on the other side of each lemon and insert the pennies. (See Figure 1.)

4. Using the multi-meter and the connecting wires measure the voltage of each one of the lemon batteries cells. Have the students record their data in Data Table 1.

If the multi-meter displays a negative voltage then the positive and negative connections are switched.

Objective: To create an electrochemical battery from a lemon that produces enough voltage and current to light a LED.

8) Describe the components of the lemon cell?
   galvanized nail = negative and copper = positive; With copper and zinc electrodes, the zinc more readily loses electrons (e-) than the copper. Therefore, e- flow from the zinc to the copper electrode.

9) What is occurring for each of the lemon cells to produce a voltage?

Electrolyte: lemon juice → citric acid; 2 Electrodes – nail (-) and copper coin (+); The nail (zinc) is the anode since this where oxidation occurs (loses e-). The copper coin is the cathode since this where reduction occurs (gains e-).

A chemical reaction occurs when two or more molecules interact and a chemical change occurs. All chemical reactions involve a change in energy. (Law of Conservation: matter or energy cannot be created or destroyed only changed).

This energy change allows for the conversion of chemical energy to electrical energy.

Metals differ in their tendency to give up electrons. This difference allows for an imbalance of charges and since opposite charges attract the electrons released from one metal will be attracted to the other metal. These metals are called electrodes. For the electron exchange between the two metals to begin and/or continue they must be placed in an electrolyte (a solution of ions). With copper and zinc electrodes, the zinc more readily
loses electrons (e-) than the copper. Therefore, e- flow from the zinc to the copper electrode. For this example citric acid (C₆H₈O₇) is used as the electrolyte. An acid has an easily detached hydrogen ion. Hydrogen ions are positive, and the remaining part of the acid (citrate) becomes negative when the hydrogen is removed. As the zinc electrode loses e-, positive zinc ions are produced. The acetate ions are more attracted to the zinc ions than the H+ and will pair up leaving the H+ to bond with the extra electrons on the copper electrode. Since the copper electrode has lost its extra e- to the H+ it can accept more from the zinc electrode. This continues the process until the zinc is used up and the battery is dead.

10) Record the individual voltages of each of the lemons in Data Table 1. Each one should read 0.85 V to 1 V; if the measurements are producing very low or zero volt readings the electrodes may be touching one another or there is a problem with the wire connections.

11) When each lemon cell is placed in series the voltages add up. Record in Data Table 2 the calculated values of the following combinations: A + B, A + B + C, and A + B + C + D (you may have to do more combinations if this does not produce enough electrical energy for the LED).
   Indicate the correct way to connect the lemons in series: positive terminal → Cu penny; Zn nail (on same cell) → Cu penny (2nd cell); Zn nail (on 2nd cell) → negative terminal

12) Record in Data Table 2 the measured voltages for the combinations. Is there any difference? If so, explain why.
   There usually is a slight difference due to internal resistance of the cells and in the connecting wires.

13) Based on your calculated voltages predict how many lemons will be needed for the LED bulb to work.

14) How many lemon cells were needed to light the LED? How did this compare to your prediction? Usually about 3 or 4 lemons will be needed

(REMEMBER: since the LED is a diode it will only work in one direction)
### DATA TABLE 1: Individual Voltage Readings

<table>
<thead>
<tr>
<th>LEMON</th>
<th>VOLTAGE READING (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>

### DATA TABLE 2: Combination Voltage Readings

<table>
<thead>
<tr>
<th>COMBINATION</th>
<th>PREDICTED VOLTAGE (V)</th>
<th>MEASURED VOLTAGE(V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A + B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A + B + C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A + B + C + D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Combinations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Changing Chemical Energy into Electrical Energy: Film Canister Battery

Name: ___________________________  Date:  ___________  Period:  _______

Objective:
To create an electrochemical battery that produces enough voltage and current to light a LED.

Materials:
- 4 film canisters
- white vinegar
- 4 pieces of copper wire (~8 cm)
- 4 galvanized nails
- 7 connecting wires with alligator clips
- multi-meter (or voltmeter)
- 2 incandescent lamps in holders
- 1 LED light
- 2 D batteries with holder
- masking tape
- marker/pen
- Optional: a calculator or another LCD display, soldering iron and solder or electrical tape, screwdriver

Procedure and Observations:
5. Using the marker/pen and masking tape label each canister as A, B, C, and D. Remove the caps and carefully pour the vinegar into each of the film canisters (3/4 of the way full) and then replace the caps.

6. Place the galvanized nails in one of the holes of the caps of each canister.

7. Place the copper wire in the other hole of each canister.

8. Using the multi-meter (set to the voltage reading specified by your teacher) and the connecting wires measure the voltage of each one of your film canister batteries. Place your measurements in Data Table 1.

   If the multi-meter displays a negative voltage then the positive and negative connections are switched. Noting this, which part of your film canister battery (the galvanized nail or the copper wire) is the positive electrode and which is the negative electrode? What does this mean in terms of electron movement?

   **DATA TABLE 1: Individual Voltage Readings**

<table>
<thead>
<tr>
<th>Film Canister</th>
<th>Voltage Reading (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>

9. Choose two of the canisters and using the rules of series circuits predict the total voltage. Connect the two canisters in series with one another and measure their total voltage. Repeat this procedure with three and then four in series. Place all information in Data Table 2.
<table>
<thead>
<tr>
<th>Combination</th>
<th>Predicted Voltage</th>
<th>Measured Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two in Series (   and   )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three in Series ( , and )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four in Series</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. Place two D batteries in series. Knowing that each is about 1.5 V what would be the total voltage for two in series? _____________. Using the multi-meter determine the total voltage: _____________.

11. Connect the two D batteries to the screws on the base of the lamp holder. Does the light come on?

    Switch the leads on the lamp. Does the light come on?

Using the combination of Film Canister Cells that produces the voltage closest to the two D batteries connect to the base of the other lamp holder. Does the light come on?

    Switch the leads on the lamp. Does the light come on?
12. Using the combination of Film Canister Cells that produces a voltage between 1.7 V – 2.4 V (or the combination specified by the teacher) connect to the leads of an LED lamp. Does the light come on?

Switch the leads on the LED. Does the light come on?

Optional:

13. Unscrew and remove the back plate of an inexpensive calculator.

14. Remove battery from the calculator.

15. Solder, tape or clip wire leads to the positive and negative terminals of the battery holder. (Calculators that require an AAA or AA battery are easier to attach, but button battery powered calculators will also work – it just takes a little more time to make the connections and keep them in place. Remind students who are soldering (not recommended) the solder safety precautions:

- DO NOT touch the tip of the soldering iron.
- ALWAYS return the soldering iron to its stand when not in use.
- Work in a well-ventilated area.
- Wash your hands after soldering.

16. Connect your leads to two Film Canister Cells.

17. Turn on the calculator and perform the following calculations:

\[
476 \times 219 = \underline{\quad} \quad \quad \quad 698/42 = \underline{\quad}
\]

Questions:

1. Name the three main parts of a battery. Assign each of these parts to the components of the Film Canister Cell.
2. Why must the Film Canister Cells be placed in a series arrangement rather than a parallel arrangement?

3. Why will the batteries light up the incandescent lamp but not the Film Canister Battery even though their voltages are similar?

4. What is an LED and why is it able to be lit by the Film Canister Battery?

5. Why will the LED only light in one direction?
TEACHER RESOURCE GUIDE

B. Changing Chemical Energy into Electrical Energy: Film Canister Battery

Objective:
To create an electrochemical battery that produces enough voltage and current to light a LED.

Materials:
- 4 film canisters (many photo labs will give you their empty film canister – the problem now is that most people have a digital camera and do not use film; film canisters can be ordered from Educational Innovations (www.teachersource.com) for $12.95 (~40 count) or $49.95 (~200 count))
- white vinegar (4-5% acetic acid; lemon-lime soda or lemon juice works as well)
- 4 pieces of copper wire (~8 cm) (10-14 gauge wire works best since it sturdy but still malleable enough to work with. Copper can be ordered on-line but it usually comes in large and expensive rolls. A building supply store allows for a portion of the wire to be cut from the roll (7½ ft is enough for 28 pieces (~8 cm)). It is suggested that the teacher cut the wire prior to the lab)
- 4 galvanized nails (this means they are zinc coated; they are easily found at building supply or hardware stores)
- 7 connecting wires with alligator clips (pieces of thin copper or insulated wire can be used instead)
- multi-meter (or voltmeter)
- 2 incandescent lamps in holders (2.5 V – 3.5 V are recommended)
- 1 LED light (clear bulbs with red or pink glow are usually the easiest to detect; Recommended: 5mm Red LED (clear-color lens; typical voltage 1.7 V, with a max voltage of 2.4 V; 20 mA max); these can be purchased through an electronics store or on-line)

-2 D batteries with holder (2 series battery holders are recommended or the batteries will need to be connected in series with wire; battery holders can be purchased at an electronics store or on-line)

-masking tape

-marker/pen

-Optional: a calculator or another LCD display, soldering iron and solder or electrical tape, screwdriver

The teacher should punch two holes in each of the film canister caps using the galvanized nail (see pictures below) prior to lab.

