CHALLENGES IN PHYSICAL SCIENCE®

Batteries

Teacher's Guide

A Supplemental Curriculum for Middle School Physical Science

From Project DESIGNS: Doable Engineering Science Investigations Geared for Non-science Students

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To the Teacher

"Wow, it works! I can't believe it works!" Expressions of stunned astonishment at the accomplishment of building a working electric motor draw fellow classmates to this minute mechanical marvel. Wobbling and anemic, the motor struggles, straining to make each turn. Assembled from nails and wire, this was the first working device that this middle-schooler had ever built. Soon her classmates followed with their own successes. Over the next few weeks, their motors improved through students' innovations, discovering along the way: imbalance and balance, friction and lubrication, short circuits and insulation, and how to strengthen invisible magnetic fields. Students competed and cooperated, dissected motors from toys and shared their findings. Science was slowly mastered and skills strengthened. Journals filled with data and drawings. Soon motors whirred at 6,000 rpm and beyond, matching the performance of those in their tape recorders and toy cars. The progression of the class—from first copying a poorly performing prototype through successive improvements that revealed the underlying science—marked the birth of the DESIGNS (Doable Engineering Science Investigations Geared for Non-science Students) philosophy in my classroom twenty years ago. Building and improving devices formed the core of a technology and science course for youngsters who were still learning about their own interests and abilities.

Inspired by the MIT undergraduate engineering competitions, challenges that are suitable to teach the elements of science and technology at the middle school level are not easy to find. Most students are unfamiliar with even the simplest of hand tools. The innards of common devices they use each day are hidden from view. It takes support and encouragement to explore the unknown. Recreating the youthful experiences reported by adults enticed into scientific and technological careers has been our aim. Such projects are too often out-of-school events, supported by a knowledgeable adult, and are rare in families without technological expertise. Uncovering the path to exciting and lucrative careers that are too often untrod by girls and other underserved groups, DESIGNS challenges provide an exciting entry into these fields.

This set of challenges is the output of an extraordinary group of teachers, educators, and scientists. With the support of the National Science Foundation and the Smithsonian Institution we have brainstormed, tested, written, drawn, invented, and struggled. We have failed more often than succeeded, but the result of our three-year effort has been worth it. This collection of activities is fun, contains much science, and is thoroughly tested in a variety of classrooms. They capture students' imaginations and energy. They are not simple to master, but the built-in rapid iteration process tends to test students' ideas rather than their spirits. Failures are frequent but small, each a learning experience that can be absorbed and used. The challenges are designed so that successful strategies are often counter-intuitive, reflecting what we have learned about children's ideas and how they change. Students exhibit little difficulty generating ideas for improvement. But only when their ideas fail do they see a need to pay attention to others' success and restructure their own thinking.

This project has been the beneficiary of many previous development efforts, both our own and those of others. We have attempted to credit all those who helped directly, but we also wish to thank those who remain nameless, teachers with a great suggestion at a workshop, a clever idea from an article, a scientist's solution to a difficult problem, and most of all the thousand or so middle school students who contributed their time and passion as we worked out the bugs in our design of DESIGNS.

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Introduction

About CHALLENGES IN PHYSICAL SCIENCE

CHALLENGES IN PHYSICAL SCIENCE Goals that Cross All Modules

Each of the six CHALLENGES IN PHYSICAL SCIENCE modules contains three or more challenges. Embedded within each challenge are three important goals. They are as follows:

1. **Support learning through clear student goals.** Each student goal is presented as a clearly defined challenge in physical science. These challenges are invitations to students to improve the performance of a simply designed device commonly found in their world.
2. **Empower students as problem-solvers.** Students are encouraged to use their prior knowledge to develop strategies to make progress in each challenge. Students discover and utilize physical science concepts as they achieve the goal characterized by the challenge.
3. **Encourage students to be critical creators of knowledge.** Students propose, test, and eventually defend their ideas. Teachers probe student strategies and interpretations, and encourage students to assess their own and others' evidence.

Students quickly recognize the goal that is posed as a challenge. For example, if the challenge is to improve a working model of a windmill, students easily visualize what is expected and what constitutes a successful outcome. The student who encounters the poorly designed windmill interacts with the basic model, decides what might be changed, makes those changes, and evaluates the results.

CHALLENGES IN PHYSICAL SCIENCE makes two important assumptions about students who accept the challenge: 1) they understand the goal, and 2) they accept the goal as their own. Students who accept ownership of the goal are more likely to be motivated to complete the work they begin. Students also appreciate the link between each challenge and its real-world application. Student interaction with science is often through the technology that results from scientists' work. Each challenge offers students an interesting task centered on the theme of improving an existing design (e.g., a windmill, a battery, or an electromagnet).

All of the challenges were crafted so that students could easily recognize the goal, quickly obtain feedback from their work, and effectively act on that feedback. This strategy is intended to invite students to act, and to empower and support their learning once they accept the invitation. Students who accept the challenge soon find that the problem becomes very compelling. They are motivated for several reasons. The iterative nature of the activity provides timely feedback. The feedback provided by nature is always available, always impartial, and typically unambiguous. Students can quickly determine if their ideas and actions are bringing them closer to the goal they recognized in the challenge. The interaction between the challenge, the supportive teacher, and the problem-solving student is critical in helping students to be self-directed, critical creators of knowledge.

CHALLENGES IN PHYSICAL SCIENCE challenges/goals are also intended to encourage teachers to continually assess whether the classroom setting supports student work in meeting the module goals. From this perspective, teachers focus on encouraging students to follow their own convictions. As a result, students are less dependent on the instructor for the "right answers." Instead, they seek to improve the strategies they use in meeting the design challenge. Often great progress is made when students discover that their beliefs are not supported in nature. Students who learn to question nature directly learn to increasingly value their experiments and become more interested in their results. Students who are motivated to accept the challenge need less assistance from the teacher to proceed. Students uncomfortable with this freedom may still seek the teacher's help. However, teachers who let the challenges guide the students help build students' confidence in their problem-solving ability. Teachers ultimately act to support student understanding of how science proceeds instead of what science has produced.

CHALLENGES IN PHYSICAL SCIENCE vs. National Standards

CHALLENGES IN PHYSICAL SCIENCE goals agree philosophically with the following goals for school science as articulated in the *National Science Education Standards* (p. 13):

- Experience the richness and excitement of knowing about and understanding the natural world.
- Use appropriate scientific processes and principles in making personal decisions.
- Engage intelligently in public discourse and debate about matters of scientific and technological concern.

However, in an attempt to go beyond philosophical agreement with these goals, CHALLENGES IN PHYSICAL SCIENCE strives to create guiding principles that help direct the work of students and teachers. To this end, CHALLENGES IN PHYSICAL SCIENCE goals support the grades 5–8 Content Standards in the *National Science Education Standards* for Science as Inquiry, which include (p. 143):

- Abilities to do scientific inquiry.
- Understanding about scientific inquiry.

Furthermore, CHALLENGES IN PHYSICAL SCIENCE's goals directly support the grades 5–8 Science and Technology requirements in the *National Science Education Standards*. In particular, CHALLENGES IN PHYSICAL SCIENCE seeks to create opportunities for children so that, "as a result of activities in grades 5–8, all students should develop abilities of technological design" (p. 161). The underlying objective is that students will be able to perform the following (pp. 165–166):

- Identify appropriate problems for technological design.
- Design a solution or product.
- Implement a proposed design.
- Evaluate completed technological designs or products.
- Communicate the process of technological design.

All CHALLENGES IN PHYSICAL SCIENCE goals provide a framework to support scientific inquiry and technological design. This framework is the foundation on which students distinguish the difference between science and technology. Students work towards recognizing that the goal of science is to create knowledge, while the goal of technology is to apply that knowledge into developing the tools people use to solve problems. To support experimenting as well as the building of tools, CHALLENGES IN PHYSICAL SCIENCE uses materials that are inexpensive, readily available, and easily recognized by students as common items that constitute a part of their everyday world.

Skills that Cross All Modules

Science is a unique tool for understanding nature. It assumes that systems (such as the devices in a module) can be understood by first breaking them down into parts that can be later modified. Students learn by making changes to the variables they identify within a design (e.g., increasing the number of wire wrappings in an electromagnet). Students are encouraged to experiment, generate ideas, formulate conclusions, and support their ideas and conclusions with explanations. At the end of the project the students should be able to perform the design process and fabricate their best designs. As a result, they formulate and articulate theories about how each design works. Whether their theories are naive or sophisticated, students test their beliefs through each of their design modifications.

An important outcome of the module goals is that students develop both manipulative and cognitive skills in science. Three skills in particular are realized through student work:

1. **Articulating and testing prior notions** about how a design works. In many ways this skill represents the traditional view of what scientists do: asking questions, forming hypotheses, testing those hypotheses, etc. Students can easily identify the parts of the devices with which they are working. These "parts" represent the design variables that students can control as a scientist or engineer might. Students want to know what will happen to their designs when they choose to modify, add, or remove variables. Their questions become the guiding principles behind how they test their ideas.

2. **Judging the impact or magnitude of a change.** When a student wonders how a change might impact the original design, the student is posing the question directly to nature. Once the change has been implemented, nature provides the answer. Students judge the impact of their own ideas. They see that not all changes result in the same effect or even have any effect. Because the teacher is outside the question-answer cycle, students concentrate on looking to nature to find answers to their questions.

3. **Making convincing arguments** that a change has resulted in a meaningful improvement to the design. Students are expected to evaluate the impact of changes as well as judge the magnitude of change. They are encouraged to employ tools (such as graphs, tables, and charts) to support claims that some changes had a greater impact than others, or that a change had no impact at all.

To the extent that these skills are practiced in the module, CHALLENGES IN PHYSICAL SCIENCE supports the broadest standard in the *National Science Education Standards*. "As a result of activities in grades K–12 all students should develop understanding and abilities aligned with the following concepts and processes" (pp. 117–118):

- **Evidence, models, and explanation:** Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems.
- **Constancy, change, and measurement:** Energy can be transferred and matter can be changed. . . . Changes can be quantified. . . . Different systems of measurement are used for different purposes.

Introduction to the Batteries Module

Descriptions of the Batteries' Challenges

Challenge 1: Find the Best Electrodes

Challenge Objective

Students test combinations of two electrodes at a time to determine which pair works best.

Challenge Scenario

You are an archaeologist working in a remote desert location. Your water supply is running short and you need to send word to the base camp that you need more. When you turn on your walkie-talkie, however, the battery is dead. You have no other batteries for it. You know that certain materials will react with each other to produce electricity, so you begin by testing the materials that you find in your camp. You must find the materials that produce the most voltage to run your walkie-talkie.

Challenge 2: Find the Best Electrolyte

Challenge Objective

Students test the various electrolytes provided by the teacher to determine which will act as the best conductor.

Scenario Change

Now that you have found the two materials that react with each other to produce the most voltage, you must find a substance in which they can react most efficiently. You have several liquids in your camp that you must test to see which will produce the most voltage.

Challenge 3: Increase Volts

Challenge Objective

Students use the knowledge that they gained from Challenges 1 and 2 to construct a battery cell in a film canister using the materials and amounts specified. They then test this battery to determine how many volts it produces.

Next, students divide the electrode materials in half to construct two cells from the same amount of material used in the previous iteration. They connect these cells in a series to make a battery and test the circuit to see an increase in the number of volts from the first test. Students should learn that the amount of material used in a single electrochemical reaction has little effect on the voltage produced by the reaction. In order to increase the voltage produced, additional, separate electrochemical reactions must be produced.

Scenario Change

You have only a limited amount of the best electrode material available. You must increase the voltage of your battery without using more electrode material.

Challenge 4: Turn On the Clock

Challenge Objective

Students use the knowledge that they gained from Challenges 1, 2, and 3 to construct a battery cell or series of battery cells that will provide sufficient voltage to turn on a liquid crystal display (LCD) clock. The materials for the electrodes and electrolyte should be those that students found to be best in their previous challenges. The battery that they construct must have sufficient voltage to power the clock (approximately 1.2 volts). Batteries that do not power the LCD clock should be tested using the digital volt meter (DVM) to make sure that connections have been made properly.

