# ENGINEERING BATTERIES

**STEM$^2$D Topics:**
*Science, Technology, Chemistry, Mathematics, Design*

**Target Population:**
*Students, ages 14 -18*


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**ENGINEERING BATTERIES** is part of the STEM$^2$D Student Activity Series. The content and layout were both developed by the Smithsonian Science Education Center as part of Johnson & Johnson's WiSTEM$^2$D initiative (Women in Science, Technology, Engineering, Mathematics, Manufacturing, and Design), using a template provided by FHI 360 and JA Worldwide. This series includes a suite of interactive and fun, hands-on activities for girls (and boys), ages 5-18, globally.



Design and illustrations by Sofia Elian

# ENGINEERING BATTERIES

## Topics: Science, Technology, Chemistry, Mathematics, Design
## Target Population: Students, ages 14-18

## ACTIVITY DESCRIPTION

This activity introduces students to electrochemistry. Students create a multicell battery using common household materials. In preparation for the activity, students learn about the battery's inventor, its design, and its chemistry. Students are then challenged to assemble a battery of similar concept capable of providing usable electricity. Students test their battery using a professional electric multimeter and demonstrate the produced power by illuminating one or more light-emitting diodes (LED).

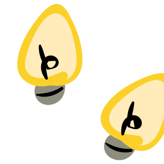
The activity shows the principles of oxidation-reduction reactions. Students will discover how different pairs of electrodes and electrolytes can yield a variety of electrical properties. This can serve as the basis for a brief discussion on the challenges scientists face when designing batteries to satisfy specific consumer and industrial energy storage needs. Finally, students will learn about series and parallel circuits by assembling their multicell battery and explore the basic principles and relationships of Ohm's law.

***ESTIMATED TIME:***
The introduction and activity should take at least 60 minutes to complete.

## STUDENT DISCOVERIES
**Students will:**

- Assemble and describe the components of a typical battery, its function, and its general chemistry.
- Describe the parts of a complete circuit and explain the path of electrical flow.
- Measure the voltage of an electrochemical cell using a professional multimeter.
- Experiment to identify an ideal electrolyte (water or acetic acid).
- Describe power and the relationship between current, voltage, and resistance using Ohm's law.

## GETTING READY

**Materials:**

| | |
|---|---|
| • 1 Student Activity Guide per student | – |
| • 1 Electric multimeter per group | $5-25+ |
| • 1 Ice cube tray with 16 compartments per group | $5 |
| • 1 6 oz. cup of vinegar (acetic acid) per group | $3-5 |
| • 1 6 oz. cup of water per group | – |
| • Cups (9 oz. filled to line, not brim) to contain 6 oz. of vinegar/water | $1-5 |
| • 7 Galvanized (zinc-coated) nails per group | $5-10 |
| • 7 Solid core copper wires (3 inch long) per group | $5-10 |
| • 2 Low current/low voltage LEDs per group | $5-10 |
| • Sample AA or AAA alkaline batteries for reference testing | $5 |
| • 2 Rolls of paper towels per class | – |

## FACILITATOR BACKGROUND

### How to use this guide:

This guide will assist you in teaching the chemistry behind the activity and provide you with helpful insight to explain key concepts. As the activity leader, you are encouraged to take ownership of the lesson, draw on your own knowledge, and leverage your unique personality to communicate the information in this lesson. You will find key vocabulary highlighted throughout the entire guide and defined in the Vocabulary Sheet. Definitions should be conveyed to the students as needed by asking eliciting questions, such as, "What do you think X might refer to?"

**Additional helpful tips:**

- Because of time constraints, it's highly recommended that materials be set up prior to students arriving in the classroom.
- Activity leaders should spend the first 20–30 minutes building rapport with students, e.g., conveying your personal and professional stories; how you got started in your profession; why you're passionate about STEM²D. Additional guidance can be found in the WiSTEM²D Spark Guide.
- Aim to introduce scientific concepts within a 20-minute period to ensure 40 minutes for the hands-on activity and follow-up discussion.
- Move swiftly and at a consistent pace. A printed outline of the covered topics is provided in the Student Activity Guide, which students can later reflect on if time is limited.
- Questions are bound to arise and it is encouraged that all activity leaders familiarize themselves with the concepts in this activity well beforehand. Students should also be encouraged to write down their questions for future discussion.
- Additional tips and references can be found throughout this teaching guide.