Procedure and Observations:

18. Using the marker/pen and masking tape label each canister as A, B, C, and D. Remove the caps and carefully pour the vinegar into each of the film canisters (3/4 of the way full) and then replace the caps.

19. Place the galvanized nails in one of the holes of the caps of each canister.

20. Place the copper wire in the other hole of each canister.

21. Using the multi-meter (set to the voltage reading specified by your teacher) and the connecting wires measure the voltage of each one of your film canister batteries. Place your measurements in Data Table 1.

If the multi-meter displays a negative voltage then the positive and negative connections are switched. Noting this, which part of your film canister battery (the galvanized nail or the copper wire) is the positive electrode and which is the negative electrode? What does this mean in terms of electron movement?
(galvanized nail = negative and copper = positive; With copper and zinc electrodes, the zinc more readily loses electrons ($e^-$) than the copper. Therefore, $e^-$ flow from the zinc to the copper electrode.)

DATA TABLE 1: Individual Voltage Readings

<table>
<thead>
<tr>
<th>Film Canister</th>
<th>Voltage Reading (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>

(Each one should read 0.85 V to 1 V; if the students are getting very low or zero volt readings their electrodes may be touching one another or there is a problem with the wire connections)

22. Choose two of the canisters and using the rules of series circuits predict the total voltage. Connect the two canisters in series with one another (indicate the correct way to connect the canisters: positive terminal $\rightarrow$ Cu wire; Zn nail (on same cell) $\rightarrow$ Cu wire (2nd cell); Zn nail (on 2nd cell) $\rightarrow$ negative terminal) and measure their total voltage. Repeat this procedure with three and then four in series. Place all information in Data Table 2.

DATA TABLE 2: Combination Voltage Readings

<table>
<thead>
<tr>
<th>Combination</th>
<th>Predicted Voltage</th>
<th>Measured Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Two in Series ( and )

Three in Series ( , and )

Four in Series

23. Place two D batteries in series. Knowing that each is about 1.5 V what would be the total voltage for two in series? ___________. Using the multi-meter determine the total voltage: ___________. (this should give a reading of about 3.1 V)

24. Connect the two D batteries to the screws on the base of the lamp holder. Does the light come on? (Yes)

Switch the leads on the lamp. Does the light come on? (Yes)

Using the combination of Film Canister Cells that produces the voltage closest to the two D batteries connect to the base of the other lamp holder. Does the light come on? (No)

Switch the leads on the lamp. Does the light come on? (No)

25. Using the combination of Film Canister Cells that produces a voltage between 1.7 V – 2.4 V (or the combination specified by the teacher) connect to the leads of an LED lamp. Does the light come on?

Switch the leads on the LED. Does the light come on?

(since the LED is a diode it will only work in one direction)

Optional: (If the students have their own calculators out have them put them away)

26. Unscrew and remove the back plate of an inexpensive calculator.
27. Remove battery from the calculator.

28. Solder, tape or clip wire leads to the positive and negative terminals of the battery holder. (Calculators that require an AAA or AA battery are easier to attach, but button battery powered calculators will also work – it just takes a little more time to make the connections and keep them in place. Remind students who are soldering (not recommended) the solder safety precautions:

- DO NOT touch the tip of the soldering iron.
- ALWAYS return the soldering iron to its stand when not in use.
- Work in a well-ventilated area.
- Wash your hands after soldering.

29. Connect your leads to two Film Canister Cells.

30. Turn on the calculator and perform the following calculations:

\[
476 \times 219 = (104,244) \quad 698/42 = (16.62)
\]

Questions:

6. Name the three main parts of a battery. Assign each of these parts to the components of the Film Canister Cell. (Electrolyte: vinegar; 2 Electrodes – nail (-) and copper wire (+); The nail (zinc) is the anode since this where oxidation occurs (loses e-). The copper wire is the cathode since this where reduction occurs (gains e-).

A chemical reaction occurs when two or more molecules interact and a chemical change occurs. All chemical reactions involve a change in energy. (Law of Conservation: matter or energy cannot be created or destroyed only changed).

This energy change allows for the conversion of chemical energy to electrical energy.

Metals differ in their tendency to give up electrons. This difference allows for an imbalance of charges and since opposite charges attract the electrons released from one metal will be attracted to the other metal. These metals are called electrodes. For the electron exchange between the two metals to begin and/or continue they must be placed in an electrolyte (a solution of ions). With copper and zinc electrodes, the zinc more readily loses electrons (e-) than the copper. Therefore, e- flow from the zinc to the copper electrode. For this example acetic acid (CH3COOH) is used as the electrolyte. An acid
has an easily detached hydrogen ion. Hydrogen ions are positive, and the remaining part of the acid (acetate) becomes negative when the hydrogen is removed (H+ and CH3COO- respectively). As the zinc electrode loses e-, positive zinc ions are produced. The acetate ions are more attracted to the zinc ions than the H+ and will pair up leaving the H+ to bond with the extra electrons on the copper electrode. Since the copper electrode has lost its extra e- to the H+ it can accept more from the zinc electrode. This continues the process until the zinc is used up and the battery is dead.

7. Why must the Film Canister Cells be placed in a series arrangement rather than a parallel arrangement? (In series circuits the voltage of each individual cell is added together for the total voltage of the circuit. In parallel the voltage remains the same regardless how many cells you connect together. Since the voltage needs to be increased to power the lights a series circuit is the only option.)

8. Why will the batteries light up the incandescent lamp but not the Film Canister Battery even though their voltages are similar?

(The Film Canister Battery only produces a very small amount of current due its internal resistance. The D batteries have less internal resistance and will allow more current to the bulb. Even with multiple canister cells, the amount of current flowing through the wire is not enough. Though the voltage is high enough (~2.5 volts with three cells), the current is too weak.

Connecting a bulb to a voltage source allows charges to flow from one contact to the other. The charges will also pass through the wires and filament of the bulb. As the charges move through the filament they are continuously bumping into the filament’s atoms (usually tungsten). These collisions cause the atoms to vibrate which releases energy in the form of heat. The bound electrons in the vibrating atoms are raised to a higher energy level temporarily. When they fall back to their original levels, the electrons release extra energy in the form of photons. Unfortunately, this process is not very efficient. Most incandescent bulbs allow only 10% of its energy to go to light the rest is lost as heat. This is why there is such a push for alternative light bulbs.)

9. What is an LED and why is it able to be lit by the Film Canister Battery? (Light Emitting Diode; a light source created by current moving through a semiconducting diode.

A diode is a very simple semiconducting device. A semiconductor is a material with a varying ability to conduct current. Usually semiconductors are created from a poor conductor that has had atoms of another material added to it. This process is called doping. As electrons move through the semiconductor they will drop from a higher orbital to a lower orbital. When this occurs energy is released as a photon (light particle). A larger drop in energy releases a higher-energy photon (higher frequency – can vary color of LED). All diodes release light, however most are not efficient since the semiconducting material will absorb a lot of the light energy. LEDs are made to release a large number of photons outward and in a particular direction. For more information about how LEDs and semiconductors work HowStuffWorks has good diagrams about these subjects.)
10. Why will the LED only light in one direction?

(This is due to the semiconducting nature of the diode.

Since extra atoms are used in doped materials (see question 4) free electrons (N-type; negative e- are attracted to + area) or holes (P-type; basically positively charged particles; since e- can jump from hole to hole the holes appear to move towards the negatively-charged area) where electrons can go are created. Either of these additions makes the material more electrically conductive.

A diode is composed of a N-type material attached to a portion of a P-type material, with electrodes on each end. This set up allows current in only one direction. When no potential difference is applied across the diode, e- from the N-type material fill holes from the P-type material along the junction between the layers, forming a depletion zone (becomes an insulator and charges cannot flow).

To remove the depletion zone, e- from the N-type area must move to the P-type area and the holes would then appear to move in the opposite direction. This is accomplished by connecting the N-type side to the negative end of a voltage source and the P-type side to the positive end. The free e- in the N-type material are attracted to the + electrode and repelled by the negative electrode. The holes in the P-type material move in the opposite direction. When the potential difference between the electrodes is large enough, the e- in the depletion zone move out of their holes and begin to move freely. The depletion zone disappears, and charge moves across the diode.

If the electrodes are switched so the P-type side is connected to the negative end and the N-type side is connected to the positive end, current will not flow. This is due to the e- in the N-type material being attracted to the positive electrode and the positive holes in the P-type material being attracted to the negative electrode. No current moves across the diode because the holes and the e- are moving in the wrong direction and the depletion zone increases.

For more information about how LEDs and semiconductors work HowStuffWorks has good diagrams about these subjects.)
Changing Chemical Energy into Electrical Energy: The Lemon Battery

Name: ____________________________ Date: _______________ Period: ____

Objective:
To create an electrochemical battery that produces enough voltage and current to light a LED.

