



**Drained: The Search for Long-Lasting Batteries**

*December 2017/January 2018 Issue*

<http://www.acs.org/chemmatters>

**Teacher’s Guide**



**Teacher's Guide for**

***Drained: The Search for Long-Lasting Batteries***

**December 2017/January 2018**

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# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Reaction rates** | During a unit on reaction rates or kinetics, teachers can use the redox reaction inside the lithium-ion battery as an example of the way temperature affects the rate of reactions.  |
| **Oxidation/Reduction reactions** | The half-reactions that occur at the anode and cathode of the lithium ion battery can be part of a lesson on oxidation/reduction reactions, as can the reaction in Volta’s original experiment. |
| **Electrochemistry** | The lithium-ion battery can be used as an example of an electrochemical reaction—using chemicals to produce electricity—complete with the activity series, EMF calculations, and cell potentials. The more commonly used example of the voltaic pile from this article can also be used. |
| **Electrochemical cells** | A discussion of the Li-ion battery (or batteries in general) can lead to differentiating between cells and batteries (e.g., 1.5-V dry cells vs 9-V batteries). |
| **Reversible reactions** | When teaching about reversible reactions in equilibrium, teachers can use the oxidation/reduction reactions occurring in the discharging and charging of a lithium-ion battery as a prime example. |
| **Ions** | The ions in the battery electrolyte, as well as in the anode and cathode, demonstrate the importance of the ionic state of many elements in chemical reactions.  |
| **Nanotechnology** | The two current research projects utilizing nanotechnology described in the article: the silicon nanowires proposed for use as the anode in place of carbon in one project, and the use of bundles of gold nanowires as the cathode in another are examples that can be used to highlight the progress of nanotechnology in chemistry.  |

# Teaching Strategies and Tools

## Standards

* Links to **Common Core Standards for Reading**:

**ELA-Literacy.RST.9-10.1.** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

**ELA-Literacy.RST.9-10.5.** Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, and energy).

**ELA-Literacy.RST.11-12.1.** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

**ELA-Literacy.RST.11-12.4.** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

* Links to **Common Core Standards for Writing**:

**ELA-Literacy.WHST.9-10.2F.** Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).

**ELA-Literacy.WHST.11-12.1E.** Provide a concluding statement or section that follows from or supports the argument presented.

* In addition to the writing standards above, consider asking students to debate issues addressed in some of the articles. Standards addressed:

**ELA-Literacy.WHST.9-10.1B.** Develop claim(s) and counterclaims fairly, supplying data and evidence for each while pointing out the strengths and limitations of both claim(s) and **counterclaims** in a discipline-appropriate form and in a manner that anticipates the audience’s knowledge level and concerns.

**ELA-Literacy.WHST.11-12.1.A.** Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that logically sequences the claim(s), counterclaims, reasons, and evidence.

* Links to **Next Generation Science Standards**:

**HS-PS1-5**: Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

**HS-ETS1-2.**

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

* **Disciplinary Core Ideas:**
* LS1.A: Structure and Function
* **Crosscutting Concepts:**
* Cause and effect: Mechanism and explanation
* Structure and function
* Stability and change
* **Science and Engineering Practices:**
* Constructing explanations and designing solutions
* Obtaining, evaluating, and communicating information
* **Nature of Science:**
* Scientific knowledge is based on empirical evidence

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in the December 2017/January 2018 issue:

* Metric units
* Structural Formulas
* Fermentation
* pH
* Electrochemistry
* Oxidation & Reduction
* Amines
* Allotropes
* Physical properties
* London dispersion forces

# Reading Supports for Students

The pages that follow include reading supports in the form of an Anticipation Guide, a Graphic Organizer, and Student Reading Comprehension Questions. These resources are provided to help students as they prepare to read and in locating and analyzing information from the article.

The borders on these pages distinguish them from the rest of the pages in this Teacher’s Guide—they have been formatted for ease of photocopying for student use.

* **Anticipation Guide (p.8):** The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

As an alternative to using the Anticipation Guide for this article, consider this idea to engage your students in reading.

