

ChemMatters[®]

Demystifying Everyday Chemistry

Teacher's Guide

February 2021

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Teacher's Guide

Is Cold Brew Really Different from Iced Coffee?

February 2021

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Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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. Cold brew coffee takes much longer to make than iced coffee.
		2. The fruit from coffee beans contains only one seed.
		3. Caffeine content increases as coffee is roasted.
		4. Water can dissolve polar coffee molecules.
		5. Making cold brew requires far more coffee grounds than making hot coffee.
		6. As cold brew coffee sits in contact with coffee grounds, more compounds dissolve.
		7. When coffee is roasted, different chemical processes occur at different temperatures.
		8. Light roast coffee beans are heated to a higher temperature than dark roast coffee beans.
		9. Cold brew coffee is more acidic than hot brewed coffee.
		10. Cold brew coffee is made at room temperature or colder.

Student Reading

Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Explain the difference between iced coffee and cold brew coffee.
2. What environmental factors influence the character of the coffee you drink?
3. Compare and contrast the two most economically important varieties of coffee.
4. Cold brew coffee is becoming increasingly popular and some say tastes better than its hot brew coffee and iced coffee counterparts. Explain some the reasons for the unique flavor of cold brew.
5. In general, the solubility of a compound in water (or any solvent) increases with increasing temperature. Explain the reason for this chemical phenomenon on the molecular level.
6. Water is known as the universal solvent because of its ability to dissolve many compounds based on its polar nature. Define polarity and explain, using electronegativity, why water has partial positive and negative charges as part of its structure.
7. Based on your knowledge of chemical principles, explain why coffee beans are grinded into grounds before brewing opposed to using the full coffee beans in the brewing process.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Create a diagram (hand drawn or digitally) illustrating and explaining the coffee bean roasting process. The diagram must include a discussion of the Maillard reaction, caramelization, first crack, pyrolysis, and second crack. Include the temperature at which each part of the process occurs, what happens at each phase, and the result.

2. An important draw to coffee, aside from taste, is the energy boost it provides from the caffeine. Research and explain how caffeine boosts energy and alertness inside the body. Draw the structure of caffeine with the point of the pentagonal portion at the top. You will notice the structure looks surprisingly similar to a person with the pentagonal ring being the head and the hexagonal ring being the body. Use your structure of caffeine to create a mascot for your theoretical chemistry themed coffee shop!

3. Create your own cold brew coffee or tea! The process of making cold brew coffee or tea is surprisingly easy. Create a great tasting cold brew coffee or tea is a bit more complicated. There are many cold brew recipes that can be found online that can serve as a foundation for your new brew flavor. Select your favorite coffee blend or tea and try adding some flavors (fruits, nuts, etc.) to create a brand-new brew. Who knows, you may just invent your new favorite drink!

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe the chemistry concepts related to brewing coffee.

	Describe in your own words	Effect on taste of coffee
VOCs		
Polarity		
Surface area		
Maillard reaction		
Water vaporization		
Solubility		

Summary: Write a tweet (280 characters or less) describing what you learned about the chemistry of cold brew coffee.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Explain the difference between iced coffee and cold brew coffee.

Iced coffee is brewed using hot water then added to ice to cool. Cold brew coffee is made using cold water and takes longer to make.

2. What environmental factors influence the character of the coffee you drink?

The variety of the plant, the soil, climate, altitude, and how the beans are processed.

3. Compare and contrast the two most economically important varieties of coffee.

Coffee beans are produced by species of waxy leaved trees. The trees produce a fruit called “cherries” and their seeds contain coffee beans.

Coffea arabica: produces more expensive, mild, lower caffeinated arabica coffee

Coffea Canephora: Produces more harsh tasting, higher caffeinated robusta coffee

4. Cold brew coffee is becoming increasingly popular and some say tastes better than its hot brew coffee and iced coffee counterparts. Explain some the reasons for the unique flavor of cold brew.

Temperature affects the solubility of compounds in water. Solubility increases with increasing temperature and some compounds that dissolve in water at higher temperatures will not dissolve in the colder water used in cold brew. Therefore, the different chemical composition of the brews results in a different state. Also, cold brew requires significantly more coffee grounds and results in a more concentrated coffee brew.

5. In general, the solubility of a compound in water (or any solvent) increases with increasing temperature. Explain the reason for this chemical phenomenon on the molecular level.

Molecular motion increases with increasing temperature. The increased speed and motion of the molecules allows solvent molecules to more effectively break apart solute molecules, which is required for a substance to dissolve.

6. Water is known as the universal solvent because of its ability to dissolve many compounds based on its polar nature. Define polarity and explain, using electronegativity, why water has partial positive and negative charges as part of its structure.

Polarity is the property of having poles. In chemistry, we look at poles as having positive and negative portion of the molecule. Electronegativity is an elements attraction towards shared electrons in a covalent bond. Oxygen, due to its increased effective number charge (7 more proton in its nucleus compared to hydrogen) and higher number of valence electrons, has a significantly higher electronegativity compared to hydrogen. This causes the electron density in the covalent bond between oxygen and hydrogen to shift towards oxygen creating a partial negative charge on oxygen, and a partial positive charge on the hydrogen. The polarity of water allows ionic compounds and polar covalent molecules to dissolve in water due to an electrostatic attraction between the water and solute molecules (opposite charges attract).

7. **Based on your knowledge of chemical principles, explain why coffee beans are grinded into grounds before brewing opposed to using the full coffee beans in the brewing process.**

Grinding coffee beans into grounds increases the surface area of the coffee beans and allows the chemical compounds that are responsible for the taste and aroma of coffee to dissolve in water more effectively. The increased surface area allows more of the coffee molecules to be exposed to water and increases the solubility in water. According to the principles of collision theory, an increase in surface area will increase the rate of a reaction. Similar to the way small sticks and a tinder bundle is more effective in starting a fire compared to a large log.

Questions for Further Learning

1. **Create a diagram (hand drawn or digitally) illustrating and explaining the coffee bean roasting process. The diagram must include a discussion of the Maillard reaction, caramelization, first crack, pyrolysis, and second crack. Include the temperature at which each part of the process occurs, what happens at each phase, and the result.**

Answers will vary but must include all expectations outlined in the question.

2. **An important draw to coffee, aside from taste, is the energy boost it provides from the caffeine. Research and explain how caffeine boosts energy and alertness inside the body. Draw the structure of caffeine with the point of the pentagonal portion at the top. You will notice the structure looks surprisingly similar to a person with the pentagonal ring being the head and the hexagonal ring being the body. Use your structure of caffeine to create a mascot for your theoretical chemistry themed coffee shop!**

Caffeine has many interacts inside body but in short, caffeine acts as a nervous system stimulant which can affect brain activity, muscle activity, and your heart. All of which will result in the side effect of more alertness and energy. Caffeine mascots and ads will vary.