Materials:
- 4 lemons
- 4 pre-1982 pennies
- 4 galvanized nails
- 7 connecting wires with alligator clips
- multi-meter
- 2 incandescent lamps in holders
- 1 LED light
- 2 D batteries with holder
- marker
knife/razor blade

Optional: nickel, dime, and/or quarter (post-1965; before this time they were mainly composed of silver now they are made of copper alloys)

Procedure and Observations:

1. Using the marker label each lemon as A, B, C, and D.

2. Puncture on one side of each lemon with the galvanized nails.

3. With the knife/razor blade make a small incision (large enough to fit a penny) on the other side of each lemon and insert the pennies.

4. Using the multi-meter (set to the voltage reading specified by your teacher) and the connecting wires measure the voltage of each one of your lemon batteries. Place your measurements in Data Table 1.

If the multi-meter displays a negative voltage then the positive and negative connections are switched. Noting this, which part of your Lemon Battery Cell (the galvanized nail or the copper coin) is the positive electrode and which is the negative electrode? What does this mean in terms of electron movement?

DATA TABLE 1: Individual Voltage Readings

<table>
<thead>
<tr>
<th>LEMON</th>
<th>VOLTAGE READING (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>
5. Choose two of the lemons and using the rules of series circuits predict the total voltage. Connect the two lemons in series with one another and measure their total voltage. Repeat this procedure with three and then four in series. Place all information in Data Table 2.

DATA TABLE 2: Combination Voltage Readings

<table>
<thead>
<tr>
<th>COMBINATION</th>
<th>PREDICTED VOLTAGE (V)</th>
<th>MEASURED VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two in Series (</td>
<td></td>
<td></td>
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<tr>
<td>and</td>
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<td></td>
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<tr>
<td>Three in Series (</td>
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<td>and</td>
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<td></td>
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<tr>
<td>Four in Series</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Place two D batteries in series. Knowing that each is about 1.5 V what would be the total voltage for two in series? ____________. Using the multi-meter determine the total voltage: ____________.

7. Connect the two D batteries to the screws on the base of the lamp holder. Does the light come on?

Switch the leads on the lamp. Does the light come on?

Using the combination of Lemon Battery Cells that produces the voltage closest to the two D batteries connect to the base of the other lamp holder. Does the light come on?
Switch the leads on the lamp. Does the light come on?

8. Using the combination of Lemon Battery Cells that produces a voltage between 1.7 V – 2.4 V (or the combination specified by the teacher) connect to the leads of an LED lamp. Does the light come on? Switch the leads on the LED. Does the light come on?

Extension:

1. Predict if the nail or the penny can be replaced by a nickel, dime, or quarter. Explain your prediction.

2. Remove the nail from one of your lemons. Using the knife/razor blade make an incision right above or below the puncture mark. The incision should be large enough to fit a quarter.

3. Place one of the coins (nickel, dime or quarter) in this incision. Connect this coin to the negative terminal and the penny to the positive terminal of the multi-meter. Record your data in Data Table 3.

4. Repeat procedure 2 with the other two coins and record your data in Data Table 3.

5. Remove the coins from the lemon. Replace the nail into the lemon. In the penny’s location place one of the other coins (nickel, dime or quarter). Connect the nail to the negative terminal and the coin to the positive terminal of the multi-meter. Record your data in Data Table 4.

6. Repeat procedure 2 with the other two coins and record your data in Data Table 3.

DATA TABLE 3: Voltage Readings with Replacement of Galvanized Nail with Coins
<table>
<thead>
<tr>
<th>COIN TYPE</th>
<th>VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td></td>
</tr>
<tr>
<td>Dime</td>
<td></td>
</tr>
<tr>
<td>Quarter</td>
<td></td>
</tr>
</tbody>
</table>

DATA TABLE 4: Voltage Readings with Replacement of Penny with other Coins

<table>
<thead>
<tr>
<th>COIN TYPE</th>
<th>VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td></td>
</tr>
<tr>
<td>Dime</td>
<td></td>
</tr>
<tr>
<td>Quarter</td>
<td></td>
</tr>
</tbody>
</table>

7. Based on your results what can you conclude about the composition of the nickel, dime and quarter? Support your answer.

Questions:
1. Name the three main parts of a battery. Assign each of these parts to the components of the Lemon Battery Cell.

2. Why must the Lemon Battery Cells be placed in a series arrangement rather than a parallel arrangement?

3. Why will the batteries light up the incandescent lamp but not the Lemon Battery even though their voltages are similar?

4. What is an LED and why is it able to be lit by the Lemon Battery?

5. Why will the LED only light in one direction?
C. Changing Chemical Energy into Electrical Energy: The Lemon Battery

Objective:
To create an electrochemical battery that produces enough voltage and current to light a LED.

Materials:
- 4 lemons (limes may be used instead; other citrus fruit can be used but usually are less acidic and will produce a smaller voltage)
- 4 pre-1982 pennies (these pennies are almost 100% Copper and work better than the post-1982 pennies; if post-1982 pennies must be used more lemon cells may be needed; copper wire (10-14 gauge is another alternative)
- 4 galvanized nails (this means they are zinc coated; they are easily found at building supply or hardware stores)
- 7 connecting wires with alligator clips (pieces of thin copper or insulated wire can be used instead)
- multi-meter (or voltmeter)
- 2 incandescent lamps in holders (2.5 V – 3.5 V are recommended)
- 1 LED light (clear bulbs with red or pink glow are usually the easiest to detect; Recommended: 5mm Red LED (clear-color lens; typical voltage 1.7 V, with a max voltage of 2.4 V; 20 mA max); these can be purchased through an electronics store or on-line)

-2 D batteries with holder (2 series battery holders are recommended or the batteries will need to be connected in series with wire; battery holders can be purchased at a electronics store or on-line)

(marker)

-knife/razor blade

-Optional: nickel, dime, and/or quarter (post-1965; before this time they were mainly composed of silver now they are made of copper alloys)

**Procedure and Observations:**

31. Using the marker label each lemon as A, B, C, and D.

32. Puncture on one side of each lemon with the galvanized nails. (See pictures below.)

33. With the knife/razor blade make a small incision (large enough to fit a penny) on the other side of each lemon and insert the pennies. (The teacher may want to assist the students with this task or prior to the lab already have made the incisions; See pictures below.)

34. Using the multi-meter (set to the voltage reading specified by your teacher) and the connecting wires measure the voltage of each one of your lemon batteries. Place your measurements in Data Table 1.

If the multi-meter displays a negative voltage then the positive and negative connections are switched. Noting this, which part of your Lemon Battery Cell (the galvanized nail or the copper coin) is the positive electrode and which is the negative electrode? What does this mean in terms of electron movement?

(galvanized nail = negative and copper = positive; With copper and zinc electrodes, the zinc more readily loses electrons (e-) than the copper. Therefore, e- flow from the zinc to the copper electrode.)

**DATA TABLE 1: Individual Voltage Readings**
(Each one should read 0.85 V to 1 V; if the students are getting very low or zero volt readings their electrodes may be touching one another or there is a problem with the wire connections)

35. Choose two of the lemons and using the rules of series circuits predict the total voltage. Connect the two lemons in series with one another (indicate the correct way to connect the lemons: positive terminal $\rightarrow$ Cu penny; Zn nail (on same cell) $\rightarrow$ Cu penny (2$^{nd}$ cell); Zn nail (on 2$^{nd}$ cell) $\rightarrow$ negative terminal) and measure their total voltage. Repeat this procedure with three and then four in series. Place all information in Data Table 2.

DATA TABLE 2: Combination Voltage Readings

<table>
<thead>
<tr>
<th>Combination</th>
<th>Predicted Voltage</th>
<th>Measured Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two in Series (       and       )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three in Series (     ,       and       )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four in Series</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

36. Place two D batteries in series. Knowing that each is about 1.5 V what would be the total voltage for two in series? ____________. Using the multi-meter determine the total voltage: ____________. (this should give a reading of about 3.1 V)
37. Connect the two D batteries to the screws on the base of the lamp holder. Does the light come on? (Yes)

Switch the leads on the lamp. Does the light come on? (Yes)

Using the combination of Lemon Battery Cells that produces the voltage closest to the two D batteries connect to the base of the other lamp holder. Does the light come on? (No)

Switch the leads on the lamp. Does the light come on? (No)

38. Using the combination of Lemon Battery Cells that produces a voltage between 1.7 V – 2.4 V (or the combination specified by the teacher) connect to the leads of an LED lamp. Does the light come on?

Switch the leads on the LED. Does the light come on?