* Ask students to list ways they can make the batteries in their cell phones last longer.
* After students have made their lists, they should read the article and compare their original thoughts to the information in the article.
* **Graphic Organizer (p. 9):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

If you use the aforementioned organizers to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

* **Student Reading Comprehension Questions (p. 10):** The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.
* Most of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them make decisions in their personal lives.
* The infographic on page 19 provides more information to support the article “Drained: The Search for Long Lasting Batteries” on pages 10-12.
	+ You could ask students what batteries and pencils have in common (graphite), then ask them to elaborate on the physical properties of graphite that makes it appropriate for both uses.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles.
* You might also ask them how information in the articles might affect their health and/or consumer choices. Also ask them if they have questions about some of the issues discussed in the articles.

“Drained: The Search for Long-Lasting Batteries”, *ChemMatters*, December 2017/January 2018 Issue

Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Anticipation Guide

“A Close-up Look at the Quality of Indoor Air” (*ChemMatters*, April/May 2016 Issue)

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. The easiest way to improve your phone’s battery life is to stop turning on your phone’s screen to check for notifications.
 |
|  |  | 1. Sending data requires about the same amount of power to transmit as talking on your phone.
 |
|  |  | 1. You should let your battery discharge almost all of the way between charges.
 |
|  |  | 1. Today’s batteries and the original batteries all have the same components: an anode, a cathode, and an electrolyte.
 |
|  |  | 1. The solvent in a lithium ion battery is water.
 |
|  |  | 1. If two different metals are connected by an electrolyte solution, an electric potential is created.
 |
|  |  | 1. Batteries have been greatly improved to keep up with their use in electronics.
 |
|  |  | 1. The first battery was produced in 1800.
 |
|  |  | 1. Carbon atoms and silicon atoms can hold onto the same number of lithium ions.
 |
|  |  | 1. The iPhone’s battery operates best between 0°C and 35°C.
 |

## Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

“Drained: The Search for Long-Lasting Batteries”, *ChemMatters*, December 2017/January 2018 Issue

**Directions**: ***As you read*** complete the graphic organizer below to describe the chemistry of batteries.

|  |  |  |  |
| --- | --- | --- | --- |
| ***Battery Part*** | ***Anode*** | ***Cathode*** | ***Electrolyte*** |
| **What it does/ What happens** |  |  |  |
| **Single use alkaline battery** |  |  |  |
| **Lithium-ion rechargeable battery** |  |  |  |
| **Future possibilities being researched** |  |  |  |

**Summary:** On the back of this paper, list two ways to increase the battery life of current cell phone batteries, and why these methods work.

## Student Reading Comprehension Questions

“Drained: The Search for Long-Lasting Batteries”, *ChemMatters*, December 2017/January 2018 Issue

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name

**Directions**: Use the article to answer the questions below.

* 1. What is the dominant type of rechargeable battery used for electronics?
	2. How are temperature and battery life related?
	3. What are the three components of a battery?
	4. Describe the reactions that take place in common, single-use alkaline batteries.
	5. What are the most common materials used in making a lithium-ion battery?
	6. Why isn’t water a good material to use as the solvent for the electrolyte of the lithium-ion battery?

**Student Reading Comprehension Questions, cont.**

“Drained: The Search for Long-Lasting Batteries”, *ChemMatters*, December 2017/January 2018 Issue

* 1. How did Alessandro Volta make the first battery, and how did it work?
	2. Identify and describe the reactions that occur to power a cell phone.
	3. Give the equations for (a) the oxidation reaction, and (b) the reduction reaction that occur in a lithium-ion battery.
	4. What was the major problem with using silicon in place of carbon in a lithium battery?
	How was it overcome?
	5. What are the two problems with using liquid electrolytes in lithium batteries?
	6. Describe two recent innovations in the development of lithium batteries.

## Answers to Student Reading Comprehension Questions

1. **What is the dominant type of rechargeable battery used for electronics?**

*The dominant type of rechargeable battery used for electronics is the lithium-ion battery.*

1. **How are temperature and battery life related?**

*Temperature and battery life are related, because the chemical reactions that power the battery speed up as temperature rises, shortening battery life. If the battery is kept cool, the reactions slow down and the life of the battery is extended.*

1. **What are the three components of a battery?**

*The three components of a battery are*

* 1. *the anode, or negative end;*
	2. *the cathode, or positive end; and*
	3. *the electrolyte, the ion transporter.*
1. **Describe the reactions that take place in common, single-use alkaline batteries.**

