Activity 1  Batteries

GOALS
In this activity you will:
• Make observations about commercial batteries.
• Make an electrochemical cell.
• Understand the chemistry of an electrochemical cell.
• Use an electrochemical cell to power a toy.

What Do You Think?
Many toys use batteries. You pop these small metal containers into a toy and it “comes to life.”

• What is a battery and how does it work?
The What Do You Think? question is provided to get you engaged in the activity. It is meant to grab your attention. It is also used to find out what you already know or think you know. Don’t worry about being right or wrong. Discussing what you think you know is an important step in learning.

Record your ideas about this question in your Active Chemistry log. Be prepared to discuss your responses with your small group and the class.

Investigate
Part A: Commercial Batteries
1. There are many different batteries available commercially. Your teacher will provide you with some examples.

a) List all the types of batteries that you can think of (AA, C, D, etc.). Record your observations of the physical properties of the batteries such as size, shape, markings, etc.
Part B: Electrochemical Cells

1. In this part of the activity you will make an electrochemical cell (a battery) that produces the greatest voltage. An electrochemical cell is prepared by immersing different metals in a solution of its ions. (An ion is a charged atom or group of atoms.) A porous cup makes it possible for ions to flow between solutions. The porous cup permits the flow of dissolved ions, but prevents too much mixing of the solutions. An example of the setup is shown in the diagram.

2. Pour 75 mL of Zn(NO₃)₂ salt solution for the zinc electrode into the 250-mL beaker.

3. Fill the porous cup about \( \frac{3}{4} \) full of the Cu(NO₃)₂ salt solution for the copper electrode. Be careful not to spill the contents of the porous cup into the beaker solution. Also, make sure that the solution in the beaker does not enter the top of the cup.

4. Attach wire leads to the zinc and copper metal electrodes. The zinc will be placed in the Zn(NO₃)₂ and the copper will be placed in the Cu(NO₃)₂. The metal electrode is always placed in its own salt solution. Attach one wire lead to the voltmeter. (If the voltmeter has selectable scales, select a scale with an appropriate range of 0 to 2 V.) Very quickly and lightly touch the second wire lead to the other electrode of the voltmeter. If the needle moves in the positive direction (electrons are flowing from the negative terminal through the wire to the positive terminal), secure the wire to the electrode. If the needle moves in the negative direction, detach the first wire lead, reverse the positions of the leads, and attach them to the electrodes.
5. You will now vary the metal strips (electrodes) in your cell to find the combination that produces the greatest voltage. Every time a new metal is used as an electrode, the salt solution must also be changed.

<table>
<thead>
<tr>
<th>Electrode choices</th>
<th>Salt solutions (1 M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg</td>
<td>Mg(NO₃)₂</td>
</tr>
<tr>
<td>Zn</td>
<td>Zn(NO₃)₂</td>
</tr>
<tr>
<td>Fe</td>
<td>Fe(NO₃)₃</td>
</tr>
<tr>
<td>Cu</td>
<td>Cu(NO₃)₂</td>
</tr>
</tbody>
</table>

To achieve any voltage, one metal must release electrons and the other metal must capture electrons. The metals you will use in this activity are listed in a specific order (Mg, Zn, Fe, Cu). Magnesium has the greatest tendency to release electrons, while copper has the least tendency to release electrons. This information may guide you in your selection of metals for your battery.

Remember, in this part of the activity you are to create the electrochemical cell with the greatest voltage (electrical potential difference). You will only be permitted to test three electrode combinations, so choose wisely!

6. Determine what information you will need. Construct an appropriate data table in your Active Chemistry log.

7. Test your three electrode pairs, making sure to rinse the beaker and the porous cup thoroughly between each test. Check with your teacher about the proper disposal of the liquids.

8. Answer the following questions in your log.
   a) Which electrode pair produced the greatest voltage?
   b) Share your data with the other groups.
   c) Explain the observed order in terms of the activity series of metals (the tendency of metals to release electrons).
   d) Describe any modifications to the setup that you used that might affect the voltage.

Part C: Powering a Toy

1. Bring a battery-powered toy from home. Your teacher may supply you with some examples. Examine the toy that you have chosen.
   a) What voltage does it require to power it? Record this in your Active Chemistry log.

2. Determine how many of the electrochemical cells that you tested in Part B will be needed in a series to power your toy. The total voltage of batteries in series is equal to the sum of the voltages of each battery. In order to connect batteries in a series, you must connect a wire between the negative terminal of the first battery and the positive terminal of the second battery and then the negative terminal of the second battery to the positive terminal of the third battery, and so on. Then you will have a lead coming off of the positive terminal of the first battery and a negative lead coming off of your last battery.