(since the LED is a diode it will only work in one direction)

Extension:

8. Predict if the nail or the penny can be replaced by a nickel, dime, or quarter. Explain your prediction. (any appropriate hypothesis is acceptable – many students will probably answer that the coins could replace the nail due to color)

9. Remove the nail from one of your lemons. Using the knife/razor blade make an incision right above or below the puncture mark. The incision should be large enough to fit a quarter. (The incision making may need to be done by the teacher)

10. Place one of the coins (nickel, dime or quarter) in this incision. Connect this coin to the negative terminal and the penny to the positive terminal of the multi-meter. Record your data in Data Table 3. (the voltage reading should be very close to zero since the coins are mainly made from copper – just like the penny)

11. Repeat procedure 2 with the other two coins and record your data in Data Table 3. (similar results should occur)

12. Remove the coins from the lemon. Replace the nail into the lemon. In the penny’s location place one of the other coins (nickel, dime or quarter). Connect the nail to the negative
terminal and the coin to the positive terminal of the multi-meter. Record your data in Data Table 4. *(the voltage reading should be very similar to that of the penny: 0.9 V – 1 V)*

13. Repeat procedure 2 with the other two coins and record your data in Data Table 3. *(similar results should occur)*

DATA TABLE 3: Voltage Readings with Replacement of Galvanized Nail with Coins

<table>
<thead>
<tr>
<th>COIN TYPE</th>
<th>VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td></td>
</tr>
<tr>
<td>Dime</td>
<td></td>
</tr>
<tr>
<td>Quarter</td>
<td></td>
</tr>
</tbody>
</table>

DATA TABLE 4: Voltage Readings with Replacement of Penny with other Coins

<table>
<thead>
<tr>
<th>COIN TYPE</th>
<th>VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td></td>
</tr>
<tr>
<td>Dime</td>
<td></td>
</tr>
<tr>
<td>Quarter</td>
<td></td>
</tr>
</tbody>
</table>
14. Based on your results what can you conclude about the composition of the nickel, dime and quarter? Support your answer.

The composition of the nickel, dime and quarter is similar to the penny’s make-up. If two electrodes are made of the same material then they would have the same reaction in the electrolyte and no potential difference would be detected.

The coins are made of a Cupro-nickel alloy. The nickel is 25% Ni and 75% Cu. Both the dime and quarter are 8.33% Ni and 91.77% Cu. So even though the coins appear to be more like the nail they are actually more like the penny.

Questions:

11. Name the three main parts of a battery. Assign each of these parts to the components of the Lemon Battery Cell. (Electrolyte: lemon juice \( \rightarrow \) citric acid; 2 Electrodes – nail (-) and copper coin (+); The nail (zinc) is the anode since this where oxidation occurs (loses e-). The copper coin is the cathode since this where reduction occurs (gains e-).

A chemical reaction occurs when two or more molecules interact and a chemical change occurs. All chemical reactions involve a change in energy. (Law of Conservation: matter or energy cannot be created or destroyed only changed).

This energy change allows for the conversion of chemical energy to electrical energy.

Metals differ in their tendency to give up electrons. This difference allows for an imbalance of charges and since opposite charges attract the electrons released from one metal will be attracted to the other metal. These metals are called electrodes. For the electron exchange between the two metals to begin and/or continue they must be placed in an electrolyte (a solution of ions). With copper and zinc electrodes, the zinc more readily loses electrons (e-) than the copper. Therefore, e- flow from the zinc to the copper electrode. For this example citric acid (\( C_6H_8O_7 \)) is used as the electrolyte. An acid has an easily detached hydrogen ion. Hydrogen ions are positive, and the remaining part of the acid (citrate) becomes negative when the hydrogen is removed. As the zinc electrode loses e-, positive zinc ions are produced. The acetate ions are more attracted to the zinc ions
than the H+ and will pair up leaving the H+ to bond with the extra electrons on the copper electrode. Since the copper electrode has lost its extra e- to the H+ it can accept more from the zinc electrode. This continues the process until the zinc is used up and the battery is dead.

12. Why must the Lemon Battery Cells be placed in a series arrangement rather than a parallel arrangement? (In series circuits the voltage of each individual cell is added together for the total voltage of the circuit. In parallel the voltage remains the same regardless how many cells you connect together. Since the voltage needs to be increased to power the lights a series circuit is the only option.)

13. Why will the batteries light up the incandescent lamp but not the Lemon Battery even though their voltages are similar?

(The Lemon Battery only produces a very small amount of current due its internal resistance. The D batteries have less internal resistance and will allow more current to the bulb. Even with multiple canister cells, the amount of current flowing through the wire is not enough. Though the voltage is high enough (~2.5 volts with three cells), the current is too weak.

Connecting a bulb to a voltage source allows charges to flow from one contact to the other. The charges will also pass through the wires and filament of the bulb. As the charges move through the filament they are continuously bumping into the filament’s atoms (usually tungsten). These collisions cause the atoms to vibrate which releases energy in the form of heat. The bound electrons in the vibrating atoms are raised to a higher energy level temporarily. When they fall back to their original levels, the electrons release extra energy in the form of photons. Unfortunately, this process is not very efficient. Most incandescent bulbs allow only 10% of its energy to go to light the rest is lost as heat. This is why there is such a push for alternative light bulbs.)

14. What is an LED and why is it able to be lit by the Lemon Battery? (Light Emitting Diode; a light source created by current moving through a semiconducting diode.

A diode is a very simple semiconducting device. A semiconductor is a material with a varying ability to conduct current. Usually semiconductors are created from a poor conductor that has had atoms of another material added to it. This process is called doping. As electrons move through the semiconductor they will drop from a higher orbital to a lower orbital. When this occurs energy is released as a photon (light particle). A larger drop in energy releases a higher-energy photon (higher frequency – can vary color of LED). All diodes release light, however most are not efficient since the semiconducting material will absorb a lot of the light energy. LEDs are made to release a large number of photons outward and in a particular direction. For more information about how LEDs and semiconductors work HowStuffWorks has good diagrams about these subjects.)

15. Why will the LED only light in one direction?

(This is due to the semiconducting nature of the diode.)
Since extra atoms are used in doped materials (see question 4) free electrons (N-type; negative e- are attracted to + area) or holes (P-type; basically positively charged particles; since e- can jump from hole to hole the holes appear to move towards the negatively-charged area) where electrons can go are created. Either of these additions makes the material more electrically conductive.

A diode is composed of an N-type material attached to a portion of a P-type material, with electrodes on each end. This set up allows current in only one direction. When no potential difference is applied across the diode, e- from the N-type material fill holes from the P-type material along the junction between the layers, forming a depletion zone (becomes an insulator and charges cannot flow).

To remove the depletion zone, e- from the N-type area must move to the P-type area and the holes would then appear to move in the opposite direction. This is accomplished by connecting the N-type side to the negative end of a voltage source and the P-type side to the positive end. The free e- in the N-type material are attracted to the + electrode and repelled by the negative electrode. The holes in the P-type material move in the opposite direction. When the potential difference between the electrodes is large enough, the e- in the depletion zone move out of their holes and begin to move freely. The depletion zone disappears, and charge moves across the diode.

If the electrodes are switched so the P-type side is connected to the negative end and the N-type side is connected to the positive end, current will not flow. This is due to the e- in the N-type material being attracted to the positive electrode and the positive holes in the P-type material being attracted to the negative electrode. No current moves across the diode because the holes and the e- are moving in the wrong direction and the depletion zone increases.

For more information about how LEDs and semiconductors work HowStuffWorks has good diagrams about these subjects.)
SAFETY:

- Never eat or drink anything in the laboratory.
- Always follow proper laboratory dress code.
- Always read all instructions before beginning the experiments.
- Never rewire or take apart any element within the circuit.
- Never short circuit the batteries.
- Unhook all circuit components when finish (or at the end of each period)
- Clean all appropriate materials
- Allow all equipment to cool before storing.

PART A: Creating an Electrochemical Cell

OBJECTIVE: To identify the main components of an electrochemical cell and the factors that affects its voltage.

MATERIALS:

- Multi-meter (with probes)
- Film canister (with top)
- An 8mm piece of copper wire (12-14 gauge)
- Two galvanized nails (steel nail with zinc coating)
- Distilled or purified water
- Lemon juice (from concentrate) or table salt
- A lemon (or other citrus fruit)
- Knife (suggested that the instructor be in charge of the knife or razor blade)
- A pre-1982 penny
- A post-1965 nickel, dime, or quarter
- Two alligator clip wires

### Parts of a Film Canister Electrochemical Cell

#### Procedure:

1. Take the film canister lid and one of the nails and poke two holes in the top as shown in Figure 1 (this may already have been done for you).

![Figure 1](image)

2. Fill the canister with the distilled or purified water about \( \frac{3}{4} \) the way full.

3. Place the lid on the canister and insert one of the nails in one of the holes and the copper wire in the other.

4. DESCRIBE the three main parts of an electrochemical cell. Assign each of these parts to the components of the Film Canister Cell.

5. PREDICT the voltage of your Film Canister Electrochemical Cell. _______ V
6. Set the multi-meter to your teacher’s instructions and attach the probes.

7. Attach one alligator clip end to the galvanized nail and the other to one of the multi-meter probes.

8. Attach the other alligator clip end to the copper wire and the other to the second multi-meter probe.

ANALYZE: If the multi-meter displays a negative voltage then the positive and negative connections are switched. Noting this, which part of your Film Canister Cell (the galvanized nail or the copper wire) is the positive electrode and which is the negative electrode? What does this mean in terms of electron movement?

9. COMPARE the multi-meter voltage reading (________ V) to your predicted reading. Explain any differences or similarities between the two voltages.

10. Unhook the alligator clips from the galvanized nail and copper wire. Remove lid and add 20 drops of lemon juice (or ~ 6 g salt). Replace top and gently shake container.

