ChemMatters

Demystifying Everyday Chemistry

Teacher's Guide

April 2024

ACS Chemistry for Life®

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April Teacher's Guide Introduction

Lesson Ideas

For each of the articles, encourage students to think about how science is done, how we know what we know, and how chemistry connects to their lives.

Teaching Ideas for this issue:

1. "Chemistry in Pictures" on page 2 shows a photograph of the displacement of copper metal by silver ions. If possible, demonstrate the reaction for your students. Ask them what we can learn about the chemistry of metals from this reaction.

2. "Open for Discussion" on page 4 discusses the meaning of sustainability, and historic sustainability policies employed by indigenous people of the Americas. Ask students what role chemistry can play in future efforts to balance society's needs and wants with Earth's finite resources. You may want to refer to this article after students read the article about lithium mining on pages 11-14.

3. The "Chemistry in Person" column on page 19 showcases Nobel Laureate M. Stanley Whittingham, who was awarded the Nobel Prize in Chemistry for his work to develop lithium-ion batteries. Encourage students to read the interview to learn what he is doing now to address sustainability and make chemistry more relevant.

4. This issue of ChemMatters relates well to the Chemists Celebrate Earth Week theme: Get a Charge Out of Chemistry. You can find more information and teaching ideas at https://www.acs.org/education/outreach/ccew.html. In particular, the CCEW 2024 issue of "Celebrating Chemistry" (https://www.acs.org/education/outreach/celebrating-chemistry-editions.html) is a good reference for chemistry students as they read the articles in this issue, even though the information is aimed at students in middle school.

5. Note: Safe battery disposal is not specifically addressed in this issue, but students may have questions. In most municipalities, disposal of regular alkaline batteries (such as AAA, AA, C, D, 9V) in the regular trash is OK, in others recycling is encouraged. One activity could be to have students research the local regulations and raise awareness among their peers regarding proper disposal of non-rechargeable alkaline batteries. With respect to rechargeable batteries, these should always be taken to a hazardous waste disposal site because they pose a fire hazard.

6. Assign a team of students to read each feature article, then present what they learned in a podcast, PowerPoint or similar presentation, poster or brochure, or some other engaging format.
    - Prior to reading the article, give students the Anticipation Guide for the article along with the graphic organizer and links to other information provided.
    - Be sure to ask students to include information providing evidence for the claims made in the article.

7. Alternatively, students can create concept maps about the important chemistry concepts in the article they choose.

5E Lesson Ideas for individual articles:

Engage	Provide the Anticipation Guide or ask a thoughtful question (see the individual Teacher's Guide for each article) to engage students in the reading. Students should record their initial ideas individually, in pen, so they can't be erased. Students can then discuss their initial ideas in small groups or as a whole class.
Explore	Students read the article to discover more about the concepts in the article. During this phase, students will revisit their beginning ideas and record how the information in the article supports or refutes their initial ideas, providing evidence from the article.
Explain	Students answer questions and/or complete the graphic organizer provided for each article, then discuss their learning with their classmates. Students should recognize the evidence for the claims made in the articles, and how the evidence supports the claims.
Elaborate	Students can pose questions for further study. For some articles, there are related ACS Reactions videos students can watch to learn more about the concepts presented. See the individual Teacher's Guide for each article to learn more.
Evaluate	Students write a short summary of what they learned that describes how it connects to their lives. Students may also present their learning to their classmates or others.

ChemMatters
Demystifying Everyday Chemistry

Teacher's Guide

Save It for Later: Batteries Keep Us Energized

April 2024

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Anticipation Guide

Directions: ***Before reading the article*****,** in the first column, write "A" or "D," indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

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. Solar powered chargers depend on batteries to store energy.
		2. Batteries that store energy for as long as two weeks may be the size of a car.
		3. About one-third of the energy produced worldwide is lost before reaching the consumer.
		4. Both electrolytic cells and voltaic cells are electrochemical cells.
		5. Electrolytic cells work spontaneously.
		6. Disposable batteries can hold a charge for years if they are not used.
		7. The anode of a lithium-ion battery is made of lithium.
		8. Lithium is more abundant than sodium.
		9. Fuel cells need a constant supply of fuel.
		10. Hydrogen fuel cells produce harmful emissions.

Student Reading Comprehension Questions

Name: ______________________________

Directions: Use the article to answer the questions below.

1. Our lives require a constant supply of energy for powering appliances, transportation, as well as heating and cooling. How much energy produced globally is "lost"? List two ways that energy can be lost.
2. How do batteries generate electricity? What type of chemical reactions are involved?
3. Explain what happens in a redox reaction.
4. What are some similarities and differences between an electrolytic cell and a voltaic cell?
5. Is a rechargeable phone battery a voltaic or electrolytic cell? Explain.
6. Study the image of the electrolytic cell. Explain where oxidation occurs and what substance undergoes oxidation. Similarly, explain where reduction occurs and what substance undergoes reduction. Which way do electrons flow?
7. Explain the composition of Volta's first battery. What are the two reactions that occur in Volta's pile?
8. List some advantages of both disposable and rechargeable batteries.
9. The following questions relate to lithium-ion batteries.
   a. Where can graphite be found in this battery?
   b. What elements tend to be used for the mixed metal oxide compound?
   c. In which direction do lithium ions flow when the battery is being discharged?
10. Hydrogen fuel cells provide many advantages over gas-powered cars. Why have they been slow to develop?

Student Reading Comprehension Questions, cont.

<u>Questions for Further Learning</u>

Write your answers on another piece of paper if needed.