   A series battery setup is shown in the diagram on the next page.
Active Chemistry Ideal Toy

**Chem Words**
- **electrochemical cell**: a cell or a battery that uses chemical reactions to generate electricity.
- **voltage**: a measure of the difference in electrochemical potential between two electrodes.
- **volts**: the electrical potential of an electrochemical cell. They represent the "push" that drives electrons through the wire connecting the two metals.
- **current**: the rate of flow of electric charge.
- **battery**: a system that directly converts chemical energy to electrical energy.

**OXIDATION-REDUCTION REACTIONS AND ELECTROCHEMICAL CELLS**

**Electrochemical Cell**

An **electrochemical cell** is a cell or a battery that uses chemical reactions to generate electricity. When two metals of differing electron-releasing tendencies are connected, an electrical potential is created between the two metals. The electrical potential (voltage) is measured in volts (V) and represents the energy that drives electrons through the wire connecting the two metals. A 9-V battery has a larger electrical potential than a 1.5-V battery. **Current** describes the rate of flow of electric charge. Larger batteries can generate larger currents than smaller batteries.

Some metals tend to lose electrons (become oxidized) more readily than other metals. Examine the Metal Activity Series shown on the next page. A metal that is higher in the activity series will "give up," or release, electrons more readily than one that is lower. You can make use of these differing tendencies to convert chemical energy to electrical energy. As you may have found in the activity, metals that are furthest apart in the activity series will produce the largest voltages.

**Metal Activity Series**

A **battery** is a system that directly converts chemical energy to electrical energy. The Consumer Electronics Association claims that there

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3. Use alligator clips to hook the electrode from one electrochemical cell to the different metal electrode of the next electrochemical cell. Continue in this fashion until you have enough voltage to power your toy. You will have to share your cell with other teams to get enough voltage to run some toys.

4. Compare your setup to the battery arrangement in the toy.
   a) How many electrochemical cells were required?
   b) How long do you think it will take for your battery to die?

**Chem Talk**

If each cell is 1.5 V, the total voltage is 4.5 V.
were over 4.9 billion dollars worth of batteries sold in the U.S. in 2002. The typical batteries used in toys are more correctly called electrochemical cells.

If you examine any commercial battery you will see two terminals. One terminal is marked (+), or positive, while the other is marked (−), or negative. These are typically located at the ends of the battery.

Electrons (which are negative) flow from the negative terminal of the battery. If connected to the positive terminal, the electrons will flow toward the positive. Wires and a load provide the path for the electrons. The load may be a motor or a light or something else that runs on electricity (the flow of electrons).

Before considering how your chemical batteries worked, look at a simpler system.

Consider the following reactions:

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

In certain situations, neutral zinc (Zn) loses two electrons. When that happens, a Zn ion and two free electrons are formed. Since the zinc has lost two electrons, the charge on the Zn ion is +2.

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

In certain situations, a copper (Cu^{2+}) ion tends to gain two electrons. When that happens, a neutral copper atom is formed. The Cu ion had a charge of +2 so it needed two electrons to become electronically neutral.

When the neutral zinc and the copper ion interact, as shown by these reactions, the neutral zinc supplies electrons to the copper ion. This flow of electrons is produced by the potential difference (voltage) and the result is a battery.

The zinc reaction of losing electrons is called oxidation. The copper reaction of gaining electrons is reduction. Each of the two reactions are called half-reactions.

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

(loss of electrons = oxidation, occurs at the anode)

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

(gain of electrons = reduction, occurs at the cathode)

A mnemonic device to remind you of these two processes is:

LEO the lion says GER
Loss Electrons Oxidation Gain Electrons Reduction

Chem Words

load: a motor, light bulb, or other device that runs on electricity (the flow of electric charge).
ion: an atom or molecule that has acquired a charge by either gaining or losing electron(s).
oxidation: the process of a substance losing one or more electrons.
reduction: the process of a substance gaining one or more electrons.
half-reactions: two separated parts of a redox reaction. One part is the oxidation reaction and the other part is the reduction reaction.
oxidized: the acquiring of a positive charge on an atom or molecule by losing electron(s).
reduced: the acquiring of a negative charge on an atom or molecule by gaining electron(s).
redox reaction: a chemical reaction in which the valence electrons of one substance are transferred to the valence shell of the second substance.
spectator ions: ions that do not chemically react in the overall reaction.
dry cell: an electrochemical cell in which the electrolyte is a paste instead of a solution.
The pair of reactions occurring at the same time is called an **oxidation-reduction** (often called **redox**) reaction.

$$\text{Zn}(s) + \text{Cu}^{2+}(aq) \rightarrow \text{Zn}^{2+}(aq) + \text{Cu}(s)$$

One of the characteristic properties of metals is that they tend to lose or “give up” electrons more easily compared to nonmetal atoms. When an atom has lost electrons, it has been **oxidized**. No atom or particle can be oxidized unless some other particle is simultaneously reduced. An atom is **reduced** when it gains electrons.