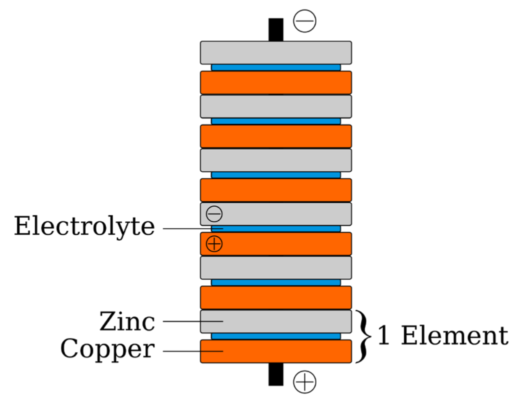
# STEP-BY-STEP ACTIVITY

## *ENGINEERING BATTERIES*

1. Set up each student work area according to the materials list.
2. Hand out the Student Activity Guide and assemble students into groups of four.
3. Introduce the electric battery by drawing attention to Figure 1, which details the world's first battery design—the Voltaic Pile by Italian physicist Alessandro Volta in 1799.

   **A.** *Describe the positive* ***zinc anode****, the negative* ***copper cathode****, and the saltwater-soaked spacers used as an* ***electrolyte****.*

   **B.** *Describe how each element is in fact an individual battery or* ***electrochemical cell*** *that when wired together sequentially (in series) yields a higher voltage [more on that later].*




*"A copper-zinc voltaic pile" by Borbrav is licensed under CC BY SA 3.0*

4. Briefly introduce modern batteries.

   *Note: If time is a concern, you may save this for a post-activity discussion on the design challenges scientists face to make batteries safer, smaller, and longer lasting.*

   *Confer that while modern batteries work much in the same way as Alessandro's battery, much research has gone into improving their chemistries. Today, battery designers must choose between chemicals with certain trade-offs, such as weight,* ***energy density****, longevity, recharge ability, environmental implications, and even safety considerations. Point out how several mobile phones and laptops have been recalled because of faulty batteries causing a fire. Briefly describe some battery types:*

   ***A. Alkaline battery:*** *This is a typical household battery. It is cost-effective but not rechargeable. The* ***electrodes*** *are made of zinc and manganese-oxide with an alkaline electrolyte.*

   ***B. Nickel-cadmium battery:*** *This is a common rechargeable battery. The electrodes are nickel-hydroxide and cadmium, which is toxic to the environment if disposed of improperly.*

   ***C. Lithium-ion battery:*** *This is used in high-current environments where a good power-to-weight ratio is needed, including in laptop computers and mobile phones. It is rechargeable but relatively expensive and can pose an extreme fire hazard if damaged.*

5. *Introduce the chemistry in context:*

***A.*** *Ask rhetorically how these chemicals work together. Explain that the battery students will create in this activity uses some of the same chemicals found in Alessandro's battery, except they will be using different forms of those materials:*

- A galvanized nail for the anode – galvanized meaning it is zinc coated to be rust-resistant. The zinc in these nails will provide the electrons in your battery.
- A copper wire will be used for the cathode, which will receive the electrons.
- A soluble electrolyte that will dissociate into negatively and positively charged ***ions*** called ***anions*** and ***cations***. We'll be using household vinegar as our electrolyte.

***B.*** *Discuss the chemistry. Vinegar is made up of water and acetic acid. Acetic acid dissociates or **ionizes** in water to form negatively charged acetate and positively charged hydrogen ions:*

- Write the equation on the board:

$$CH_3COOH \rightarrow CH_3COO^-_{(aq)} + H^+_{(aq)}$$

*When an electric potential is applied to the solution, the cations of the solution are drawn to the electrode that has an abundance of electrons while the anions are drawn to the electrode that has a deficit of electrons.*

Have students think about how that electric potential is kicked off (catalyzed).

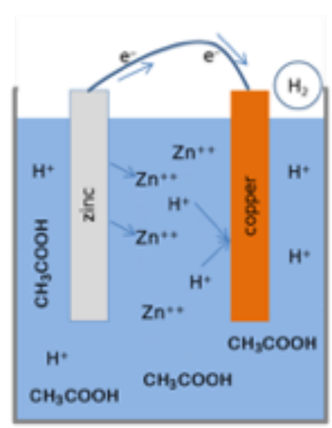
***C.*** *Have students look closely at their battery and discuss with them two key chemical processes at work called **oxidation** and **reduction**.*

While the battery cell is in operation, metallic zinc dissolves into the acid electrolyte as charged ions ($Zn^{2+}$), leaving two negatively charged electrons ($e^-$) behind in the zinc metal. This process of giving up electrons is called oxidation and the zinc is said to be oxidized.

- Write the equation on the board:

$$Zn \rightarrow Zn^{2+}_{(aq)} + 2e^-$$

Those two negatively charged electrons transfer to the copper where they attract and combine with positively charged hydrogen ions (H+) on its surface to form a neutral hydrogen molecule (H2). This process of gaining electrons is called reduction




*"Cross-section of a copper/zinc cell with a sulfuric acid electrolyte." by Easchiff is licensed under CC BY SA 3.0*

and the hydrogen is said to be reduced.