11. PREDICT if the voltage will change with the addition of the lemon juice. If so will it increase or decrease. Explain your prediction.

12. Connect the alligator clips back to the galvanized nail and copper wire.

13. COMPARE the multi-meter voltage reading (________ V) to your predicted reading. Explain any differences or similarities between the two voltages.
Parts of a Lemon Electrochemical Cell

14. Take the lemon and insert a galvanized nail in one top side of the lemon and with the knife make a small slit on the opposite side large enough for a penny. Insert penny.

15. Connect the alligator clips to the nail and penny and attach to the multi-meter. Record the voltage across the lemon in Data Table 1. REMEMBER if the multi-meter displays a negative voltage then the positive and negative connections are switched. Noting this, which part of the Lemon Cell (the galvanized nail or the penny) is the positive electrode and which is the negative electrode?

16. PREDICT if the nail or the penny can be replaced by a nickel, dime, or quarter. Explain your prediction.

17. Remove the nail from one of your lemons. Using the knife/razor blade make an incision right above or below the puncture mark. The incision should be large enough to fit a quarter.

18. Place one of the coins (nickel, dime or quarter) in this incision. Connect this coin to the negative terminal and the penny to the positive terminal of the multi-meter. RECORD your data in Data Table 1.

19. Remove the coin from the lemon. Replace the nail into the lemon. In the penny’s location place one of the other coins (nickel, dime or quarter). Connect the nail to the negative terminal and the coin to the positive terminal of the multi-meter. RECORD your data in Data Table 1.
DATA TABLE 1: Voltage Readings with Replacement of Galvanized Nail with Coins

<table>
<thead>
<tr>
<th>ELECTRODES</th>
<th>VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galvanized Nail and Penny</td>
<td></td>
</tr>
<tr>
<td>Nickel, Dime or Quarter and Penny</td>
<td></td>
</tr>
<tr>
<td>Galvanized Nail and Nickel, Dime or Quarter</td>
<td></td>
</tr>
</tbody>
</table>

20. Based on your results what can you conclude about the composition of the nickel, dime and quarter? Support your answer.

PART B: Changing Chemical Energy into Electrical Energy

OBJECTIVE: To create an electrochemical battery that produces enough voltage and current to light a LED.
MATERIALS:

- 4 film canisters
- white vinegar
- 4 pieces of copper wire (~8 cm)
- 4 galvanized nails
- 7 connecting wires with alligator clips
- multi-meter (or voltmeter)
- 2 incandescent lamps in holders
- 1 LED light
- 2 D batteries with holder
- masking tape
- marker/pen

PROCEDURE:

39. Using the galvanized nail poke holes in each of the film canister lids like in Part A: Figure 1. With the marker/pen and masking tape label each canister as A, B, C, and D. Carefully pour the vinegar into each of the film canisters (3/4 of the way full) and replace the caps.

40. Place the galvanized nails in one of the holes of the caps of each canister.

41. Place the copper wire in the other hole of each canister.

42. Using the multi-meter (set to the voltage reading specified by your teacher) and the connecting wires measure the voltage of each one of your film canister batteries. RECORD your measurements in Data Table 2.

DATA TABLE 2: Individual Voltage Readings

<table>
<thead>
<tr>
<th>Film Canister</th>
<th>Voltage Reading (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>
43. Choose two of the canisters and using the rules of series circuits predict the total voltage. Connect the two canisters in series with one another and measure their total voltage. Repeat this procedure with three and then four in series. RECORD your information in Data Table 3.

DATA TABLE 3: Combination Voltage Readings

<table>
<thead>
<tr>
<th>Combination</th>
<th>Predicted Voltage</th>
<th>Measured Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two in Series (    and    )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three in Series (  ,  and  )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four in Series</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

44. Place two D batteries in series. Knowing that each is about 1.5 V PREDICT the total voltage for two in series? __________. Using the multi-meter MEASURE the total voltage: _______V.

45. ANALYZE: Connect the two D batteries to the screws on the base of the lamp holder with the incandescent bulb. Does the light come on?

Switch the leads on the lamp. Does the light come on?

Using the combination of Film Canister Cells that produces the voltage closest to the two D batteries connect to the base of the other lamp holder. Does the light come on?
Switch the leads on the lamp. Does the light come on?

46. ANALYZE: Using the combination of Film Canister Cells that produces a voltage between 1.7 V – 2.4 V (or the combination specified by the teacher) connect to the leads of an LED lamp. Does the light come on?

Switch the leads on the LED. Does the light come on?

QUESTIONS:

16. Why must the Film Canister Cells be placed in a series arrangement rather than a parallel arrangement?

17. Why will the batteries light up the incandescent lamp but not the Film Canister Battery even though their voltages are similar?

18. What is an LED and why is it able to be lit by the Film Canister Battery? Why will the LED only light in one direction?

PART C: Resistors in Series and Parallel Circuits

OBJECTIVE: To demonstrate how resistance changes with series and parallel circuits.

MATERIALS:
- three resistors
- a multi-meter with probes
- six alligator clip wires

PROCEDURE:

1. RECORD the amount of resistance across each resistor (indicated by the label) and include the tolerance for each.

   DATA TABLE 4: Resistance from Labels

<table>
<thead>
<tr>
<th>RESISTOR</th>
<th>RESISTANCE (Ω)</th>
<th>TOLERANCE (%)</th>
</tr>
</thead>
</table>


2. MEASURE the amount of resistance across each resistor using the multi-meter.

   DATA TABLE 5: Resistance from the Multi-meter

<table>
<thead>
<tr>
<th>RESISTOR</th>
<th>RESISTANCE (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td></td>
</tr>
</tbody>
</table>

3. DRAW a schematic diagram for a series circuit including the three resistors. You can label your resistors as R1, R2 and R3.

4. What is the equation for calculating equivalent resistance in a series circuit? What happens to the equivalent resistance of a series circuit when additional resistors are added?

5. CALCULATE the total resistance for a series combination of your three resistors.
   a) Equivalent resistance (series – label readings) = _______________ Ω
   b) Equivalent resistance (series – multi-meter) = _______________ Ω

6. MEASURE the equivalent resistance for your three resistors in a series combination using the multi-meter.

   Equivalent resistance (series) = _______________ Ω

7. CALCULATE percent error. \( \% \text{ Error} = \left[ \left( \frac{|O - A|}{A} \right) \right] \times 100 \)

   O (observed) = values from 5 (a) and 5 (b)  \quad A (accepted) = value from 6

   a) Percent error (series – label readings 5(a)) = _______________%
b) Percent error (series- multi-meter 5 (b)) = ___________________%

8. Which reading gave you a smaller percent error? Why?

9. Draw a schematic diagram for a parallel circuit including the three resistors. You can label your resistors as R1, R2 and R3.

10. What is the equation for calculating equivalent resistance in a parallel circuit? What happens to the equivalent resistance of a parallel circuit when additional resistors are added?

11. CALCULATE the total resistance for a parallel combination of your three resistors.

   a) Equivalent resistance (parallel – label readings) = ________________ Ω

   b) Equivalent resistance (parallel – multimeter) = ________________ Ω

12. MEASURE the equivalent resistance for your three resistors in a parallel combination using the multi-meter.

    Equivalent resistance (parallel) = ________________ Ω

13. Calculate percent error. % Error = [(O - A)/A] x 100

    O (observed) = values from 11 a) and 11 b) A (accepted) = value from 12

    a) Percent error (parallel – label readings) = ___________________%

    b) Percent error (parallel- multi-meter) = ___________________%

14. Which reading gave you a smaller percent error? Why?

15. What are some possible error sources that you may have encountered?

PART D: Electrical Energy and Capacitance
OBJECTIVE: To construct a capacitor and to calculate its capacitance. To determine the relationship between the capacitance and the distance between the parallel plates.

MATERIALS:

- Aluminum foil
- Three Hardcover textbooks
- 2 leads with alligator clips
- Multi-meter
- Calipers
- Ruler

PROCEDURE:

1. Cut two pieces of aluminum foil so that they are slightly larger than the book you are using (this will be the plates of your capacitor). MEASURE the length and width of these foil sheets (they should be the same size). CALCULATE the area of your capacitor and record it in Data Table 6.

2. Make sure both pieces of foil are smooth and flat. Place one piece on top of page #201 in your book. Place the second piece on top of page #199. You now have one sheet of paper serving as a dielectric between the foil pieces.

3. Connect one lead to each foil piece. Connect the other end of the leads to the multi-meter. See Figure 3.

4. Place the two other books on top of the book containing the aluminum foil. Make sure that the foil is not touching the desk, the other piece of foil or any other object.

5. MEASURE and record the capacitance reading from the multi-meter in Data Table 7.

6. Repeat steps 2-5 for ten more trials with 2, 3, 4, 5, 10, 15, 20, 30, 40, and 50 sheets of paper of your textbook acting as the dielectric between the foil pieces.
7. Using the calipers **MEASURE** the total thickness of several hundred sheets of paper in your textbook (Remember each page has 2 page numbers). Record your answer in Data Table 6.

8. **RECORD** the total number of sheets you measured and calculate the thickness of one sheet of paper. Record your answers in Data Table 6.