*In single-use alkaline batteries,*

* 1. *the zinc metal of the anode is oxidized to Zn2+ ions, while*
	2. *the manganese(IV) oxide (MnO2) of the cathode is reduced to manganese(II) oxide (MnO), or manganese(III) oxide (Mn2O3), depending on the type of electrolyte.*
1. **What are the most common materials used in making a lithium-ion battery?**

*The most common materials used in making a lithium-ion battery are lithium cobalt oxide (LiCoO2) for the cathode; graphite (C6) for the anode; and a combination of lithium salts, such as LiPF6, LiBF4, or LiClO4 for the electrolyte.*

1. **Why isn’t water a good material to use as the solvent for the electrolyte of the lithium-ion battery?**

*Water is not a good solvent because it reacts vigorously with alkali metals.*

1. **How did Alessandro Volta make the first battery, and how did it work?**

*To make the first battery, Alessandro Volta “stacked alternating discs of zinc and copper separated by wet paper soaked in salt, which served as the electrolyte. This device created a physical link between two metals through which electrons could be exchanged to create an electrochemical potential. When wires connecting the top and the bottom of the pile were brought together, they made a spark.”*

1. **Identify and describe the reactions that occur to power a cell phone.**

*An oxidation reaction takes place when an electron is released from the graphite anode; a lithium ion moves from between the graphite through the Li+-permeable membrane, into the cathode. The released electron travels through the external circuit and powers the phone. In a reduction reaction, the electron returns to the cathode to allow for LiCoO2 production and completes the circuit.*

1. **Give the equations for (a) the oxidation reaction and (b) the reduction reaction that occur in a lithium battery.**
	1. *Oxidation/Anode: LiC6 🡪 Li+ + C6 + e–*
	2. *Reduction/Cathode: CoO2 + Li+  + e– 🡪 LiCoO2*
2. **What was the major problem with using silicon in place of carbon in a lithium-ion battery? How was it overcome?**

*The problem with using silicon in lithium-ion batteries is that silicon swells as it absorbs lithium ions and then shrinks when the ions are pulled out of the silicon. This swelling and shrinking causes the silicon to fracture after only a few cycles, ruining the battery.*

1. **What are the two problems with using liquid electrolytes in lithium batteries?**

*The problems with using liquid electrolytes in lithium batteries are:*

1. *the liquid restricts how fast lithium ions can flow, and*
2. *the liquids also limit the temperature range over which the battery can function.*
3. **Describe two recent innovations in the development of lithium batteries.**

*The article describes three innovations. Students could use any two of the following three.*

1. *Yi Cui of Stanford, worked to make silicon a viable replacement for carbon in the lithium battery, since each silicon atom can hold onto four lithium ions instead of one lithium ion per carbon atom. Since silicon expands and shrinks in the process it has a tendency to fracture after a few cycles. Cui’s team developed a silicon nanowire electrode that leaves room for thin hairs of silicon to swell and shrink as they absorb or release lithium ions.*
2. *Mya Le Thai, a graduate student at the University of California, Irvine, used bundles of gold nanowire, coated with manganese(IV) oxide to help hold the charge, and a Plexiglas-like gel to prevent corrosion, to make the cathode of the battery. The nanowires provide more surface area in a smaller volume. This new cathode fully charges and discharges up to 200,000 times without damaging the metal, compared to the 5,000 to 7,000 charges a lithium-ion battery can withstand before dying.*
3. *Yuki Kato and Ryoji Kanno, in collaboration with Toyota, have created different crystalline structures that include atoms of lithium, silicon, phosphorus, sulfur, and carbon though which ions could flow faster than the traditional liquid electrolyte currently in use. The crystalline electrolyte holds more charge, charges faster, and increases the safe operating temperature range of the battery.*