Scenario Change

Your experiments have shown how you can achieve the maximum voltage output from your battery cell. Now you must combine cells so that you have enough volts to operate your walkie-talkie and call for more water!

Module Goals

The focus of this module is electrochemistry. The module is not intended to provide analytical information on electrical theory. Discussions of electrical circuits are provided only in the context that will enable students and teachers to use them to further their understanding of electrochemical reactions.

This module allows students to explore the nature of chemical change, the production of electricity and energy transfer by manipulating design elements and construction materials in a battery cell made with common household materials.

Explorations of electrolyte and electrode materials lead to the challenge to improve the design of a cell so that it will power a Liquid Crystal Display (LCD) clock. Constraints within the challenge focus students' attention on the variables and concepts involved in the chemical reactions that can be used to produce electricity.

Content Goals of the Module

1. From the perspective of the *National Science Education Standards* (Physical Science: Content Standard B): "As a result of their activities in grades 5–8, all students should develop an understanding of properties and changes of properties in matter [and] transfer of energy" (p. 149). The underlying concepts that students recognize are:
   - Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties (p. 154).
   - Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways (p. 155).
   - Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced (p. 155).

2. From the perspective of CHALLENGES IN PHYSICAL SCIENCE:

   The student's goal is to improve a battery cell design so that it is able to produce a greater number of volts. To this end, students encounter the following concepts in order to successfully meet this challenge:

   A. Solutions which conduct electricity are called electrolytes. Some electrolytes are more effective than others in allowing electricity to pass through them.

   1) Electricity will not flow through some substances. Substances that stop or resist the flow of electricity are called **insulators.**
   2) Some solutions will allow electricity to flow through them easily. Solutions (or other materials) that allow electricity to flow through them are called **conductors.** Some liquids are good conductors, especially many acidic liquids.

   B. Not all conductors are equal. Some conductors allow more electricity to flow through them than others. The ability of a material to conduct electricity is described in terms of its **conductivity.**

   C. Certain pairs of metals react electrochemically with each other when placed in a solution that is a good conductor. These pairs of metals are referred to as **electrodes.**

   1) The chemical reaction occurs at the atomic level and involves the transfer of electrons from one metal to the other.
   2) An electrolytic solution is required for the chemical reaction to take place between the electrodes.
   3) Some chemical reactions are accompanied by visible changes in the electrodes or in the electrolytic solution. These changes can include discoloration, bubbles, or accumulation of "crud" or gel-type substances.

D. Some pairs of metal electrodes react with each other electrochemically to a greater extent than other pairs. The reaction can be measured by creating a circuit.

1) Conductive wires can be attached to the electrodes. A device called a **digital volt meter** (DVM) can then be attached to the wires. The amount of energy produced by the reaction taking place is measured by the DVM in units of measure known as **volts.**

E. Increasing the amount of material used for the electrodes does not necessarily increase the voltage of the battery.

1) Creating two separate cells from the same amount of electrode material will cause an increase in voltage when the cells are connected in series in a circuit. Adding additional cells to the circuit will further increase the voltage.
2) Standard batteries purchased for use in radios, flashlights, etc. are constructed by connecting several individual cells to produce sufficient voltage.

Scientific Concepts and Knowledge

Chemical Energy and Electrical Energy

In the Batteries Module students utilize the concepts of chemical and electrical energy. They are defined as follows:

- **Chemical energy:** energy produced by the reaction of two or more chemical substances when placed in combination with each other. This reaction takes place on the atomic level.
- **Electrical energy:** energy produced by a flow of charged particles brought about by any number of causes, including a chemical reaction.

The challenges will examine ways to increase chemical reactions to produce more electrical energy. Explanations at the atomic level will not be included, however, because learning research indicates that they are too advanced for middle-school-aged children.

Chemical energy and electrical energy are portrayed in the challenges by the following variables:

1. **The substance used as an electrolytic solution.** The electrolytic solution provides the medium in which the chemical reaction of the two metal substances occurs. Some solutions are able to promote this interaction more readily than others.

2. **The types of metals used as electrodes.** The electrodes are two substances that, when placed in an electrolytic solution, react with each other to produce chemical energy. This means one or both change, chemically forming a new substance. This change may visually result in a color change, gas production, or corrosion. This energy can be harnessed as electrical energy. The two substances are referred to as an electrochemical couple.

Voltage

One measure of the "strength" of electricity is called volts. The technical definition of the term *volt* is quite complex and involves discussion of the energy that electrons transfer as they pass through a circuit. Students should only be concerned with voltage as a quantitative measure that enables them to compare the magnitude of one chemical reaction to another.

Electrical Circuits

In order to harness chemical energy as electrical energy, an electrical circuit must be made. This circuit can be quite simple. A single metal wire connecting the two electrodes will allow the electrical current to pass through it from one electrode to the other. In order to measure the amount of electrical force, a meter that measures the flow of energy can be placed in the circuit.

A circuit can also be made by linking the cells together, thus increasing the voltage. Often commercially available electronic devices that run on batteries are polarized. In other words, the flow of electricity can only go in one direction. You will recognized a polarized item by seeing the + and – symbols on the case where the battery is housed. When connecting the battery circuit built in the classroom to a polarized item such as an LCD clock, remember that the electrical current must flow in the correct direction. If the circuit does produce sufficient voltage (according to the DVM) but does not activate the clock, reverse the leads connected to the terminals on the clock. This will reverse the direction of the current.

The Voltaic Cell and Battery

The definitions of the voltaic cell and the battery are as follows:

1. **Voltaic cell:** the combination of two chemicals (electrodes) which react with each other on the atomic level when placed in an electrolytic solution. As the chemical reaction occurs, charged particles flow from one electrode to the other creating electrical energy.

2. **Battery:** the combination of two or more voltaic cells.

In Challenges 1 and 2 students are creating a single voltaic cell. In Challenges 3 and 4 students connect two or more voltaic cells to form a battery. Common usage of the term *battery* however, enables us to refer to this voltaic cell as a "battery cell" or simply a "cell." The term *voltaic cell* is named after the first apparent creator of it, Alessandro Volta (1745–1827).

Dry Cells and Wet Cells

Batteries can be divided into two classifications: wet and dry. These properties simply refer to the substance used as an electrolyte.

1. **Dry cell:** The most commonly thought of type of battery, used in flashlights, radios, or watches. The electrolyte is a paste rather than a liquid and is therefore considered to be dry.

2. **Wet cell:** The type of battery used in automobiles and other vehicles. The electrolyte is a liquid.

Students will be creating a wet cell in the challenges presented in this module.

Science Process Skills

Process Goals

- Controlling variables
- Teamwork
- Recordkeeping
- Multiple iterations
- Hypothesizing
- Synthesizing
- Interpreting data
- Relating observed behaviors to actual science concepts

Science Technology Society

The following STS connections are intended:

- Competition in industry
- Creative design: innovation, ingenuity
- Utilization of alternative energy sources and energy storage devices
- Roles in the working world
- Presentation skills

Assessment

Students' understanding of science concepts will be revealed in their work as they progress through the challenges. Assessment tools are provided for the teacher, but observations of the progress of each student, revealed in class discussions, worksheets, reports, storyboards, and design modifications will portray the complete picture of the student's progress.

History of THE Electric Battery

The late 1700s were wondrous years for human progress. Thoughts and ideas were being formulated around the world that would forever change how we live. Scientists worldwide were making great advances in many fields, including biology, chemistry, and physics. Many of the conveniences we take for granted in our modern lives can be directly attributed to the work of these scientists. Whenever you listen to your portable radio or use any electrical device that does not require a power cord, you are benefiting from research done by scientists two hundred years ago.

Animal Electricity

In 1780, Luigi Galvani (1737–1798) was a professor of anatomy at the University of Bologna in Italy. While conducting a dissection of a frog on a silver plate he observed that when his metal scalpel made contact with the muscle tissue, the frog would twitch uncontrollably. He reasoned that this reaction was due to electricity generated within the frog. He believed that the scalpel's metal merely triggered the reaction. Galvani's theory of animal electricity received widespread attention on both sides of the Atlantic and was supported by many prominent scientists of the day.

The First Battery

At the University of Pavia in 1794, the physicist Alessandro Volta (1745–1827) was experimenting with electrical reactions and was aware of Galvani's discovery. Although the two scientists were good friends and shared their ideas in letters, they disagreed about how the electrical force was produced. In a series of well-constructed experiments Volta became convinced that it was the different metals used for the plate and scalpel that created the electrical charge and not the frog's muscles.

Volta decided to perform the experiment in a slightly different way. He decided to use strips of the metals copper and zinc, rather than the silver of the plate and the metal of the scalpel. Placing a strip of copper on one side of his tongue and a strip of zinc on the other, he experienced an unpleasant taste in his mouth. When he wrapped an insulator around one of the metal strips and repeated the experiment, nothing happened; some ingredient was missing. He performed the experiment again by placing the strips of copper and zinc in brine, a type of salt solution. To his delight, he was able to produce an electrical charge. Today we refer to the brine solution as an electrolyte, while the strips of metal are electrodes. The electrodes react with each other chemically in the electrolyte to produce electrochemical energy. The combination of these materials was named the "voltaic cell" after its discoverer, Alessandro Volta.

Volta took his idea one step further. He assembled stacks of disks of the metals, placing paper soaked in brine as an electrolytic membrane between them. By stacking a series of these cells on top of each other he developed the first electrochemical battery, referred to as the voltaic pile.[1]

Meanwhile, however, Galvani had fallen on hard times. Because he did not accept the new government of Napoleon Bonaparte, he lost his academic position at the university. His wife had recently died as well, and his theory about the battery had been proven wrong. He died at his family home without knowing how his discovery would change the world.[2] He also would never realize that his theory of animal electricity, or the concept that all living cells possess some type of electrical property, was correct and was the forerunner of the field of science called electrophysiology.

Batteries for Everyone

In 1836 John Frederick Daniell (1790–1845), an English chemist and physicist, developed a type of wet-cell battery that produced electricity for much longer than the voltaic pile. The secret to this new design was the addition of sulfuric acid to the electrolyte. When he placed a copper cylinder and a zinc rod in the sulfuric acid electrolyte, the

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[1] *Encyclopedia Britannica,* 1998.

[2] Ibid.

amount of energy produced was greatly increased. Daniell learned that the addition of the new substance to the electrolyte improved its ability to conduct electricity.

In 1866 the French chemist Georges Leclanché (1839–1882) produced the Leclanché battery which was the forerunner of many modern batteries. He used ammonium chloride as an electrolyte, and zinc and manganese dioxide as electrodes. In a modified form, this cell is the portable battery that we commonly use in such devices as flashlights or radios.[3]

Mass production of batteries in the United States came about quickly. In 1890 the National Carbon Company in Cleveland, Ohio began selling dry-cell batteries in large quantities to consumers anxious to purchase them. Today this company is known as Union Carbide.[4] The battery industry has thrived ever since.

Today we use two types of batteries: wet cell and dry cell. The difference is simple. The wet cell uses a wet substance for the electrolyte, such as the brine in Volta's battery or the sulfuric acid in Daniell's. The dry cell, a more modern battery type, uses a partially dry, pasty substance as an electrolyte. The advantage of the dry cell is that it is more portable. Leclanché developed the first effective dry-cell battery.

The term *battery* is used generically to refer to any device that converts chemical energy directly into electrical energy. Although technically incorrect, we commonly refer to a single voltaic cell, a voltaic pile or an array of cells, all as batteries. By its true definition, only two or more voltaic cells connected together form a battery.

Today batteries are used for so many applications that it would be difficult to imagine life without them. Research is still being carried out to produce more efficient and environmentally friendly batteries. Within our lifetime, radical improvements will undoubtedly occur that will make this portable source of power better than ever.

[3] *Encyclopedia Britannica,* 1998.
[4] *Enercell Battery Guidebook*, Master Publishing, Inc., Richardson, Texas, 1990.