9. **CALCULATE** the Capacitance using your information in Data Table 1 and your dielectric constant as $\kappa = 3.5$. Record your answers in Data Table 2. **Calculate** percent error.

**DATA TABLE 6: Capacitance Components**

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total thickness of all sheets</td>
<td></td>
</tr>
<tr>
<td>Total number of sheets measured</td>
<td></td>
</tr>
<tr>
<td>Thickness per sheet</td>
<td></td>
</tr>
<tr>
<td>Area of Capacitor</td>
<td></td>
</tr>
</tbody>
</table>

**DATA TABLE 7: Capacitance Measurements**

<table>
<thead>
<tr>
<th>TRIAL</th>
<th>NUMBER OF SHEETS</th>
<th>CAPACITANCE MEASURED (F) (OBSERVED)</th>
<th>CAPACITANCE CALCULATED (F) (ACTUAL)</th>
<th>PERCENT ERROR</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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</tbody>
</table>
• Plot capacitance (y-axis) versus the number of sheets of paper (x-axis) on the graph on the following page. Draw the best-fit line through your data points.

PROBLEMS:

1. Using your graph and data describe the relationship between the capacitance and plate separation. Is the relationship a 1/d, 1/d², or 1/d³ relationship? How are you able to tell from your graph or data?
2. Calculate $\varepsilon$ (permittivity constant) if $C = 1.51 \times 10^{-5}$ F, $\kappa = 3.5$, $A = 0.061$ m$^2$ and $d = 1.01 \times 10^{-4}$ m.

3. Why is a 1 F capacitor potentially dangerous?

4. Why do people say not to open a TV set even though you just turned it off?
TEACHER’S GUIDE TO LAB PRACTICUM:
ELECTRICAL ENERGY, CURRENT AND CIRCUITS

Name: _____________________________ Group Number: _____ Date: _____________ Period: ______

SAFETY:

• Never eat or drink anything in the laboratory.
• Always follow proper laboratory dress code.
• Always read all instructions before beginning the experiments.
• Never rewire or take apart any element within the circuit.
• Never short circuit the batteries.
• Unhook all circuit components when finish (or at the end of each period)
• Clean all appropriate materials
• Allow all equipment to cool before storing.

PART A: Creating an Electrochemical Cell

OBJECTIVE: To identify the main components of an electrochemical cell and the factors that affects its voltage.

MATERIALS:

• Multi-meter (with probes) (or Voltmeter)
• Film canister (with top) (many photo labs will give you their empty film canister – the problem now is that most people have a digital camera and do not use film; film canisters can be ordered from Educational Innovations (www.teachersource.com) for $12.95 (~40 count) or $49.95 (~200 count))
• An 8mm piece of copper wire (12-14 gauge) (12-14 gauge wire works best since it sturdy but still malleable enough to work with. Copper can be ordered on-line but it usually
comes in large and expensive rolls. A building supply store allows for a portion of the wire to be cut from the roll (7½ ft is enough for 28 pieces (~8 cm)). It is suggested that the teacher cut the wire prior to the lab)

- Two galvanized nails (this means they are zinc coated; they are easily found at building supply or hardware stores)
- Distilled or purified water
- Lemon juice (from concentrate) or table salt (salt is cheaper but lemon juice is easier to use and dissolve and gives a more dramatic result)
- A lemon (or other citrus fruit)
- Knife (suggested that the instructor be in charge of the knife or razor blade)
  A pre-1982 penny (these pennies are almost 100% Copper and work better than the post-1982 pennies; if post-1982 pennies must be used more lemon cells may be needed; copper wire (10-14 gauge is another alternative)
- A post-1965 nickel, dime, or quarter
  Two alligator clip wires (pieces of thin copper or insulated wire can be used instead)

Parts of a Film Canister Electrochemical Cell

Procedure:

21. Take the film canister lid and one of the nails and poke two holes in the top as shown in Figure 1 (this may already have been done for you).

   (It is suggested that the teacher pre-punch all the lids for Safety and Time Concerns)

22. Fill the canister with the distilled or purified water about ¾ the way full.

23. Place the lid on the canister and insert one of the nails in one of the holes and the copper wire in the other.

24. DESCRIBE the three main parts of an electrochemical cell. Assign each of these parts to the components of the Film Canister Cell.

The Main Parts of an Electrochemical Cell are: two electrodes (the nail and copper wire) in an electrolyte (vinegar) solution. An electrode is an electric conductor which current will enter or leave the electrolytic cell. The electrodes will need to of different materials and follow redox reactions so one is reduced and the other oxidized. An electrolyte is a
dissolved compound that has broken into ions (anions and cations). When an electric field across the electrolyte the anions and cations move in opposite directions and current is conducted.

25. PREDICT the voltage of your Film Canister Electrochemical Cell. _______ V
   Answers will vary

26. Set the multi-meter to your teacher’s instructions (the voltage should be between 0.25 – 0.6 V and the meter should be set accordingly) and attach the probes.

27. Attach one alligator clip end to the galvanized nail and the other to one of the multi-meter probes.

28. Attach the other alligator clip end to the copper wire and the other to the second multi-meter probe.

ANALYZE: If the multi-meter displays a negative voltage then the positive and negative connections are switched. Noting this, which part of your Film Canister Cell (the galvanized nail or the copper wire) is the positive electrode and which is the negative electrode? What does this mean in terms of electron movement?

(The galvanized nail = negative and copper = positive; With copper and zinc electrodes, the zinc more readily loses electrons (e-) than the copper. Therefore, electrons flow from the zinc to the copper electrode.)

29. COMPARE the multi-meter voltage reading (_______ V) to your predicted reading. Explain any differences or similarities between the two voltages.
   Answers will vary but the students should reasonably explain any differences. For example: The student may predict a lower voltage than the reading thinking that there would be no reaction.

30. Unhook the alligator clips from the galvanized nail and copper wire. Remove lid and add 20 drops of lemon juice (or ~ 6 g salt). Replace top and gently shake container.

31. PREDICT if the voltage will change with the addition of the lemon juice. If so will it increase or decrease. Explain your prediction. The students should have a basic
knowledge of electrolytes and know that lemon juice is acidic and will break easily into ions. Therefore the voltage should rise.

(Electrolyte: water and lemon juice; 2 Electrodes – nail (-) and copper wire (+); The nail (zinc) is the anode since this where oxidation occurs (loses e-). The copper wire is the cathode since this where reduction occurs (gains e-).

A chemical reaction occurs when two or more molecules interact and a chemical change occurs. All chemical reactions involve a change in energy. (Law of Conservation: matter or energy cannot be created or destroyed only changed).

This energy change allows for the conversion of chemical energy to electrical energy.

Metals differ in their tendency to give up electrons. This difference allows for an imbalance of charges and since opposite charges attract the electrons released from one metal will be attracted to the other metal. These metals are called electrodes. For the electron exchange between the two metals to begin and/or continue they must be placed in an electrolyte (a solution of ions). With copper and zinc electrodes, the zinc more readily loses electrons (e-) than the copper. Therefore, electrons flow from the zinc to the copper electrode. For this example acetic acid (\(\text{CH}_3\text{COOH}\)) is used as the electrolyte. An acid has an easily detached hydrogen ion. Hydrogen ions are positive, and the remaining part of the acid (acetate) becomes negative when the hydrogen is removed (H+ and \(\text{CH}_3\text{COO}^-\) respectively). As the zinc electrode loses e-, positive zinc ions are produced. The acetate ions are more attracted to the zinc ions than the H+ and will pair up leaving the H+ to bond with the extra electrons on the copper electrode. Since the copper electrode has lost its extra e- to the H+ it can accept more from the zinc electrode. This continues the process until the zinc is used up and the battery is dead.

32. Connect the alligator clips back to the galvanized nail and copper wire.

33. **COMPARE** the multi-meter voltage reading (_______ V) to your predicted reading. Explain any differences or similarities between the two voltages.

(The voltage should read between 0.85 V to 1 V; if the students are getting very low or zero volt readings their electrodes may be touching one another or there is a problem with the wire connections)

**Parts of a Lemon Electrochemical Cell**
34. Take the lemon and insert a galvanized nail in one top side of the lemon and with the knife make a small slit on the opposite side large enough for a penny. Insert penny.

(It is suggested that the teacher slice all the lemons for Safety and Time Concerns)

35. Connect the alligator clips to the nail and penny and attach to the multi-meter. Record the voltage across the lemon in Data Table 1. REMEMBER if the multi-meter displays a negative voltage then the positive and negative connections are switched. Noting this, which part of the Lemon Cell (the galvanized nail or the penny) is the positive electrode and which is the negative electrode?

(The galvanized nail = negative and copper penny = positive. With copper and zinc electrodes, the zinc more readily loses electrons (e-) than the copper. Therefore, electrons flow from the zinc to the copper electrode.)