# Possible Student Misconceptions

1. **“Batteries should be recharged when the charge drops below 20%, and they should be charged to 100%.”** *Lithium-ion batteries can be charged at any state of charge without harming the battery. They can be charged to 100% and kept on the charger without damaging the battery. Cell phones are equipped with a sensor that reduces the current to the battery when it approaches full charge. However, it is best for the battery if the charge stays between 30% –80% charge. Previous rechargeable batteries may have had restrictions about when to charge them, but lithium-ion batteries do not. However, periodically letting the battery charge fall below 10% before recharging it does help maintain the digital power gauge inside the phone. This gauge sets the range of charge from
0–100%. When the battery is kept above 30% this gauge develops memory and begins to detect 70% charge as full charge, thus decreasing the charge capacity of the battery. Letting the battery run down to 10% and charging to 100% helps keep the range of the gauge true.*
2. **“Electrons can flow through an electrolyte solution.”** *In an electrochemical cell the conduction of electricity through an electrolyte solution does not involve the electrons themselves passing through the solution. Electrons move only through the wires that connect the anode and cathode. Ions formed at either electrode create a charge imbalance in the electrochemical cell, which is alleviated by ions already in the electrolyte solution moving to either the anode or the cathode until the charge equilibrium of the solution is restored.*
3. **“Storing batteries in the freezer extends their life.”** *Storing lithium-ion batteries in the freezer can cause the liquid electrolyte in the batteries to expand and change the shape of the housing. Also, moisture in the freezer can contaminate the battery and possibly lead to the battery becoming short-circuited. While it is true that cooler temperatures slow down the secondary chemical reactions within the battery, the freezer is not a good place to store batteries. You can however store the batteries in the refrigerator. The batteries should be stored with 30–50% state of charge in an airtight container along with a packet of desiccant.*
4. **“Lithium batteries have memory and this will affect how they charge.”** *Memory effect is something that was observed in Ni-Cd rechargeable batteries. In Ni-Cd batteries, if the batteries are consistently recharged before they fully discharge, the battery develops a memory for the amount of charge used to recharge the battery and over time operates to that capacity rather than full capacity. To alleviate this problem the batteries must be almost fully discharged before they are recharged. Lithium batteries do not exhibit this memory effect or voltage depression. Therefore, you can recharge the battery whenever you want to, no matter what level of charge it has. You can even charge the battery while using the phone without harming the battery. While the lithium-ion battery itself does not have memory, frequent partial discharges create a condition called digital memory in the device’s power gauge. To recalibrate the power gauge, let the battery discharge to 5%–10% and then recharge.*
5. **“Turning off your phone can damage the battery.”** *Turning off your phone does not damage the battery. You can turn the phone completely off—and even remove the battery—without any fear of harming the battery. In fact, sometimes a simple reboot can actually help restore battery functionality.*
6. **“Using the internet will run down the battery faster than anything else.”** *Actually, it is the screen being on that drains the battery the most. You can turn the brightness of the screen down to reduce its use of battery, but it is still a battery hog. Activities that are graphic-intensive, like on-line gaming or watching YouTube videos, deplete the battery more than any other type of activity.*
7. **“A battery does not lose charge unless it is used.”** W*hether it is being used or is turned off, a battery will continue to lose charge***.** *The lifespan of a lithium-ion battery is limited by the manufacture date. It starts losing life the minute it leaves the production line at the factory. The battery will slowly discharge over time until it loses all of its electrochemical potential. When you purchase a cell phone battery ask for one with the most recent date. While turning a device off conserves the battery, it does not completely stop the battery from discharging.*

# Anticipating Student Questions

1. **“Why is lithium the element chosen for use in cell phone batteries?”** *At 6.94 g/mol, lithium is the lightest of all the metals. Whether it is used for a cell phone or a car, the lighter the weight of the battery, the better. Also, the lithium half-cell has one of the greatest electrochemical potentials at 3.05 volts, resulting in high energy density and a higher power-to-mass ratio for this element. Lithium is relatively high on the activity series of metals, meaning that lithium atoms will easily oxidize to its cation in a chemical reaction, providing a ready source of electrons. These are the chemistry reasons lithium is so attractive for use in batteries. Economically, lithium is relatively inexpensive and is easy to obtain from brine solutions created at mining sites.*
2. **“Why does my cell phone turn itself off if I leave it in the sun?”** *Cell phones are equipped with several safety devices, one of which is an internal temperature sensor. When the sensor detects temperatures higher than a preprogrammed set value, it turns the phone off in order to protect the battery from thermal runaway. Thermal runaway is a chain reaction that can quickly lead to the battery exploding. Even with the phone shut down, the electrolyte still may heat up to its boiling point, increasing the internal pressure of the battery to the point that it explodes. Some batteries are equipped with vent holes so gas can escape without damaging the battery casing. However, these cannot accommodate rapid increases in pressure caused by boiling electrolyte.*
3. **“What was happening that caused the new Samsung phones to explode?”** *After much research, Samsung found that the flaw in the Samsung Galaxy Note 7 phones that was causing some phones to explode was not in the electronics or programming of the phone, but in a problem with the batteries. In the race to make a battery smaller and more efficient, some of the Samsung batteries were too cramped in their housing, which caused the two electrodes to touch. In the second batch of batteries that were made for the phone by a different manufacturer, the electrode separators were flawed. In some batteries the separators were punctured, while in others layers of insulating separators were missing. In both sets of batteries, the flaws led to the anode and cathode coming into direct contact. This causes the battery to short-circuit and experience what is known as thermal runaway. Thermal runaway happens when heat that is generated by rapid charging or discharging causes the electrolyte in the battery to react with other chemicals, creating a gas which releases more heat at a faster rate, in what becomes an uncontrolled feedback loop. An explanation with video can be found at these two sites:* <https://www.cnet.com/news/samsung-answers-burning-note-7-questions-vows-better-batteries/> *or* <https://www.theverge.com/2016/9/8/12841342/why-do-phone-batteries-explode-samsung-galaxy-note-7>*.*
4. **“Is the voltage produced by the lithium-ion battery the highest voltage chemists can produce in an electrochemical cell?”** *No, there are other chemical combinations of anode and cathode materials that can result in higher voltage. One of the highest voltages would come from a reaction involving the reduction of fluorine atoms in acidic solution to produce hydrogen fluoride, and the oxidation of lithium atoms to their ions, according to the following half-reactions.*