Class Preparation and Set-Up

Module Materials

Materials for the Battery Cells

- Data Sheets for each challenge
- 5% salt solution
- 10% salt solution
- 20% salt solution
- Distilled water
- Cola
- Tap water
- Aluminum foil, 2 inch (5 cm) squares, rolled (two per team)
- Copper wire, 14 gauge stranded bare antenna wire[1] (two inches [5 cm] per team for Challenges 1 and 2, 12 inches [30.5 cm] per team for Challenges 3 and 4)
- Iron nails, 10 penny (two per team)
- Toothpicks (two per team)
- Jumbo zinc-plated paper clips (two per team for Challenges 1 and 2, 14 per team for Challenge 3)
- Zinc-coated wire fencing, 1/2 inch (1.3 cm) grid (two 1 inch × 2 inch [2.5 × 5 cm] sections per team)
- Glass microscope slides, 1 × 3 inch (2.5 × 7.6 cm); (two per team)
- Pennies (two per team)
- Cellophane tape (one per team)
- Film canisters, 35 mm size (six per team, not all needed for each challenge)
- Index cards, 3 × 5 inch (7.6 × 12.7 cm); (two per team)
- Permanent marking pens (one per team)
- Styrofoam™ grocery trays pre-cut to make film canister stands (one per team)
- Scissors (one pair per team)
- Ruler (one per team)
- Electrode rinse container with water (one per team for Challenge 2)

[1]Radio Shack™ #278-1329 wire is recommended.

Materials for Testing Station

- Alligator clip test leads[2]
- Grabber-probe test leads[3]
- DVM Digital volt meter with test leads[4]
- LCD clock[5]
- Film canister stand

Construction

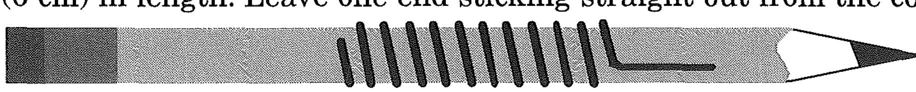
Based on the success or failure of their tests, the students design and create improved structures. Careful records are kept of each design, including the number of the test, as well as discussion of the reasons for success or failure. To keep these records, students can use journals, record sheets, or storyboards, all of which may be used later for student assessment at the teacher's discretion. At the end of each day it is important to have a full class discussion on the ideas which emerged during that class period.

Standard Design Battery for Challenges 1 and 2

1. Fill the film canister 2/3 full with electrolyte solution. Label the canister.
2. Select two types of electrodes and attach an alligator clip to each.
3. Connect the other ends of the alligator clips to the DVM
4. Place the metals in the electrolyte solution, making sure that the metals do not touch each other.
5. Record the reading from the DVM. (Note: most readings will probably be in tenths or hundredths of volts.) For information on DVMs, see *Using the Digital Volt Meter (DVM)* at the end of this section.

Standard Design Battery for Challenge 3

1. Coil the copper wire around a pencil so that it does not exceed 2 1/2 inches (6 cm) in length. Leave one end sticking straight out from the coil.



2. Cut an index card to a height of 1 7/8 inches (4.8 cm).
3. Roll the strip of paper into a cylinder with a diameter of approximately 1 inch. Secure the roll with cellophane tape.

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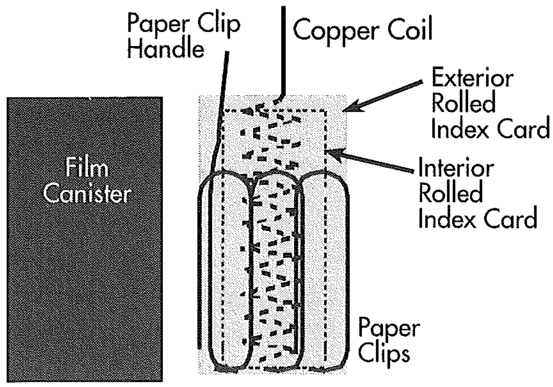
[2]Mini-Alligator 14-inch Insulated test cable set (Radio Shack™ #278-1156) are recommended for all challenges.

[3]Micro-clip Jumper wires 20-inch (Radio Shack™ #278-017) is recommended for Challenge 4.

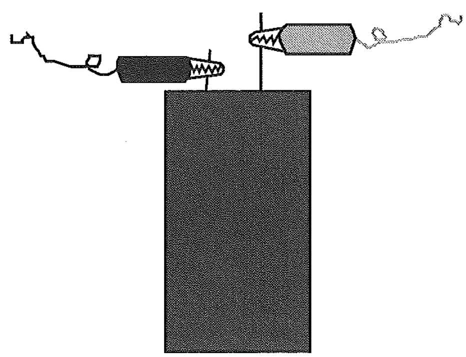
[4]Digital Multimeter (Sears™ #982015) is recommended for all challenges.

[5]Anywhere® clock (Radio Shack™ #63-736) is recommended for Challenge 4.

4. Attach 13 paper clips to the bottom edge of the cylinder. This tube must fit into the film canister. If it doesn't, make another with a smaller diameter.
5. Straighten one end of an additional paper clip to form a long handle. Attach the remaining clip portion to the bottom of the paper roll, contacting the other paper clips. You now have a handle by which to raise and lower the paper clip roll as well as a terminal to which you can attach the alligator clip.

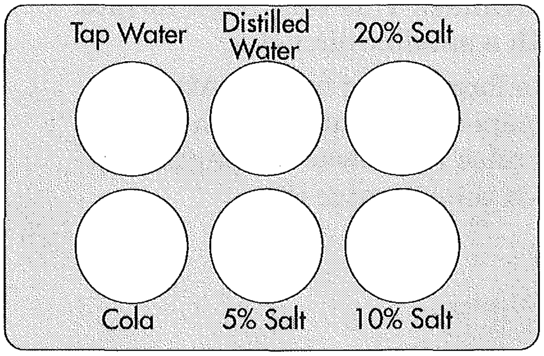


6. Place the paper clip section into the film canister.
7. Cut another index card to the same size listed in Step 2.
8. Roll the second index card so that it is slightly smaller than the first. Secure it with cellophane tape. This index card will separate the paper clip section from the copper coil.
9. Place the second rolled index card inside the paper clip section.
10. Insert the copper wire coil into the center of the rolled index card.
11. Add electrolyte solution to the film canister until it is 2/3 full.
12. Attach the alligator clips to the paper clip handle and the copper wire. You are now ready to test the battery cell.

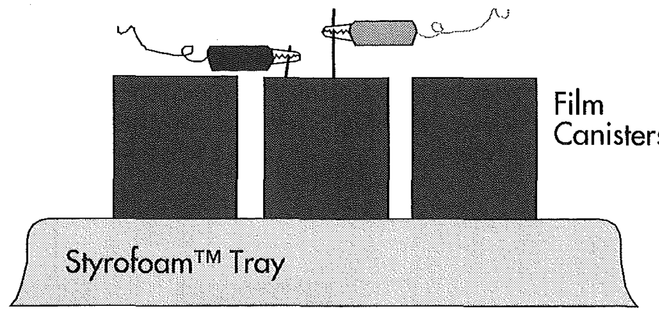


Film Canister Stand

Styrofoam grocery trays can be used to make a stand for the film canisters. Choosing sufficiently large trays, cut six 1 1/4 inch (3 cm) diameter holes in each tray. Place the trays upside down. As students place the canisters containing their electrolyte solutions in the tray, they can label each on the tray with a permanent marking pen.

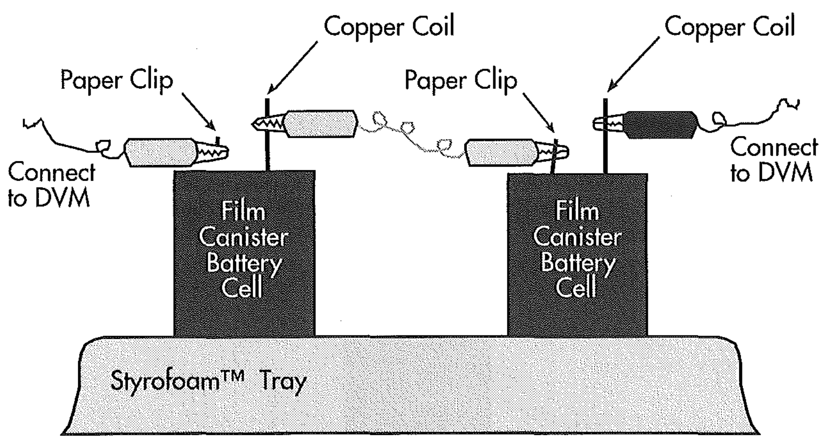


Styrofoam™ Tray



Testing Station for Challenges 1, 2, and 3

- The tests in Challenges 1 and 2 are conducted quite simply by connecting the two electrodes to a DVM, creating a complete circuit. The result is read in volts. (See *Using the Digital Volt Meter (DVM)* on the following page for instructions regarding the use and effectiveness of these devices.) In Challenge 3 two cells are connected in series and the combined voltage is read. Challenge 3 requires that the circuit be arranged correctly; like electrode materials should not be connected to each other (e.g., aluminum cannot be connected to aluminum).



Testing Station for Challenge 4

- The intent of Challenge 4 is to operate an actual device. Students construct batteries in film canisters, then link the reactive metals of the batteries to the terminals of an LCD clock using alligator clips. If the clock lights up, the test is successful.
- Make sure that the circuit constructed in Challenge 4 is connecting the positive and negative terminals correctly. If the initial test of the student's battery does not work, reverse the leads and try the test again.
- For unsuccessful iterations, students should test their batteries on the DVM to determine if the battery's voltage is too low or if their battery is not functioning at all.

Using the Digital Volt Meter (DVM)

A DVM is a device that can be used to measure the amount of voltage produced by a cell, battery, or circuit.

Basic Operation

1) Connect the red test lead to the V/Ω jack. Connect the black test lead to the COM jack.

2) Set the rotary/function switch to the highest scale on the VDC setting, switching down the scale until a satisfactory range is obtained. Since the rotary/function switch also serves as the off/on switch on most DVM units, the meter should read (+ or –) 000. For use in the battery module the most accurate readings will be registered on the 2000 m (2K millivolt) scale.

3) Attach one end of a red alligator clip test lead to the red test lead from the DVM. Attach one end of a black alligator clip test lead to the black test lead from the DVM. You are now ready to measure voltage.

Quick Test of DVM Operations

Using the steps outlined above, try testing a new AA battery. Place one alligator clip on the positive terminal and the other on the negative terminal of the battery. The readout (if the DVM is set on the 2000 m scale) should indicate a number between 1000 and 1900. If a negative sign appears in front of the readout (for example: –1500), the polarity between the meter and battery has been reversed. Switch the test leads attached to the battery and the negative symbol should disappear. Note that on the 2000 m scale no decimal point appears.

Measuring the Voltage of a Batteries Module Cell

1) Attach the DVM leads to the cell and correct for proper polarity if needed (for example, the copper electrode is usually the positive terminal whereas the other electrode is the negative terminal). Wait 10 seconds for the voltage to register properly. Monitor the readout on the meter. Most electrode readings will either rise or fall as the chemical reactions take place. If a change is noted use the first two significant digits to record voltage.
touching.

Pretest

Before constructing the standard design, administer the pretest to determine students' thoughts about electrochemical reactions.

Brainstorming Questions

Lead a class discussion by asking students the following questions:

- What do you think is inside a battery?
- How do you think a battery works?
- How do we use batteries?
- Do batteries make energy?
- Do batteries store energy?

Challenge 1
FIND THE Best Electrodes

Challenge Objective

Test combinations of two electrodes at a time to determine which pair works best.

Challenge Scenario

You are an archaeologist working in a remote desert location. Your water supply is running short and you need to send word to the base camp that you need more. When you turn on your walkie-talkie, however, the battery is dead. You have no other batteries for it. You know that certain materials will react with each other to produce electricity, so you begin by testing the materials that you find in your camp. You must find the materials that produce the most voltage to run your walkie-talkie.

Materials

- Aluminum foil
- Copper wire
- Iron nail
- Toothpick
- Jumbo zinc-plated paper clips
- Zinc-coated wire fencing
- Glass microscope slide
- Penny
- 10% salt solution
- Data Sheet
- Film canister, 35 mm size

Test Station Materials

- Alligator clip test leads
- DVM (digital volt meter) with test leads
- Film canister stand

Troubleshooting Tips

Meter Problems

- If no readout appears on the DVM screen, make sure the meter is turned on. Check its battery (usually a 9-volt battery, accessible from the rear).
- If the meter shows a readout but doesn't display voltage, make sure that the function setting switch is on the proper setting. Also, make sure that test leads are properly attached. Test the meter with a known functioning battery, such as one purchased recently from a store.
- If the meter readout fluctuates erratically, increase the voltage DC setting by one interval on the function switch (i.e., 200 mV to 20 volts).