3. **Create your own cold brew coffee or tea. The process of making cold brew coffee or tea is surprisingly easy. Create a great tasting cold brew coffee or tea is a bit more complicated. There are many cold brew recipes that can be found online that can serve as a foundation for your new brew flavor. Select your favorite coffee blend or tea and try adding some flavors (fruits, nuts, etc.) to create a brand-new brew. Who knows, you may just invent your new favorite drink!**

This part of the assignment can be optional. Warn students not to attempt to make cold brew coffee or tea without teacher or parent permission. Students should also be mindful of food allergies if they are making a coffee or tea they are going to share.

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

Lessons and lesson plans

Polarity Activity: In this activity, students will kinesthetically demonstrate the use of electronegativity in determining covalent bond types. <https://teachchemistry.org/periodical/issues/may-2019/modeling-polarity>

Simulations and animations

Solubility Animation: In an animation, students will have an opportunity to visualize on the particulate level how solubility works. Examples of ionic compounds and a polar covalent compound show how when water is attracted to charged parts, they dissolve, and when they're not attracted to charged parts they stay solid. <https://teachchemistry.org/classroom-resources/solubility-animation>

Reaction Rate: The process of dissolving is physical, not chemical. But this simulation does a nice job letting students adjust factors that relate to the speed of how a process can progress.

<https://teachchemistry.org/classroom-resources/reaction-rates-simulation>

Related lesson: <https://teachchemistry.org/classroom-resources/simulation-activity-investigating-reaction-rates>

Labs and demos

Solubility & Compound Type: In this lesson, students determine whether unknown substances are polar, nonpolar, or ionic by testing their solubilities. <https://teachchemistry.org/classroom-resources/solubility-and-compound-type>

Other Resources

Open for Discussion: Caffeine: Have students learn more about the effects of caffeine on their body. <https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/archive-2013-2014/caffeine.html>

3D rendering: This model allows students to get a better idea of what the structure of caffeine looks like. <https://www.acs.org/content/acs/en/education/resources/undergraduate/chemistryincontext/interactives/brewing-and-chewing/3d-model-caffeine.html>

Compound Chemistry Infographic: Coffee Chemistry: Arabica vs. Robusta: <https://www.compoundchem.com/2018/09/30/arabica-robusta/>

Video: Using chemistry to unlock the difference between cold- and hot-brew coffee. https://www.youtube.com/watch?v=Feb1fB4P8jQ&feature=emb_title

Video: ACS Reactions explore the chemistry of caffeine. <https://www.acs.org/content/acs/en/pressroom/reactions/videos/2014/the-science-of-caffeine-the-worlds-most-popular-drug.html>

Video: ACS Reactions explains how coffee is made. <https://www.acs.org/content/acs/en/pressroom/reactions/videos/2017/the-universe-in-a-cup-of-coffee.html>

Video: ACS Reactions explains the Maillard reaction. <https://www.acs.org/content/acs/en/pressroom/reactions/videos/2016/maillard-the-most-delicious-chemical-reaction-in-the-world.html>

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Gases
- Molecules & Bonding: Polarity
- Organic Chemistry: Functional groups; molecular structure
- Solutions

Correlations to Next Generation Science Standards

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

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-ETS1-3

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

Disciplinary Core Ideas:

- PS1.A: Structure and Properties of Matter
- ETS1.C: Optimizing the Design Solution

Science and Engineering Practices:

- Planning and carrying out investigations

Nature of Science:

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

Crosscutting Concepts:

- Cause and effect: Mechanism and explanation
- Structure and Function

Correlations to Common Core State Standards

See how *ChemMatters* correlates to the [Common Core State Standards](http://www.acs.org/chemmatters) at www.acs.org/chemmatters.

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, if they enjoy cold brew coffee, or if they know what it is. Also ask them where coffee comes from and how roasting affects the flavor of coffee.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about roasting coffee beans and making cold brew.
- Students may find this ACS Reactions Video about roasting coffee beans interesting and fun: Coffee Roasting Chemistry Showdown: <https://youtu.be/4Wey8GSgIkw>
- Try the *Coffee GC-MS* puzzle with your students! You can find a on the next page and online at www.acs.org/chemmatters.

Coffee GC-MS Puzzle

Many compounds in coffee are identified using a technique called gas chromatography/mass spectroscopy (GC/MS). In the GC part, the compounds are vaporized and separated into their gaseous forms. The gases feed directly to the MS. Inside the MS, an ion beam knocks an electron off the sample molecule, then sends the ion down into a charged chamber. The distance the ion travels down the chamber is used to calculate the mass to charge (m/z) ratio of the ion, giving the molecular mass of the compound. Because the ions are generally unstable, they also fall apart, usually in pretty predictable patterns. Scientists use the mass of the original ion and the masses of its pieces to identify the compound.

Similarly, the names of the following compounds found in coffee have been broken apart into smaller pieces. Use your smarts (and maybe some help from the coffee article) to reassemble the compounds. An example has been provided.

	GC/MS result	Answer
<i>Example:</i>	<i>LIFT 2 FUR HOURLY</i>	<i>2-FURFURYLTHIOL</i>
1.	ER WAT	
2.	COS SURE	
3.	CAFE FINE	
4.	FIB OR ANVIL	
5.	I CAN IN	
6.	DECAL HEAD YET	
7.	CLAY TIDE	

Coffee GC-MS Puzzle – Answer Key

Many compounds in coffee are identified using a technique called gas chromatography/mass spectroscopy (GC/MS). In the GC part, the compounds are vaporized and separated into their gaseous forms. The gases feed directly to the MS. Inside the MS, an ion beam knocks an electron off the sample molecule, then sends the ion down into a charged chamber. The distance the ion travels down the chamber is used to calculate the mass to charge (m/z) ratio of the ion, giving the molecular mass of the compound. Because the ions are generally unstable, they also fall apart, usually in pretty predictable patterns. Scientists use the mass of the original ion and the masses of its pieces to identify the compound.

Similarly, the names of the following compounds found in coffee have been broken apart into smaller pieces. Use your smarts (and maybe some help from the coffee article) to reassemble the compounds. An example has been provided.

	GC/MS result	Answer
<i>Example:</i>	<i>LIFT 2 FUR HOURLY</i>	<i>2-FURFURYLTHIOL</i>
1.	ER WAT	<i>WATER</i>
2.	COS SURE	<i>SUCROSE</i>
3.	CAFE FINE	<i>CAFFEINE</i>
4.	FIB OR ANVIL	<i>RIBOFLAVIN</i>
5.	I CAN IN	<i>NIACIN</i>
6.	DECAL HEAD YET	<i>ACETALDEHYDE</i>
7.	CLAY TIDE	<i>DIACETYL</i>

Teacher's Guide

How Safe are Hair Dyes?