11. Research the environmental impacts of lithium-ion EV batteries.

12. Draw a diagram that shows how a voltaic cell works. Include the anode, cathode, voltage meter, and salt bridge. Use arrows to indicate the direction of the flow of electrons. Explain the function and significance of the salt bridge.

Graphic Organizer

Name: ______________________________

Directions: As you read, complete the graphic organizer below to summarize important points in the article.

Importance of batteries	
Types of batteries described in the article	
Problems with current batteries	
Ideas for future batteries	
Fuel Cell advantages	
Fuel Cell disadvantages	
How we can ease the environmental impact of batteries right now.	

Summary: On the back of this sheet, write a one-sentence (20 words maximum) of the article.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Our lives require a constant supply of energy for powering appliances, transportation, as well as heating and cooling. How much energy produced globally is "lost"? List two ways that energy can be lost.
   About 2/3 of energy produced globally is lost. The production of electricity involves significant heat loss. On a personal level, energy is lost when people don't conserve it – by leaving on lights and using inefficient appliances and equipment.

2. How do batteries generate electricity? What type of chemical reactions are involved?
   Inside batteries, electrons move from one element to another due to differences in the elements or compounds reduction potential. That is, one element or compound prefers to lose electrons while the other prefers to gain electrons, this potential difference causes electrons in a circuit to move. The movement of electrons is electricity. The reactions involved are known as oxidation-reduction reactions, or redox.

3. Explain what happens in a redox reaction.
   A redox reaction involves both oxidation and reduction reactions. These reactions occur simultaneously. Electrons are lost in oxidation reactions (lose electrons oxidation – LEO) and electrons are gained in reduction reactions (gain electrons reduction – GER).

4. What are some similarities and differences between an electrolytic cell and a voltaic cell?
   Similarities: Both electrolytic and voltaic cells have two electrodes; a cathode where reduction occurs (Reduction Cathode – RedCat), and an anode where oxidation occurs (Anode Oxidation – AnOx). Both also contain an electrolyte solution.

   Differences: Voltaic cells undergo spontaneous chemical reactions based on the potential differences of the materials used; electrolytic cells need electricity to cause a nonspontaneous reaction to occur.

5. Is a rechargeable phone battery a voltaic or electrolytic cell? Explain.
   Both! When not plugged into the wall or other source of electricity, the phone battery works as a voltaic cell, undergoing spontaneous chemical reactions. Eventually, the battery discharges enough electricity that it needs to be recharged. When you plug in your phone to a wall socket for example, a nonspontaneous reaction occurs (electrolytic cell) and electrons are sent in the opposite direction to build up stored energy.

6. Study the image of the electrolytic cell. Explain where oxidation occurs and what substance undergoes oxidation. Similarly, explain where reduction occurs and what substance undergoes reduction. Which way do electrons flow?
   Oxidation occurs at the anode and reduction occurs at the cathode. Bromide ions are being oxidized and sodium ions are being reduced. Electrons flow from the anode to the cathode.

7. Explain the composition of Volta's first battery. What are the two reactions that occur in Volta's pile?
   Volta's voltaic cell was made up of alternating zinc and silver discs. The discs were separated with a cloth soaked in sodium hydroxide or salt water to serve as the electrolyte solution. The zinc (Zn^0) is oxidized to zinc ions (Zn^{2+}) and the hydrogen ions (H^+) in the water are reduced to hydrogen gas (H_2).

   $Zn \rightarrow Zn^{2+} + 2e^-$ (oxidation occurs at the anode)
   $2H^+ + 2e^- \rightarrow H_2$ (reduction occurs at the cathode)

8. List some advantages of both disposable and rechargeable batteries.
   Disposable batteries are less expensive, can store a charge when not in use for long periods of time, and are useful in medical applications where recharging is not possible. Rechargeable batteries can be used numerous times, which reduces the environmental impact on landfills.

9. The following questions relate to lithium-ion batteries.
   a. Where can graphite be found in this battery?
      Graphite is the anode.
   b. What elements tend to be used for the mixed metal oxide compound?
      The mixed metal oxides used as the cathode are most commonly composed of lithium, oxygen, and cobalt.
   c. In which direction do lithium ions flow when the battery is being discharged?
      Lithium ions flow from the graphite, through the separator, to the metal oxide when the battery is being used but is not plugged into an electrical source.

10. Hydrogen fuel cells provide many advantages over gas-powered cars. Why have they been slow to develop?
    Fuel cells need a constant supply of reactants, in this case, hydrogen and oxygen gas. Oxygen can come from the air, but elemental hydrogen is harder to produce. California is the only state to offer hydrogen-fuel stations. Until hydrogen gas is readily available, it will be difficult to replace the gasoline fuel system.

11. Research the environmental impacts of lithium-ion EV batteries.
    Answers will vary depending on student research. Some examples include toxic chemical leaks especially in landfills, risk of fire due to improper storage, use of large quantities of water involved in lithium mining.

12. Draw a diagram that shows how a voltaic cell works. Include the anode, cathode, voltage meter, and salt bridge. Use arrows to indicate the direction of the flow of electrons. Explain the function and significance of the salt bridge.
    The diagram should show two breakers each with an electrode submerged in a solution connected with an inverted U-tube (salt bridge). Electrons flow from the anode to the cathode. The voltage meter can be drawn to show that some current is flowing. The salt bridge allows for the flow of ions that reduces the charge buildup that occurs in both cells. Without the salt bridge, the reaction would stop as too much charge would quickly build up in both cells - (positive ions in the oxidation cell and negative ions in the reduction cell).