Electrode/Cell Problems

If extremely low voltage readings are measured, check for the following:

- Check the meter to make sure that it is functioning properly.
- Make sure the electrodes aren't touching. Contact between electrodes will give a near-zero voltage.
- Check the connections between test leads and electrodes.
- Make sure that electrodes are the right type to produce an electrochemical reaction.
- Check the electrolyte. If it's not a conductor, voltage readout will be minimal.
- Alligator clips should not touch the electrolyte solution.

Procedures

Set-Up

Construct and display a basic battery using the 10% salt solution electrolyte, a paper clip, and a piece of rolled aluminum foil.

Demonstration

Show students the basic battery cell and demonstrate how to connect the alligator clips and read the voltage on the DVM. Avoid dipping the alligator clips into the electrolyte.

Class Discussion

Ask students to explain how they think the basic battery works. Ask them to speculate on how to improve its performance through design changes.

Cooperative Learning Groups

Challenge student teams to find the combination of electrodes that produces the most voltage.

Instructions to Students

All teams must document and publish their progress. After running each test, teams post their results on a graph or chart for public viewing.

Challenge 1: Data Sheet

Find the Best Electrodes

TEAM NAME: **DATE:**

Procedures

1. Place a film canister in the stand provided by the teacher.
2. Fill the canister 2/3 full with the electrolyte.
3. Connect one alligator clip to each electrode in the pair that you are testing.
4. Connect the other ends of the alligator clips to the DVM test leads.
5. Immerse the electrodes in the electrolyte. Make sure that the alligator clips do not go into the electrolyte!
6. Wait 10 seconds, then read and record the first two digits of the number displayed on the DVM. The third digit will indicate if the voltage is increasing or decreasing.
7. Remove one electrode and replace it with the next to be tested.
8. Repeat steps 5–7 until all electrodes are tested and the Voltage Chart below is completely filled in.

Voltage Chart

	Aluminum foil	Copper wire	Paper clip	Tooth-pick	Glass plate	Zinc-coated fencing	Penny	Iron nail
Aluminum foil								
Copper wire								
Paper clip								
Toothpick								
Glass plate								
Zinc-coated fencing								
Penny								
Iron nail								

Test Results

9. Which two materials produced the highest reading?

______________________________ ______________________________

10. Which two materials produced the lowest reading?

______________________________ ______________________________

11. What do you think was happening to produce the electricity?

____

____

____

____

____

Challenge 1 Wrap-Up

Questions for Class Discussion

- Which design changes did you find to be the most useful?
- Why do you think they worked so well?
- What combination of electrode materials worked the best?
- What combination of electrode materials worked the worst?

Performance Variables

- Materials used for electrodes

  Certain combinations produce greater electrochemical reactions.
- Material used for electrolyte

  This variable is held constant for this challenge so that students will focus on the electrode materials and learn how they interact.

Competence & Performance Criteria

Each student's design should be evaluated to determine if it produced sufficient and reliable voltages during the tests. Additionally, students should be evaluated based on the results that they recorded on their Data Sheets as well as the organization and neatness of their Data Sheets.

Challenge 2

FIND THE Best Electrolyte

Challenge Objective

Test the various electrolytes provided by the teacher to determine which will act as the best conductor.

Scenario Change

Now that you have found the two materials that react with each other to produce the most voltage, you must find a substance in which they can react most efficiently. You have several liquids in your camp that you must test to see which will produce the most voltage.

Materials

- The two electrodes that produced the best results in Challenge 1
- 5% salt solution
- 10% salt solution
- 20% salt solution
- Distilled water
- Cola
- Tap water
- Data Sheet
- Film canisters
- Electrode rinse container with water

Test Station Materials

- Alligator clip test leads
- DVM (digital volt meter) with test leads
- Film canister stand

Troubleshooting Tips

Meter Problems

- If no readout appears on the DVM screen, make sure the meter is turned on. Check its battery (usually a 9-volt battery, accessible from the rear).
- If the meter shows a readout but doesn't display voltage, make sure that the function setting switch is on the proper setting. Also, make sure that test leads are properly attached. Test the meter with a known functioning battery, such as one purchased recently from a store.
- If the meter readout fluctuates erratically, increase the voltage setting by one interval on the function switch (i.e., 200 mV to 20 volts).

Electrode/Cell Problems

If extremely low voltage readings are measured, check for the following:

- Check the meter to make sure that it is functioning properly.
- Make sure the electrodes aren't touching. Contact between electrodes will give a near-zero voltage.
- Check the connections between test leads and electrodes.
- Make sure that electrodes are the right type to produce an electrochemical reaction.
- Check the electrolyte. If it's not a conductor, voltage readout will be minimal.
- Alligator clips should not touch the electrolyte solution.

Procedures

Set-Up

Refer students to the basic battery set-up constructed for Challenge 1.

Demonstration

Show students the basic battery and demonstrate how to connect the alligator clips and read the voltage on the DVM.

Class Discussion

Ask students to explain what they think the electrolyte does. Ask them to speculate on how to improve its performance through design changes.

Cooperative Learning Groups

Challenge student teams to find the electrolyte that works as the best conductor to produce the most voltage.

Instructions to Students

All teams must document and publish their progress. After running each test, teams post their results on a graph or chart for public viewing.

Challenge 2: Data Sheet

Find the Best Electrolyte

TEAM NAME: **DATE:**

Procedures

1. Place six canisters in your test stand.
2. Fill each canister 2/3 full with each type of electrolyte. Write the name of the electrolyte on the test stand in front of the canister.
3. Connect the two best electrodes from Challenge 1 to alligator clips on the DVM.
4. Immerse the electrodes in the first electrolyte.
5. Read and record the voltage.
6. Repeat steps 4 and 5 until all electrolytes have been tested. Make sure that you rinse the electrodes in water between each test.

Electrolyte Table

Electrolyte	Voltage
5% salt solution	
10% salt solution	
20% salt solution	
Distilled water	
Cola	
Tap water	

Test Results

7. Which electrolyte caused the battery to produce the highest voltage?

8. Why do you think this electrolyte worked the best? What was happening in the battery?

Challenge 2 Wrap-Up

Questions for Class Discussion

- Which electrolyte was the best conductor?
- Why do you think this electrolyte worked so well?
- Which electrolyte was the poorest conductor?

Performance Variables

- Substance used for electrolyte

  Certain electrolytes are better conductors than others.
- Materials used for electrodes

  This variable is held constant for this challenge so that students will focus on the electrolyte to learn about conductive properties. The best materials for the electrodes, determined from Challenge 1, are used here.

Competence & Performance Criteria

Each student's design should be evaluated to determine if it produced sufficient and reliable voltages during the tests. Additionally, students should be evaluated based on the results that they recorded on their Data Sheets as well as the organization and neatness of their Data Sheets.

Challenge 3
Increase Volts

Challenge Objective

Construct a battery cell in a film canister and test it to determine how many volts it produces. Then, divide the electrode materials in half and construct two battery cells. Test these cells in a series circuit to see if the number of volts increases.

Scenario Change

You have only a limited amount of the best electrode material available. You must increase the voltage of your battery without using more electrode material.

Materials

- 14 jumbo zinc-plated paper clips
- 12 inches (30.5 cm) of copper wire
- Two 3-inch x 5-inch (7.6 x 12.7 cm) index cards
- 10% salt solution
- Two film canisters
- Alligator clips
- Data Sheet
- Cellophane tape

Test Station Materials

- Alligator clip test leads
- DVM (digital volt meter) with test leads
- Film canister stand

Troubleshooting Tips

Meter Problems

- If no readout appears on the DVM screen, make sure the meter is turned on. Check its battery (usually a 9-volt battery, accessible from the rear) and fuse.
- If the meter shows a readout but doesn't display voltage, make sure that the function setting switch is on the proper setting. Also, make sure that test leads are properly attached. Test the meter with a known functioning battery, such as one purchased recently from a store.
- If the meter readout fluctuates erratically, increase the setting by one interval on the function switch (i.e., 200mV to 20 volts).

Electrode/Cell Problems

- When adding paper clips to the cell make sure that they are all touching.
- If there is no increase in voltage when the two cells are attached to each other, make sure that the cells are connected in series (see assembly instructions).
- Make sure that the electrodes are not touching. Contact between electrodes will give a near-zero voltage.

Procedures

Set-Up

Make a battery cell in a film canister by following the procedures shown on the student Data Sheet.

Demonstration

Connect an alligator clip to one of the paper clips. Connect another alligator clip to the end of the copper wire. Read the voltage produced on the DVM.

Class Discussion

Ask students to explain how they think the battery works in the circuit. Ask them to speculate on ways to alter the battery's performance so that they can increase or decrease the voltage.

Cooperative Learning Groups

Challenge student teams to produce the greatest amount of voltage.

Instructions to Students

All teams must document and publish their progress. After running each test, teams post their results on a graph or chart for public viewing.

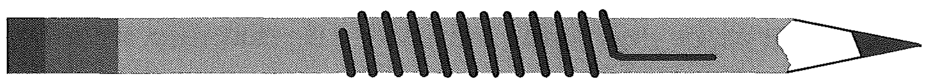
Challenge 3: Data Sheet

Increase Volts

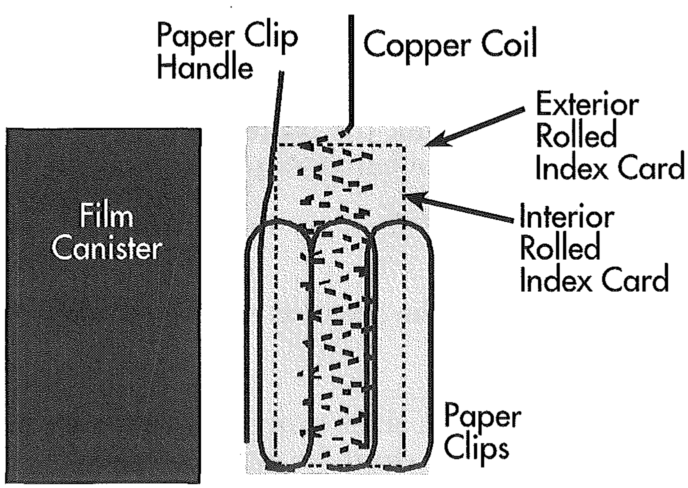
TEAM NAME: **DATE:**

Procedures

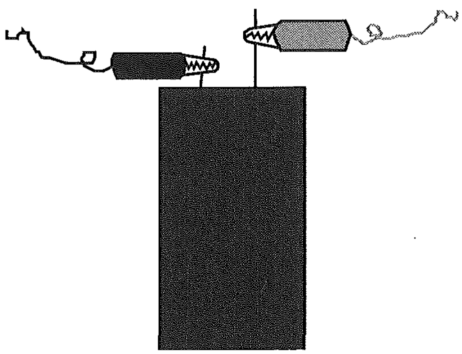
1. Coil the copper wire around a pencil so that it does not exceed 2 1/2 inches (6 cm) in length. Leave one end sticking straight out from the coil.



2. Cut an index card to a height of 1 7/8 inches (4.8 cm).
3. Roll the strip of index card into a cylinder with a diameter of approximately 1 inch (2.5 cm). Secure the roll with cellophane tape.
4. Attach 13 paper clips to the bottom edge of the cylinder. This tube must fit into the film canister. If it doesn't, make another that is smaller.
5. Straighten one end on an additional paper clip to form a long handle. Attach the remaining clip portion to the bottom of the paper roll, contacting the other paper clips. You now have a handle by which to raise and lower the paper clip roll as well as a terminal to which you can attach the alligator clip.



6. Place the paper clip section into the film canister.
7. Cut another index card to the same size listed in Step 2.
8. Roll the second index card so that it is slightly smaller than the first. Secure it with cellophane tape. This index card will separate the paper clip section from the copper coil.
9. Place the second rolled index card inside the paper clip section.
10. Insert the copper wire coil into the center of the rolled index card.
11. Add electrolyte solution to the film canister so that it is 2/3 full.
12. Attach the alligator clips to the paper clip handle and the copper wire. You are now ready to test the battery cell.