February 2021

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This helps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.	
<u>Answers</u>	18
Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.	
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Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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. Hair color chemistry has changed dramatically in the first part of the 21 st century.
		2. Consumers should do a skin-patch test before using synthetic hair dyes because of the possibility of contact allergic reactions.
		3. Hydrogen peroxide has two different roles in the hair dyeing process.
		4. Ammonia is used in most permanent hair dyes because it is acidic.
		5. Only one step is needed to apply permanent hair color.
		6. Nonreactive hair dyes are semipermanent and last for about six washings before fading.
		7. Endocrine-disrupting chemicals are found in many personal care products.
		8. More studies are needed to determine if there is a causal relationship between endocrine-disrupting chemicals and breast cancer.
		9. Scientists are working on a milder permanent hair color effect using electrostatic and polar surface interactions.
		10. Polydopamine, a synthetic melanin, is a polymer containing carbon, hydrogen, oxygen, and nitrogen.

Student Reading

Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. How long do reactive dyes last in hair?
2. Who developed the first synthetic hair dye?
3. Explain the probability of being exposed to hair-color chemicals through the scalp.
4. What were the results of Llanos' 2017 Women's Circle of Health study?
5. Explain the results of the NIEHS Sister Study.
6. Explain the benefits and drawbacks of using permanent hair dye.
7. What is the chemical formula for *p*-phenylenediamine?
8. What are the two primary components in reactive hair dye and how do they function?
9. How are semipermanent hair colors different from permanent hair dyes?
10. What synthetic melanin are researchers studying and how is it created?

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe the purpose of chemicals found in permanent hair dye.

Chemicals	Structural Formula	Purpose
<i>p</i> -phenylenediamine (PPD)		
Hydrogen peroxide		
Ammonia		
Resorcinol		
Indoaniline dye		
Polydopamine		

Summary: Write a short email to a friend who uses permanent hair dye describing what you learned from the article.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. How long do reactive dyes last in hair?

Reactive dyes last for several weeks or until new growth makes it necessary to add color.

2. Who developed the first synthetic hair dye?

Eugene Schueller developed the first synthetic hair dye.

3. Explain the probability of being exposed to hair-color chemicals through the scalp.

The probability of being exposed to hair-color chemicals through the scalp is about 1%.

4. What were the results of Llanos' 2017 Women's Circle of Health study?

Black women who used dark hair dye had a 51% increase in breast cancer risk and a 72% increased risk of estrogen receptor-positive breast cancer as compared with Black women who did not color their hair.

5. Explain the results of the NIEHS Sister Study.

The study found that permanent-dye use was associated with a 45% higher risk of breast cancer for Black women and a 7% higher risk for White women when compared with participants who did not color their hair.

6. Explain the benefits and drawbacks of using permanent hair dye.

Permanent hair color is popular because it provides consistent results and lasts for long periods of time. Drawbacks are that using permanent hair dye damages hair, can cause skin sensitization and can cause allergic reactions.

7. What is the chemical formula for *p*-phenylenediamine?

*The formula for *p*-phenylenediamine is $C_6H_4(NH_2)_2$*

8. What are the two primary components in reactive hair dye and how do they function?

The two primary components in hair dye are an alkalizing agent and an oxidizer. An oxidizer removes electrons from other reactants. An alkalizing agent is a substance that can buffer against a change in pH.

9. How are semipermanent hair colors different from permanent hair dyes?

Semipermanent hair colors coat the hair shaft while permanent hair dyes penetrate the cuticle of the hair.

10. What synthetic melanin are researchers studying and how is it created?

Researchers are studying polydopamine. Polydopamine is created through the oxidation of dopamine.

Questions for Further Learning

1. How does an alkaline ingredient get color into a strand of hair?

Alkalline ingreidients get color into hair by swelling the outer hair layer or cuticle, allowing the dye and hydorogen peroxide into the middle layer off the hair. The hydrogen peroxide the oxidizes melanin to make it colorless so only the dye molecules are seen.

2. Products marketed to Black women may contain high levels of endocrine-disrupting chemicals. Research the impacts of endocrine-disrupting chemicals. Select one endocrine-disrupting chemical and create an infographic to explain its impact on the endocrine system.

Student responses will vary but should clearly describe the impact of the endocrine-disrupting chemical on the endocrine system.

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

Labs and demos

Under the Microscope: Forensic Hair Analysis: This lab guide explains how to mount hair to a slide and differentiate between animal and human hair. <https://www.carolina.com/teacher-resources/Interactive/forensic-hair-analysis-activity/tr10879.tr>

Lessons and lesson plans

Chemistry of Permanent Hair Dyes: This poster provides information about the different chemical compounds used to create different colors of hair dye. <https://www.compoundchem.com/wp-content/uploads/2015/05/The-Chemistry-of-Permanent-Hair-Dye-Colours.png>

Dyes and Dying: In this lesson plan students test dyes on different types of fabrics. <https://www.flinnsci.com/api/library/Download/c46ad9cfbff64e9cae7caf3aed645692#:~:text=Dyes%20are%20organic%20compounds%20that%20can%20be%20used,important%20role%20in%20how%20and%20why%20dyes%20work.>

Endocrine Disruptors: In this lesson students perform research to learn about endocrine disruptors and their impact on society. <http://sciencenetlinks.com/lessons/changing-world-1-endocrine-disruptors/>

Other Resources

A Close Look at the Properties of Hair and Scalp: Students can use this website to learn more about the structure of hair. https://www.texascollaborative.org/hildasustaita/module_files/overview.html

Faces of Chemistry: Hair Colourants: This video explains how hair dyes are used to color hair. <https://youtu.be/eQBbEThc1Po>

Evolution of Materials Science: In this activity, students are tasked with creating a video about the development of a current-day product. Additional personal care products related to hair and/or hair dye could be a topic to assign students. <https://teachchemistry.org/classroom-resources/the-evolution-of-materials-science-in-everyday-products>

Correlation vs. Causation: A classics website that helps students depict the common misnomer of the two concepts. <https://www.tylervigen.com/spurious-correlations>

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Electrochemistry: Oxidation
- Molecules & bonding: Covalent bonding, intermolecular forces
- Organic Chemistry: Molecular structure

Correlations to Next Generation Science Standards

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

HS-PS1-3

Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

HS-ETS1-3

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

Disciplinary Core Ideas:

- PS1.A: Structure and Properties of Matter
- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Cause and Effect: Mechanism and explanation.
- Structure and Function

Science and Engineering Practices:

- Analyzing and interpreting data
- Constructing explanations and designing solutions

Nature of Science:

- Science addresses questions about the natural and material world.

Correlations to Common Core State Standards

See how *ChemMatters* correlates to the [Common Core State Standards](http://www.acs.org/chemmatters) at www.acs.org/chemmatters.

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 use permanent hair dye or know someone who does. Ask students if they know what chemicals are in hair dye, and if they have ever wondered if hair dye is safe.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about hair dyes (and other personal care products) and how they will use their new understanding to make decisions about using personal care products.
- Before or after reading the article, consider showing the 5-minute ACS Reactions Video: How Does Hair Dye Work? <https://youtu.be/zeReQ1wlcis>. The information in the video complements the information in the article relating to the hair dyeing process, but there is no mention of possible risks of using permanent hair dye.