- Write the equation on the board:

$$2H^{+}_{(aq)} + 2e^{-} \rightarrow H_{2(g)}$$

**D.** *Recall that the hydrogen ions are provided by the acid electrolyte. In this way, the acid electrolyte neutralizes the charge imbalance caused by negative electrons as they transfer from the zinc to the copper. This allows for electrons to continuously flow as the reaction continues until the chemicals are used up.*

The reaction as a whole can be written as:

$$Zn + 2H^{+} \rightarrow Zn^{2+} + H_2$$

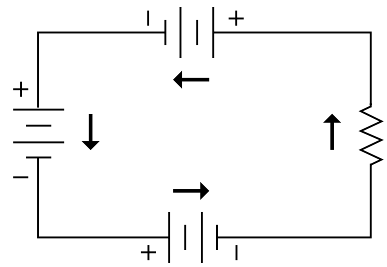
**E.** *Tell students that if they look closely during the experiment, they might be able to see the hydrogen gas bubbling up from the copper wire.*

6. Introduce basic electrical theory:

**A**. *Tell students the important thing is that the flow of these electrons produces useable electricity that can power electrical devices placed in their path.*

*B. Tell students they can also alter the electrical flow to suit their needs. For example, we might need to power a higher voltage device and we can do so by connecting the individual electrochemical cells together in* ***series*** *to make for a battery with greater* ***voltage****. In this case the total voltage is the sum of the individual cell voltages.*

- Reference the wiring diagram (Figure 3) in the Student Activity Guide: Notice how the three cells are connected negative to positive.



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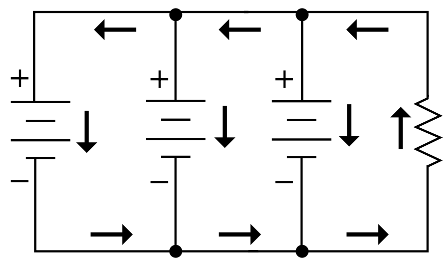
**C.** *Propose to students that perhaps we instead need a longer-lasting energy source, in which case we can connect the electrochemical cells together in* ***parallel*** *to provide the original voltage but supplied by each cell at a fraction of its stored energy for longer lasting power.*

***TEACHING TIP:***
*Ensure this makes intuitive sense to the students – that by adding extra cells in parallel, we spread the electrical demand across a greater num ber cells, depleting each individual cell at a slower rate.*

- Reference the wiring diagram (Figure 4) in the Student Activity Guide: Notice how the cells are connected by their like terminals, i.e., positive to positive and negative to negative.



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***D.*** *Introduce Ohm's law by stressing that as electrons pass through a material (even a wire) they encounter* ***resistance****. The resistance varies across materials. Some materials, such as copper, offer very low resistance, making them ideal* ***conductors.*** *Tell students that the relationship between electrical current (measured in amperes or I), it's voltage (measured in volts or V), and a circuit's resistance (measured in ohms "Ω" or R) is expressed by Ohm's law.*

***E.*** *Write the equation on the board:* ***V = I R***

- Write an example on the board: **0.3A = 3.0V / 10Ω**

  Explain that an idealized example for the LED connected to the battery might look like this… 0.3 amperes of current at 3 volts with a resistance of 10 ohms. Students will soon see how their circuit compares.

7. Introduce proper use of the electric multimeter. The activity requires the instructor to demonstrate the use of a standard electric multimeter. Specifically, students will need to understand how to connect the multimeter probes, switch the multimeter on, and set the multimeter to test for DC voltage. Additional features to test for DC current and circuit continuity are useful but not necessary. A helpful primer on using a multimeter can be found at https://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-multimeter.

8. (Re)introduce the activity. Tell students the battery they will create in this activity is very much like Alessandro Volta's battery. It uses a galvanized nail as the zinc anode, a  wire as the copper cathode, and white vinegar (acetic acid) and water as electrolytes. They will assemble the components on each cube of an ice tray – each of these represents an individual electrochemical cell. As we learned earlier, each cell can be thought of as an individual battery and wired together in series to produce a higher voltage.