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Graphic Organizer Rubric

If you use the Graphic Organizer 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

Additional Resources and Teaching Strategies

Additional Resources

❖ Labs and demonstrations

- Lab: Students will investigate the relative reactivity of three metals. They will use this knowledge to relate the activity series to cell potential.
  https://teachchemistry.org/classroom-resources/reactivity-electrochemistry
- Lab: Students investigate how to build a galvanic cell and compare collected data to theoretical values of cell potential.
  https://teachchemistry.org/classroom-resources/four-way-galvanic-cell
- Animation: Students will view an animation of a galvanic cell, focusing on the particulate level. There is an accompanying worksheet for them to describe the parts of the galvanic cell and identify the reactions that took place within.
  https://teachchemistry.org/classroom-resources/animation-activity-galvanic-cells
- Map: Students can investigate their state battery recycling laws using this interactive map.
  https://www.call2recycle.org/recycling-laws-by-state/
- Lithium Mining in Utah: Students design and carry out an experiment to collect a mineral from a solution in a way that simulates how lithium is mined.
  https://energy.utah.gov/wp-content/uploads/OED-LESSON-3.5_-Lithium-Mining-in-Utah-1.pdf

❖ Lessons and lesson plans

- Lesson: Students learn more about lithium-ion batteries and how its developers were awarded the 2019 Nobel Prize in Chemistry.
  https://www.compoundchem.com/2019/10/09/2019nobelchemistry/

Teaching Strategies

Consider the following tips and strategies for incorporating this article into your classroom:

- **Alternative to Anticipation Guide:** Before reading, ask students where they use batteries in their everyday lives. Ask if they have ever thought about the chemistry involved in making and using batteries. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
  - As they read, students can find information to confirm or refute their original ideas.
- After they read, ask students what they learned about the importance of batteries in our lives, problems caused by battery use, and possible solutions to these problems. Ask how they might use the information in the future.
- **Note:** Safe battery disposal is not specifically addressed in this issue, but students may have questions. In most municipalities, disposal of regular alkaline batteries (such as AAA, AA, C, D, 9V) in the regular trash is OK, some municipalities do recycle these batteries as well. However, rechargeable batteries should always be taken to a hazardous waste disposal site because they pose a fire hazard.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Electrochemistry
- Electrolytic cells
- Oxidation
- Reduction
- Redox reaction
- Spontaneous vs. nonspontaneous reactions

Correlations to Next Generation Science Standards

This article relates to the following performance expectations and dimensions of the NGSS:

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- PS.3.D: Energy in Chemical Processes
- ETS1.B: Developing Possible Solutions

Crosscutting Concepts:

- Systems and system models
- Energy and matter: Flows, cycles, and conservation

Science and Engineering Practices:

- Constructing explanations (for science) and developing solutions (for engineering)

Nature of Science:

- Science is a human endeavor.

See how *ChemMatters* correlates to the **Common Core State Standards** online.

Teacher's Guide

How Did the Battery Get Its Name?

April 2024

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Anticipation Guide

Name: ______________________________

Directions: ***Before reading the article*****,** in the first column, write "A" or "D," indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

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. Alessandro Volta coined the term "battery."
		2. Batteries change chemical energy to electricity.
		3. Volta's first battery was a voltaic pile consisting of zinc, copper or silver, and salt water.
		4. Zinc is oxidized at the anode of many batteries.
		5. The electrolyte in many alkaline batteries is NaOH.
		6. The electrolyte in a battery provides a path for electron flow.
		7. Alkaline batteries are named according to size.
		8. Batteries of different sizes have different voltages.
		9. Button and coin batteries were developed in the 1970s.
		10. The numbers in coin batteries tell the size of the battery in cm.

Student Reading Comprehension Questions

Name: ______________________________

Directions: Use the article to answer the questions below.

1. What was the name of the scientist who came up with the name "battery"? What is the original definition of the word?

2. In Volta's battery or any voltaic cell, what causes the electrons to move? Write the two half reactions that occur in Volta's battery? Which reaction is the oxidation and which reaction is the reduction?

3. Why are the more common non-reusable batteries called "alkaline batteries"?

4. Define anode and cathode and briefly explain their roles in electron transfer.

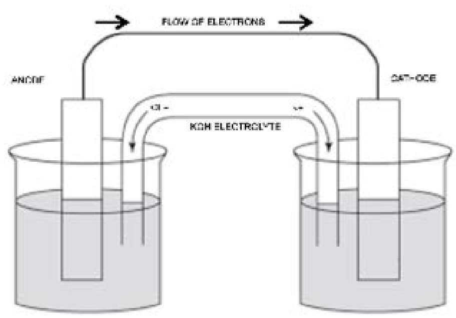
5. Briefly describe the original naming/lettering system for batteries. Briefly explain the new naming procedure. Why do we not see any B batteries?

6. Explain what it means for voltage to be an "intrinsic" property.

7. Explain the difference between voltage and current. Using these terms, why do we have different sizes of batteries?

8. Explain, in terms of current and power, why it is necessary to use multiple batteries in a device.

9. Examine the diagram below of a voltaic cell. Notice the direction of flow of electrons, as well as the flow of the electrolyte solution (KOH). Explain why the ions in the electrolyte are needed for the cell to work.



10. Consider the equation:

$$Zn(s) + 2OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^-$$

When the reactant, Zinc, has been completely converted to zinc oxide (ZnO), what will happen to the reaction, and the battery? With this in mind, how do you think rechargeable batteries work?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

11. Research and describe the similarities and differences between series and parallel. What are some examples of devices that use either of these set-ups?