Teacher's Guide

Mirror Volcanoes: Terror from Below

February 2021

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Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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. A volcano in the early 1800s triggered global warming.
		2. Lava caused the complete evaporation of the water in Hawaii’s largest freshwater lake.
		3. Earth’s mantle gets hot enough to melt rocks.
		4. Magma originates in Earth’s outer core.
		5. Convection in Earth’s mantle is believed to be responsible for breaking up the lithosphere into large plates.
		6. Adding water to a crystal at high temperature and pressure increases its melting point.
		7. Gases in magma are mostly water vapor, carbon dioxide, and sulfur dioxide.
		8. Pumice is a volcanic rock that forms in an explosive eruption.
		9. You can estimate the temperature of lava from its color.
		10. Scientists monitor earthquakes and volcanic gases to predict eruptions.

Student Reading

Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. What are the different layers of Earth? What are the compositions of each layer? What are the phases of each layer?
2. What is the main chemical found in magma? Based on this chemical, scientists know lava originates from which layer of Earth?
3. Define *solidus*. What is the solidus of the rock in the upper mantle of Earth?
4. Define *incandescence*. Which color of visible light represents lower temperatures? Which color represents higher temperatures?
5. What is *laze*? What is the chemical in laze that contributes to its caustic properties? How does it affect us?
6. Pumice is a common rock formed in volcanic eruptions. How is pumice formed, making it able to float on water?
7. Look up the frequency and energy values of visible light waves. How can we use these values to determine the temperatures of volcano emissions from afar?
8. Explain how flux melting is related to the concept of colligative properties (i.e., freezing point). Compare this to how adding salt to ice changes the ice to liquid water.
9. Explain how it is hard for gases to escape from substances with high viscosity. What makes something viscous? Compare the structures and viscosities of silicon dioxide (in volcanoes) and water.

Student Reading Comprehension Questions, cont.

10. Incandescence is used to determine how hot the volcanic emissions are. We can use this procedure in other situations. What would be another time we could measure temperatures using incandescence?
11. In the sidebar at the beginning of the article, it was asked to determine the amount of energy needed to completely boil away the entire lake. Calculate the energy needed using the information given in the sidebar.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Geologists also use thermal imaging, which measures infrared waves, instead of visible light waves. Where are infrared waves on the electromagnetic spectrum? Research thermal imaging, and explain how it is used to measure the heat of volcano emissions and how scientists use it in other situations.
2. Explain decompression melting. Use a basic phase diagram or molecular structure to explain why melting occurs when pressure decreases, and the temperature remains constant. Water does the opposite! Water melts with increasing pressure. Use phase diagrams and/or the molecular structure of water to explain this.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe what you learned about any six of the vocabulary concept words in bold type.

Vocabulary concept word	Definition in your own words	New information you learned about the concept

Summary: Most people associate volcanoes with Earth science, not chemistry. Write a short description of the chemistry of a volcano.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. What are the different layers of Earth? What are the compositions of each layer? What are the phases of each layer?

		Composition	Phases
Lowest	Inner core	iron, nickel, sulfur	Solid/Rigid
	Outer Core	Iron, nickel, sulfur	Liquid
	Lower Mantle	Silicate materials	Solid/Rigid
	Upper Mantle/asthenosphere	Silicate materials	Solid/Rigid
	Lithosphere	Silicate materials	Solid/Rigid
Highest	Crust	Granite and Basaltic	Solid/Rigid

2. What is the main chemical found in magma? Based on this chemical, scientists know lava originates from which layer of Earth?

Magma is made of molten silicate rocks. This is different from the chemicals in the liquid outer core layer, so magma comes from the solid lower mantle.

3. Define *solidus*. What is the solidus of the rock in the upper mantle of Earth?

Solidus is the temperature at which rock starts to melt. In the upper mantle, the solidus of the peridotite is about 2000 °C.

4. Define *incandescence*. Which color of visible light represents lower temperatures? Which color represents higher temperatures?

Incandescence is when visible light is emitted from very hot objects. Yellow is the hottest with temperatures above 1000 °C. Orange is cooler, and red is the “coolest” at about 800 °C.

5. What is *laze*? What is the chemical in laze that contributes to its caustic properties? How does it affect us?

Laze is short for lava haze. It is a toxic fog that occurs when lava boils away the salty sea water. The salt then reacts with the water in the gas phase, creating gaseous hydrochloric acid. This can affect a person’s breathing, and irritate the skin and eyes.

6. Pumice is a common rock formed in volcanic eruptions. How is pumice formed, making it able to float on water?

Pumice is made from superheated rock in a volcanic explosion. The gases in the rock escape, which creates lots of holes in the rock, and leaves empty openings and pores. This gives pumice a very low density.

7. Look up the frequency and energy values of visible light waves. How can we use these values to determine the temperatures of volcano emissions from afar?

Visible light is part of the electromagnetic spectrum, which consists of waves of electromagnetic energy. Each of the colors of visible light have certain frequency and energy values. The higher the frequency (and lower the wavelength), means higher energy. The color with the highest energy (thus creating hotter temperatures) would be blue, followed by green, then yellow, then orange and finally red.

8. Explain how flux melting is related to the concept of colligative properties (i.e., freezing point). Compare this to how adding salt to ice changes the ice to liquid water.

Colligative properties describe how a melting point or boiling point of a substance is altered when an impurity is added. With flux melting, water from hydrous minerals from the crust works its way down into the hot mantle. The water molecules are impurities, which come between the particles in the mantle rock. This breaks the attractions and causes the rock to liquefy at a lower temperature than normal. This is how we “melt” ice with salt. When we add salt, the salt particles do the same to the attractions between water molecules, causing the ice to liquefy.

9. Explain how it is hard for gases to escape from substances with high viscosity. What makes something viscous? Compare the structures and viscosities of silicon dioxide (in volcanoes) and water.

Substances with high viscosity are typically larger molecules, with stronger intermolecular forces. Lower temperatures make these intermolecular forces stronger. This prevents gases from moving through these substances, thus requiring more heat and pressure to get through (which causes greater explosions). Silicon dioxide has a higher molecular mass compared to water, and the network covalent bonding is much stronger than the hydrogen bonding of water. Additionally, at cooler temperatures, SiO₂ is closer to a solid phase than water.

10. Incandescence is used to determine how hot the volcanic emissions are. We can use this procedure in other situations. What would be another time we could measure temperatures using incandescence?

We can use these to also determine the heat produced by stars in the universe. Stars emitting different colors would give us an idea of how much heat they produce.

11. In the sidebar at the beginning of the article, it was asked to determine the amount of energy needed to completely boil away the entire lake. Calculate the energy needed using the information given in the sidebar.