13. Indicate the type of material used for the electrodes and electrolyte:

    Electrolyte: ____________________ Electrode 1: ____________________

    Electrode 2: ____________________
14. Test your battery at the test station. Record the number of volts: ___
15. Disassemble your battery, but do not take apart the index card rolls.
16. Divide the materials used for the electrodes in half. (Have the teacher cut the copper wire in half for you.)
17. Make *two* battery cells each with half of the original electrode material. Follow steps 1–12 to create two battery cells. Fill each canister 2/3 full with electrolyte.

Challenge 3: Data Sheet (continued)

TEAM NAME: **DATE:**

18. Indicate the type of each material used.

Battery A	Battery B
Electrolyte: ________________	Electrolyte: ________________
Electrode 1: ________________	Electrode 1: ________________
Electrode 2: ________________	Electrode 2: ________________

19. Test both batteries at the test station. Record the number of volts.

Battery A: ________________ volts
Battery B: ________________ volts

Test Results

20. Compare the voltage reading from the first test to voltage results of the second test. Do you notice anything unusual about the tests? Did the batteries constructed with half as much electrode material produce half as many volts?

____

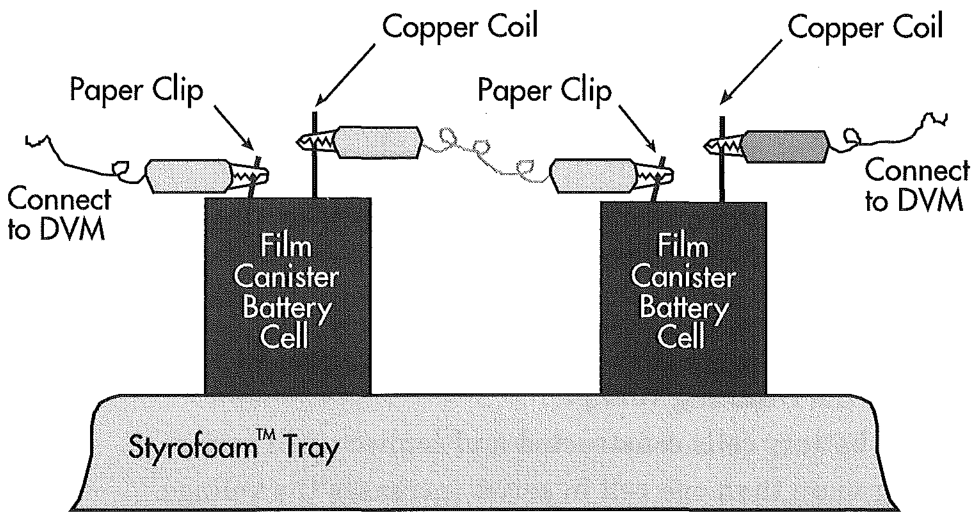
____

____

____

____

21. Connect the batteries to each other in a series circuit as shown in the diagram below. Test the circuit and record your results below:



Circuit volts: ________

22. Did your test of the circuit produce more or fewer volts than each single battery cell? Explain what you think happened.

____

____

____

Challenge 3 Wrap-Up

Questions for Class Discussion

- Which design changes did you find to be the most useful?
- Why do you think they worked so well?
- Why did the number of volts produced remain the same for each battery regardless of the amount of electrode material used?
- What alterations did you make to increase the voltage?

Performance Variables

- Amount of materials used for electrodes

  Altering the amount of material used for the electrodes has little or no effect on the resulting voltage.
- Number of battery cells constructed and connected in series

  Combining more than one cell in series increases the voltage.

Competence & Performance Criteria

Each student's design should be evaluated to determine if it produced sufficient and reliable voltages during the tests. Additionally, students should be evaluated based on the results that they recorded on their Data Sheets as well as the organization and neatness of their Data Sheets.

Challenge 4
Turn On the Clock

Challenge Objective

Using the materials from the previous challenges, construct a battery cell or series of battery cells that will provide sufficient voltage to turn on a liquid crystal display (LCD) clock.

Scenario Change

Your experiments have shown how you can achieve the maximum voltage output from your battery cell. Now you must combine cells so that you have enough volts to operate your walkie-talkie and call for more water!

Materials

- 5% salt solution
- 10% salt solution
- 20% salt solution
- Distilled water
- Cola
- Tap water
- Aluminum foil
- Copper wire
- Iron nail
- Jumbo zinc-plated paper clips
- Zinc-coated wire fencing
- Glass microscope slide
- Penny
- Cellophane tape
- Index cards
- Permanent marking pen
- Film canister stand
- Scissors
- Ruler
- Film canisters
- Alligator clip test leads
- Data Sheet (one for each iteration)

Test Station Materials

- DVM (digital volt meter)
- LCD clock in circuit using grabber-probe test leads
- Alligator clip test leads

Troubleshooting Tips

Meter Problems

- If no readout appears on the DVM screen, make sure the meter is turned on. Check its battery (usually a 9-volt battery, accessible from the rear) and fuse.
- If the meter shows a readout but doesn't display voltage, make sure that the function setting switch is on the proper setting. Also, make sure that test leads are properly attached. Test the meter with a known functioning battery, such as one purchased recently from a store.
- If the meter readout fluctuates erratically, increase the setting by one interval on the function switch (i.e., 200 mV to 20 volts).

Electrode/Cell Problems

- When adding paper clips to the cell make sure that they are all touching.
- If there is no increase in voltage when the two cells are attached to each other, make sure that the cells are connected in series (see assembly instructions).

If extremely low voltage readings are measured, check for the following:

- Check the meter to make sure that it is functioning properly.
- Make sure the electrodes aren't touching. Contact between electrodes will give a near-zero voltage.
- Check the connections between test leads and electrodes.
- Make sure that electrodes are the right type to produce an electrochemical reaction.
- Check the electrolyte. If it's not a conductor, voltage readout will be minimal.
- Alligator clips should not touch the electrolyte solution.

LCD Clock Does Not Operate

- Make sure that the clock works with its original battery.
- Make sure that the test leads from students' cells are connected to the proper terminals of the clock.
- Make sure that the students' cells produce enough voltage to power the clock.

Procedures

Set-Up

Construct two batteries in film canisters and connect them in a series circuit as a model for students to review.

Demonstration

Demonstrate how the battery cells in the circuit will produce increased voltage on the DVM. Tell the students that at least 1.2 volts are required to turn on the LCD clock.

Class Discussion

Ask students to explain how they think the battery works in the circuit. Ask them to speculate on ways to improve the design so that sufficient voltage is generated to turn on the LCD clock.

Cooperative Learning Groups

Challenge student teams to make a battery or series of batteries that powers the LCD clock.

Instructions to Students

All teams must document and publish their progress. After running each test, teams post their results on a graph or chart for public viewing.

Challenge 4: Data Sheet

Turn On the Clock

TEAM NAME: **DATE:**

1. In this Challenge we must generate enough power to operate a liquid crystal display (LCD) clock. These clocks require approximately 1.2 volts to operate.
2. Examine the results of the first three challenges. Using your knowledge of the materials and the construction of batteries, make a battery cell or series of cells that will power the LCD clock.
3. Sketch your design below. Indicate the type and amount of each electrode and electrolyte used as well as the connections that must be made between the batteries to form a circuit.

4. Test your battery at the LCD clock test station. Circle one:

   SUCCESSFUL   UNSUCCESSFUL

5. If the test was unsuccessful, measure the voltage and record the amount:

   _________ volts

6. Why do you think that the design succeeded or failed? What features of the battery cell could you alter to improve its performance?

   ____

   ____

   ____

   ____

   ____

7. If the design failed, alter it, complete another Data Sheet, and test it again.

Challenge 4 Wrap-Up

Questions for Class Discussion

- Which design changes did you find to be the most useful?
- Why do you think they worked so well?
- What combination of electrode materials worked the best?
- Which electrolytic solution worked the best?
- How did your design increase the voltage supply to the clock?

Performance Variables

- Materials used for electrolyte

  Certain electrolytes work as conductors better than others. A good conductor is required to promote the electrochemical reaction caused by the electrodes.
- Materials used for electrodes

  Certain combinations of materials produce a greater electrochemical reaction than others.
- Number of battery cells constructed

  Increasing the number of separate electrochemical reactions taking place and placing these in series within a circuit increases the overall energy produced.

Competence & Performance Criteria

Each student's design should be evaluated to determine if it produced sufficient and reliable voltages during the tests. Additionally, students should be evaluated based on the results that they recorded on their Data Sheets as well as the organization and neatness of their Data Sheets.

Wrap-Up Activities

Class Discussion Questions

Use any of the following questions to initiate student discussion about ideas explored during the design challenges:

- Did you ever think about chemical reactions before doing these challenges? What were your thoughts?
- How are the challenges that you encountered here different from what an engineer would have to deal with when designing a battery in the "real world"? What other factors might the engineer consider?
- What would you do to explain how a battery works to a young child?
- In what other situations would your understanding of chemical reactions and electrical circuits be useful?
- In what other situations could you use your design skills or your experience building and testing models?
- Form an analogy comparing a battery with some other device.

Report Topics

The following topics are suggested for student reports, presentations, or journal entries:

- Write the history of how you developed your design for one of the challenges. Where did you have the most success? Why did you make your design changes?
- Describe how your ideas changed during the design process from one challenge to the next.
- Write a creative story featuring a battery. Use the story to explain chemical reactions and electrical circuits.
- Now that you have completed the Batteries Module, list any questions that you still have about designing batteries. Include ideas for how you might find answers to your questions through research and/or experimentation.

Storyboard Frame Design

Once students have completed the challenges they will have records of their designs on their Data Sheets. This information may be used in creating storyboards.

A storyboard is a formal poster which is built during the design challenges. A large sheet of cardboard or poster board can be used. Divide the sheet into several large sections. After each design iteration, ask students to record their designs on the storyboard (they may either sketch the design or tape components of their actual battery cells to the storyboard). The storyboards can be displayed in the classroom as "works in progress."

The following items should be included in the storyboard frames:

- Drawing of the design
- Material used for the electrolyte
- Materials used for the electrodes
- Volts measured
- Successful or unsuccessful when attempting to power the LCD clock
- The changes made from the previous design
- The changes that the student would make to a future design

In-Class Assignments or Homework Assignments

Teacher's Note

Throughout the module, you may wish to assign additional work for students to complete either in class, while waiting between test trials, or at home. These activities support cross-curricular team teaching and can be assigned through other classes. You can also use the assignments as a re-teaching tool, or as part of student assessment.

Vocabulary

The vocabulary sheet provided is a list of terms and concepts encountered during the module. Students should use complete sentences and should write definitions in their own words. They may use dictionaries or science books to assist with definitions, but should not copy directly from these references. Students should display their understanding of the terms by using examples from the challenges that they have completed.

Graphing

Students make bar graphs using their data from Challenges 1 and 2. These graphs provide a visual representation and method of comparison for the different types of electrolytes and electrodes.

The History of Batteries

Students answer questions about what they have learned from reading the **History of Batteries**.

Devices that Use Batteries

Students are encouraged to look around them and consider the multitude of uses for batteries.

Assessment

Assessing Student Competence

Students have effectively mastered the concepts presented in this module if they have achieved the following:

- Student can use batteries to explain the concepts of chemical reactions and electrochemical reactions.
- Student has an understanding of the principles behind an electrochemical reaction.
- Student can use the battery to explain how an electrochemical reaction works and how a circuit must be formed to test this reaction.
- Student can record volts using a DVM.
- Student can graph data results.

Criteria

Science Process Skills

The student has learned the correct science process skills if the following criteria have been met:

- The student was able to **define single variables** during the design process and **formulate experiments** that tested the importance of each variable.
- The student has used the results of one experiment to provide information for the next.
- The student has used the data sheets effectively to record information about each design.

Concept Knowledge

Evaluate the student's knowledge of concepts by answering the following questions:

- How is the student thinking about electrochemical reactions in the context of the battery design?
- Is the student able to explain electrochemical reactions and electrical circuits using examples from the various designs?

Student Products

Teachers may wish to have students produce final products that encapsulate the results of the challenges in a format other than the storyboard. Portfolios, posters, and reports are suggested products for this purpose and can be used to assess the student's understanding of the module.