Graphic Organizer

Name: ______________________________

Directions: As you read, complete the graphic organizer below to define terms from the article, with examples.

	Definition	Example or Interesting Fact
Battery		
Voltaic Pile		
Alkaline Battery		
Electrolytic Cell		
Voltage		
Anode		
Cathode		

Summary: On the back of this sheet, write three interesting facts you learned about naming batteries.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. What was the name of the scientist who came up with the name “battery”? What is the original definition of the word?
   Benjamin Franklin coined the term “battery.” The term battery is originally a military term meaning weapons working together.

2. In Volta’s battery or any voltaic cell, what causes the electrons to move? Write the two half reactions that occur in Volta’s battery? Which reaction is the oxidation and which reaction is the reduction?
   The difference in potential for reduction between the zinc and the copper causes the electrons to move and produce electricity.

   Oxidation: $Zn \rightarrow Zn^{2+} + 2e^-$

   Reduction: $2H^+ + 2e^- \rightarrow H_2$

3. Why are the more common non-reusable batteries called “alkaline batteries”?
   The most common batteries are called alkaline because they contain potassium hydroxide as the electrolyte. (Metal hydroxides are labeled alkaline).

4. Define anode and cathode and briefly explain their roles in electron transfer.
   Anode: the part of the cell/battery where the electrons leave (or, where the chemicals are oxidized).

   Cathode: the part of the cell/battery where the electrons are accepted (or, where the chemicals are reduced).

5. Briefly describe the original naming/lettering system for batteries. Briefly explain the new naming procedure. Why do we not see any B batteries?
   The original naming system was based on the letters of the alphabet. The larger the battery, the higher up on the lettering scale. Now, we use a new code, which contains letters (for the chemical and the shape of the battery) and numbers (for the size). A and B batteries used to exist, but devices have changed and they are no longer used.

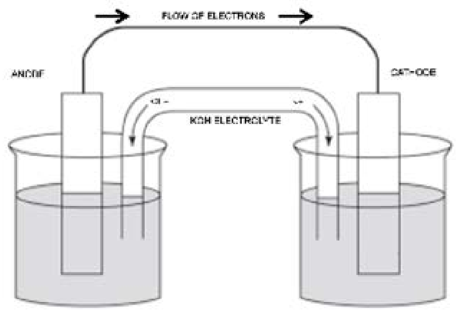
6. Explain what it means for voltage to be an “intrinsic” property.
   An intrinsic property is independent of the amount of the material present. Concentration is a good example, if you pour a glass of juice from a bottle into an empty glass, the concentration remains the same in the glass as it was in the bottle. The voltage produced by a substance will be the same no matter how much of the substance is present.

7. Explain the difference between voltage and current. Using these terms, why do we have different sizes of batteries?
   Voltage measures the potential difference between two different chemical species, whereas current is the amount of electrons flowing past a point per unit of time in a circuit. Even though batteries of different sizes have the same voltage, larger batteries have a higher current. If the current is larger, then a larger amount of electrons are available to run larger devices.

8. Explain, in terms of current and power, why it is necessary to use multiple batteries in a device.
   The power of a battery is the combination of both current (the number of electrons moving through the circuit) and voltage, the potential difference between the chemical species being oxidized and reduced.

To increase the voltage, multiple batteries may be needed. The larger voltage provides a larger amount of power for the devices.

9. Examine the diagram below of a voltaic cell. Notice the direction of flow of electrons, as well as the flow of the electrolyte solution (KOH). Explain why the ions in the electrolyte are needed for the cell to work.



When electrons flow to one end (the cathode), there is an imbalance of negative charge in the cell. To rebalance the charges, the cations (positive ions) in the electrolyte move towards the cathode to counter the increased negative charge. The anions (negative ions) in the electrolyte flow to the anode, to replace the negative charges lost by the removal of the electrons.

10. Consider the equation:

$$Zn(s) + 2OH^{-}(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^{-}$$

When the reactant, Zinc, has been completely converted to zinc oxide (ZnO), what will happen to the reaction, and the battery? With this in mind, how do you think rechargeable batteries work?
When the zinc has been completely used up, there is no more material to produce electrons. The reaction will end, and the battery will not work anymore ("the battery died"). With rechargeable batteries, an outside power source (i.e. electrical outlet) reverses the reaction so it can start over again.

11. Research and describe the similarities and differences between series and parallel. What are some examples of devices that use either of these set-ups?
A series connection is made when the batteries are connected end to end. When this happens, the voltage of each battery is added. This provides more power to devices. The current stays the same, so the batteries will last longer. This is good for many devices found in home or school (remotes, calculators, toys, etc).

A parallel connection is made when all the positives are connected to one wire, and all negatives are connected to another wire. The voltage remains the same, but the current increases overall. This is good for larger devices (i.e. car batteries) that need a large amount of current to run.