To solve this problem, you need to calculate the heat in two steps. The first step is to find the heat needed to raise the temperature of the liquid water to 100 °C. At this point (step 2), the temperature remains constant, and the heat added is breaking the intermolecular forces between the molecules. We need 2 equations, and we add the heat values together to get the total heat.

Part 1: Heating to 100 °C

Use $Q = mc\Delta T$, where Q is the heat (in Joules), m is mass, c is the specific heat of water (4.184 J/g °C), and ΔT is the change in temperature ($T_{final} - T_{initial}$)

$$\text{Mass: } (1\text{g water} = 1\text{ cm}^3)$$

$$59423\text{ M}^3 \times 1 \times 10^6\text{ cm}^3/1\text{ m}^3 = 5.9423 \times 10^{10}\text{ cm}^3 = 5.9423 \times 10^{10}\text{ g}$$

$$Q = mc\Delta T$$

$$Q = (5.9423 \times 10^{10}\text{ g})(4.184\text{ J/g }^\circ\text{C})(100\text{ }^\circ\text{C} - 18\text{ }^\circ\text{C})$$

$$Q = 2.0387 \times 10^{13}\text{ J}$$

Part 2: Changing to gas

Use $Q = \text{mass} \times \Delta H_{\text{vap}}$. ΔH_{vap} is the heat of vaporization, or heat needed to convert 1 g of liquid water to steam @ 100°C.

$$40.6\text{ kJ/mol} \times 1\text{ mol}/18\text{g} = 2.26\text{ kJ/g}$$

$$Q = (5.9423 \times 10^{10}\text{ g})(2.26\text{ kJ/g})$$

$$Q = 1.34 \times 10^{11}\text{ kJ} = 1.34 \times 10^{14}\text{ J}$$

Part 3: Add the 2 heat values:

$$Q_{\text{total}} = 2.0387 \times 10^{13}\text{ J} + 1.34 \times 10^{14}\text{ J}$$

$$Q_{\text{total}} = 1.55 \times 10^{14}\text{ J}$$

Questions for Further Learning

1. Geologists also use thermal imaging, which measures infrared waves, instead of visible light waves. Where are infrared waves on the electromagnetic spectrum? Research thermal imaging, and explain how it is used to measure the heat of volcano emissions and how scientists use it in other situations.

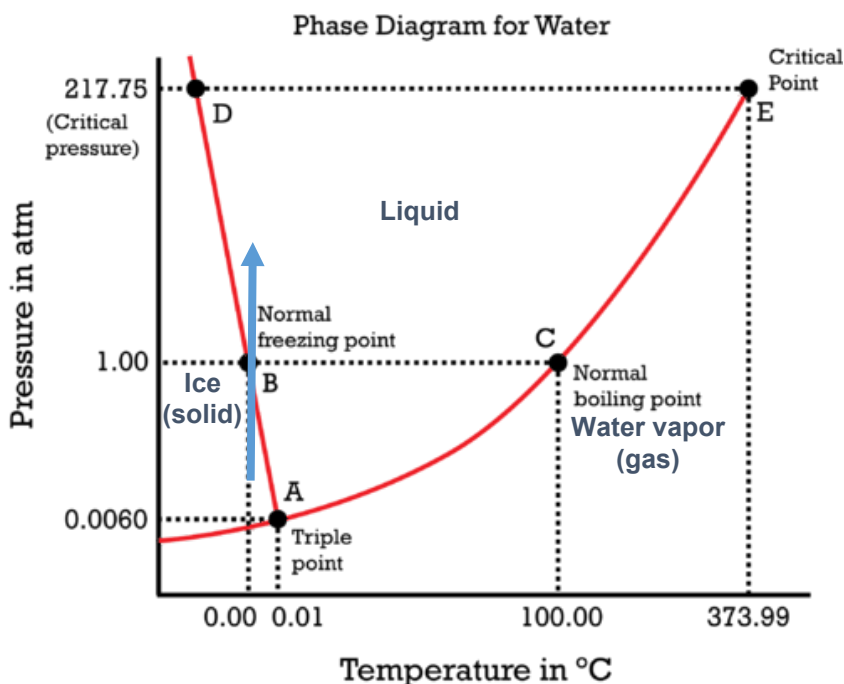
In the article, a scientist uses a thermal camera to determine the temperature near a volcano. These can be used in place of using incandescence for measuring temperatures. Thermal cameras measure infrared waves. These waves are just outside of the visible spectrum. Infrared waves are emitted from heat. A thermal camera measures the magnitude of infrared rays and translates these measurements to temperature values. See this link for info: <https://bit.ly/3oBecj9>.

2. Explain decompression melting. Use a basic phase diagram or molecular structure to explain why melting occurs when pressure decreases, and the temperature remains constant. Water does the opposite! Water melts with increasing pressure. Use phase diagrams and/or the molecular structure of water to explain this.

Decompression means lessening the pressure on a substance. When the pressure decreases, the molecules of the substance are allowed to spread apart from each other, thus weakening the attractive forces between the molecules. This makes the substance turn to liquid.

Water does the opposite. Water molecules, because of its structure, form rings when they solidify. When pressure is applied to the solid water, the rings are broken, causing the water to liquefy.

Students can use phase diagrams to show this. In the phase diagram below, following the blue arrow we can see that when the pressure is increased and the temperature stays constant, we see that ice is melted – going from a solid to a liquid.



Credit: CK-12 Foundation - Christopher Auyeung

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

Labs and demos

The Lovely Lava Lamp: In this lab, students add food coloring to a mixture of oil and water and record their observations. They then add an Alka-Seltzer tablet, record their observations and answer a series of questions about the chemical and physical changes that took place.

<https://teachchemistry.org/classroom-resources/lava-lamp>

How to Make a Cartesian Diver: In this activity, students create your own cartesian diver using a pipette and learn how to make a transform your diver into squidy diver. <https://buggyandbuddy.com/cool-science-kids-make-cartesian-diver/>

Lessons and lesson plans

Teaching Earth Chemistry – Chemistry Solutions Article: This article looks at how plate tectonics operate. Use various visuals to collect evidence to complete a data table that teachers or students can use to explain conclusions about our questions: Why do some volcanoes erupt explosively while others usually do not, and how does earth chemistry lead to this result? <https://teachchemistry.org/periodical/issues/march-2020/part-3-teaching-earth-chemistry>

Investigating how the Chemistry of Plate Tectonics Affects Volcanoes: In this activity, students will learn about the impact chemistry has on plate tectonics and volcanoes. Students will analyze graphs and charts in order to better understand these topics during this investigation. <https://teachchemistry.org/classroom-resources/investigating-plate-tectonics-volcanoes>

Projects and extension activities

Infrared thermometers are popular now because of COVID-19. Have students use (or teacher demonstrate) some common infrared thermometers in class, and if possible, compare their readings with a basic lab thermometer. How similar are the readings? Read through the user manual or research online to see what the accuracy claims are for these thermometers.