 F2 (g) + 2 H+ + 2 e– 🡪 2 HF(aq) Eo = + 3.03 V

 2 Li(s) 🡪 2 Li+ + 2 e– Eo = + 3.05 V

 F2(g) + 2H+(aq) + 2 Li(s) 🡪 2 HF(aq) + 2 Li+(aq) Eo = + 6.08 V

*While this reaction may generate more voltage, the safety concerns and difficulty in working with the materials involved—fluorine gas especially— would hinder using this reaction in batteries*. *To get higher voltages, single electrochemical cells are connected in series with one another. An example is the 9-V battery. If you carefully cut the casing away from the battery, you find six 1.5-V cells connected together inside.*

1. **“I see the term ‘dry cell battery’ used sometimes. What do they mean by that?”** *Actually, to the chemist, the terms cell and battery are different things. A cell is a single electrochemical unit producing a given amount of electrical energy, or voltage, while a battery indicates that several cells have been joined together to produce a collective higher voltage. Most of the “batteries” we use to power flashlights and small battery-operated devices are single cells. Whether it is a D cell, C cell, AA, or AAA “battery”, they all produce the same voltage—1.5 volts. The 9-V battery is a true battery. It is the combination of six 1.5-V cells connected in series to produce 9-V of potential energy.*

*The term “dry” refers to the electrolyte used in the cell. In a dry cell, the electrolyte is in the form of a paste with only enough liquid to allow ion—and thus—current flow. In a typical alkaline battery, the electrolyte is a paste of ammonium chloride, NH4Cl. In a wet cell, the electrolyte is liquid and the battery will need to be kept in an upright position to prevent the liquid from leaking out. The battery in a car uses wet-cell technology, while batteries used in portable electronics use dry cell technology.*

# Activities

**Labs and demos**

**Making a two-cell battery:** Students make their own two-cell battery with aluminum and copper electrodes immersed in an electrolyte solution, changing the electrolyte solution as they try to determine which electrolyte solution is best suited for making batteries. The procedure is well illustrated. (<https://www.teachengineering.org/activities/view/cub_electricity_lesson03_activity2>)

**Making and evaluating electrochemical cells and batteries:** After a brief introduction to the history of batteries, students prepare five different types of electrochemical cells—“Voltaic Pile”, “Electrochemical Cell”, “Lemon Cell”, “Storage Cell”, and “Dry Cell”. Students measure the output and evaluate the usefulness of each type of cell. (<http://www.chymist.com/batteries.pdf>)

**Simulations**

**Electrochemical cell voltmeter:** The students prepare virtual cells with different electrodes and electrolyte concentrations and measure their voltages. Increasing levels of difficulty are provided, which call on the student to calculate the voltage and enter the answer. (<http://web.mst.edu/~gbert/Electro/Electrochem.html>)

**“Voltaic Cell Virtual Lab”:** This electrochemical cell simulator gives students four choices for each anode and cathode, as well as four electrolyte options. After designing the cell, students virtually measure the voltage. (<http://www.kentchemistry.com/moviesfiles/Units/Redox/voltaiccelll20.htm>)