The following are 2 resources to check out.

https://ca.renogy.com/blog/batteries-in-series-vs-parallel-what-are-the-differences/#:~:text=Connecting%20batteries%20in%20series%20increase,ampere%20hour%20ratings(capacity)

https://www.quora.com/Why-do-we-use-3-AAA-instead-of-1-or-2-AA-batteries-Is-there-a-huge-output-difference#:~:text=If%20you%20connect%20three%20AA,charge%20capacity%20and%20energy%20capacity

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Graphic Organizer Rubric

If you use the Graphic Organizer 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

Additional Resources and Teaching Strategies

Additional Resources

- **Labs and demonstrations**
  - https://www.acs.org/content/dam/acsorg/education/outreach/celebrating-chemistry/2024-ccew/batteries-from-nature.pdf
  - https://www.acs.org/education/outreach/celebrating-chemistry-editions/2024-ccew/build-a-battery-workshop-explore-electrolytes.html
- **Lessons and lesson plans**
  - https://teachchemistry.org/classroom-resources/battery-basics
  - https://teachchemistry.org/classroom-resources/columbia-dry-cell-battery
  - https://teachchemistry.org/classroom-resources/what-powers-your-world
  - https://teachchemistry.org/classroom-resources/hybrid-and-electric-cars-video-questions
- **Simulations**
  - https://teachchemistry.org/classroom-resources/voltaic-cells

Teaching Strategies

Consider the following tips and strategies for incorporating this article into your classroom:

- **Alternative to Anticipation Guide:** Before reading, ask students when they think batteries were invented. Also ask them if they know what's inside a flashlight battery and what different battery sizes mean. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
  - As they read, students can find information to confirm or refute their original ideas.
  - After they read, ask students what they learned about the development of batteries, and why there are so many kinds of batteries.
- After students have read and discussed the article, ask students what information they would like to share with friends and family about battery choices.
- **Note to teachers:** This article refers to naming household batteries, not larger batteries. However, 9V batteries were not mentioned. These are 9V alkaline batteries, which are basically six alkaline cells like those described in the article wrapped together in a bundle.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Anode
- Cathode
- Electricity
- Electrolytic cells
- Oxidation
- Reduction

Correlations to Next Generation Science Standards

This article relates to the following performance expectations and dimensions of the NGSS:

HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends on the changes in total bond energy.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- PS.1.A: Structure and Properties of Matter
- PS.1.B: Chemical Reactions
- ETS.1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Systems and system models
- Energy and matter
- Structure and function

Science and Engineering Practices:

- Constructing explanations (for science) and developing solutions (for engineering)

Nature of Science:

- Science is a human endeavor.

See how *ChemMatters* correlates to the **Common Core State Standards** online.

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Demystifying Everyday Chemistry

Teacher's Guide

Lithium: The 21st Century Gold Rush

April 2024

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Name: ______________________________

Anticipation Guide

Directions: *Before reading the article*, in the first column, write "A" or "D," indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

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. Lithium is used in the cathode of lithium-ion batteries.
		2. Lithium is always found combined with other elements in nature because of its high reactivity.
		3. Lithium carbonate becomes more soluble in water as the temperature increases.
		4. Most of the world's lithium deposits are found in the United States.
		5. In the Lithium Triangle countries, lithium is obtained by evaporating water from brine to concentrate the lithium.
		6. Direct lithium extraction works well for brines with low lithium ion concentrations.
		7. Future alternatives to lithium-ion batteries include sodium-ion batteries.
		8. Where speed and portability are not important, flow cell batteries are being considered as a safer alternative to lithium-ion batteries.
		9. Vanadium flow batteries being developed use different oxidation states of vanadium.
		10. Lithium metal is easily recycled.

Student Reading Comprehension Questions

Name: ______________________________

Directions: Use the article to answer the questions below.

1. Why does the electronics industry prefer to use lithium carbonate over other types of metals?
2. Which countries make up the Lithium Triangle?
3. Based on the graph in the article, which year had the lowest price of lithium at the start of the year?
4. List the names and formula of the three lithium compounds isolated and refined in the Lithium Triangle.
5. Which two states in the United States contain most of the lithium deposits in the country?
6. Name two possible sources of energy for flow batteries.
7. Explain how lithium is recovered in the Lithium Triangle.
8. Describe how the Direct Lithium Extraction process works.
9. Explain why researchers are looking for ways to use iron and manganese to replace cobalt in lithium cobalt oxide.

Questions for Further Learning

Write your answers on another piece of paper if needed.

10. Name two common uses of lithium batteries and explain the characteristics of the batteries that make them useful for those devices.

11. What role does temperature play in separating lithium carbonate?

12. Explain why alkali metals react easily with other elements.

13. Describe both the advantages and disadvantages of sodium-ion batteries when compared with lithium-ion batteries.

14. The article briefly describes some problems associated with the mining of lithium and cobalt. Perform additional research and explain at least two of these problems in greater detail.

15. The article lists three alternatives to lithium-ion batteries: new cathode materials for lithium-ion batteries, sodium-ion batteries, and flow batteries. Select one of the alternatives, research the advancements on the alternative, and create a poster explaining the benefits of using the alternative.

Name: ______________________________

Graphic Organizer

Directions: As you read, complete the graphic organizer below to describe the chemistry involved in mining lithium and possible alternatives to lithium-ion batteries.

Chemistry of lithium		
Common uses for lithium-ion batteries		
Current sources of lithium		
Lithium extraction processes	1.	2.
Advantages to lithium-ion batteries		
Disadvantages to lithium-ion batteries		
Alternatives to lithium-ion batteries	1. 2. 3.	

Summary: On the back of this sheet, write a short summary (20 words or less) of the article.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Why does the electronics industry prefer to use lithium carbonate over other types of metals?
   The electronics industry prefers lithium carbonate because it is easy to purify.

2. Which countries make up the Lithium Triangle?
   Chile, Bolivia, and Argentina make up the Lithium Triangle.

3. Based on the graph in the article, which year had the lowest price of lithium at the start of the year?
   2021 had the lowest price of lithium at the start of the year.

4. List the names and formula of the three lithium compounds isolated and refined in the Lithium Triangle.
   The three forms of lithium produced in the Lithium Triangle are lithium hydroxide (LiOH), lithium chloride (LiCl), and lithium carbonate (Li_2CO_3).