*A. Instruct students to begin the activity by following the instructions in their Student Activity Guide.*

## Post-Activity Discussion:

1. Describe the different parts of your battery and explain its path of electrical flow.

   *The battery consists of an anode (zinc nail), cathode (copper wire), and an electrolyte (acetic acid). The path of electron flow is from negative to positive (from zinc to copper). However, by convention, electricity is thought of as positive and is said to flow from positive to negative.*

2. Which electrolyte provided the higher voltage in your battery? Why?

   *Vinegar. Acetic acid dissociates in solution to provide a significant amount of charged ions ($CH3COO^-$ and $H^+$). Because of its strong hydrogen bonds, water contains only a small amount of dissociated ions ($H_3O^+$ and $OH^-$ or others by way of impurities), making it a weak electrolyte.*

3. What do you expect to occur to the zinc electrode's mass while your battery is in operation? Why would this happen?

   *The zinc nail's mass will decrease with battery operation as zinc ions are transferred into the electrolyte during oxidation. This is why batteries "last" for only a set duration.*

4. What happens to your battery's voltage as additional electrochemical cells are added in series? What effect does this have on the brightness of the LED?

   *The voltage increases as a direct sum of each individual cell voltage. The LED glows brighter with higher voltages, eventually burning out at its maximum rated voltage.*

5. What would happen to your battery's voltage if an additional eight electrochemical cells were added in parallel? What effects would this have on the LED's longevity?

   *The voltage output would remain unchanged, but the available stored energy would increase (nearly double), effectively providing longer-lasting light. The intensity of the LED would remain unchanged.*

6. Using Ohm's law, calculate the number of amperes your vinegar battery could theoretically supply to a device with a resistance value of 10 ohms. Refer to your activity results for the voltage.

   *$V = IR$, so $V/R = I$*

# ACTIVITY LEADER CHECKLIST:

***DID YOU . . .***

- ☐ Read Spark WiSTEM2D? This is essential reading for all volunteers interested inworking with youth. It defines the STEM2D principles and philosophy and provides research-based strategies and tips for engaging and interacting with female students. Download at www.STEM2D.org.
- ☐ Visit the implementation site and observe the young people? (optional) If visiting, take note of the following:
    - ☐ How does the site encourage orderly participation? For example, do the young people raise their hands when responding to questions or during discussions? How are interruptions handled? Do you see any potential problems with managing the class of young people?
    - ☐ What does the site do to make each student feel important and at ease?
    - ☐ How is the room arranged? Will you need to move desks or chairs for any part of your presentation?
    - ☐ How can you engage the site representative in your presentation?
- ☐ Meet with and finalize the logistics with the Site Representative?
    - ☐ Confirm the date, time, and location of the activity?
    - ☐ Confirm the number of students attending? Knowing this will help you decide how to group the students into teams, as well as the appropriate materials to purchase.
- ☐ Recruit additional volunteers, if needed?
- ☐ Prepare for the activity:
    - ☐ Read the entire activity text prior to implementation?
    - ☐ Customize the activity, if desired, to reflect your background and experiences, as well as the cultural norms and language of the students in your community?
    - ☐ Complete the Tell My Story Form, which will prepare you to talk about your educational and career path with the students?
    - ☐ If teams are needed for this activity, please ask the teacher in advance to organize the students into teams.
- ☐ Practice your presentation, including the hands-on, minds-on activity? Be sure to:
    - ☐ Do the activity; make sure you can explain the concepts to students, if needed, and that you know the correct answers.
- ☐ Obtain the required materials (see the Materials and Estimated Materials Costs sections) and, if asked for in the Getting Ready section, photocopy the Student Handouts and Materials Testing Sheets. In addition:
    - ☐ Organize the materials to ensure each team has everything listed in the Materials section—keep in mind some materials are shared among the teams.
- ☐ Prepare the space? Specifically:
    - ☐ Make sure tables and chairs are arranged to accommodate teams of students.
    - ☐ Bring a camera, if desired, to take photographs.
- ☐ Obtain and collect permission slips and photo release forms for conducting the activity if applicable?
- ☐ Have fun!

# Tell My Story Form

This form will help volunteers serving as activity leaders prepare to talk about their **STEM²D** interests, education, and career path.

## ABOUT YOU

Name: ______________________________

Job Title: ______________________________

Company: ______________________________

When/Why did you become interested in STEM²D? ______________________________

______________________________

______________________________

What do you hope young people, especially females, will get out of this activity? ______________

______________________________

## FUN FACT

Share a little about your background. Ideas:

- Share a memory from childhood where you first had your spark or interest in STEM.
- Detail your journey; highlight what you have tried, what you learned, steps to success, etc.
- Failures or set backs are also great to talk about—difficulties, and/or challenges and how you overcame them.

## EDUCATION AND CAREER PATH

What classes/courses did you take in secondary school and in college that helped or interested you most?

______________________________

______________________________

How did you know you wanted to pursue a STEM²D career?