**Media**

**Recent developments with lithium-ion batteries:** An interview (6:51) with Helena Braga, the co-developer of the glass lithium-ion battery, provides an opportunity for students to see and hear from a scientist currently working on battery technology. The video explains the dangers of exploding Li-ion batteries, and animated explanations compare how lithium-ion batteries and glass lithium-ion batteries operate. (<https://www.youtube.com/watch?v=wl0I2vl6ul0>)

**Lithium mining and purification for use in batteries**: This short video (7:21) shows students how lithium is mined and extracted for use in the lithium-ion battery. (<https://www.youtube.com/watch?v=Lt6oKRQqoSc>)

**Use of computer modeling to design better batteries:** This video (7:47) contains information about using computer simulation of molecular modeling and chemical experimentation to determine optimal combinations of components for future lithium batteries.

(<https://www.youtube.com/watch?v=8iT9B7aJNKc>)

**Lessons and lesson plans**

**“Electrical Energy Storage” in batteries and voltaic piles:** Part one of this 65-minute lesson contains a lecture about how electrical energy is stored and how a battery works. Part two concerns the voltaic pile and provides students the opportunity to experiment with a voltaic pile made with pennies, nickels, and wet paper towel squares soaked in water or lemon juice. (<http://www.uwyo.edu/scienceposse/resources/lesson-plans/former-fellow-lesson-plans/luke-dosiek/luke-diosiek-fun-with-electricity-electrical-energy-storage.pdf>)

**“Voltaic Cells”:** In this one class-period lesson, students use information from a PowerPoint presentation to learn about voltaic cells and how to calculate cell potential. Students use a provided flowsheet to label the movement of ions in a voltaic cell, and then they conduct an open inquiry to create a cell with the highest energy output. (<http://www.cpalms.org/Public/PreviewResourceLesson/Preview/156833>)

**Projects and extension activities**

**Environmentally focused lessons about batteries:** Sponsored by the Rechargeable Battery Recycling Corporation and National Geographic, these lessons and activities focus on renewable energy and recycling. Instructions for five activities are included, along with excellent diagrams and a historical timeline of “Electricity and Batteries” beginning in 600 B.C. through 2001. (<http://www.panasonic.com/environmental/rbrc_lesson_plan.pdf>)

**Research latest developments in battery technology:** Students can be assigned one of the new developments in lithium-ion battery technology to research and prepare a poster presentation to the class. Some ideas they can research are batteries that use graphene as the carbon anode, batteries that use glass as the separator, batteries that use water as the electrolyte, or batteries that use sulfur. Some topics can be found at these Web sites: <https://www.sciencedaily.com/news/matter_energy/batteries/> or <https://en.wikipedia.org/wiki/Research_in_lithium-ion_batteries>.

# References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles
published from the magazine’s inception in October 1983 through April 2013; all available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [**http://ww.acs.org/chemmatters**](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get the past 30 Years of *ChemMatters* on DVD!” (the icon on the right of the screen)**

**Selected articles and the complete set of
Teacher’s Guides for all issues from the past three
years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMatters Online”*.**

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In the April 2011 *ChemMatters* article “Did You Know?” author Pages describes how a lithium-air battery works, compared to a lithium-ion battery. Scientists studying new types of batteries are looking at lithium-air batteries as an option for future cars. (Pages, P. Electrochemistry: Making Better Electric Cars. *ChemMatters*, 2011, *29* (2), p 4)

A discussion of the environmental impact of lithium batteries includes information about where and how lithium is mined, as well as how lithium batteries work, compared to other batteries. A diagram of a lithium battery illustrates the charging process. (Goode, R. & Sitzman, B. Lithium-ion Batteries: A Clean Source of Energy. *ChemMatters*, 2011, *29* (3), p 5)

Author Tinnesand provides an article about electric cars that contains a diagram of a car’s lithium-ion battery, compared with a diagram of a typical lead-acid battery. He explains the benefits of using lithium compared to lead in batteries used for electric cars. (Tinnesand, M. Drivers Start Your (Electric) Engines. *ChemMatters*, 2013, *31* (1), pp.14–16)

The Teacher’s Guide for the February, 2013 *ChemMatters* article above contains additional information about lithium resources and how they are mined. The guide also elaborates on why lithium is suited for use in batteries.