36. PREDICT if the nail or the penny can be replaced by a nickel, dime, or quarter. Explain your prediction.

(Any appropriate hypothesis is acceptable – many students will probably answer that the coins could replace the nail due to similar color)

37. Remove the nail from one of your lemons. Using the knife/razor blade make an incision right above or below the puncture mark. The incision should be large enough to fit a quarter. (The incision making may need to be done by the teacher)

38. Place one of the coins (nickel, dime or quarter) in this incision. Connect this coin to the negative terminal and the penny to the positive terminal of the multi-meter. RECORD your data in Data Table 1. (The voltage reading should be very close to zero since the coins are mainly made from copper – just like the penny)

39. Remove the coin from the lemon. Replace the nail into the lemon. In the penny’s location place one of the other coins (nickel, dime or quarter). Connect the nail to the...
negative terminal and the coin to the positive terminal of the multi-meter. RECORD your data in Data Table 1.
(The voltage reading should be very similar to that of the penny: 0.85 V – 1 V)

DATA TABLE 1: Voltage Readings with Replacement of Galvanized Nail with Coins

<table>
<thead>
<tr>
<th>ELECTRODES</th>
<th>VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galvanized Nail and Penny</td>
<td></td>
</tr>
<tr>
<td>Nickel, Dime or Quarter and Penny</td>
<td></td>
</tr>
<tr>
<td>Galvanized Nail and Nickel, Dime or Quarter</td>
<td></td>
</tr>
</tbody>
</table>

40. Based on your results what can you conclude about the composition of the nickel, dime and quarter? Support your answer.

The composition of the nickel, dime and quarter is similar to the penny’s make-up. If two electrodes are made of the same material then they would have the same reaction in the electrolyte and no potential difference would be detected.

The coins are made of a Cupro-nickel alloy. The nickel is 25% Ni and 75% Cu. Both the dime and quarter are 8.33% Ni and 91.77% Cu. So even though the coins appear to be more like the nail they are actually more like the penny.

PART B: Changing Chemical Energy into Electrical Energy

OBJECTIVE: To create an electrochemical battery that produces enough voltage and current to light a LED.
MATERIALS:

- 4 film canisters (many photo labs will give you their empty film canister – the problem now is that most people have a digital camera and do not use film; film canisters can be ordered from Educational Innovations (www.teachersource.com) for $12.95 (~40 count) or $49.95 (~200 count))
- white vinegar (4-5% acetic acid; lemon-lime soda or lemon juice works as well)
- 4 pieces of copper wire (~8 cm) (10-14 gauge wire works best since it sturdy but still malleable enough to work with. Copper can be ordered on-line but it usually comes in large and expensive rolls. A building supply store allows for a portion of the wire to be cut from the roll (7½ ft is enough for 28 pieces (~8 cm)). It is suggested that the teacher cut the wire prior to the lab)
- 4 galvanized nails (this means they are zinc coated; they are easily found at building supply or hardware stores)
- 7 connecting wires with alligator clips (pieces of thin copper or insulated wire can be used instead)
- multi-meter (or voltmeter)
- 2 incandescent lamps in holders (2.5 V – 3.5 V are recommended)
- 1 LED light (clear bulbs with red or pink glow are usually the easiest to detect; Recommended: 5mm Red LED (clear-color lens; typical voltage 1.7 V, with a max voltage of 2.4 V; 20 mA max); these can be purchased through an electronics store or on-line)
- 2 D batteries with holder (2 series battery holders are recommended or the batteries will need to be connected in series with wire; battery holders can be purchased at a electronics store or on-line)
- masking tape
- marker/pen

PROCEDURE:

47. Using the galvanized nail poke holes in each of the film canister lids like in Part A: Figure 1. (It is suggested that the teacher pre-punch the lids for safety and time concerns) With the marker/pen and masking tape label each canister as A, B, C, and D. Carefully pour the vinegar into each of the film canisters (3/4 of the way full) and replace the caps.

48. Place the galvanized nails in one of the holes of the caps of each canister.

49. Place the copper wire in the other hole of each canister.

50. Using the multi-meter (set to the voltage reading specified by your teacher) and the connecting wires measure the voltage of each one of your film canister batteries. RECORD your measurements in Data Table 2.

DATA TABLE 2: Individual Voltage Readings
51. Choose two of the canisters and using the rules of series circuits predict the total voltage. Connect the two canisters in series with one another and measure their total voltage. Repeat this procedure with three and then four in series. RECORD your information in Data Table 3.

(Indicate the correct way to connect the canisters: positive terminal → Cu wire; Zn nail (on same cell) → Cu wire (2nd cell); Zn nail (on 2nd cell) → negative terminal)

**DATA TABLE 3: Combination Voltage Readings**

<table>
<thead>
<tr>
<th>Combination</th>
<th>Predicted Voltage</th>
<th>Measured Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two in Series (       and       )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three in Series (     ,         and        )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four in Series</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Each one should read 0.85 V to 1 V; if the students are getting very low or zero volt readings their electrodes may be touching one another or there is a problem with the wire connections)
52. Place two D batteries in series. Knowing that each is about 1.5 V PREDICT the total voltage for two in series? ___________. Using the multi-meter MEASURE the total voltage: _________V. Since voltage adds in series circuits the students should predict a voltage around 3 V. They will probably measure slightly lower/higher due to the difference in emf (open circuit terminal voltage and the multi-meter requires very little current) and terminal voltage (voltage of a battery within a closed circuit with a load).

53. ANALYZE: Connect the two D batteries to the screws on the base of the lamp holder with the incandescent bulb. Does the light come on? (YES)

Switch the leads on the lamp. Does the light come on? (YES)

Using the combination of Film Canister Cells that produces the voltage closest to the two D batteries connect to the base of the other lamp holder. Does the light come on? (NO)

Switch the leads on the lamp. Does the light come on? (NO)

54. ANALYZE: Using the combination of Film Canister Cells that produces a voltage between 1.7 V – 2.4 V (or the combination specified by the teacher) connect to the leads of an LED lamp. Does the light come on? (YES/NO)

Switch the leads on the LED. Does the light come on? (YES/NO)

(Since the LED is a diode it will only work in one direction.)

QUESTIONS:
19. Why must the Film Canister Cells be placed in a series arrangement rather than a parallel arrangement?

(In series circuits the voltage of each individual cell is added together for the total voltage of the circuit. In parallel the voltage remains the same regardless how many cells you connect together. Since the voltage needs to be increased to power the lights a series circuit is the only option.)

20. Why will the batteries light up the incandescent lamp but not the Film Canister Battery even though their voltages are similar?

(The Film Canister Battery only produces a very small amount of current due its internal resistance. The D batteries have less internal resistance and will allow more current to the bulb. Even with multiple canister cells, the amount of current flowing through the wire is not enough. Though the voltage is high enough (~2.5 volts with three cells), the current is too weak.

Connecting a bulb to a voltage source allows charges to flow from one contact to the other. The charges will also pass through the wires and filament of the bulb. As the charges move through the filament they are continuously bumping into the filament’s atoms (usually tungsten). These collisions cause the atoms to vibrate which releases energy in the form of heat. The bound electrons in the vibrating atoms are raised to a higher energy level temporarily. When they fall back to their original levels, the electrons release extra energy in the form of photons. Unfortunately, this process is not very efficient. Most incandescent bulbs allow only 10% of its energy to go to light the rest is lost as heat. This is why there is such a push for alternative light bulbs.)

21. What is an LED and why is it able to be lit by the Film Canister Battery? Why will the LED only light in one direction?

(Light Emitting Diode; a light source created by current moving through a semiconducting diode.

A diode is a very simple semiconducting device. A semiconductor is a material with a varying ability to conduct current. Usually semiconductors are created from a poor conductor that has had atoms of another material added to it. This process is called doping. As electrons move through the semiconductor they will drop from a higher orbital to a lower orbital. When this occurs energy is released as a photon (light particle). A larger drop in energy releases a higher-energy photon (higher frequency – can vary color of LED). All diodes release light, however most are not efficient since the semiconducting material will absorb a lot of the light energy. LEDs are made to release a large number of photons outward and in a particular direction.

(This is due to the semiconducting nature of the diode.)
Since extra atoms are used in doped materials (see question 4) free electrons (N-type; negative e- are attracted to + area) or holes (P-type; basically positively charged particles; since e- can jump from hole to hole the holes appear to move towards the negatively-charged area) where electrons can go are created. Either of these additions makes the material more electrically conductive.

A diode is composed of an N-type material attached to a portion of a P-type material, with electrodes on each end. This set up allows current in only one direction. When no potential difference is applied across the diode, e- from the N-type material fill holes from the P-type material along the junction between the layers, forming a depletion zone (becomes an insulator and charges cannot flow).

To remove the depletion zone, e- from the N-type area must move to the P-type area and the holes would then appear to move in the opposite direction. This is accomplished by connecting the N-type side to the negative end of a voltage source and the P-type side to the positive end. The free e- in the N-type material are attracted to the + electrode and repelled by the negative electrode. The holes in the P-type material move in the opposite direction. When the potential difference between the electrodes is large enough, the e- in the depletion zone move out of their holes and begins to move freely. The depletion zone disappears, and charge moves across the diode.