5. Which two states in the United States contain most of the lithium deposits in the country?
   Nevada and Utah are the two states that have most of the lithium deposits in the United States.

6. Name two possible sources of energy for flow batteries.
   Flow batteries can be used to store wind or solar energy.

7. Explain how lithium is recovered in the Lithium Triangle.
   In the Lithium Triangle brine from saltwater deposits is pumped into ponds where the water evaporates until the concentration of lithium is at 6%. The brine is then pumped to a facility where it is purified.

8. Describe how the Direct Lithium Extraction process works.
   The Direct Lithium Extraction method uses a lithium-selective membrane to separate lithium ions from other types of ions.

9. Explain why researchers are looking for ways to use iron and manganese to replace cobalt in lithium cobalt oxide.
   Researchers are looking for ways to use iron and manganese because they are more abundantly available than cobalt.

10. Name two common uses of lithium batteries and explain the characteristics of the batteries that make them useful for those devices.
    Common uses of lithium batteries include cell phones, laptops, electric cars, pacemakers, digital cameras, and golf carts. Lithium batteries are used in these devices because they charge quickly, last for a long time, and have a high power density.

11. What role does temperature play in separating lithium carbonate?
    Lithium carbonate becomes less soluble in water at warmer temperatures, so it separates from the rest of the solution making it easier to access.

12. Explain why alkali metals react easily with other elements.
    Alkali metals react easily with other elements because the atoms are large and they have very low ionization energy, that is, it doesn't take much energy to remove an electron.

13. Describe both the advantages and disadvantages of sodium-ion batteries when compared with lithium-ion batteries.
A disadvantage is that sodium-ion batteries generate less energy per unit of mass. Sodium is heavier than lithium but would produce the same number of electrons per atom, so we'd need more mass of sodium than we do for lithium which would make the batteries heavier for the same amount of energy. Advantages of sodium-ion batteries include lower production costs, there is a greater abundance of sodium in the earth's crust and it can be more reliably sourced.

14. The article briefly describes some problems associated with the mining of lithium and cobalt. Perform additional research and explain at least two of these problems in greater detail.
Student responses will vary. The article explains that the mining of lithium is being contested in Nevada because the lithium is located on a site that is sacred to Native Americans. Cobalt is difficult to source and mining it has destroyed the landscape and exploited local laborers.

Graphic Organizer Rubric

If you use the Graphic Organizer 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

Additional Resources and Teaching Strategies

Additional Resources

❖ Lessons and lesson plans

- ➢ How Far Can We Go?- This AACT lesson plan leads students through the process of comparing the densities of lithium ion and lead acid batteries to develop an understanding of the relationship between electrochemical cell potential and stored chemical energy.
- ➢ What Powers Your World? - Students can use this lesson from AACT to explore the way batteries work to power everyday objects.
- ➢ Building Batteries - Chemistry - This lesson plan from the Utah Office of Energy Development provides instructions for experimenting with battery creation.

❖ Simulations

- ➢ Galvanic/Voltaic Cells – Students can use this simulation to investigate battery function by testing a variety of different electrodes.

❖ Projects and extension activities

- ➢ Hybrid and Electric Cars Video – This AACT activity includes a video and questions related to the ways that batteries power hybrid and electric cars. Lithium battery function is also included in the video.

Teaching Strategies

Consider the following tips and strategies for incorporating this article into your classroom:

- **Alternative to Anticipation Guide:** Before reading, ask students where they might find lithium-ion batteries in their everyday lives, and why they are important. Ask them about the chemistry of lithium, and if they know where lithium is mined. Ask about hazards posed by lithium-ion batteries. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
    - As they read, students can find information to confirm or refute their original ideas.
- After reading, ask students what they learned about lithium-ion batteries, including where they are used, how lithium is mined, problems with lithium-ion batteries, and alternatives for the future.
- Consider asking students to read the “Open for Discussion” article on page 4 of this issue to consider relating sustainability to the production of batteries.
- Students can also read the “Chemistry in Person” article to learn more about lithium-ion batteries from an interview with the 2019 Nobel laureate who helped develop them.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Anode
- Cathode
- Oxidation
- Oxidation number
- Reduction
- Solubility
- Precipitate
- Separating mixtures

Correlations to Next Generation Science Standards

This article relates to the following performance expectations and dimensions of the NGSS:

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- PS.1.A: Structure and Properties of Matter
- PS.2.B: Types of Interactions
- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Scale, proportion, and quantity
- Systems and system models
- Energy and matter: Flows, cycles, and conservation

Science and Engineering Practices:

- Constructing explanations (for science) and designing solutions (for engineering)

Nature of Science:

- Scientific knowledge assumes an order and consistency in natural systems.

See how *ChemMatters* correlates to the **Common Core State Standards** online.

ChemMatters

Demystifying Everyday Chemistry

Teacher's Guide

The Earth's Chemical Fingerprint

April 2024

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Anticipation Guide

Name: ______________________________

Directions: ***Before reading the article*****,** in the first column, write "A" or "D," indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

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. In our solar system, only Earth has water vapor in the atmosphere.
		2. Scientists agree about where Earth's water came from.
		3. Planets close to the sun do not have solid compounds containing hydrogen such as methane and ammonia.
		4. Deuterium's mass is almost twice that of hydrogen.
		5. Earth, the sun, and comets have similar deuterium-to-hydrogen ratios.
		6. Asteroids far from the sun contain carbon and water ice.
		7. Any hydrogen atom can react with oxygen to form water.
		8. Earth's crust has more water than Earth's mantle.
		9. Solar radiation may have blasted away any water on the early Earth.
		10. Scientists look for water because water is required for life.