# Web Sites for Additional Information

**Lithium-ion batteries**

A good Web site for students to explore how lithium-ion batteries work can be found at Explain that Stuff. Animated gifs simulate how a lithium-ion battery works, while thorough explanations give students more information about the different components of these batteries. (<http://www.explainthatstuff.com/how-lithium-ion-batteries-work.html>)

Battery University has a plethora of information on all types of batteries. The “courses” are listed in the left-hand corner, with the courses specific to lithium-ion batteries numbered BU-204–208, BU-304–310, and BU-409–410. (<http://batteryuniversity.com/learn/article/lithium_based_batteries>)

**Samsung cell phone explosions**

In “Samsung Galaxy Note 7 recall: Here’s what happens now”, a short video (2:31) accompanied by illustrated explanations details why the Note 7s had problems with their lithium-ion batteries and what steps Samsung took to prevent future problems. (<https://www.cnet.com/news/samsung-galaxy-note-7-return-exchange-faq/>)

“The Science Behind Exploding Phone Batteries” explains how the lithium-ion battery works and what went wrong with the Samsung Galaxy Note 7. A short video (3:41) accompanies the explanation. (<https://www.theverge.com/2016/9/8/12841342/why-do-phone-batteries-explode-samsung-galaxy-note-7>)

**Lithium-ion battery care**

Knowing the best practices when it comes to caring for a lithium-ion battery can help ensure the battery will see its full life. “How to Charge and When to Charge” from Battery University answers several questions about battery maintenance. (<http://batteryuniversity.com/learn/article/how_to_charge_when_to_charge_table>)

“8 Essential Tips to Keep Your Phone’s Battery Healthy” is the title of the *Popular Mechanics* article that tells what a battery is made of, how it works, and how to keep it working well. (<http://www.popularmechanics.com/technology/gadgets/a15731/best-way-to-keep-li-ion-batteries-charged/>)

**John Goodenough—inventor of the lithium-ion battery**

Students might enjoy learning about the inventor of the lithium-ion battery, John Goodenough**.** In this 2017 NPR interview (3:24) the 95-year-old professor of material science at the University of Texas in Austin talks about his current work that may revolutionize this battery. (<http://www.npr.org/sections/alltechconsidered/2017/05/22/529116034/at-94-lithium-ion-pioneer-eyes-a-new-longer-lasting-battery>)

Biographical information about Professor Goodenough can be found here: <https://en.wikipedia.org/wiki/John_B._Goodenough>.

**Goodenough-Braga glass battery**

Information about the new Braga-Goodenough battery that uses a special glass as the electrolyte can be found on its Wikipedia site. The wiki also includes the skepticism surrounding the glass battery. (<https://en.wikipedia.org/wiki/Glass_battery>)

The University of Texas press release about the new Braga-Goodenough glass electrolyte battery can be found here: <https://news.utexas.edu/2017/02/28/goodenough-introduces-new-battery-technology>.

**Current research**

 The Wikipedia page on battery research is very well organized in outline form, making it easy to find information about specific current findings. If you are assigning student projects on the recent developments in batteries, this would be a good first stop. (<https://en.wikipedia.org/wiki/Research_in_lithium-ion_batteries>)

 Nature.com has a catalog of recent battery research papers. The site is equipped with a search tool that will help sift through the thousands of entries. This site will only allow you to read up to 8 articles before requiring a subscription to *Nature* or payment of a fee per article. (<https://www.nature.com/subjects/batteries>)

**ACS battery webinar**

“The Chemistry of Hello: Lithium-ion Batteries” (48:07) is the title of an American Chemical Society webinar featuring Dee Strand from Wildcat Discovery Technology and Mark Jones from Dow Chemical. The chemistry of cell phone lithium-ion batteries is presented in depth in order to answer common questions people ask concerning their cell phone battery. (<https://www.youtube.com/watch?v=l4uMuKShQvM&t=1638s>)

# About the Guide

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Articles from past issues of *ChemMatters* and related Teacher’s Guides can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013, along with all the related Teacher’s Guides since they were first created with the February 1990 issue of *ChemMatters*.

The DVD also includes Article, Title, and Keyword Indexes that cover all issues from February 1983 to April 2013. A search function (similar to a Google search of keywords) is also available on the DVD.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558. Purchase information can also be found online at <http://tinyurl.com/o37s9x2>.