In the activity, the Zn metal and the Cu$^{2+}$ ions were kept separated by using a porous barrier. This separation forces the electrons to flow through the wire and the load from the anode (Zn) to reach the cathode (Cu). In this way electricity is produced that can do useful work. The Zn anode is bathed in a solution of Zn(NO$_3$)$_2$ while the Cu cathode sits in a solution of Cu(NO$_3$)$_2$ in the porous cup. Because the nitrate ions (NO$_3^-$) do not participate in the reaction, they are referred to as **spectator ions**. Typically, they are not written into the equation.

When the wire is connected, the zinc metal is oxidized to Zn$^{2+}$ ions, which dissolve into the solution. The Cu$^{2+}$ ions are converted to neutral copper atoms that come out of the solution as copper metal.

As the reaction takes place, the zinc half-cell becomes positive and the copper half-cell becomes negative. This would slow and eventually stop the reaction unless the two sides can become electrically neutral. The porous cup allows for the negative NO$_3^-$ ions to move from the copper half-cell to the zinc half-cell. This keeps both sides neutral and the reaction continues.

Your car battery is a wet cell battery that functions similarly to the electrochemical cells that you created. However, most toy batteries are **dry cell** batteries. They operate on exactly the same principles as your electrochemical cells, but the electrolytic substances are in a paste form.
Chem Essential Questions

What does it mean?
Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your Active Chemistry log.

<table>
<thead>
<tr>
<th>MACRO</th>
<th>NANO</th>
<th>SYMBOLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do you know that a battery is working?</td>
<td>Describe what is occurring at the nanoscopic level when a cell is producing electrical energy.</td>
<td>Make a sketch of a cell. Be sure to label all of the important parts.</td>
</tr>
</tbody>
</table>

How do you know?
What evidence do you have to support the idea that your battery actually produced electrical energy?

Why do you believe?
Batteries are such an important part of your life. The electronics that are part of the items you use every day are, for the most part, limited only by the batteries that power them. Propose future breakthroughs that could take place as technology continues to improve batteries, making them more powerful, longer lasting, and smaller/lighter.

Why should you care?
Many toys are powered by batteries. Write an explanation of how the battery works as part of your toy explanation. Include a labeled diagram.

Reflecting on the Activity and the Challenge
In this activity, you explored how batteries work. You know that metals tend to give up electrons. If an electrical-charge difference can be created between the electrodes (terminals), then a current can be generated and chemical energy is converted to electrical energy! You were able to witness this using the voltmeter. By connecting batteries in a series more energy is available, thus increasing the electrical potential. You may decide that the new toy product that you propose will require batteries. Your new knowledge of batteries should assist you in the design of your toy.
1. For the highest electrical potential, should an electrochemical cell’s two metals be close together or far apart on the activity series? Explain.

2. Predict whether the electrical potential of cells composed of these metal pairings will be higher or lower than that of the pairs you tested:
   a) Zn and Cr  
   b) Zn and Ag  
   c) Sn and Cu

3. Notice that silver, platinum, and gold have good reduction potential. Why are these elements not generally found in batteries?

4. Predict the direction of electron flow in an electrochemical cell made from each pair of metals in solutions of their ions.
   a) Mg and Cu  
   b) Zn and Cu  
   c) Ag and Mg

5. a) Identify the anode and the cathode for the metal pairs in Question 4.
   b) Write the half-reactions for each metal pair in Question 4.

6. List some of the pros and cons of batteries. Consider cost, size, and disposal issues, among others.

7. Which half-reaction correctly represents reduction?
   a) Ag → Ag⁺ + e⁻  
   b) Au⁺⁺ + 3e⁻ → Au  
   c) F₂ → 2F⁻ + 2e⁻  
   d) Fe²⁺ → Fe³⁺ + e⁻

8. Which reaction is an example of an oxidation-reduction reaction?
   a) AgNO₃ + KI → AgI + KNO₃  
   b) Cu + 2AgNO₃ → Cu(NO₃)₂ + 2Ag  
   c) 2KOH + H₂SO₄ → K₂SO₄ + 2H₂O  
   d) Ba(OH)₂ + 2HCl → BaCl₂ + 2H₂O

9. Where does oxidation occur in an electrochemical cell?
   a) at the cathode  
   b) at the cathode and the anode in the electrolytic cell  
   c) at the anode  
   d) neither the cathode nor the anode

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**Inquiring Further**

**Storing batteries**

Design and conduct a test for determining the best way to store batteries in order to extend their life.