Other Resources

Mount Kilauea Volcano Eruption, BBC Earth: Volcanos are certainly destructive, but without them, there would be no breathable atmosphere, oceans, land, or life. <https://youtu.be/L4qDgsyFw7M>

How Does Thermal Imaging Work? <https://bit.ly/3oBecj9>

Compound Chemistry Infographic: Lava and Volcano Gases

<https://cen.acs.org/content/dam/cen/96/28/09628-feature2-volcanoes.jpg>

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Energy & Thermodynamics
- States of Matter
- Quantitative Chemistry

Correlations to Next Generation Science Standards

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

HS-ESS2-3

Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.

Disciplinary Core Ideas:

- ESS2.A Earth Materials and Systems
- ESS2.B: Plate Tectonics and Large-Scale System Interactions

Crosscutting Concepts:

- Cause and effect
- Energy and Matter
- Systems and System Models
- Stability and Change

Science and Engineering Practices:

- Analyzing and interpreting data
- Constructing explanations (for science) and designing solutions (for engineering)

Nature of Science:

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

Correlations to Common Core State Standards

See how *ChemMatters* correlates to the [Common Core State Standards](http://www.acs.org/chemmatters) at www.acs.org/chemmatters.

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 seen a volcano. Ask students how they think volcanoes form.
 - As they read, students can find information to confirm or refute their original ideas. *Do not tell students the answers prior to reading.*
 - After they read, ask students what surprised them about information in the article.

Teacher's Guide

To Mars and Back

February 2021

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Activate students' prior knowledge and engage them before they read the article.	
<u>Reading Comprehension Questions</u>	35
These questions are designed to help students read the article (and graphics) carefully. They can help the teacher assess how well students understand the content and help direct the need for follow-up discussions and/or activities. You'll find the questions ordered in increasing difficulty.	
<u>Graphic Organizer</u>	38
This helps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.	
<u>Answers</u>	39
Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.	
<u>Additional Resources</u>	43
Here you will find additional labs, simulations, lessons, and project ideas that you can use with your students alongside this article.	
<u>Chemistry Concepts, Standards, and Teaching Strategies</u>	45

Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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. Scientists waited until astronauts had walked on the moon to begin planning Mars missions.
		2. Most of the oxygen produced on Mars will be needed for rocket launches.
		3. Combustion reactions produce light and heat.
		4. Mars' atmosphere is mostly methane.
		5. The first robot landed on Mars in 1996.
		6. NASA plans to produce oxygen on Mars so that humans can return to Earth.
		7. The rover Perseverance will take an instrument to Mars to test the technology to produce oxygen on Mars.
		8. Solar power is very reliable on Mars.
		9. A nuclear fission reactor has been proposed to produce energy on Mars.
		10. The oxygen generator would accompany astronauts to Mars.

Student Reading

Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. What significant atmospheric gas is largely missing from the Mars atmosphere, making human missions to the planet difficult?
2. The dream of sending humans to Mars is appearing more and more achievable with advances in technology and with an increasing number of successful unmanned missions. What, however, makes the return back from Mars a more difficult task than the trip that would get humans there?
3. Launching a rocket requires a great deal of energy. How is this energy generated when launching from Earth? Why will this strategy be ineffective if launching from Mars?
4. The Oxygen Factor sidebar models a combustion reaction using gasoline as the fuel. Write the balanced chemical equation for this reaction, using **whole-number** coefficients.
5. Solve the problem at the end of The Oxygen Factor sidebar--assume that 600 gallons has two significant figures. Express your answer in kilograms of O₂.
6. The fuel and oxygen mixture requires a large activation energy to combust. This means that every fuel molecule that reacts with oxygen must acquire this energy to react. Yet, it is only necessary to provide the initial spark of energy, rather than continually supplying enough energy for each fuel molecule to react. How can the fuel molecules continue reacting after the initial spark is taken away?

Student Reading Comprehension Questions, cont.

7. Why can't NASA just send extra oxygen with the astronauts so there will be enough oxygen for the combustion needed in the return launch from Mars?

8. MOXIE is an instrument designed to take the carbon dioxide from the Mars atmosphere and chemically isolate some of its oxygen atoms in order to generate oxygen gas (O_2) that is required for a combustion reaction.
 - a. Using the description of the process from the article, write chemical equations to show the two basic steps, including adding or removing electrons, that generate oxygen gas from carbon dioxide. These two steps, when added, should be equivalent to the electrolysis equation shown. (You do not need to include the cathode, anode, or conductor material, but should recognize that without these the process could not occur.)
 - b. For the overall electrolysis process, draw a particle diagram to show 10 molecules of carbon dioxide as a "before" picture and the appropriate product particles as an "after" picture.

9. MOXIE is being used in this mission as a proof-of-concept, rather than to functionally generate massive amounts of oxygen. If this test device can generate 6.00 grams of O_2 in an hour, then what is the daily consumption of carbon dioxide in grams?

10. An instrument that makes use of a nuclear reaction is also being explored for use on Mars. Write a balanced nuclear equation to represent the reaction modeled in the Powering Mars sidebar.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Sketch a picture of the electrochemical cell used in the MOXIE instrument.
 - a. On the sketch, identify the following:
 - i. Where oxidation occurs, along with the oxidation half-reaction.
 - ii. Where reduction occurs, along with the reduction half-reaction.
 - iii. The species that gets oxidized.
 - iv. The species that gets reduced.
 - v. The direction of electron flow between the anode and cathode.
 - b. Is this a galvanic cell or an electrolytic cell? Justify your answer with information from the article.

2. The standard reduction potentials for experimental technologies are not as well-known as those for simple aqueous solutions. For this exercise, you will use the more well-known aqueous potentials for the half-reactions involved in the MOXIE process, as shown below. In aqueous solution, oxide ions exist as hydroxide ions. All hydrogen species below are a result of water being the solvent.



- a. What is the value of the standard cell potential for the electrolysis reaction shown in the article? Show your work.
- b. How can the standard cell potential help justify that this reaction requires an input of energy to proceed?

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe problems and possible solutions encountered as scientists plan for astronauts to travel to Mars.

Problem	(Possible) solution involving chemistry
Launching rocket from Earth to Mars	
Returning humans to Earth from Mars	
Producing oxygen using MOXIE	
Reliable energy sources on Mars	
Producing methane from carbon dioxide	

Summary: Write a one-sentence summary of the article describing how chemistry is important as scientists plan for astronauts to travel to Mars.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. What significant atmospheric gas is largely missing from the Mars atmosphere, making human missions to the planet difficult?

Oxygen gas, O₂

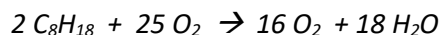
2. The dream of sending humans to Mars is appearing more and more achievable with advances in technology and with an increasing number of successful unmanned missions. What, however, makes the return back from Mars a more difficult task than the trip that would get humans there?