Portfolios

Students create a portfolio using copies of their Data Sheets as well as any written assignments. Ask students to include an introduction explaining what they learned during the module.

Posters

Students design a poster which explains each design challenge using drawings, diagrams, and written explanations.

Reports

Students are assigned a report topic from the list shown in the **Wrap-Up Activities** section of this module. Researching and writing reports allows students to analyze a particular challenge or concept more deeply, increasing their understanding of the module topic.

Answers for Worksheets

Vocabulary

Use with student pages 29–30

Write definitions to the following terms in complete sentences and in your own words. You may use dictionaries or science books to help you with definitions. Use examples from the challenges that you have completed.

electrochemical reaction ***When placed together in a conductive solution, some materials interact and change to produce energy. When a chemical change produces electricity, the result is known as an electrochemical reaction.***

electrolyte ***A solution that allows electrical energy to travel through it.***

electrode ***A material that reacts with another material electrochemically to form electricity. A circuit can be formed between electrodes, enabling the flow of electricity.***

circuit ***A path constructed from one electrode of a battery to another which allows electricity to flow in a complete circle, flowing out from one electrode and back in to the other.***

volt ***A unit of measure that indicates the force of electricity used or produced.***

battery ***A device in which an electrochemical reaction is formed to produce electricity.***

LCD ***Liquid Crystal Display. This device, commonly used for digital readout devices such as clocks or thermometers, requires very little energy to operate.***

conductor ***Any material in any state (i.e., solid, liquid, or gas) that promotes the flow of electricity.***

insulator ***Any material in any state (i.e., solid, liquid, or gas) that inhibits the flow of electricity.***

Graphing

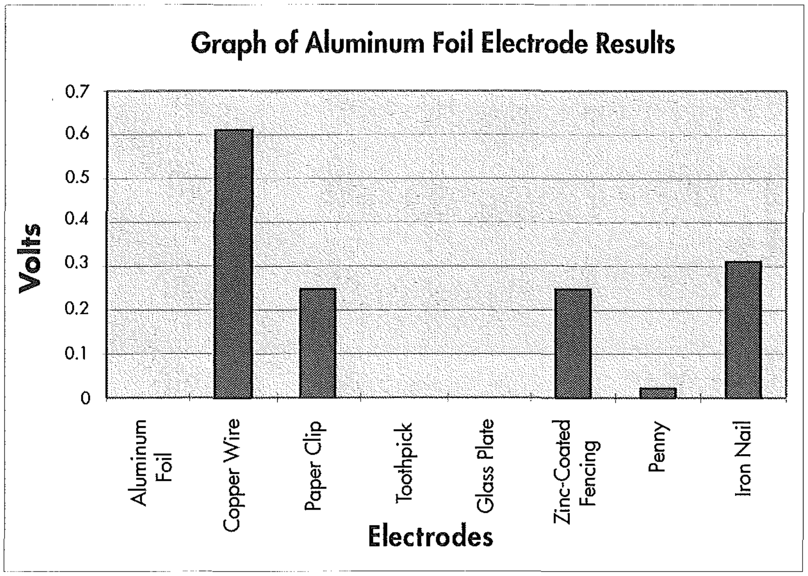
Use with student pages 31–36

Using the data from the challenges, create the following graphs.

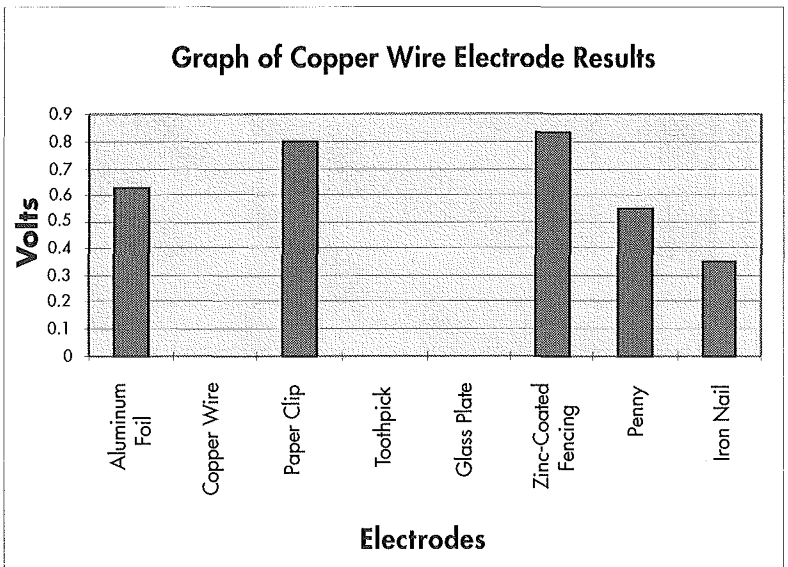
Challenge 1: Find the Best Electrodes

Using the blank graphs below, make bar graphs for the results of each electrode tested showing the number of volts measured for each combination.

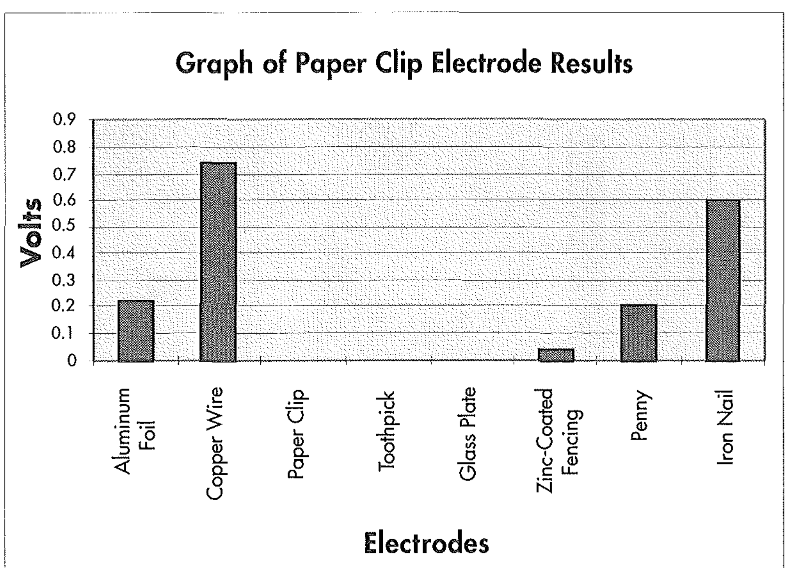
Graphs will vary from those presented here depending on students' test results. These are provided as examples only.



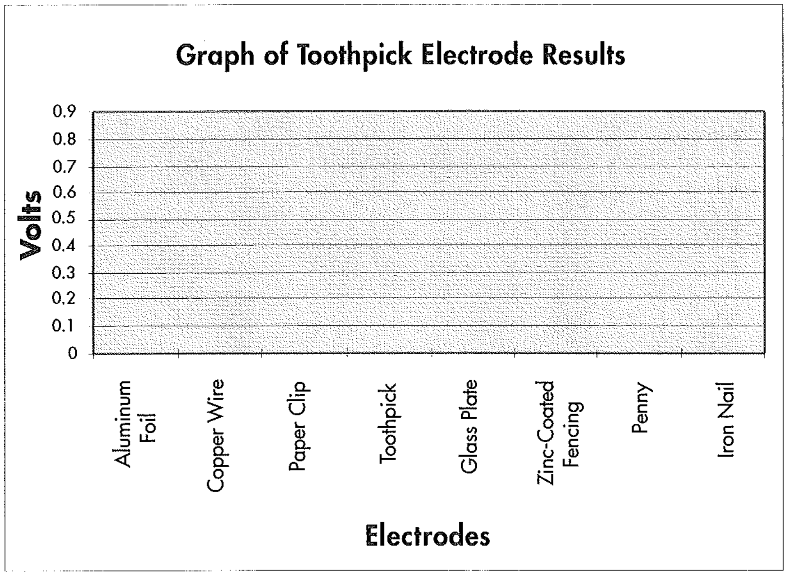
Graph of Aluminum Foil Electrode Results
Volts
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Aluminum Foil
Copper Wire
Paper Clip
Toothpick
Glass Plate
Zinc-Coated Fencing
Penny
Iron Nail
Electrodes

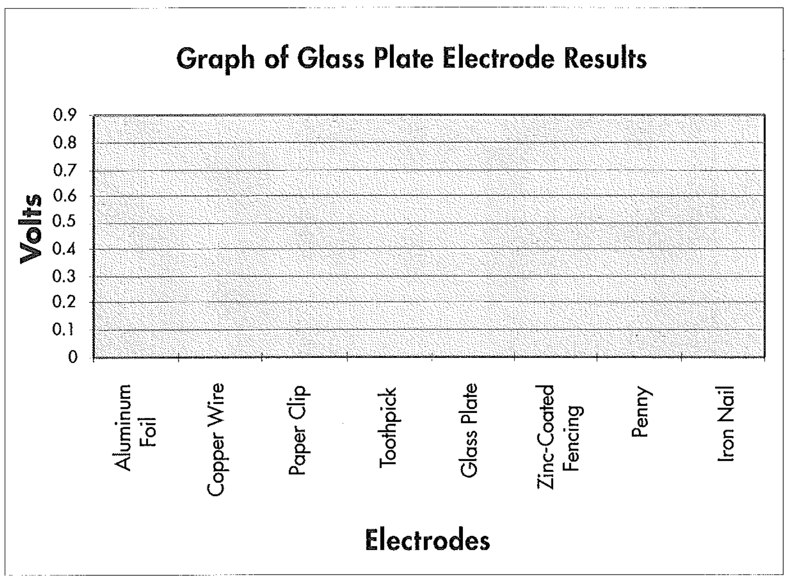


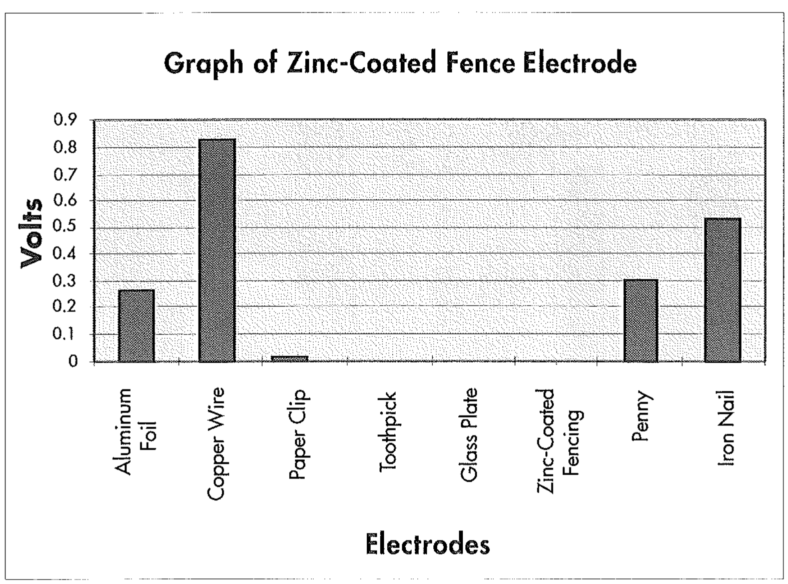
Graph of Copper Wire Electrode Results
Volts
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Aluminum Foil
Copper Wire
Paper Clip
Toothpick
Glass Plate
Zinc-Coated Fencing
Penny
Iron Nail
Electrodes