______________________________

______________________________

What was your postsecondary path, including the institution you attended and your degree? *If you switched disciplines, make sure you explain why to the students.*

______________________________

______________________________

What your current position entails. *Be sure to include how you use STEM²D on a typical work day.*

______________________________

______________________________

# STUDENT ACTIVITY SHEET

## *TEACHER'S EDITION:*

## Student Instructions:

*Caution: copper wire ends are sharp.*

1. Wrap a copper wire (cathode) around the mid-section of a zinc-coated nail (anode). Place the nail into the first cube (cell) on the tray and the lose end of the copper wire into the adjacent cube.

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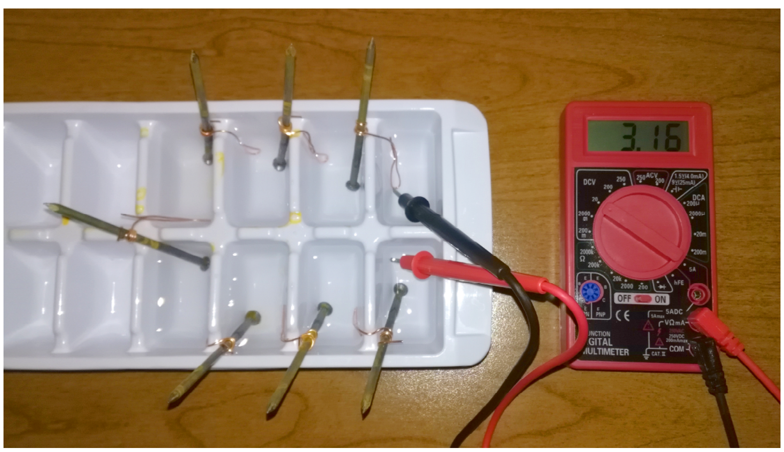
2. Repeat Step 1 so that eight cubes are connected together in series, resembling a U shape. Be sure that no copper wire is in direct contact with a nail in the same cell as this will short the cell.

3. Fill each of the eight cubes nearly full with vinegar. Ensure each nail and adjacent wire is submerged.

***TEACHING TIP:***

*The voltage produced in Steps 4 and 8 should be approximate 3-6 V. However, the output current will be low and may vary due to surface contact between the elec trodes and the amount of electrolyte. Precision and consistency should be encouraged.*

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4. Use your multimeter to compare the voltage produced by individual cells (cube) with that produced by all cells. Submerge the red probe in the first cell and the black probe in each other cell through to the last as pictured. Record the total voltage on the worksheet.

5. Connect the first and last cubes by placing a light-emitting diode (LED) between them (one leg submerged in each cell) to demonstrate the produced power. Reverse the LED if it does not illuminate.

6. Remove all of the prepared nails, rinse them, and place them in the eight unused cubes on the opposite side of the ice tray. The arrangement should resemble Steps 1 and 2.

7. Fill each of these new cubes nearly full with tap water.

8. Test the produced voltage as in Step 4 and record the result. Connect the first and last cubes by placing a LED between them to demonstrate.

*TEACHING TIP:*

*Students may observe negative numbers on their multimeter. This is due to incorrect polarity and can be remedied by reversing the order of the probes. Similarly, standard LEDs are uni-directional (the long wire indicating its positive terminal). If an LED fails to illuminate simply reverse their placement.*

## VOCABULARY:

**ANODE:** The positively charged electrode by which the electrons leave an electric device

**CATHODE:** The negatively charged electrode by which electrons enter an electric device

**CONDUCTOR (ELECTRICAL):** A type of material (e.g., a copper wire) that allows for the flow of an electric current

**CURRENT (ELECTRIC):** A flow of electric charge, often carried by moving electrons in a wire or ions in an electrolyte

**ELECTRON:** A subatomic particle with a negative charge; it is the primary carrier of electricity in solids

**ELECTROCHEMICAL CELL:** A device capable of generating electrical energy from chemical reactions or using electrical energy to cause chemical reactions

**ELECTRODE:** A conductor through which electricity enters or leaves a material

**ELECTROLYTE:** A substance that produces an electrically conducting solution

**ENERGY DENSITY:** The amount of energy stored per unit mass or volume

**ION:** An atom or molecule with an electric charge due to the loss or gain of one or more electrons

**OXIDATION-REDUCTION:** A type of chemical reaction that involves a transfer of electrons between two species; oxidation denotes the loss of electrons or an increase in oxidation state whereas reduction denotes an electron gain or decrease in oxidation

**PARALLEL CIRCUIT:** A closed circuit in which the current divides into two or more paths before recombining to complete the circuit

**RESISTANCE (ELECTRICAL):** A quantitative measure of a material's opposition to the flow of electric current

**SERIES CIRCUIT:** A closed circuit in which the current follows one path only

**SHORT CIRCUIT:** An electric circuit that allows a current to travel along an unintended path with no or a very low electrical impedanceresulting in an excessive amount of current flowing into the circuit

