



**October/November 2018**

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

**Teacher’s Guide**



**Teacher's Guide for**

# “Mars vs. Titan: A Showdown of Human Habitability”

**Oct/Nov 2018**

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## Tools and Resources

### Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |

|  |  |
| --- | --- |
| **The greenhouse effect** | The study of harmful effects of greenhouse gases located in the Earth’s atmosphere presents the opportunity to include methane’s protection of Titan’s atmosphere. |
| **Activation energy** | When students use energy to activate chemical reactions in the chemistry laboratory, reference can be made to the source of the high-energy particles that provide energy to drive the formation of complex organic compounds in Titan’s atmosphere. |
| **Organic chemistry building blocks** | The study of the basic organic chemistry of carbon chains can be used to explain astronomers’ search for carbon as an indication of possible life forms elsewhere in the universe. |
| **Phase changes** | The possible collapse of Titan’s atmosphere if N2 were to condense can add interest and relevance to the importance of the phase change that occurs at the boiling point of a substance. |
| **Scientific process** | When students ask, “How do scientists know how to identify habitable locations across the universe?” the information in this article can provide examples of how scientists approach and study scientific problems. |
| **Electromagnetic spectrum** | Information in this article can add interest and importance to the study of ultraviolet radiation, including how spectrophotometers are used to measure properties and identify material in extraterrestrial space. |

### Standards and Vocabulary

#### Standards

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

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

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

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

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

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

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

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

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

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

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

#### Vocabulary

* **Vocabulary** and **concepts** that are reinforced in the October/November 2018 issue:

Structural formulas

Amino acids

Chemical reactions

Equilibrium

Reaction rates

Oxidation & reduction

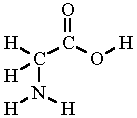
Electrochemistry

* Consider asking students to read “Open for Discussion: The Human Drive to Explore Space” to learn about the risks of space exploration prior to reading the article “Mars vs. Titan: A Showdown of Human Habitability.”
* Students may become interested in growing crystals to connect chemistry and art after reading the articles on pages 2 and 19.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.
* The *ChemMatters* Teacher’s Guide has suggestions for further research and activities.

### Possible Student Misconceptions

1. **“As soon as I finish high school, my quest will be to become one of the first pioneers to sail on the methane lakes of Titan.”** Unfortunately, there are still major challenges to solve before the technology for manned travel to Titan will have been perfected. Housing will also present problems! Humans will have to live in underground habitats on Titan for protection from low temperatures, lack of oxygen and extreme radiation from the sun.
2. **“Someday, during summer break, I assume that we will be able to travel to Titan in a spaceship.”** This will not be a short trip; the latest unmanned spacecraft required two years and 4 months to reach Titan from Earth.
3. **“I’ve seen the red colored Mars, it must be very hot!”** The red color doesn’t really mean that the planet is hot. Actually the average temperature on Mars is -55 oC—much colder than the Earth, whose average temperature is 14 oC. Many rocks on Mars contain iron that rusts (oxidizes) when exposed to the atmosphere. As the iron rusts, dust storms suspend many tiny reddish iron flakes in the thin Mars atmosphere, producing a red planet as seen from the Earth. However on the Martian surface, the space rovers that landed found soil and rocks of many colors, including orange, gold, brown and butterscotch.
4. **“I’ve heard that there are oceans on Mars.”** Eighteenth century telescope observations suggested that the dark areas on Mars were oceans and the light areas were land. Recently, the Mars Curiosity rover did not find liquid water. Curiosity’s measurements suggested some frozen water within the soil and land evidence suggested ancient oceans. The Mars Express spacecraft used radar to detect signatures similar to Earth’s liquid water under the southern ice cap of Mars.
5. **“I understand that going into space makes you weightless, like the pictures of astronauts floating in the International Space Station.”** While astronauts may feel and appear weightless in space due to lack of gravity, this is because their acceleration rate is the same as the space station, so the astronauts and the space station don’t fall to Earth; they just keep falling around it. However, in space, astronauts still retain their mass (the amount of material in the body) but not their weight (measurement of how gravity acts on the body mass); even in zero gravity where the body is weightless, it cannot be massless. The weightlessness is because they are too far from any astronomical body (star, planet, moon, etc.) to feel any gravitational pull. Note that, in addition to the psychological effect of loneliness, a 160-day trip to Mars will also take a physiological toll on your body. Weightlessness (the lack of gravity) will interfere with your heart’s ability to keep blood flowing throughout your cardiovascular system and, since your muscles and bones are not working hard, they will begin to weaken. More details can be found at <https://www.nasa.gov/hrp/bodyinspace>.
6. **“I read that Mars supports strange, but intelligent life.”** Since the 1700s, astronomers have considered and written about the possibility of life on Mars. Early telescopes seemed to indicate evidence of oceans and irrigation canals. Scientific fiction writers enlarged on these speculations and described Martians with monstrous tentacle-arms and eyes in the back of their heads. As early as the 1965 Mariner spacecraft, these myths were dispelled. Today scientists look for the possibility of complex organic molecules and the possibility of microorganisms on Mars.
7. **“The picture caption says that molecules can have 8,000 daltons, but I thought that Dalton was the guy who said that all matter is made of atoms.”** You are correct, John Dalton postulated that all matter is made up of indivisible and indestructible atoms, and that atoms of each element are identical. However, dalton (symbol Da) is also a biochemistry term used to measure the mass of large complex molecules like proteins. This unit is named after Dalton, whose atomic theory provided a method of calculating relative atomic masses. One dalton is the approximate mass of one nucleon (proton or neutron). The mass of one hydrogen atom is numerically the same as 1 dalton or 1 g/mol.

### Anticipating Student Questions

1. **“How many habitable planets may be located in our galaxy?”** NASA launched the Kepler Mission spacecraft in 2009 to survey Earth’s region of the Milky Way galaxy. Data released estimates that our galaxy contains about 40 billion planets the size of Earth and approximately 11 billion of these orbit sun-like stars.
2. **“I heard that methane is a more powerful greenhouse gas than carbon dioxide. Is this true?”** Yes, methane absorbs and traps about 30 times more of the sun’s infrared radiation per molecule than does carbon dioxide.
3. **“What does ΔHo = -311 kJ/mol mean in the equation for the chemical reaction?”** ΔHo shows the value for the change in energy during this chemical reaction. The value is negative, indicating that energy was released as the new chemical bonds formed in the product.
4. **“Are there other planets, beside those around our sun?”** Yes, during the past two decades many planets (exoplanets) have been located orbiting around stars outside our solar system.
5. **“What is the structural formula for the simplest amino acid, glycine?”** As discussed in the article, glycine has “a hydrogen [atom] as its side chain”. Note that the molecular formula, NH2‐CH2‐COOH, shows an amino group (NH2-) on the left and an organic acid group (-COOH) on the right. Looking at the structural formula for glycine, shown on the right, we can see that the hydrocarbon group (-CH2-), sandwiched between the amino group and the acid group, actually contains two hydrogen atoms as its side chains. Other groups can substitute for one or both of these hydrogens, thus forming other amino acids, as shown in the formula for tryptophan in the article.

(<http://www.chem.purdue.edu/jmol/molecules/glycine.html>)

1. **“What is the chemical reaction that shows the amount of energy that microorganisms can absorb from the reduction of iron(III) oxide (Fe2O3)?”** As shown in the diagram on page 8, the CO2 produced by volcanoes located in Mars’ mantle is photodissociated by ultraviolet light from the sun to produce CO. Since there is no elemental carbon (C) on Mars, iron is probably reduced by the CO to produce 25 kJ/mol of energy that can be absorbed by microorganisms, as shown in this reaction:

3 CO + Fe2O3 🡪 2 Fe + 3 CO2 ΔHo = -25 kJ/mol

1. **“How do scientists plan to extract water from rocks on Mars?”** The temperature on Mars is usually well below the freezing point of water. Microwaves can be used to extract any frozen water from Martian rocks and soils. However while water absorbs microwaves, ice does not. To extract the water, microwave beams can be aimed at rocks or holes drilled in rocks. The heated rocks will melt the ice, yielding liquid water.(<https://www.space.com/24052-incredible-tech-mining-mars-water.html>)
2. **“I don’t understand the term ‘ultraviolet photodissociation’ used to describe carbon escaping from Mars’ atmosphere and leaving a small amount of oxygen.”** As shown in the figure, photodissociation occurs when photons from the sun strike the CO2 and CO molecules, breaking them apart (dissociation). A photon’s energy is inversely proportional to its wavelength so the shorter wavelengths of ultraviolet, x-ray and gamma radiations have sufficient energy to break the intermolecular covalent bonds between these molecules.
3. **“Why is Titan considered the prequel for Earth?”** Titan is in a frozen prebiotic state, uncontaminated by life, so scientists can study what our planet might have looked like before life evolved here.
4. **“Why is Mars considered the sequel to Earth?”** Mars has a central metal core and a solid surface of silicate rocks and metals, all similar to Earth. While there is no direct evidence, scientists have long suspected that frozen water exists at the base of the Martian polar caps. These similar characteristics and the lack of biological life suggest that it can be considered a post-terrestrial world.

### Activities

**Labs and demos**

**“Experimenting with UV Sensitive Beads” (30 min):** These activities from Stanford University’s Solar Center (for NASA), designed to adapt to grades 2–12, include a hands-on lab, experimental design, and analysis of the electromagnetic spectrum and NASA data. (<http://solar-center.stanford.edu/activities/UVBeads/UV-Bead-Instructions.pdf>)

**“The Abracadabra of Engineering Strong Structures from Flimsy Materials” (2 class periods):** Lab directions are included showing how to construct and test the strength of a “Solar Sail Mast” using cheap, everyday materials that would capture and use the sun’s energy for propulsion. Note: scroll down to the title (4th activity) for the complete instructions on a PDF file at this URL. (<https://spaceplace.nasa.gov/classroom-activities/en/>)

**Simulations**

**“Live simulation: Mars” (NASA):** Students will use a simulator to select landing and base camp sites for a 2022 mission to Mars; then they investigate sources of water, fuel and oxygen needed for their M.A.R.S. Surveyor mission. (<http://www.e-missions.net/mars/>)

**“Beers Law Lab” (PhET):** Students use a virtual spectrophotometer and vary solutions and concentrations as they study Beers Law and familiarize themselves with the function of spectrophotometers placed on spacecraft. (<https://phet.colorado.edu/en/simulation/beers-law-lab>)

**Media**

**NASA: Cosmic Origin Spectrograph (COS), video (3:09):** Installed on the Hubble spacecraft, COS uses spectroscopy to determine the properties of intergalactic gases—both material going into and being emitted from galaxies. The narrator explains how this allows scientists to look back through the history of the universe. (<https://ca.pbslearningmedia.org/resource/npe11.sci.eng.materials.cos/cosmic-origin-spectrograph/?#.W3IPYnmpXIU>)

**“Cassini: Bouncing Radio Waves off Titan’s Lakes”, video (2:32):** This short video demonstrates how the Cassini spacecraft penetrated Titan’s dense atmosphere with microwaves that bounce off Titan to be picked up by Earth’s receivers and analyzed to reveal information about the composition of Titan’s surface. (<https://www.jpl.nasa.gov/edu/teach/activity/bouncing-radio-waves-off-titans-lakes/>)

**“What has SAM found?”, video (3:36):** This video explains data from SAM, Curiosity Rover’s Sample Analysis Mars instrument that seeks chemical evidence of life on Mars in samples collected from Mars’ Gale Crater. (<https://www.youtube.com/watch?v=UN0Zj4SIz1A>)

**Lessons and lesson plans**

**“Finding Life beyond Earth”, video (1:43:15) with lessons:** The focus of this excellent NOVA video is the search for extraterrestrial life through data from spacecraft that suggest the presence of energy sources and organic material; it includes sections that consider “Life on Mars” and “Life on Titan”. (<https://www.pbs.org/video/nova-finding-life-beyond-earth/>) The program accompanying the video includes seven hands-on activities, complete with teacher directions and suggestions for grades 6-12 lessons. (<https://d43fweuh3sg51.cloudfront.net/media/assets/wgbh/nvfl/nvfl_doc_collection/nvfl_doc_collection.pdf>)

**Lesson plan, “Modeling Energy in Chemistry: Energy and the Electron”**: Students learn to prepare and share scientific arguments to describe how light interacts with atoms and leads to the relationship between energy and spectral lines.