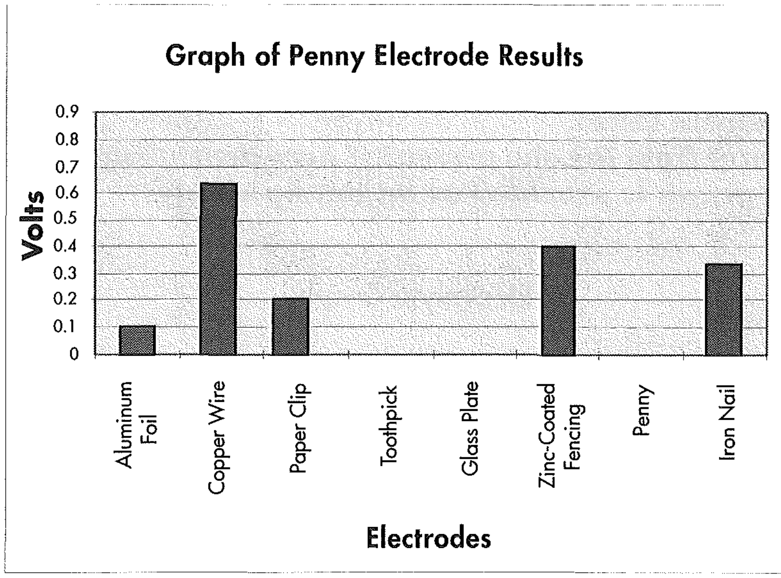


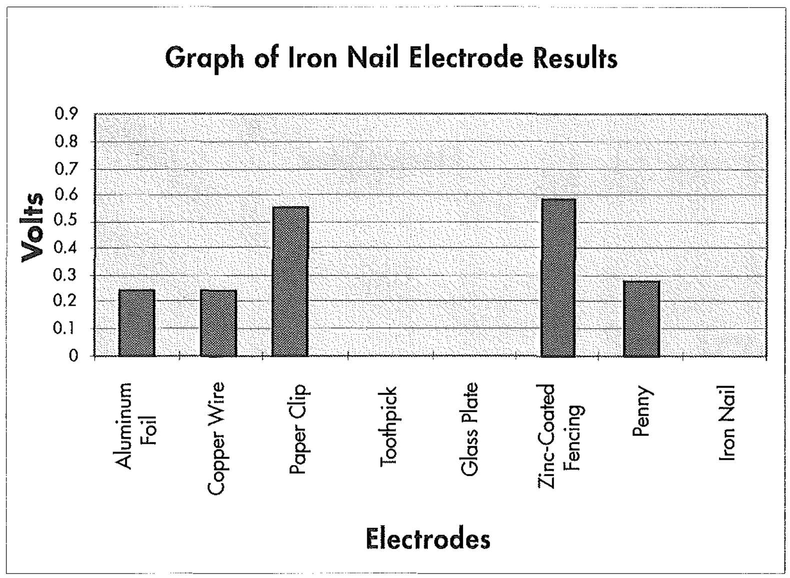
Graph of Paper Clip Electrode Results
Volts
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Aluminum Foil
Copper Wire
Paper Clip
Toothpick
Glass Plate
Zinc-Coated Fencing
Penny
Iron Nail
Electrodes


Graph of Toothpick Electrode Results
Volts
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Aluminum Foil
Copper Wire
Paper Clip
Toothpick
Glass Plate
Zinc-Coated Fencing
Penny
Iron Nail
Electrodes


Graph of Glass Plate Electrode Results
Volts
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Aluminum Foil
Copper Wire
Paper Clip
Toothpick
Glass Plate
Zinc-Coated Fencing
Penny
Iron Nail
Electrodes


Graph of Zinc-Coated Fence Electrode
Volts
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Aluminum Foil
Copper Wire
Paper Clip
Toothpick
Glass Plate
Zinc-Coated Fencing
Penny
Iron Nail
Electrodes

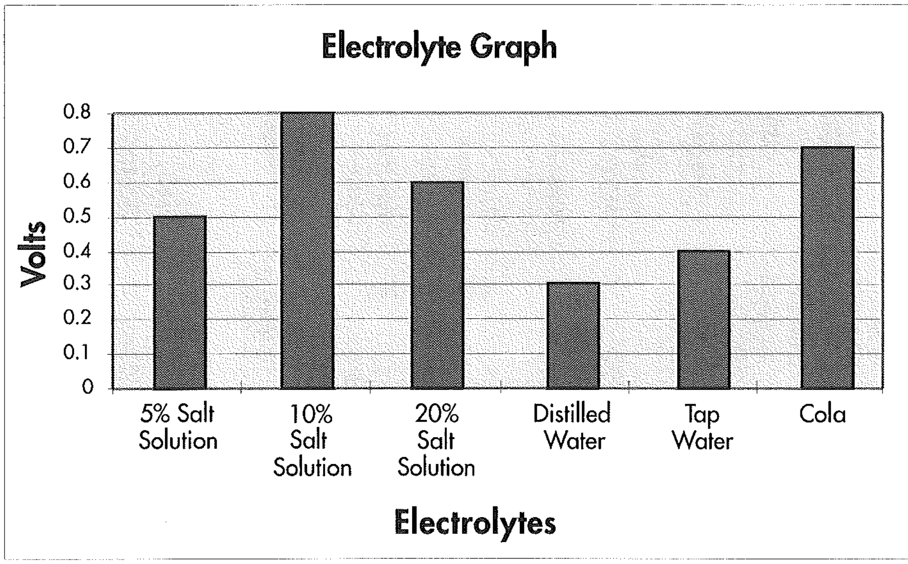

Graph of Penny Electrode Results
Volts
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Aluminum Foil
Copper Wire
Paper Clip
Toothpick
Glass Plate
Zinc-Coated Fencing
Penny
Iron Nail
Electrodes


Graph of Iron Nail Electrode Results
Volts
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Aluminum Foil
Copper Wire
Paper Clip
Toothpick
Glass Plate
Zinc-Coated Fencing
Penny
Iron Nail
Electrodes

Challenge 2: Find the Best Electrolyte

Using the blank graph, make a bar graph showing the number of volts measured for each electrolytic substance tested.

Graph will vary from the one presented here depending on students' test results. This graph is provided as an example only.



The History of the Electric Battery

Use with student pages 37–40

Answer the following questions in complete sentences.

1. Who first noticed that electricity could be produced using two metals and a third substance (in this case a frog)? When did this occur?
   Luigi Galvani, a professor of anatomy, first made this discovery in 1780.
2. According to Galvani, what produced the electricity that he observed?
   The muscle tissue of a frog.
3. How did Alessandro Volta first alter Galvani's experiment? What did he detect?
   Volta used copper and zinc metals and placed them on his tongue. He experienced an unpleasant taste, which told him that something was happening.
4. How did Volta change his own experiment to detect electricity?
   Volta put zinc and copper in a brine, which produced an electrical charge.
5. What did Volta use as an electrolyte? What materials did he use as electrodes?
   The brine served as Volta's electrolyte while the zinc and copper strips were the electrodes.

6. What is a voltaic cell?

The combination of an electrolyte and two electrodes that generates electrical energy is called a voltaic cell.

7. What is a voltaic pile?

Volta's stack of voltaic cells is called a voltaic pile.

8. What is different about the electrolyte in a voltaic pile compared to a voltaic cell?

Paper soaked in brine placed between the metal electrodes forms an electrolytic membrane which differs from the previous experiments in which the metals were placed directly into a liquid.

9. How is electrochemical energy produced?

Electrodes react with each other through an electrolyte to produce electrochemical energy.

10. What discovery by John Frederick Daniell led to a better battery?

Daniell discovered that if sulfuric acid was used as an electrolyte the amount of conductivity was increased and the ability to produce electricity improved.

11. Why was Georges Leclanché's version of the battery important?

Leclanché created the forerunner of the modern battery, using ammonium chloride as an electrolyte and zinc and manganese dioxide as electrodes.

12. When and by whom were batteries first mass-produced in the United States?

National Carbon Company in Cleveland, Ohio, began mass-producing batteries in 1890.

13. How do wet-cell and dry-cell batteries differ?

A wet-cell battery uses a liquid as an electrolytic substance. A dry-cell battery uses a partially dry, pasty material as an electrolytic substance.

14. What is the advantage of the dry-cell battery?

The advantage of the dry cell is that it is more portable.

15. What is the definition of a battery? How are batteries different from cells?

Only two or more voltaic cells connected together can be called a battery. We have commonly come to use the term in reference to a single voltaic cell, a voltaic pile, or any other combination of devices that convert chemical energy directly into electrical energy.

16. What properties are researchers trying to develop in batteries today?

Researchers are trying to develop more efficient, environmentally friendly batteries. They are trying to build batteries that can supply more electrical energy.

Devices that Use Batteries

Use with student page 41

1. Look around your home and list five devices that use batteries to work (example: a flashlight). Explain how you think each device works.

   Answers will vary but should include items such as travel alarm clocks, portable radio/tape/CD players, smoke detectors, and internal clocks in VCRs or computers.

2. If the devices were made bigger or smaller, would that change how they use batteries? Explain how it might for each.

   Answers will vary depending on the items listed in Question 1, but should indicate that if more power is required by an increase in size, an alteration in battery requirements may occur. If the size of items such as computers or VCRs with internal clocks changes, generally the clock does not change and no battery power alteration is required. Devices with more power output (e.g., brighter flashlights or louder portable stereos) often require more or larger batteries to run for the same amount of time as less powerful devices.

Assessment Answers

Pre/Posttest

Use with student pages 5–6 and 45–46

Answer the following questions in complete sentences.

1. Is there any type of activity taking place inside a battery?

   Yes. An electrochemical reaction is taking place inside a battery since the materials undergo chemical changes. This reaction produces electricity.

2. Does a battery wear out if it's not in use?

   Yes. The reaction taking place inside the battery between the two electrodes can only take place for a limited period of time. The electrodes slowly react so that the chemical reaction becomes weaker over time.

3. What do you think *chemical reaction* means?

   A chemical reaction is a process that takes place between different substances which alters them. The reaction can produce electrical energy.

4. Can you see a chemical reaction?

   Sometimes you can see the result of a chemical reaction in the form of bubbles, discoloration, or a pasty or powdery substance. Often, however, the chemical reaction is invisible, and can only be "seen" by measuring it with an external device such as a digital volt meter (DVM).

5. What, if anything, does a chemical reaction produce? Explain.

   A chemical reaction may produce electricity. Some chemical reactions produce energy which can be used and measured as electrical energy. Others can produce heat or light.

6. How do we know if a battery still works? Can we tell if it still works by looking at it?

   The only way to determine if a battery still works is to measure the amount of output from it or to test it in a battery-powered device. We cannot tell if it still works by looking at it.

7. Are some batteries better than others?

   Some batteries produce more volts than others because different electrode reactions produce different amounts of electricity. However, this does not necessarily make them better because some devices may be overpowered by high amounts of voltage. A battery may be considered better than another if it can do the same job for a lower cost or for a longer time.

Assessment

Use with student pages 47–48

Answer the following questions in complete sentences.

1. What items must be present to make a battery?

   An electrolyte and two different electrodes are necessary to produce an electrochemical reaction.

2. What is the function of the electrolyte?

The electrolyte serves as the conductive medium that enables the electrochemical reaction to take place. If the electrolytic substance is a good insulator rather than a good conductor, the electrochemical reaction will not take place and the two electrodes will retain their original properties.

3. Why don't the electrodes react chemically when you hold them near each other in the air?

Air is a poor conductor and therefore does not promote the electrochemical reaction that must occur in a battery.

4. How do we harness the electricity produced by an electrochemical reaction?

The electricity produced by an electrochemical reaction can be harnessed by connecting the two electrodes to complete a circuit. An electrical device such as a DVM or an LCD can be placed in the circuit to use the flow of electricity.

5. What is the function of the electrodes? Why can't we use two electrodes made of the same material?

The electrodes react electrochemically with each other. This reaction produces energy which we can harness in the form of electricity. (Some batteries do use identical electrodes such as lead-acid car batteries.)

6. What is a volt? Why is it important to measure volts?

A volt is one kind of measure of the strength of electricity. Measuring volts enables us to compare different batteries to determine which electrochemical reaction can best power an electrical device.

7. How can we increase volts?

Volts can be increased by connecting two or more cells together in a series circuit. Technically, this combination of two or more cells is the definition of a battery. The polarity is important when making the proper connections to increase the overall voltage of cells connected in a series.

Content/Concept Questions

Use with student pages 49–50

Answer the following questions in complete sentences.

1. Two batteries have been constructed. Each uses the same combination of electrodes. One uses a 10% salt solution as an electrolyte while the other uses plain tap water. Which battery will produce more volts? Explain your answer.

The battery with a 10% salt solution as an electrolyte will produce more volts because a 10% salt solution is a better conductor than tap water and will promote the electrochemical reaction to a greater extent.