Student Reading Comprehension Questions

Name: ______________________________

Directions: Use the article to answer the questions below.

1. Why don't planets that are closer to the sun contain solid H_2O, NH_3 or CH_4?

2. Using details from the graphic, titled "Birth of a Solar System", explain the role of gravity in the formation of our earth from a protoplanetary disk.

3. When a set of atoms are classified as isotopes, it means that they are all fundamentally the same element. Use the graphic, titled "Hydrogen's Isotopes", to answer the following questions:
    a. Which feature of the three isotopes shown allows us to call them all "hydrogen"?

    b. Chemical symbols can be written to differentiate different isotopes from each other. The type of chemical symbol used in this case is called the "isotope notation" or "isotope symbol". List the isotope name for each of the isotope symbols below. What do the "1", "2", and "3" in the isotope name represent?

Symbol	Isotope name	Common name
${}^{1}_{1}H$	Hydrogen-1	
${}^{2}_{1}H$	Hydrogen-2	
${}^{3}_{1}H$	Hydrogen-3	

    c. What do the "1", "2", and "3" in the isotope name represent?

    d. Circle each of the following symbols that, together, would represent a set of isotopes for the fictional element, X.

$${}^{28}_{14}X \qquad {}^{28}_{13}X \qquad {}^{30}_{14}X$$

4. When scientists need a way of comparing things, they often choose a reference value to which all others can be compared. This reference value, the Vienna Standard Mean Ocean Water (VSMOW) is the standard mean isotopic ratio of deuterium (D) to protium (H) in the Earth's oceans and was found to be

1.56x10^{-4}. Because this represents a ratio of amounts, it is a unitless number. One source lists the average relative abundance of hydrogen-1 (H) and hydrogen-2 (D) as shown below:

Isotope	Relative Abundance
$^{1}_{1}H$	0.999851
$^{2}_{1}H$	0.000149

a. According to this data, is there a higher ratio of deuterium in the oceans or in the rest of the earth? Use a calculation to defend your answer.

5. How is a meteorite different from an asteroid?

6. The "frost line" for our solar system is the radial distance from the sun beyond which it is possible for a particular substance to exist in the solid form. The presence of snow and icebergs on our planet shows that we are currently farther out from the sun than the water frost line in our solar system. Piani's group, however, proposes that our earth was created from the material that was inside (closer to the sun than) the water frost line when the planets were being formed. This conclusion is partially described below. Add the **reasoning** that connects the evidence to the claim. Your reasoning should clearly *identify any relevant knowledge* and *use science principles* to explain why the claim makes sense based on the evidence.

   Claim: It is likely that the earth formed from the material inside the frostline
   Evidence: The chemical fingerprints, like D/H ratios, on enstatite chondrites are very similar to those on earth.
   Reasoning: ?

7. Why does Sean Raymond believe that Earth's water came from several different places?

8. Why can studying meteorites help scientists to understand origins of the earth?

9. Studying the origins of the earth is a very large and very complex undertaking. Why are scientists interested in pursuing this knowledge?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

10. There is a quote in the article from Laurette Piani that says, "We use the meteorites as an archive for the solar system." Write a paragraph that explains the meaning of this quote, using details from the article.

11. The article ends with a quote from Sean Raymond, "Life requires water, so we want to know where the water came from, simply put." Conduct some research to identify some areas in which this knowledge could be useful.

Graphic Organizer

Name: ______________________________

Directions: As you read, complete the graphic organizer below to summarize information from the article.

	Provide an explanation or description and examples for each topic
Ideas about origin of Earth's water	1. 2. 3.
How frost line of our solar system affects planetary compounds	
How D-H ratios provide clues to source of Earth's water	
Chemical makeup of carbonaceous chondrites	
Chemical makeup of enstatite chondrites	
Chemical makeup of Earth's layers	

Summary: On the back of this sheet, write a short summary (1-2 sentences) explaining what you learned about the origin of Earth's water.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Why don't planets that are closer to the sun contain solid H_2O, NH_3 or CH_4?
   The temperatures are too hot for these to exist in anything other than their gaseous forms.

2. Using details from the graphic, titled "Birth of a Solar System", explain the role of gravity in the formation of our earth from a protoplanetary disk.
   Students should highlight the following:
   - The matter from the protoplanetary disk condensed in several phases into the bodies of our solar system
   - Gravitational attraction and the subsequent collisions of matter is what made it clump together into planets
   - Distance from the sun affected how different atoms condensed

3. When a set of atoms are classified as isotopes, it means that they are all fundamentally the same element. Use the graphic, titled "Hydrogen's Isotopes", to answer the following questions:
   a. Which feature of the three isotopes shown allows us to call them all "hydrogen"?
      They each have 1 proton.

   b. Chemical symbols can be written to differentiate different isotopes from each other. The type of chemical symbol used in this case is called the "isotope notation" or "isotope symbol". List the isotope name for each of the isotope symbols below.

Symbol	Isotope name	Common name
${}^{1}_{1}H$	Hydrogen-1	Protium
${}^{2}_{1}H$	Hydrogen-2	Deuterium
${}^{3}_{1}H$	Hydrogen-3	Tritium

   c. What do the "1", "2", and "3" in the isotope name represent?
      The mass #, which is the total # of protons + neutrons in the nucleus.

   d. Circle each of the following symbols that, together, would represent a set of isotopes for the fictional element, X.

      ${}^{28}_{14}X$ ${}^{28}_{13}X$ ${}^{30}_{14}X$

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4. When scientists need a way of comparing things, they often choose a reference value to which all others can be compared. This reference value, the Vienna Standard Mean Ocean Water (VSMOW) is the standard mean isotopic ratio of deuterium (D) to protium (H) in the Earth's oceans and was found to be 1.56×10^{-4}. Because this represents a ratio of amounts, it is a unitless number. One source lists the average relative abundance of hydrogen-1 (H) and hydrogen-2 (D) as shown below:

Isotope	Relative Abundance
${}^{1}_{1}H$	0.999851
${}^{2}_{1}H$	0.000149

   a. According to this data, is there a higher ratio of deuterium in the oceans or in the rest of the earth? Use a calculation to defend your answer.
   D/H = 0.000149/0.999851 = 0.000149 = 1.49×10^{-4}
   Since this ratio is lower than the standard ocean ratio noted above, there is a lower ratio of deuterium in the rest of the earth than in the ocean.

5. How is a meteorite different from an asteroid?
   An asteroid is a large rocky body orbiting the sun. A meteorite is a smaller piece of an asteroid that has entered and survived the earth's atmosphere with enough intact matter to reach Earth's surface.

6. The "frost line" for our solar system is the radial distance from the sun beyond which it is possible for a particular substance to exist in the solid form. The presence of snow and icebergs on our planet shows that we are currently farther out from the sun than the water frost line in our solar system. Piani's group, however, proposes that our earth was created from the material that was inside (closer to the sun than) the water frost line when the planets were being formed. This conclusion is partially described below. Add the **reasoning** that connects the evidence to the claim. Your reasoning should clearly *identify any relevant knowledge* and *use science principles* to explain why the claim makes sense based on the evidence.

   Claim: It is likely that the earth formed from the material inside the frostline
   Evidence: The chemical fingerprints, like D/H ratios, on enstatite chondrites are very similar to those on earth.
   Reasoning: ?
   Reasoning should include:
   - All matter to form planets and asteroids originated from the same protoplanetary disk
   - You'd expect a set of matter to behave similarly in similar conditions
   - Since the D/H ratios are so different in different places, it is logical to consider that masses of similar D/H ratio (and other chemical fingerprints) may have formed in the same part of the creation of the solar system

7. Why does Sean Raymond believe that Earth's water came from several different places?
Because the D/H ratios in Earth's water and land are very different from each other and from other solar system components.

8. Why can studying meteorites help scientists to understand origins of the earth?
Asteroids were formed in the same process as were the planets. Since asteroids are essentially untouched, when small parts of them break off to become meteorites and land on earth, we can study the chemical composition of the meteorites to learn how matter organized itself a long, long time ago.

9. Studying the origins of the earth is a very large and very complex undertaking. Why are scientists interested in pursuing this knowledge?
Many possible answers – It can help in the overall search for other places that can support life; it can help scientists identify good/bad conditions for forming or trapping water, and find possible solutions to the problem of water scarcity on earth and on a future possible home planet.

Graphic Organizer Rubric

If you use the Graphic Organizer 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.
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1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

Additional Resources and Teaching Strategies

Additional Resources

❖ Labs and demos

- ➢ Hands-on Modeling Isotopes: AACT Sweet Model of the Atom
https://teachchemistry.org/classroom-resources/sweet-model-of-the-atom

❖ Simulations

- ➢ PhET simulation: Isotopes and Atomic Mass https://phet.colorado.edu/en/simulations/isotopes-and-atomic-mass
- ➢ PhET simulation: Build an Atom
https://phet.colorado.edu/en/simulations/build-an-atom

❖ Lessons and lesson plans

- ➢ Video: AACT What are Isotopes? https://teachchemistry.org/classroom-resources/what-are-isotopes-video-questions
- ➢ Calculating Average Atomic Mass: AACT Candy Isotopes and Atomic Mass
https://teachchemistry.org/classroom-resources/candy-isotopes-and-atomic-mass
- ➢ Set of Lessons on isotopes, radioactivity, and half-life: AACT Radiocarbon Dating and Willard Libby
https://teachchemistry.org/classroom-resources/radiocarbon-dating-and-willard-libby

❖ Projects and extension activities

- ➢ Series of lessons on teaching Earth Chemistry: AACT Teaching Earth Chemistry
https://teachchemistry.org/periodical/issues/september-2019/teaching-earth-chemistry-1
- ➢ Researching resources needed to sustain life: AACT Working for NASA
https://teachchemistry.org/classroom-resources/working-for-nasa
- ➢ AACT Earth Month Resources:
https://teachchemistry.org/news/earth-month-resources

Teaching Strategies

Consider the following tips and strategies for incorporating this article into your classroom:

- **Alternative to Anticipation Guide:** Before reading, ask students if they have ever thought about where Earth's water came from. Ask how chemistry might help answer this question. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
  - As they read, students can find information to confirm or refute their original ideas.
- After they read, ask students how a knowledge of chemistry is helpful to scientists who are working to determine where Earth's water came from.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- States of matter
- Isotopes

Correlations to Next Generation Science Standards

This article relates to the following performance expectations and dimensions of the NGSS:

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.

Disciplinary Core Ideas:

- PS.1.A: Structure and Properties of Matter
- ESS1.C: The History of Planet Earth

Crosscutting Concepts:

- Cause and effect: Mechanism and explanation
- Systems and system models
- Stability and change

Science and Engineering Practices:

- Obtaining, evaluating, and communicating information

Nature of Science:

- Scientific knowledge is open to revision in light of new evidence.

See how *ChemMatters* correlates to the **Common Core State Standards** online.