Humans would want to return from Mars, rather than being left there like the various robots and probes. In order to do this, there would need to be a way to generate the lift-off energy. Since there is very little oxygen on Mars, combustion reactions that are typically used for lift-off would be impossible without an external source of oxygen.

3. Launching a rocket requires a great deal of energy. How is this energy generated when launching from Earth? Why will this strategy be ineffective if launching from Mars?

Combustion reactions. Combustion requires oxygen, which is abundant on earth, but not on Mars.

4. The Oxygen Factor sidebar models a combustion reaction using gasoline as the fuel. Write the balanced chemical equation for this reaction, using whole-number coefficients.



5. Solve the problem at the end of the sidebar The Oxygen Factor--assume that 600 gallons has two significant figures. Express your answer in kilograms of O₂.

$$600 \text{ gal } C_8H_{18} \times \frac{2.6 \text{ kg}}{1 \text{ gal}} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mol } C_8H_{18}}{114.232 \text{ g}} \times \frac{12.5 \text{ mol } O_2}{1 \text{ mol } C_8H_{18}} \times \frac{31.998 \text{ g } O_2}{1 \text{ mol}} \times \frac{1 \text{ kg}}{1000 \text{ g}} = 5462 \text{ kg}$$

$$= 5500 \text{ kg } O_2$$

6. The fuel and oxygen mixture requires a large activation energy to combust. This means that every fuel molecule that reacts with oxygen must acquire this energy to react. Yet, it is only necessary to provide the initial spark of energy, rather than continually supplying enough energy for each fuel molecule to react. How can the fuel molecules continue reacting after the initial spark is taken away?

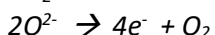
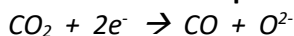
Since the reaction is exothermic, each set of reacting molecules gives off energy. This energy is used as the necessary input to reach the activation level and cause a reaction for remaining molecules.

7. Why can't NASA just send extra oxygen with the astronauts so there will be enough oxygen for the combustion needed in the return launch from Mars?

The weight of the tanks and oxygen would be an impractical load to carry, causing extra energy to be needed for lift-off and leading to the need for additional storage space.

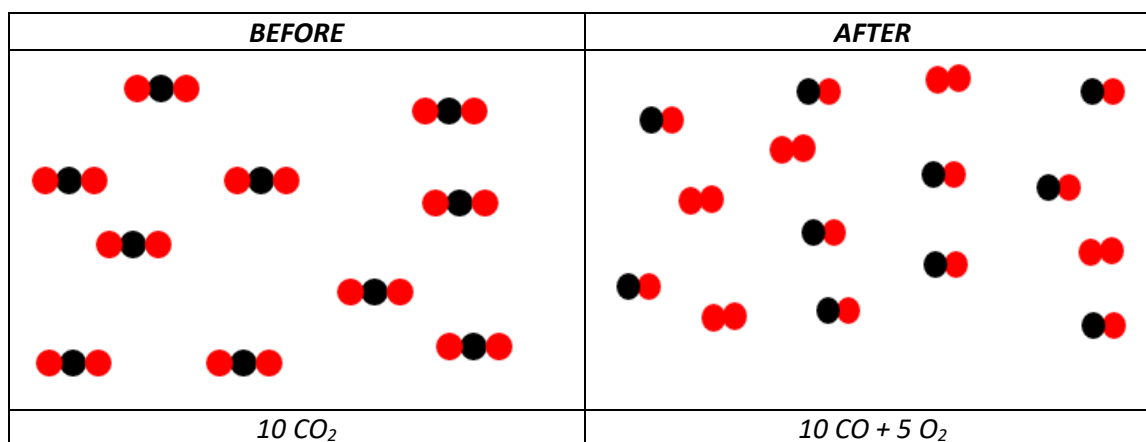
8. MOXIE is an instrument designed to take the carbon dioxide from the Mars atmosphere and chemically isolate some of its oxygen atoms in order to generate oxygen gas, O₂, that is required for a combustion reaction.

- a. Using the description of the process from the article, write chemical equations to show the two basic steps, including adding or removing electrons, that generate oxygen gas from carbon dioxide. These two steps, when added, should be equivalent to the electrolysis equation shown. (You do not need to include the cathode, anode or conductor material, but should recognize that without these the process could not occur.)



The first equation must be doubled in order to create the 2 oxide ions needed in the 2nd equation.

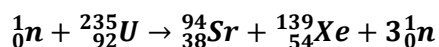
- b. For the overall electrolysis process, draw a particle diagram to show ten molecules of carbon dioxide as a “before” picture and the appropriate product particles as an “after” picture.

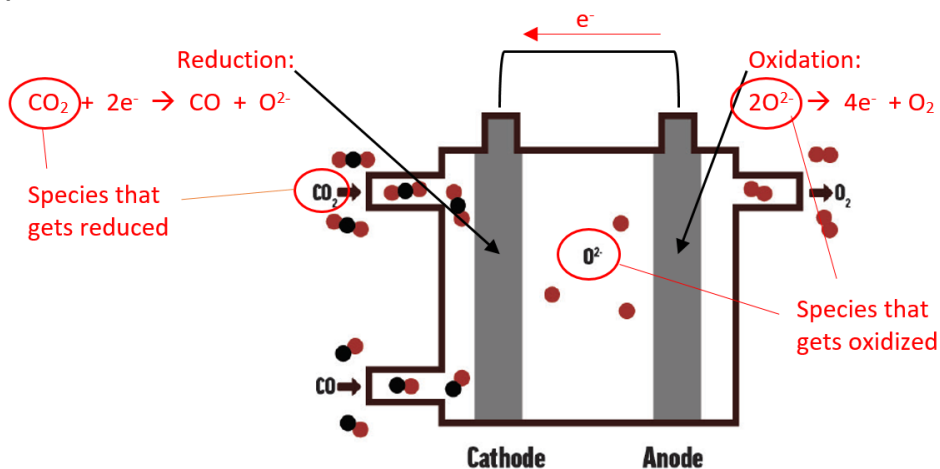


9. MOXIE is being used in this mission as a proof-of-concept, rather than to functionally generate massive amounts of oxygen. If this test device can generate 6.00 grams of O₂ in an hour, then what is the daily consumption of carbon dioxide in grams?

$$\frac{6.00\text{gO}_2}{1\text{hr}} \times \frac{1\text{mol}}{31.998\text{gO}_2} \times \frac{2\text{molCO}_2}{1\text{molO}_2} \times \frac{44.009\text{gCO}_2}{1\text{mol}} \times \frac{24\text{hrs}}{1\text{day}} = 396\text{gCO}_2 \text{ per day}$$

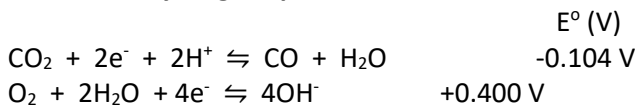
10. An instrument that makes use of a nuclear reaction is also being explored for use on Mars. Write a balanced nuclear equation to represent the reaction modeled in the Powering Mars sidebar.