(<https://teachchemistry.org/classroom-resources/modeling-energy-in-chemistry>)

**Projects and extension activities**

**“Marsbound! Mission to the Red Planet” NASA (1 hr. prep time; three 45-minute lessons):** Teachers, go to “Download grade appropriate lesson”, choose high-school level for lesson designed for students serving as project managers to plan a mission to Mars. NGSS alignment and relevant materials are also available at the site. (<https://marsed.asu.edu/lesson_plans/marsbound>)

### References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine’s inception in October 1983 through April 2013; all**

**available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [***http://ww.acs.org/chemmatters***](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get 30 Years of *ChemMatters* Magazine!” (the icon on the right of the screen).**

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



This article describes the process used by two different kinds of spectrometers to detect molecules by analyzing the electromagnetic radiation they emit when hit by cosmic rays from space; this instrumentation was aboard NASA’s 2002 Odyssey spacecraft, whose mission was to map the surface and look for the presence of water on Mars. (Simon, H. The Search for Martian Water. *ChemMatters*. 2002, *26* (3), pp 16–19)

The NASA Special Edition “Aura Launches” contains an excellent graphic that clearly shows the formation of ozone in the stratosphere and in the troposphere. (Tinnesand, M. What’s So Equal About Equilibrium? *ChemMatters*. 2005, *(23)* (1 Special Issue), pp 11–13)

The graphic can also be found on the last page at this URL: <https://www.acs.org/content/dam/acsorg/education/resources/highschool/chemmatters/articlesbytopic/equilibrium/chemmatters-sept2005-equilibrium.pdf>.

The article “‘Follow the Carbon.’ Follow the What?” describes the search for signs of habitability on Mars by NASA’s Curiosity; this rover contains instruments including a spectrometer designed to look for carbon as an indication of life on the planet. (Bleacher, L. *ChemMatters*. 2008, *20* (1), pp 16–19)

“Surviving on Mars” reviews the major challenges that will face the first astronauts who visit or attempt to colonize Mars; this is a short, concise article that explains each challenge involved in preparing for a manned mission to Mars. (Candanosa, R. *ChemMatters*. 2017, *35* (2), p 4)

This article follows the previous one and addresses the issue of growing food in Martian soil and atmospheric conditions via a science fiction book character, used to develop a scenario where the character has to find or produce the essential materials required to grow a food garden on Mars. (Candanosa, R. Growing Green on the Red Planet *ChemMatters*. 2017, *35* (2), pp 5–7)

### Web Resources for More Information

**Spectroscopy**

This site provides a brief overview of how spectroscopes analyze incoming light and identify elements by their unique chemical fingerprints; and how the results can be used to determine the temperature, mass and specific gravity of a planet, moon or star.

(<http://www.abc.net.au/science/articles/2010/10/07/3012690.htm>)

An introduction and explanation of how a spectroscope works is followed by technical details about scope construction and links to further explain the working parts of spectroscopes, such as the slit, grating, detectors and fiber optics.

(<http://bwtek.com/spectrometer-introduction/>)

**Mars and Titan—basic spacecraft data**

Lecture notes about Mars and Titan describe physical and chemical characteristics, plus evidence of current and former life, including photo evidence from rovers and spacecraft.

(<http://www.astro.wisc.edu/~townsend/static.php?ref=diploma-8>)

These two NASA sites cover basic information about Mars and Titan with an overview, section links to simple related classroom activities, and references to “Pop Culture”.

(<https://solarsystem.nasa.gov/planets/mars/in-depth/>) and (<https://solarsystem.nasa.gov/moons/saturn-moons/titan/in-depth/>)

**Mars and Titan—life clues in atmospheres**

Evidence gathered by the Mars Atmosphere and Volatile Evolution mission (MAVEN) suggests an ancient Mars with an atmosphere as thick as Earth and covered by water.

(<https://www.nasa.gov/press-release/nasas-maven-reveals-most-of-mars-atmosphere-was-lost-to-space>)

Titan’s atmosphere: A Chilean telescope found vinyl cyanide (C3H3N) molecules for cell membranes, and Cassini detected anions (C3N– and C4H–) capable of forming organic chains.

(<http://earthsky.org/space/saturn-moon-titan-atmosphere-organic-molecules-discovery>)

**Subglacial liquid water on Mars**

“Radar evidence of subglacial water on Mars” describes the data supporting the discovery of liquid water beneath the Martian southern ice cap; briny water is probably held in the liquid state by pressure from the 1.5 m-thick ice cap above and a high concentration of salt dissolved from the Martian soil.

(<http://science.sciencemag.org/content/361/6401/490.full>)

Accompanying the journal article above, this site contains 20 short YouTube videos running from 0:40 to 13:48 minutes to illustrate and explain findings of the Mars Advanced low Frequency Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument on the Mars express spacecraft.

(<https://video.search.yahoo.com/yhs/search?fr=yhs-pty-pty_email&hsimp=yhs-pty_email&hspart=pty&p=Radar+evidence+of+subglacial+liquid+water+on+Mars.+Orosei#id=1&vid=7225eb391c8940068ba6ac1a41dc8e43&action=click>)

**Human colonization of Titan**

Students will probably enjoy reading planetary scientist Amanda Hendrix’s article; she provides the rationale for her decision that she would rather live on Titan than on Mars.

(<https://www.npr.org/sections/13.7/2017/10/16/555045041/confession-of-a-planetary-scientist-i-do-not-want-to-live-on-mars>)

This is an interview with the authors about colonizing Titan whose wonderful dense atmosphere protects them from Mars’ deadly radiation; Martian colonization will require cramped life in underground tunnels.

<https://arstechnica.com/science/2017/05/forget-mars-lets-go-colonize-titan/>

**Human colonization of Mars**

Elon Musk suggests that, during successful colonization of Mars, humans can live in habitats with underground connections to escape the deadly radiation.

(<http://www.pbs.org/wgbh/nova/next/space/want-to-live-in-a-treehouse-on-mars/>)

The movie “The Martian” presents an enticing scenario where a huge storm strands an astronaut on Mars, where he must be creative to survive, by producing water from rocket fuel and designing a farm to produce his food; the trailer can be found at this site. (<https://www.youtube.com/watch?v=ej3ioOneTy8>)

**Identification of interstellar species**

TheNational Institute of Standards and Technology (NIST), using deep space surveys from telescopes, has identified 160 interstellar molecular species and has developed spectroscopic data bases to identify space material; this URL contains many links to other sites.

(<https://www.nist.gov/pml/sensor-science/optical-radiation/spectroscopic-identification-interstellar-molecules>)

NASA’s Interstellar Boundary Explorer (IBEX) satellite is mapping the boundary between our solar system and interstellar space by scanning the entire sky once per year to intercept and identify neutral atoms coming in from the galactic wind as it blows toward our sun.

(<https://www.nasa.gov/mission_pages/ibex/news/interstellar-difference.html>)

**Search for exoplanets**

This site discusses spectroscopy used to find exoplanets located in the Milky Way galaxy whose light spectrum shows presence of some of the elements essential to life on Earth.

(<https://exoplanets.nasa.gov/the-search-for-life/life-signs/>)

This article describes the role of the Transiting Exoplanet Survey Satellite, launched in 2018 to seek planets orbiting the 200,000 stars closest to Earth that show liquid water, an indication of Earth-like habitation.

(<https://www.economist.com/science-and-technology/2018/04/19/the-search-for-exoplanets-moves-to-earths-back-yard>)

## Reading Supports

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

* **Anticipation Guide (p. 17):**  The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

***-OR-*** Instead of using Anticipation Guides, consider these ideas to engage your students in reading.

**Mars vs. Titan: A Showdown of Human Habitability**

* + Before reading, ask students what they know about requirements for human space travel to other planets, and what humans would need to survive.
  + As they read the article, ask students to compare their original ideas about human space travel with information from the article. Ask them to write questions they have about the science in the article.
* **Graphic Organizer (p. 18):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

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

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

* **Student Reading Comprehension Questions (p. 19):**  The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.

Some of the articles in this issue provide opportunities, references, and suggestions for students to do further research on their own about topics that interest them.

To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles. The “Web Resources for More Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

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

### Anticipation Guide

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

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Titan is a moon of Jupiter. |
|  |  | 1. Titan is the only moon in our solar system with an atmosphere and clouds. |
|  |  | 1. Methane is a greenhouse gas. |
|  |  | 1. Scientists study organic molecules on Titan to learn more about the earliest forms of life. |
|  |  | 1. Titan is much warmer than Earth. |
|  |  | 1. Travel to Mars would take about five years. |
|  |  | 1. Mars’ atmosphere is mostly carbon dioxide. |
|  |  | 1. Iron gives Mars its red color. |
|  |  | 1. Researchers have successfully grown simple crops in simulated Martian soil. |
|  |  | 1. In the past 20 years, scientists have found hundreds of planets in the universe. |

### Graphic Organizer

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

**Directions**: As you read, complete the graphic organizer below to compare Mars and Titan.

|  |  |  |
| --- | --- | --- |
|  | **Mars** | **Titan** |
| Atmospheric components & conditions |  |  |
| Atmospheric pressure |  |  |
| Water and its form |  |  |
| Temperature |  |  |
| Possibilities for generating energy |  |  |
| Time required to get there |  |  |
| Technology needed to sustain human life |  |  |

**Summary:** On the back of this paper, write a short email to a friend explaining whether you would like to go to Mars or Titan, providing reasons supported by information in the article.

### Student Reading Comprehension Questions

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

Name

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

* 1. Why are scientists studying Mars, Titan, and other celestial bodies?
  2. List five conditions, similar to those of Earth, that scientists seek when searching for habitable locations across the universe.
  3. (a) What condition on Titan makes it similar to Earth, and (b) how do Titan’s clouds, rain, and lakes differ from those on Earth?
  4. Give two examples of methane’s important role in maintaining atmospheric conditions on Titan.
  5. Why is the formation of complex organic molecules in Titan’s atmosphere important to possible life on this moon?
  6. Give two reasons why Titan is unsuitable for terrestrial life.

**Student Reading Comprehension Questions, cont.**

* 1. (a) According to scientists, what is a possible source of energy available for native life on Titan, and (b) how much energy is produced by the chemical reaction shown in the article?
  2. Give two ways that spectrometers on spacecraft can identify individual atoms and molecules in space.
  3. What is the connection between iron and microorganisms on Mars?
  4. List three reasons why living on Mars is not ideal for humans.
  5. How can Titan, Earth, and Mars be considered a movie trilogy?

**Critical-Thinking Question**

***Write your answer on another piece of paper.***

* + 1. Elon Musk, of SpaceX, has vowed to send a colony of people to reside on Mars within the next 50 years. Given the information in this article, (a) how will people prepare for their journey, and (b) what materials will they need for sustained life on Mars?

### Answers to Reading Comprehension Questions

1. **Why are scientists studying Mars, Titan and other celestial bodies**

The study of Mars, Titan and other celestial bodies, can help scientists learn about chemical processes that occur in our solar system.

1. **List five conditions similar to those of Earth that scientists seek when searching for habitable locations across the universe.**

When searching for habitable locations across the universe, scientists look for these conditions:

1. walkable surfaces,
2. oxygen,
3. liquid water,
4. comfortable temperatures, and
5. protection from the Sun’s energetic waves.
6. **(a) What feature on Titan makes it similar to Earth, and (b) how do Titan’s clouds, rain, and lakes differ from those of Earth?**
7. The feature on Titan that makes it similar to Earth is that Titan has an atmosphere and clouds, the only moon in our solar system that does.
8. Titan’s clouds, rain, and lakes differ from those of Earth because they are composed of liquid methane and ethane, instead of liquid water as on Earth.
9. **Give two examples of methane’s important role in maintaining the atmospheric conditions on Titan.**

Two examples of the important role methane plays in maintaining Titan’s atmospheric conditions are:

* 1. methane contributes to the greenhouse gas effect by keeping the temperature high enough for nitrogen to stay in the gaseous state necessary to maintain Titan’s thick atmosphere, and
  2. methane drives the formation of complex organic molecules.

1. **Why is the formation of complex organic molecules in Titan’s atmosphere important to possible life on this moon?**

The formation of complex organic molecules in Titan’s atmosphere may be the building blocks that serve as the basis for early forms of life, including life on Earth.

1. **Give two reasons why Titan is unsuitable for terrestrial life.**

Titan is unsuitable for terrestrial life because

* 1. Earth-life is based on liquid water, and Titan’s surface temperatures are well below the freezing point of water.
  2. Titan’s atmosphere does not contain oxygen.

1. **(a) According to scientists, what is a possible source of energy available for native life on Titan, and (b) how much energy is produced by the chemical reaction shown in the article?**
   1. A source of energy to sustain Titan-life might come from the reaction between acetylene and hydrogen.
   2. The chemical reaction shown in the article produces 311 kJ/mol (for each mole of acetylene that reacts with two moles of hydrogen gas).
2. **Give two ways that spectrometers on spacecraft can identify individual atoms and molecules in space.**

Spectrometers placed on spacecraft can identify atoms and molecules in space by measuring

* 1. the wavelengths of light coming from a cloud or planet and
  2. the mass of individual chemicals.

1. **What is the connection between iron and microorganisms on Mars?**

Martian microorganisms could absorb the energy from iron reduction-oxidation reactions on the planet.

1. **List three reasons why living on Mars is not ideal for humans.**

Three reasons why living on Mars is not ideal for humans are:

* 1. Mars has hazardous levels of UV radiation,
  2. its weak magnetosphere allows the Sun’s radiation to hit planetary visitors, and
  3. Mars has little oxygen for breathing

1. **How can Titan, Earth, and Mars be considered a movie trilogy?**

The prequel Titan shows Earth before life, Earth shows the present environment with life, and Mars represents the sequel showing Earth as a post-terrestrial world.

**Critical-Thinking Question**

1. **Elon Musk, of SpaceX, has vowed to send a colony of people to reside on Mars within the next 50 years. Given the information in this article, (a) how will people prepare for their journey, and (b) what materials will they need for sustained life on Mars?**

Note to teachers: The answers below are taken from the article; however, student answers may also contain material from prior knowledge. Optional: Students may gather information from their own Internet research if this CTQ is structured as a project that builds on the information in the article.

1. Future Mars colonists will need to prepare to live on a spacecraft for the 7 month journey to reach Mars. This will require sufficient oxygen, water and food, plus materials needed for the repair and maintenance of the spacecraft. Colonists will also need spacesuits to protect themselves once they land on Mars. The spacecraft should carry spectroscopes to identify a location that contains liquid water and to look for possible organic matter as they approach possible landing sites. In preparation they will need to practice growing crops in Martian soil. (Students may also mention that physical training is needed to prepare colonists like astronauts for life in zero-gravity conditions during the journey.)
2. Colonists will need spacesuits that can withstand the low Martian pressure. The suits will need dome bubbles that shield inhabitants from the sun’s harmful radiation and provide a source of oxygen with a space for breathing. Using data obtained from growing plants on Earth in Martian soil, colonists will need to prepare to transport seeds and small seedlings of fruits and vegetables, such as tomatoes and peas.



**Teacher's Guide for**

### *The Shocking Chemistry of Electric Eels”*

**October/November 2018**

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## Tools and Resources

### Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |

|  |  |
| --- | --- |
| **Electrolytes** | The discussion of the electrolytes used in Volta’s initial battery can be used as a practical application to supplement lessons on ions and ionic solutions. |
| **Electrochemistry** | The explanations of voltage and current using a waterfall analogy supports lessons about electrical energy, while the description of the anatomy of Volta’s battery supports lessons about electrochemical cells and batteries. |
| **Activity series** | The selection of materials for an electrochemical cell is based on their ability to lose or gain electrons. The activity series table in this article helps students understand some of the differences between metals. |
| **Intermolecular forces** | During a unit on intermolecular forces, the description of the reaction in the eel’s electrocytes, where each activated cell flips a neighboring cell so the negative side of one cell is adjacent to the positive side of the one next to it, can be used to help students visualize dispersion forces and induced forces. |
| **Conductivity/ Properties of matter** | Conductivity is a concept that is covered in most units on the properties of matter. The conductivity of electrolyte solutions in the electric eel can be used as a practical example of one use of these solutions in nature. |

### Standards and Vocabulary

#### Standards

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

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

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

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

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

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

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

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

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

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

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

#### Vocabulary

* **Vocabulary** and **concepts** that are reinforced in the October/November 2018 issue:

Structural formulas

Amino acids

Chemical reactions

Equilibrium

Reaction rates

Oxidation & reduction

Electrochemistry

* Consider asking students to read “Open for Discussion: The Human Drive to Explore Space” to learn about the risks of space exploration prior to reading the article “Mars vs. Titan: A Showdown of Human Habitability.”
* Students may become interested in growing crystals to connect chemistry and art after reading the articles on pages 2 and 19.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.
* The *ChemMatters* Teacher’s Guide has suggestions for further research and activities.

### Possible Student Misconceptions

1. **“Electric eels kill their prey by electrocuting them.”** Electric eels use their electric charge primarily to immobilize their prey as the charge emitted is not sustained long enough to kill the animal. The charge simply causes the muscles in its prey or predator to contract, preventing the animal from moving. If a small fish or animal continues to move, the eel encircles its prey in order to increase the voltage of its emissions. With increased voltage a small fish may be killed. Once the prey or predator is immobilized, the eel can quickly move to swallow the fish or swim away from a predator. In the case of spiny fish, the immobilization prevents the fish from damaging the eel’s mouth, where its lungs are located. Electric eels, unlike true eels, do not have teeth.
2. **“Electric eels are a special class of eels.”** Although the electric eel looks like an eel it is a knifefish and is more closely related to the catfish than an eel. Actually, electric eels are in a class by themselves being the only species in their genus.
3. **“Electric current is the flow of electrons through initially-empty wires.”** Electric current can be compared to the water in your pipes. When you open the faucet, the water that comes out was already in the pipes, it did not come directly from the water treatment facility the moment you opened the faucet. Electric current is the flow of electrons, but those electrons are already in the wire. The electrons themselves move slowly, at a rate of about 1 meter per hour, while the speed at which the electrical energy moves when the circuit is completed is extremely fast.
4. **“No one can survive being electrocuted by an electric eel.”** Being electrocuted by an electric eel is similar to being shocked by an electric fence. It is not pleasant but is generally not life threatening. There have been some reports of persons dying after being shocked by an eel, but the cause of death was drowning after the stunned person fell into the water and could not move. The electric eel can produce a shock up to 860 volts and 1 ampere of current for 2 milliseconds. Due to the short duration of the shock, it is unlikely to be deadly for an adult human. For comparison, atrial fibrillation requires 700 milliamps be delivered across the heart muscle for 30 milliseconds or more in order to shock the heart muscle. The eel cannot maintain its shock for this amount of time.
5. **“The high voltage is what kills you.”** While high voltage is dangerous, it is actually the current that kills. Voltage and current are two different ways of measuring electricity—the flow of electrons in a conductor. Voltage is the force that pushes the electrons through the circuit, while current is the rate of electron flow. The electric eel is an example of high voltage and low current. There can also be circuits with low voltage and high current that may be more dangerous. A dentist’s water jet can be used as an analogy of a high voltage low current circuit. The water pressure in the jet’s stream would be the voltage, while the amount of water ejected is the current. It is unlikely that you would drown while the dentist is cleaning your teeth. An analogy of a low voltage but high current would be a storm drain where a lot of water passes through the drain but at low pressure. If you got swept into a storm drain during a bad storm there is a possibility of drowning.

### Anticipating Student Questions

1. **“Are there any other animals that use electrolocation?”** There are animals that use electrolocation, but not many use it the same way that the electric eel does. The electric eel can generate an electric field to find its prey using electric organ discharges. This is referred to as active electrolocation. The eel has specialized electrosensitive neurons that can detect the direction of any distortions in the field caused by other objects. Most animals that use electrolocation use passive electrolocation. They do not generate the electric fields but have specialized receptors that can detect changes in weak electric fields. Examples of animals that have passive electrolocation are sharks, rays, dolphins, some bony fish, duck-billed platypuses, spiny anteaters, and bees.
2. **“Which is the most dangerous of the electric fish?”** The electric eel is the most dangerous of the electric fish, primarily due to its size. The longest electric eels can get up to 8 feet in length, weigh 50 pounds, and produce an electric discharge of nearly 600 volts.
3. **“Are there any animals that prey on electric eels?”** The electric eel is at the top of its food chain. The only animals that eat electric eels only eat eels that have died. Humans are the only animals that seem to have an interest in catching electric eels.
4. **“Why isn’t the electric eel affected by the electricity it emits into the water?”** That is a good question and the truth is scientists do not know. The mechanism electric eels use to protect themselves from their own charge hasn’t been studied. Some have hypothesized that the eel’s size or something in the eel’s skin protects them from the charge. Also, as the charge is released into the water, it is dissipated and weakened and the large eel wouldn’t be affected. The charge affects the small animals in the water more than it affects larger ones. That being said, the eel can leap out of the water to shock a large crocodile in order to protect itself from being attacked. In cases where the eel leaps from the water, the intensity of the shock increases because it is not being dissipated by the water but is being directed through the animal predator (or hapless bystander).
5. **“Can an electric eel shock a competing electric eel?”** In water,the eel is protected from its own discharge as well as that of other eels, though the protective medium is not clearly understood. Eels have not been observed attacking other eels.
6. **“****How can an element that generally loses electrons lose them to another element that also loses electrons?”** When two metals that generally ionize by losing electrons are used in electrochemical cells, other criteria need to be examined to determine which element will lose electrons, or be oxidized, and which one will gain electrons, or be reduced. Using an activity series like the one in the Rohrig article and in most chemistry texts can help determine this. A cell created with two metals will have the metal higher on the list as its anode (where oxidation or electron loss occurs) and the other metal will be the cathode, where reduction or electron-gain occurs. The element higher on the list will require less energy to lose its outer electrons than the elements below it on the list.
7. **“What is an anode? What is a cathode**?” An anode is the terminal in an electrochemical cell or battery where electrons are lost (oxidation), while the cathode is the electrode where electrons are gained (reduction). In an electric eel, the eel’s head is the cathode and the tail is the anode. When threatened, an eel discharges its electric shock through its chin.
8. **“Do people eat electric eels? One time, I saw eel on the menu of a restaurant my family went to.”** Electric eels are generally not eaten. Their bodies are composed primarily of the three pairs of electric organs with very little edible muscle surrounding them. The eel or brood of eels that you may find in the seafood section are from the true eels and are becoming an expensive delicacy in many countries. They are popular in Japanese and Chinese cuisine.

### Activities

**Labs and demos**

**“Activity Series Lab (Microscale)”:** In this two-part lab, students test samples of Cu, Mg, Fe, Zn, and Sn against solutions of KNO3, Zn(NO3)2, Mg(NO3)2, AgNO3, CuSO4, and distilled water in part one, and they test the same metals in dilute HCl in part two to determine an activity series for the elements involved. (<https://www.auburn.wednet.edu/cms/lib03/WA01001938/Centricity/Domain/1360/GChemLabs/Activity_Series_Lab.pdf>)

**“A Voltaic Pile, the First Battery”:** This is the first lab that follows an introduction to the history of batteries. Multiple lessons and activities involving the student creation of voltaic piles, electrochemical cells, lemon cells, storage cells, and dry-cell batteries are outlined in the work cited here: <http://www.chymist.com/batteries.pdf>.

**Simulations**

**Activity series experiments, virtual labs:** These experiments allow the students to use their results from combining several metals with different ionic solutions to determine an activity series of select metals. (<http://intro.chem.okstate.edu/1515F01/Laboratory/ActivityofMetals/home.html>)

Teacher-developed data tables and class instructions for some of these activities can be found here: <http://www.mrpalermo.com/virtual-lab-activity-series.html>.

**Media**

**“You Do Not Want to Get Tased by This Eel”, (1:59) video, and “Electric Eels Carry All Their Organs in Their Head”, (4:29) video:** These two videos, accessed at the same site, below, describe the unique characteristics of the eel’s anatomy using live footage and diagrams in the first video and showing the capture and examination of an eel in the second video. (<https://www.smithsonianchannel.com/shows/electric-amazon/0/3425708>)

**“It’s True: Electric Eels Can Leap from the Water to Attack”, video (3:22):** Researcher Kenneth Catania discusses Humboldt’s experience with eels leaping from the water to shock the horses and demonstrates how the eel's’ shock is magnified when they leap from the water. (<https://video.nationalgeographic.com/video/news/electric-eels-make-leaping-attacks-vin>)

**Lessons and lesson plans**

**Lemon batteries and electric pickles, demonstration and lesson:** Electrical energy and electrochemistry are explained through the use of the glowing pickle demonstration, followed by PowerPoint presentations and a student challenge to construct a lemon battery. (<http://star.manhattan.edu/UserImage/EA%20Lesson%20Plans/LemonBatteryPickleExperimentLessonPlan.pdf>)

**Building a voltaic pile, lab activity with lessons about energy:** Students explore the Law of Conservation of Energy by reviewing common forms of energy and how they may be converted to other forms of energy. The lesson culminates with a lab activity to build voltaic piles utilizing copper pennies, zinc plated washers, and salt water-soaked cardboard. (<http://www.cpalms.org/Public/PreviewResourceLesson/Preview/128908>)

**Projects and extension activities**

**“Recreate Physics History: Build a Voltaic Pile”, two videos (6:53 and 9:45):** These videos illustrating the history surrounding Volta’s discovery complement the instructions for students to build their own voltaic pile similar to Volta’s first electrochemical battery. <https://www.arborsci.com/cool/recreate-physics-history-build-a-voltaic-pile/>

**“Virtual Chemistry Lab Activity Series”:** This lab activity uses photos of various metals placed in test tubes containing either water, HCl, or a metal salt to help students determine an activity series based on their observations. Students select highlighted elements on a periodic table to view the photos of the reactions in order to draw their conclusions. (<http://www.harpercollege.edu/tm-ps/chm/100/dgodambe/thedisk/series/series.htm>)

### References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine’s inception in October 1983 through April 2013; all**

**available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [***http://ww.acs.org/chemmatters***](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get 30 Years of *ChemMatters* Magazine!” (the icon on the right of the screen).**

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



In “Tasers”, author Rohrig writes about the effect of a Taser’s electric current on the biochemical messaging system in muscles. As the electric eel’s shock is often compared to the shock from a Taser, these explanations as well as the additional explanations of voltage and current enhance the information in the current article. (Rohrig, B. Tasers. *ChemMatters*. 2012, *30* (2), pp 18–19)

The Teacher’s Guide for the April 2012 *ChemMatters* Rohrig article above provides additional information on electromuscular disruption. A lesson listed there from Teach Engineering, about the electrochemistry of the heart muscle, contains demonstrations that could also be used to demonstrate the action of the ion channels in the electric eel. (<https://www.teachengineering.org/lessons/view/uva_pump_bme0607_less> )

“Drained: The Search for Long-Lasting Batteries” contains explanations about the chemistry of batteries that could supplement those about electric voltage and current in the Rohrig eel article. (Kossakovski, Fedor. Drained: The Search for Long-Lasting Batteries. *ChemMatters*. 2017/18, *35* (4), pp 10–12)

The Teacher’s Guide for the February 2018 *ChemMatters* article above contains links to simulations about electrochemical cell voltmeters and a voltaic cell virtual lab, as well as lessons that use voltaic pile activities.

### Web Resources for More Information

**Electric eel facts**

A good source of general information about the electric eel can be found on the Wikipedia site.

(<https://en.wikipedia.org/wiki/Electric_eel>)

Facts about the electric eel, accompanied by several videos to illustrate the topic being discussed, can be found at this site.

(<https://www.mnn.com/earth-matters/animals/stories/8-shocking-facts-about-electric-eels>)

**Electric eel research applications**

“Electric Eel-inspired Devices Could Power Artificial Human Organs” describes some of the research into the development of a type of battery that operates like an electric eel and could be used to power pacemakers, sensors, or even prosthetic organs.

(<https://www.nature.com/articles/d41586-017-08617-3>)

**“**Designing Artificial Cells to Harness the Biological Ion Concentration Gradient” is a research report on the progress of designing cells that can operate similar in fashion to the electrocytes of the electric eel.

([https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2767210**/**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2767210/))

**Electric eel predator behavior**

“Electric Eels Concentrate Their Electric Field to Induce Involuntary Fatigue in Struggling Prey” thoroughly explains with multiple charts and diagrams how the electric fields generated by an eel and their effects on prey are altered by the way the eel manipulates its long body.

(<https://www.sciencedirect.com/science/article/pii/S0960982215011471>)

**Bioelectricity**

A brief review of bioelectricity and its role in human cells can be found here.

(<https://www.encyclopedia.com/medicine/encyclopedias-almanacs-transcripts-and-maps/bioelectricity>)

This site contains a brief report about research of eel electrocytes, in hopes of learning how to modify muscle cells to power biodegradable electronics.

(<https://techxplore.com/news/2017-08-bioelectricity-eels.html>)

**Alexander von Humboldt**

“Humboldt’s Gift” is a *New Yorker*article, punctuated with several quotes from the scientist’s books and letters, that brings new appreciation for the life work of Alexander von Humboldt.

(<https://www.newyorker.com/magazine/2015/10/26/humboldts-gift>)

This site contains a summary of the life and scientific contributions of Alexander von Humboldt.

(<https://www.famousscientists.org/alexander-von-humboldt/>)

## Reading Supports

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

* **Anticipation Guide (p. 38):**  The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

***-OR-*** Instead of using Anticipation Guides for all articles, consider these ideas to engage your students in reading.

**The Shocking Chemistry of Electric Eels**

* Before reading, ask students what they have heard about electric eels and if they have ever seen an electric eel.
* As they read the article, ask students to write at least three new things they learned about electric eels and how they produce electricity.
* **Graphic Organizer (p. 39):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

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

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

* **Student Reading Comprehension Questions (p. 40):**  The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.

Some of the articles in this issue provide opportunities, references, and suggestions for students to do further research on their own about topics that interest them.

To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles. The “Web Resources for More Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

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

### Anticipation Guide

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

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Electric eels usually kill their prey by electrocution. | |
|  |  | 1. Electric eels can use low voltages to locate their prey. | |
|  |  | 1. Copper gives up electrons more easily than zinc. | |
|  |  | 1. Alessandro Volta was inspired by electric eels to produce the world’s first human-made battery. | |
|  |  | 1. The voltage in a battery is determined by how many cells are linked together. | |
|  |  | 1. The shock from an electric eel is very painful, but does not have enough current to kill a person. | |
|  |  | 1. Electric eels have special cells that can pump ions in or out of the cells, creating an electric potential. | |
|  |  | 1. It takes more than a minute for a nerve impulse to travel through an electric eel’s body. | |
|  |  | 1. The shock from an electric eel is delivered by its tail. | |
|  |  | 1. Scientists are studying electric eels to design implantable batteries in people. | |

### Graphic Organizer

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

**Directions**: As you read the article, complete the graphic organizer below to describe how electric eels produce and use electricity

|  |  |  |  |
| --- | --- | --- | --- |
|  | **What is it?** | **Voltage produced** | **How it works** |
| **Electrolocation** |  |  |  |
| **Electrocyte** |  |  |  |
| **Battery** |  |  |  |

**Summary:** In the space below, or on the back of this paper, write a short explanation of why a shock from an electric eel is painful but not lethal to humans.

### Student Reading Comprehension Questions

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

Name

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

* 1. How did Alexander von Humboldt collect the live electric eels?
  2. Describe two ways electric eels capture their prey.
  3. What is a common misconception about the electric eel (*Electrophorus electricus*)?
  4. What is the difference between an electrolyte and an electrocyte?
  5. What chemical aspect of the eel’s electric organs is similar to Volta’s first battery?
  6. What property of metals makes them have “high electrical activity”?

**Student Reading Comprehension Questions, cont.**

* 1. What is the driving force in a battery?
  2. What is a person’s reaction when shocked with a current between 50 and 150 milliamps?
  3. How is an electric potential of about 150 millivolts created in the electrocytes of the electric eel?
  4. How long does it take for a nerve impulse to travel through all the electrocytes before an electric eel can deliver a shock?

**Critical-Thinking Questions**

***Write your answers on another piece of paper, if needed.***

* + 1. Use the Activity Series in Figure 2 to explain the direction of electron flow in a lithium/copper battery.

1. Compare voltage and current as they relate to batteries.

### Answers to Reading Comprehension Questions

1. **How did Alexander von Humboldt collect the live electric eels?**

Alexander von Humboldt’s crew drove horses into the water causing the eels to come to the surface where they were easier to catch.

1. **Describe two ways electric eels capture their prey.**
2. Eels use a high-voltage jolt to stun their prey, causing all its muscles to contract at once. The eel can then capture the immobilized prey.
3. Eels send out rapid, low-voltage pulses of electricity that can cause neighboring fish to twitch. Sensing this movement in the water, the eel can locate the prey and go in for the kill.
4. **What** **is a common misconception about the electric eel (*Electrophorus electricus*)?**

A common misconception about the electric eel (*Electrophorus electricus*) is that because of its eel-like appearance and name, people think it **is** an eel when, really, it is a **fish** related to the catfish.

1. **What is the difference between an electrolyte and an electrocyte?**

An electrolyte is a compound that breaks down into ions in a solvent, creating an electrically conductive solution. An electrocyte is an electrically excitable cell.

1. **What chemical aspect of the eel’s electric organs is similar to Volta’s first battery?**

The electric organs of the electric eel contain metal ions dissolved in the fluid within and surrounding their cells to generate current, similar to the sodium and chloride ions that make up the electrically conductive solution in Volta’s first battery.

1. **What property of metals makes them have “high electrical activity”?**

The ability to lose electrons easily makes metals have high electrical activity.

1. **What is the driving force in a battery?**

The driving force in a battery is the difference in electrical potential energy, which is the battery’s voltage.

1. **What is a person’s reaction when shocked with a current between 50 and 150 milliamps?**

When someone is shocked using 50–150 milliamps of current, they feel extreme pain, respiratory arrest, severe muscular contractions and, possibly, death.

1. **How is an electric potential of about 150 millivolts created in the electrocytes of the electric eel?**

An electric potential of about 150 millivolts is created in the electrocytes of the electric eel when a nerve impulse is sent to the cells’ ion channels, causing sodium ions to rush in one side of the cells and potassium ions to rush out of the other side.

1. **How long does it take for a nerve impulse to travel through all the electrocytes before an electric eel can deliver a shock?**

It takes just 2 milliseconds for a nerve impulse to travel through all the electrocytes prior to an eel delivering a shock to its prey.

**Critical-Thinking Question(s)**

1. **Use the Activity Series in Figure 2 to explain the direction of electron flow in a lithium/copper battery.**

Since lithium is more active than copper, it will give up electrons more readily than copper does. Therefore, the electrons will flow away from lithium and toward the copper electrode when the two are connected by a wire. Thus, the lithium will be the anode and the copper will be the cathode.

1. **Compare voltage and current as they relate to batteries.**

Voltage is the difference in two electrical potential energies, while current is based on the number of electrons that pass a point in a given amount of time. Voltage is the force pushing the electrons, while current is the movement and streaming of those electrons.



**Teacher's Guide for**

### *“Feeding the World: A Story of Guano, War, and Invention”*

**October/November 2018**

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## Tools and Resources

### Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |

|  |  |
| --- | --- |
| **Le Châtelier’s principle** | The synthesis of ammonia from nitrogen and hydrogen gases is the classic example of Le Châtelier’s principle, and this article explains the principle using examples of temperature, pressure, and concentrations. |
| **Reversible reaction** | The Haber–Bosch synthesis of ammonia highlighted in this article is commonly used to teach students about reversible reactions. Examples of conditions causing this reaction to favor forward or reverse reactions are discussed. |
| **Exothermic processes** | The concept of an exothermic reaction (negative ΔH) is explained in the article and is connected to Le Châtelier’s principle. The chemical equation for the synthesis of ammonia is included with energy indicated as ΔH° = -92 kJ/mol. |
| **Catalysts** | The importance of catalysts in chemical reactions is highlighted in the Haber–Bosch synthesis of ammonia article. Iron is mentioned as the catalyst used, and a potential energy diagram for a catalyzed versus uncatalyzed reaction is featured in Figure 4 of the article. |
| **Lewis electron-dot structures** | The Haber–Bosch reaction is illustrated in Figure 2 of the article with Lewis electron dot structures that clearly show the triple bond in the N2 molecule. |
| **Multiple covalent bonds** | The article describes the triple covalent bond in the nitrogen molecule as “incredibly strong” “and almost unreactive”. The triple bond is illustrated with a Lewis electron dot structure in Figure 2. |

### Standards and Vocabulary

#### Standards

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

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

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

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

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

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

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

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

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

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

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

#### Vocabulary

* **Vocabulary** and **concepts** that are reinforced in this issue:

Structural formulas

Amino acids

Chemical reactions

Equilibrium

Reaction rates

Oxidation & reduction

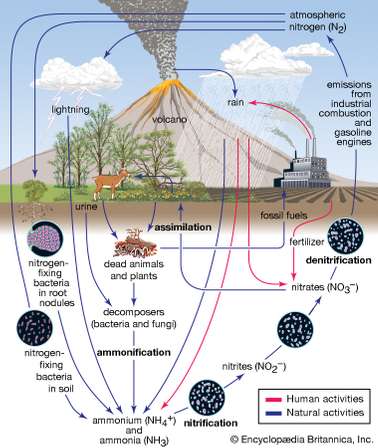
Electrochemistry

* Consider asking students to read “Open for Discussion: The Human Drive to Explore Space” to learn about the risks of space exploration prior to reading the article “Mars vs. Titan: A Showdown of Human Habitability.”
* Students may become interested in growing crystals to connect chemistry and art after reading the articles on pages 2 and 19.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.
* The *ChemMatters* Teacher’s Guide has suggestions for further research and activities.

### Possible Student Misconceptions

1. **“Natural (organic) fertilizers are better than chemical (man-made) fertilizers”** Plants cannot distinguish whether the nitrogen they use for growth and making plant proteins comes from a natural or a man-made source. So, nitrogen is nitrogen, regardless of its origin. Natural fertilizers often have smaller concentrations of the nitrogen, phosphorous, and potassium (N-P-K) that plants require, and some natural fertilizers may not contain all three of these macronutrients. Chemical fertilizers are typically more concentrated and contain all three of the macronutrients (N-P-K). They, also, are more easily transported than bulk natural fertilizers such as animal waste (manure), dead organisms, or compost. Some benefits of natural fertilizers are that they recycle materials that are considered wastes, they add compost and organic matter to the soil, and they depend on microorganisms to slowly decompose them so they are less likely to “burn”, or overfertilize plants. Chemical fertilizers have the advantages of being easy to transport and apply, generally less expensive (if a person must purchase fertilizer), and have consistent concentrations and quality.
2. **“When a chemical reaction has reached equilibrium, the concentration of reactants and products are equal, and the reaction stops.”** A chemical reaction at a specific set of equilibrium conditions does not stop, although the relative ratios of products and reactants are constant. At equilibrium, the *rate* of the forward reaction and formation of products is equal to the *rate* of reverse reaction and the re-formation of the reactants. The concentrations of the products and reactants are rarely equal. An analogy might be a student jogging on a treadmill. If the rate of the student running forward and the rate of the treadmill belt moving backward are equal, then the student’s position on the treadmill doesn’t change, even though the student is still actively running (not standing still). The runner is in equilibrium with the treadmill (rate forward = rate reverse). Considering “concentrations” in this analogy, the student may be at the midpoint along the length of the treadmill belt, but that student could also be closer to the front, or closer to the back and still be in equilibrium, as long as the student’s position doesn’t change on the belt. Equilibrium reactions appear to stop because there is no net change in concentrations of reactants or products at that set of conditions, but the reaction is still occurring—just like the runner continues to run on the treadmill.
3. **“Man-made fertilizers are not needed to produce food for the world because plant growth is a natural process.”** In 2002, it was estimated that 40% of the world’s seven billion people were kept alive with food grown using chemical fertilizers. (<http://home.cc.umanitoba.ca/~vsmil/pdf_pubs/Nitrogen%20and%20Food%20Production.pdf>) Some plants, called legumes, have a symbiotic relationship with nitrogen-fixing bacteria that allow them to “produce” the nitrogen they need to grow. A few carnivorous plants (e.g., the Venus flytrap) supplement their nitrogen requirements by digesting small insects. However, most plants must absorb nitrogen through the soil and are dependent on the nitrogen cycle to supply this critical element. Without chemical fertilizers, the food produced by the processes of natural plant growth would not be capable of sustaining the seven billion inhabitants presently on earth—much less the estimated 10 billion people by 2050.
4. **“Are ‘chemical equilibrium’ and ‘steady state’ the same thing?”** They are similar in some respects, but they are not identical. A steady state has (a) conditions that are stable within the system, (b) a constant input of energy to maintain the steady state, and (c) a higher state of entropy (disorder) than its surroundings due to the constant flow of energy into the system. A chemical equilibrium has (a) conditions stable within the system, (b) no net energy entering or leaving the system, and (c) a reduction in entropy between the system and the environment. For example, in order for a student to maintain a constant body temperature of 37°C (a steady state), the student must generate body heat from digesting food (constant input of energy), or the body temperature falls. A chemical equilibrium exists in an unopened bottle of sparkling (carbonated) water at a constant temperature. The carbon dioxide gas in the space between the bottle cap and the water contains pressurized CO2 and there is dissolved CO2 in the fizzy water. The CO2 gas is in constant movement between the gas space and the liquid, representing a chemical equilibrium that does not require external energy to maintain the constant exchange.

### Anticipating Student Questions

1. **“Why don’t plants obtain the nitrogen that they need from the air?”** While the earth’s atmosphere contains about 78% nitrogen by volume, plants are unable to directly use the atmospheric nitrogen, N2, for growth. Atmospheric nitrogen is a diatomic molecule with the two nitrogen atoms bonded together with a triple covalent bond requiring a bond-dissociation energy of 946 kJ/mol—about double that of molecular oxygen containing a double bond. This high bond strength makes N2 highly unreactive. So atmospheric nitrogen (N2) must be “fixed”, or converted into a more useful form, in order for plants to be able to use the nitrogen for growth. This nitrogen fixation process is accomplished through the nitrogen cycle. The nitrogen cycle has a biological component, where bacteria convert N2 into plant-friendly nitrates or ammonia in the soil. There is also a non-biological nitrogen fixation process when lightening converts atmospheric nitrogen into nitrogen oxides that can form plant-friendly nitrogen compounds.

([*https://www.britannica.com/science/nitrogen-cycle*](https://www.britannica.com/science/nitrogen-cycle))

1. **“How many people could live on Earth if man-made chemical fertilizers were not available?”** This is a complex question because it involves social issues such as life styles as well as biophysical factors including fertilizers, water, and energy. For example, more people could live on the earth if wealthier people and nations reduced or eliminated their consumption of meats. In 1798, Thomas Malthus predicted in his book, *An Essay on the Principle of Population*,that famine was imminent because the world’s population (about one billion people) had surpassed Earth’s carrying capacity, the maximum population of a species that can survive indefinitely in that environment. Thankfully, he was incorrect because he was unable to predict many crucial factors including the discovery of the Haber–Bosch process. In 1997, the Canadian geographer Vaclav Smil calculated that the carrying capacity of the earth would be about four billion people without the industrial fixation of nitrogen (Haber–Bosch process). Some estimates of the “organic” carrying capacity of the earth (without the use of chemical fertilizers) are as low as 2.4 billion people. (<http://agrpartners.com/wp-content/uploads/2013/09/AGR-Thought-Piece-Carrying-Capacity1.pdf>) By any estimate, the world’s population would be much smaller without the availability and use of chemical fertilizers.
2. **“How do plants use the three macronutrients nitrogen, phosphorous, and potassium?”** Plants need 17 essential elements to successfully grow. The “Big 3”, or macronutrients, are nitrogen, phosphorous, and potassium. Nitrogen is needed by plants to make proteins for enzymes and structural growth, and it is critical in producing the chlorophyll used in photosynthesis. Because of these functions, nitrogen is often considered the most important nutrient. Phosphorous is vital for using and storing energy (think ATP) in plants. Famers and gardeners often use a superphosphate fertilizer on plants because it is linked to abundant flower and seed/fruit production. Also, phosphorous is used in forming DNA. Potassium’s use in plants is more indirect, but still important. Potassium is associated with disease resistance and overall plant quality. Potassium is required for the activation of over 80 enzymes needed throughout plants.
3. **“Can fertilizers explode like a bomb?”**Nitrogen compounds are typically found in many explosives such as dynamite, or trinitrotoluene (TNT). However, chemical fertilizers like the ones you would purchase at a garden store such as 10-10-10 do not have a high enough concentration of nitrogen compounds to explode. Even higher concentrations of commercial fertilizers such as 30-30-30 don’t explode. However, a common and inexpensive ingredient used in some commercial fertilizers, ammonium nitrate, under the wrong conditions has been involved in some explosions. A 2013 explosion at the ammonium nitrate fertilizer plant in West, Texas, killed 15 people and injured many more. Another explosion at a dock in Texas City, Texas, in 1947 is considered one of the worst industrial accidents in U.S. history. A fire onboard the docked ship *SS Grandchamp* carrying 2,200 tons of ammonium nitrate caused a massive explosion which killed at least 581 people, injured more than 5,000, and destroyed about 1,000 buildings on the land. So, commonly available chemical fertilizers cannot explode like a bomb.
4. **“Why do people talk about “fixing” nitrogen when the nitrogen molecule needs to be broken apart and not put together?”**It does seem like a contradiction! In order for nitrogen to be in a useful form for plants, the relatively unreactive atmospheric nitrogen molecule must be converted or “fixed” into a more soluble compound. The term fixed is used in a sense similar to people saying that they are going to fix, or prepare, breakfast. It is certainly not using the term in the way you may say that you are going to fix (repair) your skateboard. So, the word fix, may have several uses in our language, and in the case of nitrogen, it means the nitrogen will be chemically converted to a useful form for plant.

### Activities

**Labs and demos**

**“Le Châtelier’s Soda” lab:** This American Association of Chemistry Teachers (AACT) lab (noted as AP level, but might be appropriate for other high school students) uses club soda and dry ice as a variation on the common cobalt(II) chloride activity to study how an equilibrium reaction is affected by changes in pressure, temperature, and concentration. Resources provided include the Teacher Guide, Student Activity, and Answer Key with references to the AP Curriculum Framework and NGSS. (Access is restricted to AACT members, but the article will be available for free until December 1, 2018 at <https://teachchemistry.org/classroom-resources/le-chatelier-s-soda>.)

**“Iodine Clock Reaction: A Study of the Effects of Concentration, Temperature, and a Catalyst on Reaction Rate”:** This lab from Flinn Scientific provides teacher information on conducting the activity, including sections on Materials, Safety Precautions, Preparation, Procedure, Disposal, Results and Discussion, and NGSS Alignment. (<https://www.flinnsci.com/api/library/Download/513df678faef4d5dad2c85eb789be1d9>)

**Simulations**

“**Reversible Reactions” (PhET):** Students can vary temperature, activation energy, and concentration, as reaction results are displayed in either species-formation or energy histograms. Additional teacher-submitted activities to accompany the simulation are provided. (<https://phet.colorado.edu/en/simulation/reversible-reactions>)

**“Reactions and Rates” (PhET):** This simulation provides students the opportunity to explore reactions by colliding reactant particles and designing experiments using different reactions, concentrations, and temperatures, as well as studying reversible reactions and factors affecting reaction rates. Additional teacher-submitted activities to accompany the simulation are available. (<https://phet.colorado.edu/en/simulation/legacy/reactions-and-rates>)

**Media**

**“The Chemical Reaction That Feeds the World—Daniel D. Dulek”, video (5:18):**  This TED-ED video clip (with a link to support material) explains with pictures and animations the importance of the Haber process in feeding the world through the production of ammonia. (<https://www.youtube.com/watch?v=o1_D4FscMnU>)

**“The Father of Poison Gas—Fritz Haber”, video (5:46):**  This video, part of the “Who Did What in WW1?” series, describes the work of Haber—both in saving lives through the production of fertilizers, and in killing soldiers through the production and use of chlorine and other poison gases. (<https://www.youtube.com/watch?v=ztzKHU2oaF8>)

**Lessons and lesson plans**

**“Catalysis and Catalytic Converters”:** This AACT 5Es high school lesson plan (with teacher and student instructions) introduces catalysts and reinforces stoichiometry and chemical reactions in an inquiry-based activity with possible student extensions. A teacher demonstration opens the activity before students investigate the decomposition of hydrogen peroxide. (Access is restricted to AACT members, but will be available for free until December 1, 2018 at <https://teachchemistry.org/classroom-resources/catalysis-catalytic-converters>.

**“All Things Being Equal!” lessons:** This is a set of three guided-inquiry lessons to help students correct misconceptions about equilibrium, predict changes using Le Châtelier’s principle, and use the value of the equilibrium constant to predict the extent of reactants and products. The three lessons (two activities and one lab, requiring about 35–45 minutes each are provided as a Teacher Guide with materials needed and preparation information (<http://static.nsta.org/connections/highschool/201210AllThingsBeingEqualTeachersGuide.pdf>); student materials are available at <https://www.gvsu.edu/targetinquiry/tidocuments-home.htm> but require a free registration to access them.

**Projects and extension activities**

**Establish and monitor a classroom aquarium to study nitrogen fixation and the nitrogen cycle:** A balanced aquarium (whether it is freshwater or saltwater) requires nitrogen fixation and a functioning nitrogen cycle in the tank to maintain habitable conditions for the marine organisms. Students could research the process for establishing a new aquarium; study the components and chemistry of the applicable biological nitrogen cycle; test nitrates, nitrites, ammonia, and pH levels in the aquarium with test kits; and monitor the health of the marine organisms (fish, moon jellyfish, aquatic plants) as a function of water quality.

**“Le Châtelier’s Principle and the Solubility of Carbon Dioxide” lab:** Students can apply the concept of Le Châtelier’s principle to this Flinn Scientific lab activity which uses the concepts of gas solubility, Boyle’s law, pH, and acid-base indicators as an extension of more traditional Le Châtelier’s principle activities. Seltzer (carbonated) water is studied in a 10-mL syringe to observe the changes of pressure and temperature on the carbonated water. (<https://www.flinnsci.ca/api/library/Download/b7512bb8f8b445f9938df114a188d88e>) A teacher video by the same title (12:54) demonstrates this lab activity (or possible teacher demonstration) at <https://www.youtube.com/watch?v=QtCRxvCxa6M>.

### References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine’s inception in October 1983 through April 2013; all**

**available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [***http://ww.acs.org/chemmatters***](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get 30 Years of *ChemMatters* Magazine!” (the icon on the right of the screen).**

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



In “Aquarium Chemistry: Life in the Balance”, author Ruth writes about nitrogen chemistry (the nitrogen cycle) in maintaining the water quality for organisms in an aquarium. Ruth discusses the role of ammonia, nitrates, and nitrites, as well as other chemical factors in maintaining a healthy aquarium. (Ruth, L. Aquarium Chemistry: Life in the Balance. *ChemMatters*. 2002, *20* (1), pp 6–7)

The Teacher’s Guide for the February 2002 *ChemMatters* Ruth article above provides additional information on the ammonia/ammonium equilibria and the connection to pH, including an application of Le Châtelier’s principle.

“What’s So Equal About Equilibrium?” discusses chemical equilibrium and provides analogies and examples of equilibria from everyday life. The formation of ammonia is discussed as an example of Le Châtelier’s principle. (Tinnesand, M. What’s So Equal About Equilibrium? *ChemMatters*. 2005, *23* (3), pp 11–13)

The Teacher’s Guide for Tinnesand’s September 2005 *ChemMatters* article above contains additional information about ammonia synthesis, equilibrium, Le Châtelier’s principle, and Fritz Haber. An activity, “The Equilibrium Game”, is described for use with pairs of students.

In “Nitrogen from Fertilizers: Too Much of a Good Thing”, fertilizers and the nitrogen cycle are discussed and diagrammed, along with a look at possible damage to the environment from excess fertilizers. Sidebars on “Organic Farming” and “Haber–Bosch Process: Chemistry that Changed the Way We Farm” provide additional information for consideration. (Nolte, B. Nitrogen from Fertilizers: Too Much of a Good Thing. *ChemMatters*. 2010, *28* (2), pp 5–7)

The Teacher’s Guide for the 2010 *ChemMatters* Nolte article provides more information on nitrogen and its compounds, the nitrogen cycle, ammonia, fertilizers, and nitrogen pollution. Suggestions for additional lessons, demonstrations, and student projects are included.

“Tooth Decay: A Delicate Balance” contains a large schematic representation of chemical equilibrium using balance pans filled with items to clarify equilibrium, how it changes, and how it is re-established. The article also includes descriptions of equilibria involving mineralization/demineralization of teeth and carbonic acid/bicarbonate chemistry influencing pH. (Warmflash, D. Tooth Decay: A Delicate Balance. *ChemMatters*. 2015, *33* (3), pp 8–10)

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This *JCE Classroom Activity* allows students to cheaply and quickly investigate Gibbs free energy and the effect of stresses on equilibria, using rubber bands. (Hirsch, W. Rubber Bands, Free Energy, and Le Châtelier’s Principle. *J. Chem. Educ.*, 2002, *79* (2), pp 200A–200B; https://pubs.acs.org/doi/pdf/10.1021/ed079p200A. Note that this link takes you to a brief abstract only; the full article is only available to American Chemical Society members or subscribers to the journal.)

High School teachers’ misconceptions regarding the application of Le Châtelier’s principle and the equilibrium law reduce their ability to explain chemical equilibrium to their students, and this article analyzes the misconceptions and the implications. (Cheung, D. The Adverse Effects of Le Châtelier’s Principle on Teacher Understanding of Chemical Equilibrium. *J. Chem. Educ.*, 2009, *86* (4), pp 514–518; https://pubs.acs.org/doi/pdf/10.1021/ed086p514. Note that this link takes you to a brief abstract only; the full article is only available to American Chemical Society members or subscribers to the journal.)

This article is a short biography of the controversial Fritz Haber as a scientist, war criminal, family man, and scientific colleague. The special report continues with a storyline of “Chemical Weapons Then and Now.” (Everts, S. Who Was Fritz Haber? *Chem. Eng. News*, 2015, *93* (8), pp 18–21; https://pubs.acs.org/doi/10.1021/cen-09308-cover2. Note that this link takes you to a brief abstract only; the full article is only available to American Chemical Society members or subscribers to the journal.)

### Web Resources for More Information

**Fritz Haber**

This short biography of Fritz Haber provides readers with information on his life-giving work on synthesizing ammonia for fertilizer and his deadly work with poison gas warfare.

(<https://www.smithsonianmag.com/history/fritz-habers-experiments-in-life-and-death-114161301/>)

For an audio biography (29:00) of Haber, listen to “the Chemist of Life and Death” from the British Broadcasting Corporation.

(<https://www.bbc.co.uk/radio/play/b01062gy>)

**Carl Bosch**

This site provides biographical information on the life and work of Carl Bosch.

(<https://www.thefamouspeople.com/profiles/carl-bosch-7250.php>)

**Haber–Bosch process**

The history of the discovery of the Haber–Bosch process for producing ammonia and the impact on feeding the world is explained in this Web article.

(<https://www.thechemicalengineer.com/features/cewctw-fritz-haber-and-carl-bosch-feed-the-world/>)

Read this article to learn more about how the Haber–Bosch process of ammonia synthesis has changed the world.

(<https://www.researchgate.net/publication/248828433_How_a_century_of_ammonia_synthesis_changed_the_world>)

**Ammonia**

This article looks at the global uses, annual production, and manufacture of ammonia.

(<http://www.essentialchemicalindustry.org/chemicals/ammonia.html>)

This video (2:59) shows one of Haber–Bosch’s original ammonia factories and then, through animation, explains how pure hydrogen is produced and converted into ammonia.

(<https://www.youtube.com/watch?v=uMkzxV_y7tY>)

**Le Châtelier’s principle**

This site provides an explanation of Le Châtelier’s principle with equations, and it provides examples of changes to the equilibrium from common variables.

(<https://www.chemguide.co.uk/physical/equilibria/lechatelier.html>)

Khan Academy provides this video (14:42) explanation of Le Châtelier’s principle, plus additional videos and practice.

(<https://www.khanacademy.org/science/chemistry/chemical-equilibrium/factors-that-affect-chemical-equilibrium/v/le-chatelier-s-principle>)

**Energy changes and reversible reactions**

Students can review the energy changes in chemical reactions and reversible reactions and their application to ammonia synthesis at this site.

(<http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa_pre_2011/chemreac/energychangesrev3.shtml>)

**The Guano War**

For more information on the history of the Guano War and its importance for the Western world, visit this link.

(<https://www.atlasobscura.com/articles/when-the-western-world-ran-on-guano>)

This site provides pictures of the guano trade on the Chincha Islands where the Guano War took place.

(<http://americanhistory.si.edu/norie-atlas/guano-trade>)

**Carrying capacity of Earth**

Readers can find charts and additional information on food production and world population as a result of using synthetic fertilizers at this site.

(<https://ourworldindata.org/how-many-people-does-synthetic-fertilizer-feed>)

This article shows that food production from the Haber–Bosch process is only one of the factors determining the ultimate number of people who can live on Earth.

(<http://www.bbc.com/earth/story/20160311-how-many-people-can-our-planet-really-support>)

## Reading Supports

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

* **Anticipation Guide (p. 60):**  The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

***-OR-*** Instead of using Anticipation Guides for all articles, consider these ideas to engage your students in reading.

**Feeding the World: A Story of Guano, War, and Invention**

* If you have already taught Le Chatelier’s principle, this article will be an excellent review.
* Before reading, ask students why fertilizer is so important to help feed the world’s people.
* As they read, ask students to look for different ways plants can obtain the nitrogen needed for growth.
* **Graphic Organizer (p. 61):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

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

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

* **Student Reading Comprehension Questions (p. 62):**  The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.

Some of the articles in this issue provide opportunities, references, and suggestions for students to do further research on their own about topics that interest them.

To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles. The “Web Resources for More Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

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

### Anticipation Guide

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

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Seabird poop (guano) is an excellent natural fertilizer because of its nitrogen content. |
|  |  | 1. Fertilizers supply nitrogen, phosphorus, and potassium to plants. |
|  |  | 1. Nitrogen in the air is readily available to plants. |
|  |  | 1. Proteins cannot be made without nitrogen. |
|  |  | 1. The world’s population needs fertilizers made from ammonia for food production. |
|  |  | 1. In a system at equilibrium, decreasing pressure will cause the reaction to continue in the direction that decreases pressure. |
|  |  | 1. Cooling a system at equilibrium will encourage the production of more heat. |
|  |  | 1. Removing one of the chemicals in a system at equilibrium will cause the reaction to shift to produce more of that chemical. |
|  |  | 1. Using a catalyst increases the amount of energy required for a chemical reaction to occur. |
|  |  | 1. Only about one-tenth of all the world’s food production is thrown away. |

### Graphic Organizer

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

**Directions**: As you read the article, complete the graphic organizer below to describe the different ways to make nitrogen available in plant fertilizer.

|  |  |  |
| --- | --- | --- |
|  | What is it? | How does it provide nitrogen? |
| **Guano** |  |  |
| **Nitrogen-fixing bacteria** |  |  |
| **Haber-Bosch process** |  |  |

**Summary**: On the back of this paper, write a tweet (280 characters or less) about the importance of nitrogen in food production, based on what you learned from reading the article.

### Student Reading Comprehension Questions

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

Name

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

1. (a) What is guano, and (b) why is it important?
2. (a) What are the three macronutrients crucial for plant growth, and (b) which one is essential for producing plant proteins?
3. (a) Why is atmospheric nitrogen not directly useable for plant growth, and (b) what happens to atmospheric nitrogen in the process of biological nitrogen fixation?
4. What three factors did Fritz Haber and Carl Bosch optimize for their process of producing ammonia from nitrogen and hydrogen?
5. Why is Fritz Haber considered to be a controversial figure in the history of chemistry?
6. Why do scientists consider the industrial-scale production of ammonia by Haber and Bosch to be one of the most important chemical engineering innovations in the history of the world?

**Student Reading Comprehension Questions, cont.**

1. When is a chemical system considered to be at equilibrium?
2. According to Le Châtelier’s principle, what happens to a system at equilibrium when it is subjected to a change?
3. If a reaction has a negative ΔH, (a) what is happening to the energy in the reaction, and (b) what is the name for this type of reaction?
4. What is used in the Haber–Bosch process to keep the temperature of ammonia manufacturing below 500 °C?

**Critical-Thinking Question**

***Write your answer on another piece of paper, if needed.***

* 1. Explain why high temperatures can be both an advantage and a disadvantage in the chemical reaction for producing large quantities of ammonia by the Haber–Bosch process.

### Answers to Reading Comprehension Questions

1. **(a) What is guano, and (b) why is it important?**
2. Guano is bird poop, or, more specifically, seabird excrement.
3. It is important because it contains nitrogen, a key ingredient in plant fertilizer.
4. **(a) What are the three macronutrients crucial for plant growth, and (b) which one is essential for producing plant proteins?**
5. The three macronutrients crucial for plant growth are
   1. nitrogen,
   2. phosphorous, and
   3. potassium; and
6. the one that is essential for producing plant proteins is nitrogen.
7. **(a) Why is atmospheric nitrogen not directly useable for plant growth, and (b) what happens to atmospheric nitrogen in the process of biological nitrogen fixation?**
8. Atmospheric nitrogen is not directly useable for plant growth because it contains an incredibly strong triple covalent bond, which makes it almost unreactive and useless to plants.
9. In biological nitrogen fixation, atmospheric nitrogen is converted by microorganisms into ammonia (NH3) and ammonium (NH4+), with the use of an enzyme.
10. **What three factors did Fritz Haber and Carl Bosch optimize for their process of producing ammonia from nitrogen and hydrogen?**

To produce the greatest yields of ammonia from nitrogen and hydrogen, Haber and Bosch optimized these three factors:

1. temperature,
2. pressure, and
3. a catalyst.
4. **Why is Fritz Haber considered to be a controversial figure in the history of chemistry?**

Fritz Haber is considered to be a controversial figure in the history of chemistry because of his work on both the life-saving production of ammonia and for his work in the development of deadly chemical weapons initially used in World War I.

1. **Why do scientists consider the industrial-scale production of ammonia by Haber and Bosch to be one of the most important chemical engineering innovations in the history of the world?**

The industrial-scale production of ammonia by Haber and Bosch is one of the most important chemical engineering innovations in the world because fertilizers made from ammonia help sustain food production for billions of people.

1. **When is a chemical system considered to be at equilibrium?**

A chemical system is considered to be at equilibrium when “the rates of the forward and reverse reactions are equal, and the concentrations of the reactants and products are constant.”

1. **According to Le Châtelier’s principle, what happens to a system at equilibrium when it is subjected to a change?**

Le Châtelier’s principle states that “a system at equilibrium that is subjected to a change will react with a shift in equilibrium that opposes the direction of the change in establishing a new equilibrium.”

1. **If a reaction has a negative ΔH, (a) what is happening to the energy in the reaction, and (b) what is the name for this type of reaction?**

In a reaction with a negative ΔH,

1. energy is released from the chemical reaction into the surroundings, and
2. the reaction is called exothermic.
3. **What is used in the Haber–Bosch process to keep the temperature of ammonia manufacturing below 500 °C?**

To keep the temperature of the Haber–Bosch process of ammonia manufacturing below   
500 °C, a catalyst (iron) is used.

**Critical-Thinking Question**

1. **Explain why high temperatures can be both an advantage and a disadvantage in the chemical reaction for producing large quantities of ammonia by the Haber–Bosch process.**

High temperatures can be both a chemical reaction advantage and disadvantage in the Haber–Bosch synthesis of ammonia, because high temperatures are needed to make the reaction happen quickly (producing more ammonia faster), but the high temperatures also favor the reverse reaction, the decomposition of ammonia, resulting in less ammonia, in this exothermic reaction.



**Teacher's Guide for**

### *“How Glass Changed the World”*

**October/November 2018**

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## Tools and Resources

### Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |

|  |  |
| --- | --- |
| **Covalent bonding** | In lessons about covalent bonding, students will find the properties of substances with network covalent bonds, like those in silicon dioxide used for glass manufacture, are different from most covalently bonded materials. |
| **Bond energy** | The high heat (sufficient kinetic energy) required to break the silicon-oxygen bond when sand is melted to make glass indicates the significant bond energy contained in the silicon-oxygen bond. |
| **States of matter** | While studying the states of matter, glass serves as an example of an amorphous solid—without a definite internal molecular structure—making it fall in between the categories of solids and liquids. |
| **Crystalline structures** | The amorphous structure of glass is often contrasted with crystalline structures. The use of crystalline compounds in glass can provide interesting comparisons between the properties compounds have in their crystalline state and in a molten, amorphous state. |
| **Mixtures** | Just as glass is hard to classify by the traditional chemical definitions of solids and liquids, it can prove as challenging to classify the type of mixture of various forms of glass. Some forms may be considered homogeneous solutions, while others could be seen as heterogeneous. Glass serves as an example of a material that defies being classified and challenges students’ thinking about a classification for this substance. |

### Standards and Vocabulary

#### Standards

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

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

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

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

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

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

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

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

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

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

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

#### Vocabulary

* **Vocabulary** and **concepts** that are reinforced in this issue:

Structural formulas

Amino acids

Chemical reactions

Equilibrium

Reaction rates

Oxidation & reduction

Electrochemistry

* Consider asking students to read “Open for Discussion: The Human Drive to Explore Space” to learn about the risks of space exploration prior to reading the article “Mars vs. Titan: A Showdown of Human Habitability.”
* Students may become interested in growing crystals to connect chemistry and art after reading the articles on pages 2 and 19.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.
* The *ChemMatters* Teacher’s Guide has suggestions for further research and activities.

### Possible Student Misconceptions

1. **“If a container is made of Pyrex, you can heat it and then pour cold water directly into it without damaging it.”** Some students think that because their lab glassware is Pyrex they can heat it directly over a Bunsen burner and then cool it off by placing it in a stream of cool water. They are somewhat surprised when it shatters. While Pyrex glass is able to withstand high temperatures, it does not tolerate sudden temperature changes, or thermal shock. Labels on Pyrex cookware state that the container can be frozen, microwaved, baked, and put in the dishwasher, but lots of caution directions are also provided in small print on the back. The back label cautions consumers to avoid severe hot and cold temperature changes, to use minimum amount of cooking time, to not use on any direct heat source, and to not add liquid to hot dishes or place hot dishes in the sink, immerse in water or place them on cold or wet surfaces. Pyrex dishes have been reported to explode, causing serious injuries. So, adhering to the safety precautions is very important. This list of Pyrex use restrictions can be found in the Epicurious article referenced here: <https://www.epicurious.com/expert-advice/pyrex-glassware-safety-shatter-exploding-tips-article>.
2. **“Glass flows very slowly, like a very thick liquid, and settles over time. That is why very old windows are thicker at the bottom.”** This is a myth that has been around for a long time. It is based on the observation that in antique windows the glass is often observed to be thicker at the bottom of the pane. Some have tried to explain this by stating that one of the properties of glass is that it will flow, like a liquid. The glass is thicker at the bottom of the pane because the glass continues to slowly flow, being pulled downward by gravity. In actuality, the windows are unevenly thick because of how they were manufactured. Antique glass was made by hand. Sometimes it was blown into a large cylinder and then cut down one side, allowing the molten glass to be laid flat. The glass often was wavy, bubbled, and uneven. Another early technique involved spinning molten glass on a round flat plate in order to force it to spread out like a large pizza crust. The edges turned out thicker than the middle. When the glass was cut for the window, often the thicker end was placed on the bottom for stability. Today window glass is made by floating the molten glass on top of molten tin. Tin has a lower melting point so, as the glass cools and hardens, the tin remains liquid with the hardened glass floating on top.
3. **“All compounds that are covalently bonded are supposed to have low melting points, like sugar.”** Most compounds that are covalently bonded **do** have low boiling points. This is because molecular solids, those with covalent bonds, are held together with intermolecular forces. These forces are relatively weak and, as a consequence, molecular solids are soft and have relatively low melting points (usually below 200 oC). Sand, however, is a **network** covalent solid, held together by a network of covalent bonds. Because covalent bonds are stronger than intermolecular forces, these solids are harder and have higher melting points.

### Anticipating Student Questions

1. **“What makes the silicon-oxygen bonds in sand so strong?”** The Silicon-oxygen bond is strong because the electrons between the two atoms are shared. The geometry of the bond is similar to the bent geometry found in water. What makes the silicon oxygen bond in sand itself so difficult to break is the giant network that is formed between the silicon and oxygen units. Essentially SiO2 is an **empirical** formula for sand. In reality, each silicon atom is covalently bonded to four oxygen atoms, and each of those oxygen atoms is bonded to another silicon atom. This tetrahedral structure around the silicon atom is similar to that of the arrangement of carbon atoms in diamonds, though not as symmetrical. The melting point of diamonds is over twice that of silica.
2. **“Does the flux chosen to be used when the sand is melted determine the properties of the glass product?** Fluxes lower the melting temperature of the silica but each one contributes slightly different properties to the glass. The three most common fluxes are sodium oxide (Na2O), lithium oxide (Li2O) or lithia, and potassium oxide (K2O). Na2O is most commonly used because it is both abundant and inexpensive. K2O can be used as a flux, and it creates a glass with a smaller expansion coefficient than sodium glass. Sometimes K2O will be used in conjunction with Na2O to modify the expansion properties of the glass product. Li2O lowers the melting temperature more than the other fluxes, and less of this compound is needed to get the right consistency for working with the glass. It also decreases the thermal expansion of the glass. However, due to its expense, it is reserved primarily for specialty glasses. Lead oxide (PbO) can be used as a flux as well. It provides low melting and working temperatures as well as contributes density to the glass, resulting in a glass with greater brilliance that is also easier to cut and polish. PbO also acts to stabilize the glass, preventing it from reacting with water or becoming cloudy. Na2O, K2O, and Li2O all require the use of a stabilizer that will make the glass harder and prevent it from dissolving in water. Calcium oxide or lime is the most common stabilizer.
3. **“What are the compounds used to make colored glass?”**

**Compound Color Compound Color**

Cadmium sulfide Yellow Gold chloride Red

Cobalt oxide Blue-violet Manganese Dioxide Purple

Nickel oxide Violet Sulfur Yellow-amber

Chromic oxide Emerald green Selenium oxide Reds

Carbon oxides Amber brown Antimony oxides White

Uranium oxide Fluorescent Iron oxides Greens &

yellow green browns

Copper compounds Blue, green, red Tin compounds White

Lead compounds Yellow

Manganese dioxide and sodium nitrate are used as decolorizing agents.

(<https://geology.com/articles/color-in-glass.shtml>)

1. **“When did they start using glass for windows?”** Glassstartedbeing usedin some windows shortly after A.D. 100 in Alexandria, Egypt, where a recipe for transparent glass was first created. Through experimentation with the ingredients added to the silica used to make glass, it was found that adding manganese oxide resulted in nearly transparent glass. This soon led to the use of glass for windows (although only in the most important buildings in the most important cities, like Rome and Alexandria). Early windows were usually cast, but some may have been made by rolling out the molten glass like dough. Both methods resulted in windows that were thick, cloudy, and uneven, but they let light in and kept the weather out.
2. **“How do they make Gorilla Glass®, used on cell phones, so strong?”** Gorilla glass is made so strong by an ion exchange process. A sheet of glass is placed in a bath of molten potassium salt at roughly 400° C. Smaller sodium ions leave the glass and are replaced with the larger potassium ions. The large potassium ions take up more room and get pressed together tightly when the glass cools. This creates a layer of compressive stress on the glass surface that makes it more resistant to damage. <http://www.corning.com/gorillaglass/worldwide/en/technology/how-it-s-made.html>
3. **“How is safety glass that is used in cars different from regular glass?”** Actually, there are two types of safety glass used in cars. The windshield is made by fusing a thin layer of the plastic polyvinyl butyral between two sheets of glass. The plastic holds the glass together even when it breaks, with the intent of keeping the passengers from flying out the windshield, being cut by flying glass, or being hit by an object that flies into the windshield from outside. The side and rear windows are made of tempered glass. Tempered glass is made using a process that heats the glass and then quickly cools it. The glass becomes harder and stronger. When it does break it does not break into large sharp shards like regular glass but breaks into small pebble-like pieces without sharp edges.
4. **“Where could I go to see (a) fulgurites, and (b) tektites?”**
5. Fulgurites, formed when lightning strikes the Earth melting the sand in its path, have been found all over the world wherever there is sand; however, they have also been found in rocks on the tops of mountains. Beaches and sand dunes are the most likely place to find fulgurites, as those that form in rocks are rare. Fulgurites often go undiscovered, because they form below the surface where the lightning has struck. Being fragile, when they do make it to the surface after the sand they are buried in erodes, they break up easily. Excavating the fragile fulgurites requires the skills of an archeologist. The longest excavated fulgurite on record was unearthed at a beach between Jacksonville, and Gainesville, Florida, by researchers from the University of Florida in 1997. It had two vertical branches that measured 16 ft. and 17 ft., respectively.
6. Tektites are found only where meteors have hit the Earth. They are located in broad swaths of land called strewnfields, named for how the glassy molten meteor pieces were strewn along the path of the meteor as it approached Earth. The strewnfields in North America are located in Georgia and southern Texas. The other fields are located in Australia, Ivory Coast, the Libyan Desert, central Europe, and Indochina.
7. **“Could sand recrystallize if glass were cooled very slowly after being melted?”** Complete recrystallization of glass into sand doesn’t happen but, in some glass, devitrification may occur. Devitrification is the conversion of glass material to crystallized material when the molecules in the glass change their structure into that of crystalline solids. This gives the glass a frosty or opaque appearance. When glass is held at a high temperature for too long, dust particles or other impurities can serve as nucleation points where crystals can start to form. The chemical composition of some types of glass makes them more vulnerable to devitrification than others. A high lime content can induce this condition. For some artistic applications, a degree of devitrification is desirable.

### Activities

**Labs and demos**

**“Prince Rupert’s Drops” demo:** Glass is melted and then dropped into cold water creating a teardrop shape hard enough to deflect a bullet at the rounded end but fragile enough to shatter if the tail of the drop is snapped.

Instructions for performing the demo can be found here: <https://www.youtube.com/watch?v=5zxZkK2aJig&feature=youtu.be>

A video taken by a high-speed camera of the Prince Rupert drop shattering can be found here: <https://www.youtube.com/watch?v=xe-f4gokRBs&feature=youtu.be>.

The story about the origin of Prince Rupert drops can be found here: <https://www.livescience.com/2720-secrets-prince-rupert-exploding-glass-drops.html>.

**“Glass Bead on a Wire” lab activity:** Students use borax and two different types of wire to see that glass is really a phase of matter rather than a particular material, and its color can be changed by other ions it absorbs when heated.

(<http://ceramics.org/wp-content/uploads/pcsa/Glass%20Bead%20on%20a%20Wire_Final.docx>)

**Simulations**

**“Glass Chemistry Game”:** In this online game, students listen to a narrator and then choose elements from the periodic table to make a specified color of glass.  
(<https://chemistry.cmog.org/>)

**Media**

**“How Glass is Made” video (6:37):** This video walks the viewer through each step of window-glass production, from the melting of sand to the stress testing of the final product. (<https://www.youtube.com/watch?v=IjNusHQOhTM>)

**“Glassblowing Science: How Does Glassblowing Work?” video (4:15):**  This “ACS Reactions” video takes the viewer on a trip to the McFadden Art Glass factory to watch glass objects being created, while also discussing the science involved in glassblowing. (<https://www.youtube.com/watch?v=HkLpAw9u-UU>)

**Lessons and lesson plans**

**“The Glass Age**”: In this two-part lesson plan with four activities, students learn about the history of glass and how glass technologies are changing our lives. Online resources are provided for the students to explore the science behind today’s glass engineering and to brainstorm future innovations. (<http://ymiclassroom.com/lesson-plans/glass-age/> )

**“Not Breaking Up is Hard to Do: The Properties of Glass”:** In this lesson, students will learn about the properties of glass, make sugar glass with a known recipe and test its properties, then choose a way to modify the recipe to see how the properties change. Activities where students learn about current glass innovations are also part of the lesson plan. (Access is restricted to AACT members, but the article will be available for free until December 1, 2018 at <https://teachchemistry.org/classroom-resources/not-breaking-up-is-hard-to-do>.)

**Projects and extension activities**

**“Forensic Glass Analysis”:** If you are teaching a unit on forensics, this lesson plan contains background information concerning glass making and the testing techniques used by forensic scientists to compare samples to determine the class or category of a glass sample or fragment. Students conduct an experiment that provides the student the opportunity to analyze fragments of glass for density, using a flotation method.

(<https://www.txcte.org/resource/lesson-plan-forensic-glass-analysis>)

**Glassblowing lab project:** Using glass tubing, students can make their own bud vase by melting the tubing closed and gently blowing into the tubing to create the bulb. Instructions for this activity can be found in Part B of Experiment 3, referenced here: <http://matse1.matse.illinois.edu/ceramics/c.html>.

### References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine’s inception in October 1983 through April 2013; all**

**available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [***http://ww.acs.org/chemmatters***](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get 30 Years of *ChemMatters* Magazine!” (the icon on the right of the screen).**

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



In “Glass: An Amorphous Solid”, author Baxter gives detailed information about how glass is manufactured, while also referencing the history of glass.

(Baxter, R. Glass: An Amorphous Solid. *ChemMatters*. 1998, *16* (3), pp 10–11)

“Glass: More Than Meets the Eye” discusses chemical composition, refractive index, density, and fracture patterns of glass and applies it to how forensic scientists test glass to determine the source of glass fragments found at a crime scene.

(Rohrig, B. Glass: More Than Meets the Eye. *ChemMatters*. 2006, *24* (3), pp 4–7)

“Try This: Forensic Identification of Glass Activity” in the October 2006 *ChemMatters* issue provides students with instructions on how to use density to identify glass fragments.

(Try This: Forensic Identification of Glass Activity. ChemMatters. 2006, *24* (3), p 8)

The Teacher’s Guide for the October 2006 *ChemMatters* Rohrig article above provides background information about glass history, manufacturing and forensics, and it provides links to student activities involving the forensics evaluation of glass for crime solving.

### Web Resources for More Information

**History of glass**

This excerpt from *Uncle John’s Fast Acting, Long Lasting Bathroom Reader* is a concisely-written, interesting history of glass.

(<https://www.neatorama.com/2012/09/10/The-History-of-Glass/>)

In “Glass of the Alchemists”, a tremendous amount of the history of glass is uncovered in the discussions of the alchemists and their experiments with glass.

(<https://www.cmog.org/article/glass-alchemists>)

**Glass information**

The Corning Museum of Glass Web site offers hundreds of videos and articles with information on all aspects of glass.

(<https://www.cmog.org/research/all-about-glass>)

This site contains information about the history of glass, plus links to information on how glass is made, glass blowing, stained glass, glass ingredients, and a glass historical timeline.

(<http://www.historyofglass.com/>)

**Gorilla Glass® used for electronics**

This site provides information about how Gorilla Glass**®** is made, including links to three videos that help explain the science behind this new glass.

(<http://www.corning.com/gorillaglass/worldwide/en/technology/how-it-s-made.html>)

**Making scientific glassware**

“The Scientific Glassblowing Learning Center” reports general information about scientific glassblowing, accompanied by several examples of glassware projects.

(<http://www.ilpi.com/glassblowing/glassblowing.html>)

**“**The Art of Scientific Glassblowing” is a 1-minute video showing the fabrication of a specialized piece of glassware for chemistry researchers at the University of Connecticut.

(<https://www.youtube.com/watch?v=0XOnl6YwT0M>)

**Glass blowing**

This site contains links to several videos about glass blowing, including scientific glassware, marbles, and a 1959 Oscar-winning documentary featuring glassblowers, set to jazz.

(<http://thekidshouldseethis.com/tagged/glass-blowing>)

**Glass cutting and bending techniques for the chemistry lab**

Written and illustrated instructions can be found at this site for cutting, bending, drawing down glass, as well as instructions for making closed tubes, bulb tubes, and fitting a wash bottle.

(<https://www.911metallurgist.com/blog/glass-working>)

This is a Flinn Scientific instructional video about cutting and bending glass tubing.

(<https://www.flinnsci.com/how-to-cut-fire-polish-bend-glass-tubing/vht0036>)

**Fulgurites and tektites**

This *Scientific American* article discusses fulgurites and dispels the myth behind a photo claimed to be of a fulgurite; it concludes with a precaution to be careful what you Tweet.

(<https://blogs.scientificamerican.com/but-not-simpler/what-really-happens-when-lightning-strikes-sand-the-science-behind-a-viral-photo/>)

A world map depicting the location of the tektite strewnfields, as well as pictures of the different types of tektites discovered there at this site.

(<https://www.meteorite.com/tektite-info-sales/tektite-information/>)

## Reading Supports

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

* **Anticipation Guide (p. 80):**  The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

***-OR-*** Instead of using Anticipation Guides for all articles, consider these ideas to engage your students in reading.

* **How Glass Changed the World**
  + Before reading, ask students about where we find glass in our everyday lives, and how glass is made.
  + As they read, students can add examples from the reading to their lists.
* **Graphic Organizer (p. 81):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

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

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

* **Student Reading Comprehension Questions (p. 82):**  The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.

Some of the articles in this issue provide opportunities, references, and suggestions for students to do further research on their own about topics that interest them.

To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles. The “Web Resources for More Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

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

### Anticipation Guide

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

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Glass is made from sand. |
|  |  | 1. Glass is a crystalline solid. |
|  |  | 1. Glass has a definite melting point. |
|  |  | 1. Glass is a poor electrical insulator. |
|  |  | 1. Humans learned how to make glass thousands of years ago. |
|  |  | 1. Different types of glass are made by mixing in different chemicals. |
|  |  | 1. Lead crystal glassware made today has a crystalline structure and contains lead compounds. |
|  |  | 1. Some types of glass occur naturally. |
|  |  | 1. Most glass today is made using molds. |
|  |  | 1. Glassware found in chemistry labs is inert to strong acids. |

### Graphic Organizer

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

**Directions**: As you read the article, complete the graphic organizer below to describe what makes glass special, and how it is made.

|  |  |
| --- | --- |
| ***Structure of glass*** |  |
| ***Special properties of glass*** |  |
| ***How is soda-lime glass made and where is it used?*** |  |
| ***How is borosilicate glass made and where is it used?*** |  |
| ***How are other types of glass made?*** |  |
| ***How is glass blown to create special shapes?*** |  |
| ***How is laboratory glassware made?*** |  |

**Summary:** On the back of this paper, write a once-sentence summary (15-18 words) about the importance of glass.

### Student Reading Comprehension Questions

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

Name

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

1. What type of bond is present in silicon dioxide, SiO2?
2. Compare at the molecular level the freezing of water to the cooling of molten sand.
3. Name three traits of glass that can be attributed to its amorphous state.
4. At what temperature does sand melt?
5. (a) Describe the purpose of fluxes, and (b) give 3 examples.
6. What compounds are substituted for lead in the creation of lead-free crystal?

**Student Reading Comprehension Questions, cont.**

1. What compounds are used in the manufacture of the heat-resistant glass, Pyrex?
2. Describe three types of glass that occur naturally.
3. When was glass blowing invented?
4. Give three reasons why borosilicate is glass used for laboratory glassware.

**Critical-Thinking Question**

***Write your answer on another piece of paper if needed.***

* + 1. How does the internal structure of glass contribute to its non-conductivity?

### Answers to Reading Comprehension Questions

1. **What type of bond is present in silicon dioxide, SiO2?**

Strong covalent bonds are present in silicon dioxide.

1. **Compare at the molecular level the freezing of water to the cooling of molten sand.**

When water cools, the molecules are drawn together in an orderly solid crystal structure, whereas when glass cools, the molecules do not regain an orderly structure but one that is called an amorphous solid.

1. **Provide three traits of glass that can be attributed to its amorphous state.**

Three traits of glass attributed to its amorphous state are:

1. It does not have a defined melting point and, when heated, softens gradually,
2. it is transparent to visible light, and
3. it does not conduct electricity and therefore is an excellent insulator.
4. **At what temperature does sand melt?**

Sand melts at approximately 1700 °C or 3000 °F.

1. **(a) Describe the purpose of fluxes, and (b) give three examples.**
   1. Fluxes are substances that are added to sand in the glass-making process to lower the melting point by promoting the liquefaction of the solid sand.
   2. Three examples of fluxes are calcium oxide (CaO), calcium carbonate (CaCO3), and sodium carbonate (Na2CO3).
2. **What compounds are substituted for lead in the creation of lead-free crystal?**

Barium oxide (BaO), zinc oxide (ZnO), or potassium oxide (K2O) are substituted for lead in the creation of lead-free crystal.

1. **What compounds are used in the manufacture of the heat-resistant glass, Pyrex?**

Silica, boron trioxide (B2O3), sodium oxide (Na2O), and aluminum oxide (Al2O3) are combined to make Pyrex.

1. **Describe three types of glass that occur naturally.**

The three types of naturally-occurring glass are:

1. obsidian, a jet-black mineral formed by volcanos when lava with high silica content cools,
2. tektites, rocks that formed when meteors struck the Earth millions of years ago, and
3. fulgarites, tubes formed when lightning strikes sandy areas.
4. **When was glass blowing invented?**

Glass blowing was invented in the first century BCE.

1. **Give three reasons why borosilicate glass is used for laboratory glassware.**

Three reasons why borosilicate glass is used for laboratory glassware are:

1. because it does not react with the strongest and most corrosive acids, therefore keeping the contents of the container pure,
2. solutions can be boiled, evaporated, or reacted while the glass remains unchanged, and
3. borosilicate glass is reusable and relatively easy to clean.

**Critical-Thinking Question**

1. **How does the internal structure of glass contribute to its non-conductivity of electricity?**

Electricity requires the free movement of electrons or charged particles. Silicon dioxide, the material from which glass is made, has an internal structure composed of strong covalent bonds. In this structure, all the electrons present are located in bonds and are not free to move; therefore sand would not conduct electricity. In the process of melting, the covalent bonds are not broken and electrons would still not be free to conduct electricity, even though the original organized internal structure has become distorted.

### About the Guide

Teacher’s Guide team leader William Bleam and editors Pamela Diaz, Steven Long, and Barbara Sitzman created the Teacher’s Guide article material.

E-mail: [bbleam@verizon.net](mailto:bbleam@verizon.net)

Susan Cooper prepared the anticipation and reading guides.

Christine Suh, *ChemMatters* editor, coordinated production of the Teacher’s Guide.

E-mail: [c\_suh@acs.org](mailto:c_suh@acs.org)

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

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

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