**VOLTAGE:** A quantitative measure of the potential difference in charge between two points in an electrical field

# ENGINEERING BATTERIES

## STUDENT ACTIVITY GUIDE


Smithsonian Science Education Center
Johnson & Johnson

## YOUR ENGINEERING TASK…

Chemists and battery designers are constantly challenged to produce safe, longer-lasting, and environmentally friendly batteries to meet society's energy needs. Often, designers must choose between certain trade-offs to accomplish this goal. Your task is to assemble a battery capable of providing usable electricity using only common household items. You will test your design using a multimeter and demonstrate your design by using the produced energy to illuminate one or more light sources.

**Criteria (goals):**

- Your battery must produce electricity of at least 3 volts.
- Your battery must illuminate at least one light-emitting diode (LED).

**Constraints (limits)**

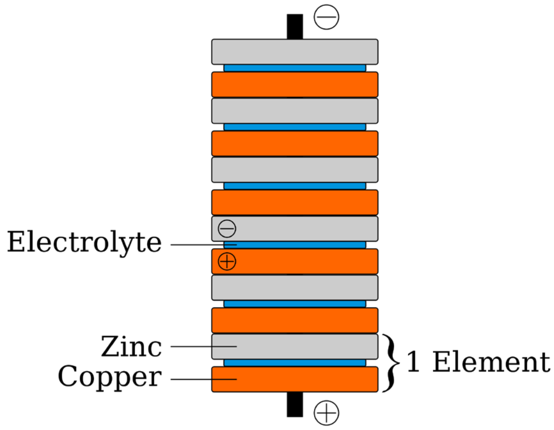
- Your battery must use only common household materials provided by the instructor.

# BACKGROUND

The type of battery you will produce is not unlike the first battery invented by Italian physicist Alessandro Volta in 1799. The battery works by way of a set of chemical reactions known as ***oxidation-reduction***, in which a positively charged anode and negatively charged ***cathode*** are assembled in an ***electrolyte*** to form an ***electrochemical cell***. Each of these cells can be thought of as an individual battery connected to another in series. In Volta's battery, a ***series*** of stacked zinc and copper discs formed the anode and cathode, respectively, separated by cardboard or felt spacers soaked in a saltwater electrolyte.


*Above: Alessandro Volta's voltaic pile (battery) on display in the Tempio Voltiano (the Volta Temple) near Alessandro Volta's home in Como, Italy Right: A diagram of the voltaic pile (Source:*

Modern batteries use a variety of chemicals to power their reactions. Often, battery designers must choose between chemicals with certain trade-offs, such as weight, ***energy density***, longevity, recharge ability, and other properties. Common battery types include:




*"A copper-zinc voltaic pile" by Borbrav is licensed under CC BY SA 3.0*

- **Alkaline battery:** *This is a typical household battery. It is cost-effective but not rechargeable. The* ***electrodes*** *are made of zinc and manganese-oxide with an alkaline electrolyte.*
- **Lead-acid battery:** *This is used in automobiles because of its ability to be recharged and handle high* ***currents*** *during engine start. The electrodes are made of lead and lead-oxide with a strong acidic electrolyte.*
- **Nickel-cadmium battery:** *This is a common rechargeable battery. The electrodes are nickel-hydroxide and cadmium, which is toxic to the environment if disposed of improperly.*
- **Nickel-metal hydride battery:** *A newer rechargeable battery type. Although less durable than thenickel-cadmium battery, it is quickly becoming the standard rechargeable battery because of its lesser toxicity and up to 40% higher energy density.*
- **Lithium-ion battery:** *This is used in high-current environments where a good power-to-weight ratio is needed, including in laptop computers and cell phones. It is rechargeable but relatively expensive and can pose an extreme fire hazard if damaged.*
- **Silver-zinc battery:** *This is used in spacecraft and other aeronautical applications because of its excellent power-to-weight (and size) ratio. The use of silver makes it an expensive choice.*

# THE SCIENCE & MATH

## Chemistry, Oxidation, and Reduction

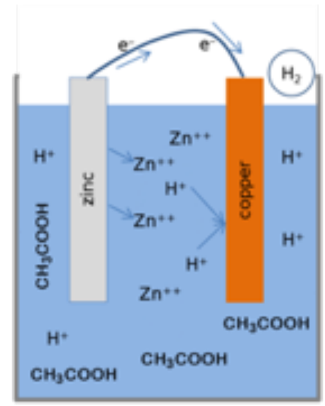
The battery you will create in this activity uses a galvanized (zinc coated) nail for the anode, which will provide electrons to a copper cathode made of simple wire. Household vinegar (acetic acid) and water are used as electrolytes in turn.

Electrolytes are chemicals that dissociate into ***ions*** either when dissolved in water or pre-packaged as a solid paste. They conduct electricity because of the mobility of their positive and negative ions called cations and anions.

The vinegar in this activity is made up of water and acetic acid. When dissolved in water, acetic acid molecules dissociate (ionize) to form acetate and hydrogen ions in solution:

$$CH_3COOH \rightarrow CH_3COO^-_{(aq)} + H^+_{(aq)}$$

On its own, a very small amount of water (0.1 millionth of it) will also spontaneously disassociate into hydronium and hydroxide. In practice, however, tap water often contains various impurities that can further yield ions, making it a very weak electrolyte.




*"Cross-section of a copper/zinc cell with a sulfuric acid electrolyte." by Easchiff is licensed under CC BY SA 3.0*

$$2H_2O \rightarrow H_3O^+_{(aq)} + OH^-_{(aq)}$$

When placed in acetic acid, metallic zinc dissolves to form charged ions ($Zn^{2+}$), leaving two negatively charged electrons (e–) behind in the zinc metal. The process of losing electrons is called ***oxidation*** and the zinc is said to be oxidized. This reaction can be written as:

$$Zn \rightarrow Zn^{2+}_{(aq)} + 2e^-$$

Simultaneously, another chemical process occurs whereby the two electrons given off by the zinc combine with positively charged hydrogen ions ($H^+$) at the copper cathode's surface to form a neutral hydrogen molecule ($H^2$). The process of gaining electrons is called ***reduction*** and the hydrogen is said to be reduced. This reaction can be written as:

$$2H+_{(aq)} + 2e^- \rightarrow H_{2(g)}$$

*See it!*

*The hydrogen molecules formed on the copper surface can be seen as bubbling hydrogen gas.*

Recall that the hydrogen ions are provided by the reaction of acetic acid in water. These ions serve to neutralize the charge imbalance caused by the transfer of negative electrons from the zinc to the copper, allowing for electrons to continuously flow until either the zinc or hydrogen is consumed and the battery is depleted. The reaction in your battery written in whole:

$$Zn + 2H^+ \rightarrow Zn^{2+} + H_2$$

## Electricity and Ohm's Law

The flow of the electrons between the zinc anode and copper cathode provides usable electricity that can be harnessed to power an appliance connected between the two electrodes. The electrons can also be transferred to additional electrochemical cells wired in ***series*** to provide a greater ***voltage*** (the sum of individual cell voltages) or in ***parallel*** to provide the same voltage supplied by each cell at a fraction of its stored energy for longer lasting power.

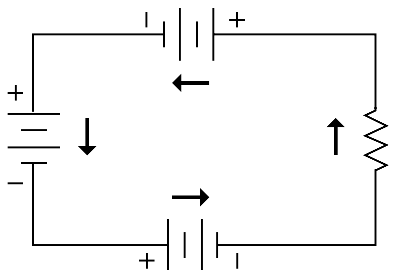


*Figure 3: Series circuit*
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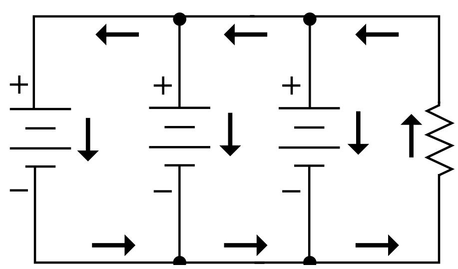

*Figure 4: Parallel circuit*
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However, as electrons pass through a material (even a wire) they encounter resistance. This resistance varies across materials of different sizes and compositions. Some materials, such as copper, offer very low resistance, making them excellent ***conductors***. The relationship between electric ***current*** (measured in amperes), its ***voltage*** (measured in volts) and a circuit's ***resistance*** (measured in ohms or "Ω") is expressed by Ohm's law given as:

$$V = I\,R$$

where V is the voltage or difference in electrical charge (the potential difference) between two points in a circuit with a resistance R. I is equal to the amount of electrons (current) flowing through the circuit.

Example: An idealized example for the LED connected to your battery might look like this:

**$0.3A = 3.0V / 10\Omega$** or 0.3 amperes of electricity at 3 volts with a resistance of 10 ohms.

# ACTIVITY INSTRUCTIONS AND WORKSHEET

**SAFETY**: Used electrolyte can irritate the skin. In case of contact, wash hands with soap and water.

The battery you will create in this activity uses a galvanized (zinc coated) nail as the anode, a copper wire as the cathode, and vinegar (acetic acid) and water as electrolytes. The components are assembled on each cube of an ice tray, representing individual electrochemical cells.