Questions for Further Learning**1. Sketch a picture of the electrochemical cell used in the MOXIE instrument.**

- a. On the sketch, identify the following:
- Where oxidation occurs, along with the oxidation half-reaction.
 - Where reduction occurs, along with the reduction half-reaction.
 - The species that gets oxidized.
 - The species that gets reduced.
 - The direction of electron flow between the anode and cathode.
- b. Is this a galvanic cell or an electrolytic cell? Justify your answer with information from the article.
Electrolytic cell – The article says that CO₂ is drawn into an electrolysis stack, meaning electricity is used to break up the molecule. It also says that it requires some electricity, but consumes less power than a toaster oven. This means it is nonspontaneous and requires energy input for the reaction to occur, making it an electrolytic cell.

2. The standard reduction potentials for experimental technologies are not as well-known as those for simple aqueous solutions. For this exercise, you will use the more well-known aqueous potentials for the half-reactions involved in the MOXIE process, as shown below. In aqueous solution, oxide ions exist as hydroxide ions. All hydrogen species below are a result of water being the solvent.



- a. What is the value of the standard cell potential for the electrolysis reaction shown in the article? Show your work.
One method is shown here, but there are many correct methods for this calculation.
- | | |
|---|-------------------------------------|
| CO ₂ + 2e ⁻ + 2H ⁺ ⇌ CO + H ₂ O | E° = -0.104 V |
| 4OH ⁻ ⇌ O ₂ + 2H ₂ O + 4e ⁻ | E° = -0.400 V |
| | E°_{cell} = -0.504 V |
- b. How can the standard cell potential help to justify that this reaction requires an input of energy to proceed?
Since the standard cell potential is negative, this means it is nonspontaneous in the designated direction, meaning it requires a steady input of energy to react.

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

Labs and demos

How Much Energy is in Your Snack Food?: An introduction to calorimetry. In this lab, students will find the amount of heat energy stored in foods and compare heat calories with food calories.

<https://teachchemistry.org/classroom-resources/how-much-energy-is-in-your-snack-food>

Measuring Heat: In this demonstration students will observe what happens to the temperature of water when different volumes of hot water are added and also when copper, the same temperature as the hot water is added. <https://teachchemistry.org/classroom-resources/measuring-heat>

Introducing Limiting Reactants: In this demonstration, the teacher will perform a series of reactions between acetic acid (vinegar) and varying amounts of sodium bicarbonate (baking soda) in order to inflate several Ziploc bags. Students will observe the reactions and analyze the quantities of reactants used as well as the results in order to understand the concept of limiting reactants. <https://teachchemistry.org/classroom-resources/introducing-limiting-reactants>

Simulations

Balancing Chemical Equations: <https://phet.colorado.edu/en/simulation/balancing-chemical-equations>

Reactants, Products, and Leftovers: <https://phet.colorado.edu/en/simulation/reactants-products-and-leftovers>

Lessons and lesson plans

Scaffolding Stoichiometry for Struggling Students: Recorded webinar

<https://teachchemistry.org/professional-development/webinars/scaffolding-stoichiometry-for-struggling-students>

Limiting Reactants using Particulate Diagrams: In this activity, students will gain practice drawing particulate diagrams. This is important because it is a big focus on the newly revised AP exam. Many teachers need more examples of what this looks like. <https://teachchemistry.org/classroom-resources/limiting-reactant-using-particulate-diagrams>

Thermochemistry Lesson Idea

- Demo the Whoosh Bottle (as in any of the links below) and ask students to generate questions from their observations.
 - <https://www.flinnsci.com/api/library/Download/bf2f0d16dd86411ea26eb0cb687dc593>
 - <https://edu.rsc.org/exhibition-chemistry/ethanol-rockets/2000047.article>
 - <https://www.grc.nasa.gov/www/k-12/rocket/whoosh.html>
- Lead discussion toward how rockets get off the ground and the amount of energy needed to do this. Then assign the article with questions.
- Lab related to energy of combustion
- Students calculate values combining stoichiometry and calorimetry and relate this to the need for large amounts of oxygen generation on Mars.

AP Chemistry Redox Lesson Idea

- After learning about galvanic cells and standard potentials, assign students to read the article and complete the questions.
- Class discussion – How is the description of the MOXIE different from the types of electrochemical cells learned about to this point (assuming only the spontaneous cells have been studied).
 - Main points:
 - The oxygen generation is not spontaneous
 - The standard cell potential would be negative
 - Energy must be added to allow the reaction
 - From where will MOXIE get this needed energy?
- Practice and calculations for nonspontaneous electrochemical cells

Projects and extension activities

Exploration of Electrolytic Cells: In this lesson, students will build several electrolytic cells, discuss and diagram their cells to further their understanding of electrolysis, and use qualitative and quantitative analysis of the electrolysis of potassium iodide. <https://teachchemistry.org/classroom-resources/exploration-of-electrolytic-cells>

How Far Can We Go?: Compare energy densities to understand the relationship between electrochemical cell potentials and utilization of stored chemical energy.

<https://teachchemistry.org/classroom-resources/how-far-can-we-go>

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Electrochemistry: Electrolysis
- Energy & Thermodynamics: Activation energy
- Nuclear chemistry: Radioactive isotopes
- Reactions & Stoichiometry

Correlations to Next Generation Science Standards

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

HS-ETS1-3

Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraint, including cost, safety, reliability, and aesthetics, as well as possible social, cultural

Disciplinary Core Ideas:

- PS1.A: Structure and Properties of Matter
- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Energy and Matter
- Structure and Function

Science and Engineering Practices:

- Developing and using models
- Planning and carrying out investigations

Nature of Science:

- Scientific investigations use a variety of methods.

Correlations to Common Core State Standards

See how *ChemMatters* correlates to the [Common Core State Standards](http://www.acs.org/chemmatters) at www.acs.org/chemmatters.

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students what problems might be encountered when human astronauts travel to Mars, and how these problems might be solved through chemistry.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about travel to Mars.
- The ACS Reactions video “How Do Rockets Work?” (4 minutes long) briefly explains the chemical requirements for a rocket launch: https://youtu.be/UEoWoQ_Nyaw
- Please note: the E° (V) values in the “Questions for Further Exploration” were obtained from the following sources: Standard Reduction Potentials for Oxygen and Carbon Dioxide Couples in Acetonitrile and N,N-Dimethylformamide (DOI: 10.1021/acs.inorgchem.5b02136) and <http://ch301.cm.utexas.edu/data/standard-potentials.php>

About the Teacher's Guide

Teacher's Guide team editors Dusty Carroll, Scott Hawkins, Matt Perekupka, and Jennifer Smith created the Teacher's Guide article material. Susan Cooper prepared the anticipation, reading guides, and connections to standards.

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