2. Why can't we use any two substances as electrodes? Why couldn't we use wood and glass, for example?

Not every substance reacts with every other substance electrochemically. These reactions take place only between certain pairs of materials. The amount of reaction can vary as well, resulting in varying amounts of electricity produced.

3. You have just produced an electrochemical reaction by placing aluminum and zinc in cola. How do you know that a reaction is taking place?

Since many reactions of this kind show no visible signs of having occurred, the only way to determine if a reaction is taking place is to form a circuit between the electrodes and measure the volts produced by the reaction.

4. A flashlight battery is filled with electricity when it is made. True or false?

FALSE

5. An electrolyte acts as a conductor in a battery. True or false?

TRUE

6. The electrodes of a battery must react electrochemically in order to generate electricity. True or false?

TRUE

7. Any two substances react electrochemically as long as they differ from each other. True or false?

FALSE

8. We measure volts to show the strength of the electricity that is produced. True or false?

TRUE

9. We can increase the number of volts simply by adding more electrode material to a battery cell. True or false?

FALSE

Open-Ended Questions

Use with student page 53

1. What types of activities are taking place inside a battery? How do these activities produce electricity?

An electrochemical reaction is taking place inside a battery. This reaction is usually invisible, but it produces energy as a result. This energy can be harnessed in the form of electricity by creating a circuit that allows the electricity to flow from one electrode to the other. By placing something in that circuit such as a DVM or an LCD clock we can detect the presence of the electricity.

2. Does a battery wear out if it isn't used? Cite evidence for your answer.

Yes, all batteries do have a "shelf life." Even though no energy is being drawn from the battery the chemicals still slowly react. This reaction can only take place for a limited amount of time, however, before the two materials used as the electrodes are altered to the point where the reaction no longer occurs. Students may witness this taking place during their voltage tests as a steady decline in the number of volts produced.

3. Explain what happens when a battery cell is linked to an electrical circuit. How does this make an LCD clock operate? Why do we need more than one cell to power the clock?

A chemical reaction takes place in a cell. The energy from the reaction can be harnessed when it is connected in a circuit. By linking both electrodes to conductive wires, a path is formed along which the electricity can travel. Linking only one electrode to a wire will not form an electrical circuit, however. A complete path must be present for the electric current to flow. An electrical device such as a DVM or LCD clock can be placed in the path and can provide evidence that electricity is flowing. More than one cell is required to run the clock because more voltage is required than a single cell is able to produce.

Generalized Rubric for Batteries' Challenges

Problem Solving

Problem Solving

4. Identifies creative but plausible solutions to the problem under consideration. The solutions address the central difficulties posed by the scenario, constraint or obstacle.
3. Proposes alternative solutions that appear plausible and that address the most important constraints or obstacles.
2. Presents alternative solutions for dealing with the obstacles or constraints, but the solutions do not address the important difficulties.
1. Presents solutions that fail to address the critical parts of the problem.

Exploring Ideas

4. Demonstrates an extensive knowledge of information resources and commands a wide range of information-gathering techniques. Demonstrates creativity and resourcefulness in collecting ideas and creating original ideas.
3. Demonstrates a knowledge of basic information resources and commands a useful range of information-gathering techniques.
2. Demonstrates a knowledge of some basic information resources but is not aware of all necessary resources, or has command of a limited set of information-gathering techniques.
1. Demonstrates little familiarity with basic information resources or demonstrates a command of only a few basic information-gathering techniques.

Evaluation/Analysis

Observing

4. Notices all detail.
3. Notices most detail.
2. Major errors in observations.
1. Many major inaccuracies.

Choosing a Solution

4. Decides which idea is likely to be the best solution and sets up a way to try and see if it works.
3. Selects what seems to be the best solution and tries it out in a way that will show if it works.
2. Selects what seems to be the best solution but does not try it out in a way to show that it works.
1. Selects what seems to be the best solution but does not try it out.

Evaluating

4. Analyzes the information in detail, accurately and insightfully determining whether it is credible and relevant to the task.
3. Accurately determines whether information is credible and relevant to the task.
2. Makes some significant errors when determining whether information is credible and relevant to the task.
1. Makes little or no attempt to determine whether the information is credible and relevant to the task or totally misjudges the credibility and relevance of the information.

Critical Thinking

4. Consistently translates issues or situations into well articulated tasks that have clearly defined goals and well articulated thinking processes. When appropriate, anticipates difficulties and develops plans to overcome them.
3. Consistently translates issues and situations into tasks that have clearly defined goals and identifiable thinking processes.
2. Sporadically translates issues and situations into tasks that have clearly defined goals and identifiable thinking processes.
1. Rarely, if ever, translates issues or situations into tasks that have clearly defined goals and identifiable thinking processes.

Testing Solutions to Problems

4. Engages in effective, fair, and complete trials of the selected alternative solutions. Trials go beyond those required to solve the problem and show a commitment to an in-depth understanding of the problem.
3. Tests the selected alternatives in trials adequate to determine their utility.
2. Tries out the alternatives, but the trials are incomplete and important elements are omitted or ignored.
1. Does not satisfactorily test the selected alternatives.

Experimental Inquiry

4. Demonstrates an understanding that the selection of manipulated and controlled variables determines whether or not an experiment will produce meaningful results.
3. Understands that the selection of manipulated and controlled variables determines whether or not an experiment will produce meaningful results and usually changes only one variable at a time.

2. Sometimes controls variables and sometimes changes one variable, but does not realize that this has caused a change in another variable that should have been controlled in order to determine which of the two (or both) had caused the new behavior.
1. Ignores the necessity to control variables and thus conclusions made from measurements taken may be invalid.

Effectively Interpreting and Synthesizing Information

4. Interprets the information or data gathered for a task in accurate and highly insightful ways. Provides a highly creative and unique synthesis of the information.
3. Accurately interprets information/data collected for a task and concisely synthesizes it.
2. Makes significant errors in interpreting the information/data determined from the activity or synthesizes the information imprecisely or awkwardly.
1. Grossly misinterprets the information assembled for the task or fails to synthesize it.

Application

Predicting/Hypothesizing

4. Makes predictions that reflect insight into the character of what makes a structure work. Uses facts and concepts of structures to make predictions.
3. Makes predictions that follow from the facts or concepts in structures.
2. Makes predictions which display a misunderstanding of some of the concepts in structures.
1. Makes predictions which display many misunderstandings of the concepts in structures.

Model Building

4. The final process or product goes beyond its intended purpose.
3. The final process or product serves its intended purpose.
2. The final process or product partially serves its intended purpose.
1. The final process or product does not serve its intended purpose.

Concept Knowledge

4. Demonstrates deep understanding of the concept, can give a working definition and use formulas correctly. Student is able to apply the concept to a variety of situations.
3. Can give a working definition of the concept. Makes some errors in measurement and use of formulas. Student attempts to apply the concept in other situations.
2. Can give a working definition of the concept. Makes errors in measurement and use of formulas. There is little attempt to apply concept to other situations.
1. Has a vague notion about the concept and does not see how it relates to real situations.

Reasoning Strategy: Experimental Inquiry

4. Provides an accurate explanation of the phenomenon. The facts, concepts, or principles used for the explanation are appropriate to the phenomenon and accurately applied. The explanation reflects thorough and careful research or understanding.
3. Provides an accurate explanation of the phenomenon. The facts, concepts, or principles used in the explanation are appropriate to the phenomenon and accurately applied with no significant errors.
2. Explains the phenomenon but misapplies or omits some facts, concepts or principles that are important for understanding the phenomenon.
1. Leaves out key facts, concepts, or principles in explaining the phenomenon, or does not use appropriate facts, concepts, or principles to explain the phenomenon.

Expressing Ideas Clearly

4. Clearly and effectively communicates the main idea or theme and provides support that contains rich, vivid, and powerful detail.
3. Clearly communicates the main idea or theme and provides suitable support and detail.
2. Communicates important information but not a clear theme or overall structure.
1. Communicates information as isolated pieces in random fashion.

Documentation

Recordkeeping

4. Demonstrates mastery over record keeping. Keeps complete, accurate records neatly and well laid out.
3. Keeps complete records with occasional minor inaccuracies.
2. Keeps mostly complete records with occasional major inaccuracies.
1. Keeps incomplete records with major inaccuracies in designs, results and thinking.

Collaborative Worker[1]

Working Toward the Achievement of Group Goals

4. Actively identifies the group's goals and works hard to meet them.
3. Is committed to the group's goals and effectively carries out assigned role and tasks.
2. Is committed to the group's goals and tasks but does not carry out assigned roles and tasks.
1. Is not committed to the group's goals and tasks and does not carry out assigned roles or tasks.

[1]Adapted from "Assessing Student Outcomes," *Performance Assessment Using the Dimensions of Learning Model*, Robert J. Marzano, Debra Pickering, Jay McTighe, Association of Supervision and Curriculum Development, Alexandria, VA, 1993.

Performing a Variety of Roles Within the Group

4. Effectively performs several roles within the group.

3. Effectively performs two roles within the group.

2. Attempts to perform more than one role within a group but encounters little success with the secondary role.

1. Resists opportunities or requests to perform more than one role within a group.

Contributing to Group Maintenance

4. Actively helps the group identify changes needed in how the group operates and works toward carrying out those changes.

3. Helps identify changes needed and works toward carrying out those changes.

2. When prompted, helps to identify changes needed in the group and/or is only minimally involved in carrying out those changes.

1. Does not attempt to identify changes needed to make the group work better and does not work toward making changes.

Extensions and Connections

Extensions

Different Batteries

The battery cells that students are creating in this module are very simple. Batteries on the market today come in a variety of sizes and designs. Have students research battery designs to learn more about the various parts of batteries manufactured today. They may find answers to any of the following: Why are some batteries so expensive? Where do the materials for batteries come from? How much more expensive is it to use a battery than it is to use electricity from an outlet?

Chemical Reactions

The chemical reactions that take place in batteries occur on the atomic level. This means that atoms combine with each other in various ways to produce energy. Advanced students may wish to learn the chemical names for the various substances used as electrodes and electrolytes. They can then research how these chemicals interact with each other and change each other. They may find answers to the following: Are chemicals "used up" in batteries? Does the weight of a battery change after it is used?

Electric Cars

Research electric (i.e., battery powered) cars to learn about the current state-of-the-art problems still to be solved. Examine information about any electric cars that are already available for sale or find out about them on the World Wide Web.

Teacher Dissection of a 9-Volt Alkaline Battery

Carefully peel off the case of a rectangular 9-volt alkaline battery to reveal the six 1.5-volt cells stacked inside. Do *not* open the individual cells! They contain a messy paste that could cause skin irritations. **This extension is provided as a demonstration for students to observe. Only teachers should perform this work! Do not perform this task on the following battery types: lithium, lead/acid, or nickel-metal. These batteries may be extremely toxic! Always use rubber gloves and wear eye protection.**

Cross-Curricular Connections

History

Batteries have been in commercial use for over 100 years. Ask students to research the uses of batteries in the past and present.

Reading

Using the vocabulary words as a guide select books for student reading that focus on the development of electricity in the 19th century.

English

Assign a creative writing project in which a student describes life without batteries, from the time that they wake up in the morning to the time that they go to sleep at night.

Biology

Ask students to research and write a report about the use of batteries in such devices as pacemakers and hearing aids. What are the special needs of these devices? How do they affect the quality of life of people who need them?

Math

Using the voltage table created in Challenge 1, have students predict the voltage produced by combinations of cells linked in circuits.

Science

Explore the chemistry behind electrochemical reactions. Carefully examine the electrodes after the reactions have taken place to see if any observable changes have occurred. Ask students to draw conclusions about the electrodes based on their results. For example, the paper clip and the zinc coated fencing produce similar results both in terms of volts produced as well as observable changes in the material. This implies that a paper clip may contain some zinc.

Art

When potters heat glaze-treated clay at high temperatures, chemical reactions occur to permanently alter the glaze. Not only does the glaze become very hard, in many cases it changes color. Study the different types of glazes and try to obtain "before" and "after" samples to show students.

Resources

World Wide Web Sites

BatteryWeb — World Wide Web Source for Wholesale Batteries
http://www.batteryweb.com

Batteries Plus — America's Batteries Stores
http://www.batteriesplus.com

General Motors EV-1 Electric Car
http://www.gmev.com

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