## Step-By-Step Instructions:

*Caution: copper wire ends are sharp.*

**1.** Wrap a copper wire (cathode) around the mid-section of a zinc-coated nail (anode), leaving a 1-2 inch overhang. Place the nail into the first cube (cell) on the tray and the lose end of the copper wire into the adjacent cube.

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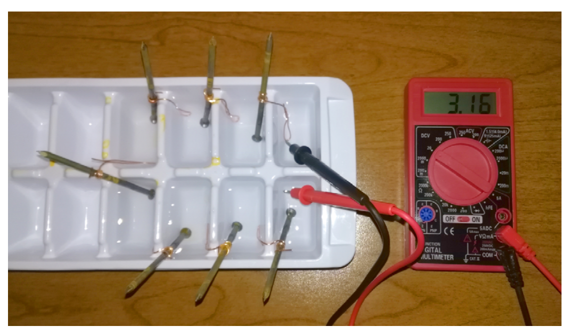
2. Repeat Step 1 so that eight cubes are connected together in series (positive to negative), resembling a U shape. Be sure that no copper wire is in direct contact with a nail in the same cell as this will short the cell.

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3. Fill each of the eight cubes nearly full with vinegar. Ensure each nail and adjacent wire is submerged.

4. Use your multimeter to compare the voltage produced by individual cells with that produced by all cells together. To do this, submerge the red probe in the first cell and the black probe in each other cell through to the last as pictured. Record the total voltage on the worksheet.

5. Connect the first and last cubes by placing a light-emitting diode (LED) between them (one leg submerged in each cell) to demonstrate the produced power. Reverse the LED if it does not illuminate.

6. Remove all of the prepared nails, rinse them, and place them in the eight unused cubes on the opposite side of the ice tray. The arrangement should resemble Steps 1 and 2.

7. Fill each of these new cubes nearly full with tap water.

8. Test the produced voltage as in Step 4 and record the result. Connect the first and last cubes by placing an LED between them to **demonstrate.**

## Experiment Results:

| Electrolyte Used: | Number of Cells: | Voltage Produced: | LED Brightness: |
|---|---|---|---|
| Vinegar (acetic acid) | | | |
| Tap Water | | | |

## **Follow-Up Discussion:**

1. Describe the different parts of your battery and explain its path of electrical flow.

2. Which electrolyte provided the higher voltage in your battery? Why?

3. What do you expect to occur to the zinc cathodes mass while your battery is in operation? Why would this happen?

4. What happens to your battery's voltage as additional electrochemical cells are added in series? What effect does this have on the brightness of the LED?

5. What would happen to your battery's voltage if an additional eight electrochemical cells were added in parallel? What effects would this have on the LED's longevity?

6. Using Ohm's law, calculate the number of amperes your vinegar battery could theoretically supply to a device with a resistance value of 10 ohms. Refer to your activity results for the voltage.

# VOCABULARY:

**ANODE:** The positively charged electrode by which the electrons leave an electric device

**CATHODE:** The negatively charged electrode by which electrons enter an electric device

**CONDUCTOR (ELECTRICAL):** A type of material (e.g., a copper wire) that allows for the flow of an electric current

**CURRENT (ELECTRIC):** A flow of electric charge, often carried by moving electrons in a wire or ions in an electrolyte

**ELECTRON:** A subatomic particle with a negative charge; it is the primary carrier of electricity in solids

**ELECTROCHEMICAL CELL:** A device capable of generating electrical energy from chemical reactions or using electrical energy to cause chemical reactions

**ELECTRODE:** A conductor through which electricity enters or leaves a material

**ELECTROLYTE:** A substance that produces an electrically conducting solution

**ENERGY DENSITY:** The amount of energy stored per unit mass or volume

**ION:** An atom or molecule with an electric charge due to the loss or gain of one or more electrons

**OXIDATION-REDUCTION:** A type of chemical reaction that involves a transfer of electrons between two species; oxidation denotes the loss of electrons or an increase in oxidation state whereas reduction denotes an electron gain or decrease in oxidation

**PARALLEL CIRCUIT:** A closed circuit in which the current divides into two or more paths before recombining to complete the circuit

**RESISTANCE (ELECTRICAL):** A quantitative measure of a material's opposition to the flow of electric current

**SERIES CIRCUIT:** A closed circuit in which the current follows one path only

**SHORT CIRCUIT:** An electric circuit that allows a current to travel along an unintended path with no or a very low electrical impedanceresulting in an excessive amount of current flowing into the circuit

**VOLTAGE:** A quantitative measure of the potential difference in charge between two points in an electrical field