If the electrodes are switched so the P-type side is connected to the negative end and the N-type side is connected to the positive end, current will not flow. This is due to the e- in the N-type material being attracted to the positive electrode and the positive holes in the P-type material being attracted to the negative electrode. No current moves across the diode because the holes and the e- are moving in the wrong direction and the depletion zone increases.

For more information about how LEDs and semiconductors work HowStuffWorks has good diagrams about these subjects.)

PART C: Resistors in Series and Parallel Circuits

OBJECTIVE: To demonstrate how resistance changes with series and parallel circuits.

MATERIALS:

• Three resistors (I prefer the large block capacitors since the resistance and tolerance is printed on them; the banded resistors work fine but the students will have to be instructed how to read them. It is also suggested not to use any with too high or two low of a resistance (there tends to be more percent error). I usually use 3 Ω - 50Ω.

• Multi-meter with probes

• 6 alligator clip wires

PROCEDURE:
16. RECORD the amount of resistance across each resistor (indicated by the label) and include the tolerance for each.

**DATA TABLE 4: Resistance from Labels**

<table>
<thead>
<tr>
<th>RESISTOR</th>
<th>RESISTANCE (Ω)</th>
<th>TOLERANCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td></td>
<td></td>
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<tr>
<td>R2</td>
<td></td>
<td></td>
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<tr>
<td>R3</td>
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</tbody>
</table>

17. MEASURE the amount of resistance across each resistor using the multi-meter.

**DATA TABLE 5: Resistance from the Multi-meter**

<table>
<thead>
<tr>
<th>RESISTOR</th>
<th>RESISTANCE (Ω)</th>
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<tbody>
<tr>
<td>R1</td>
<td></td>
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<tr>
<td>R2</td>
<td></td>
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<tr>
<td>R3</td>
<td></td>
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</tbody>
</table>

18. DRAW a schematic diagram for a series circuit including the three resistors. You can label your resistors as R1, R2 and R3.

![Schematic Diagram](image)

19. What is the equation for calculating equivalent resistance in a series circuit? What happens to the equivalent resistance of a series circuit when additional resistors are added?

\[ R_1 + R_2 + R_3 = R_{eq} \]

20. CALCULATE the total resistance for a series combination of your three resistors.

a) Equivalent resistance (series – label readings) = __________ Ω

b) Equivalent resistance (series – multi-meter) = __________ Ω
21. MEASURE the equivalent resistance for your three resistors in a series combination using the multi-meter.

Equivalent resistance (series) = _________________ Ω

22. CALCULATE percent error. % Error = \[ \frac{|O - A|}{A} \times 100 \]

O (observed) = values from 5 (a) and 5 (b) \quad A (accepted) = value from 6

a) Percent error (series – label readings 5(a)) = _________________ %

b) Percent error (series- multi-meter 5 (b)) = _________________ %

23. Which reading gave you a smaller percent error? Why?

24. Draw a schematic diagram for a parallel circuit including the three resistors. You can label your resistors as R1, R2 and R3.

(Diagram can vary)

25. What is the equation for calculating equivalent resistance in a parallel circuit? What happens to the equivalent resistance of a parallel circuit when additional resistors are added?

\[ \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{R_{eq}} \quad \text{OR} \quad R_{eq} = (R_1 + R_2 + R_3)^{-1} \]

26. CALCULATE the total resistance for a parallel combination of your three resistors.

a) Equivalent resistance (parallel – label readings) = _________________ Ω

b) Equivalent resistance (parallel – multi-meter) = _________________ Ω
27. MEASURE the equivalent resistance for your three resistors in a parallel combination using the multi-meter.

Equivalent resistance (parallel) = _________________ Ω

28. Calculate percent error.  

\[ \% \text{ Error} = \left( \frac{|O - A|}{A} \right) \times 100 \]

\( O \) (observed) = values from 11 a) and 11 b)  
\( A \) (accepted) = value from 12

a) Percent error (parallel – label readings) = ___________________%

b) Percent error (parallel- multi-meter) = ___________________%

29. Which reading gave you a smaller percent error?  Why?

30. What are some possible error sources that you may have encountered?

Connection error; tolerance; calculation error

Due to the equation the parallel readings tend to give a higher percent error.

PART D: Electrical Energy and Capacitance

OBJECTIVE: To construct a capacitor and to calculate its capacitance. Determine the relationship between the capacitance and the distance between the parallel plates.

MATERIALS:

• Aluminum foil (the heavy duty foil is recommended)
• Copper wire (this may be optional but most multi-meters require leads from the +/- voltage source area)
• Three Hardcover textbooks (one to act as the capacitor and the other two for weight; the students can press down on the book but this can tend to vary the readings if pressure is not consistent)
• 2 leads with alligator clips
• Multi-meter (must read capacitance)
• Calipers (optional- students can measure thickness with ruler)
• Ruler

PROCEDURE:
10. Cut two pieces of aluminum foil so that they are slightly larger than the book you are using (this will be the plates of your capacitor). MEASURE the length and width of these foil sheets (they should be the same size. CALCULATE the area of your capacitor and record it in Data Table 6.

11. Make sure both pieces of foil are smooth and flat. Place one piece on top of a page in your book, place ten pages on top of this foil and then place your second sheet of foil. You now have ten sheets of paper serving as a dielectric between the foil pieces.

12. Connect one lead to each foil piece. Connect the other end of the leads to the multi-meter. See Figure 3.

13. Place the two other books on top of the book containing the aluminum foil. Make sure that the foil is not touching the desk, the other piece of foil or any other object.

14. MEASURE and record the capacitance reading from the multi-meter in Data Table 7. (If the students have a difficult time getting a reading they should check to make sure the foil and leads are not touching anything. Another problem could be the voltage source so they should check that the copper wires are inserted properly. Also, more weigh may need to be added)

15. Repeat steps 2-5 for ten more trials with 20, 30, 40, 50, 60, 70, 80, 90, and 100 sheets of paper of your textbook acting as the dielectric between the foil pieces.

16. Using the calipers MEASURE the total thickness of several hundred sheets of paper in your textbook (Remember each page has 2 page numbers). Record your answer in Data Table 6.

17. RECORD the total number of sheets you measured and calculate the thickness of one sheet of paper. Record your answers in Data Table 6.

DATA TABLE 6: Capacitance Components

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total thickness of all sheets</td>
<td>If the students measure in centimeters they must convert to meters.</td>
</tr>
<tr>
<td>Total number of sheets measured</td>
<td></td>
</tr>
<tr>
<td>Thickness per sheet</td>
<td>Units should be in meters.</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Area of Capacitor</td>
<td>Units should be in square meters.</td>
</tr>
</tbody>
</table>

**DATA TABLE 7: Capacitance Measurements**

<table>
<thead>
<tr>
<th>TRIAL</th>
<th>NUMBER OF SHEETS BETWEEN PARALLEL PLATES</th>
<th>MEASURED CAPACITANCE (FARADS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td></td>
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<tr>
<td>2</td>
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<td>7</td>
<td>70</td>
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<td>8</td>
<td>80</td>
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<td>9</td>
<td>90</td>
<td></td>
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<tr>
<td>10</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
18. **CALCULATE** the dielectric constant using your information in Data Table 6 and one of the measured capacitance trials (choose one trial and repeat three times to obtain an average) in Data Table 7. Show your work in the space provided.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Number of Sheets</th>
<th>Measured Capacitance (Farads)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
<td></td>
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<tr>
<td>3</td>
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</tr>
</tbody>
</table>

Averaged Capacitance: 

_________________ F

Calculation:

Capacitance for paper varies from 1.5 to 4. It is recommended that data is collected from all groups and a class average is determined.

- Plot capacitance (y-axis) versus the number of sheets of paper (x-axis) on the graph on the following page. **Draw** the best-fit line through your data points.
Remind the students to label the x- and y-axis. It is recommended that the students put all their values in the same exponents to help them plot the data. They should plot an inverse relationship graph.

PROBLEMS:

5. Using your graph and data describe the relationship between the capacitance and plate separation. Is the relationship a $1/d$, $1/d^2$, or $1/d^3$ relationship? How are you able to tell from your graph or data?

According to the parallel plate capacitance equation ($C = \kappa \varepsilon_0 A/d$) the students should discover an $1/d$ relationship.
6. Calculate $\varepsilon$ (permittivity constant) if $C = 1.51 \times 10^{-8} \text{ F}$, $\kappa = 3.0$, $A = 0.061 \text{ m}^2$ and $d = 1.01 \times 10^{-4} \text{ m}$.

$$\varepsilon = \frac{Cd}{\kappa A} \Rightarrow \left(\frac{(1.51 \times 10^{-8} \text{ F})(1.01 \times 10^{-4} \text{ m})}{(3.0)(0.061 \text{ m}^2)}\right) = 8.33 \times 10^{-12} \text{ F/m}$$

(Permittivity of free space is $8.85 \times 10^{-12} \text{ F/m}$)

7. Why is a 1 F capacitor potentially dangerous?

1 F stores a lot of charge. Most capacitors are in the mF–pF range.

8. Why do people say not to open a TV set even though you just turned it off?

The TV has a large capacitor with a large amount of stored charge. Touching the capacitor could allow it to discharge.
Documentation of Resources: