

**Teacher’s Guide**

**To Mars And Back**

***February 2021***

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Activate students’ prior knowledge and engage them before they read the article.

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These questions are designed to help students read the article (and graphics) carefully. They can help the teacher assess how well students understand the content and help direct the need for follow-up discussions and/or activities. You’ll find the questions ordered in increasing difficulty.

[Graphic Organizer 6](#_Graphic_Organizer)

Thishelps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.

[Answers 7](#_Answers_to_Reading)

Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.

[Additional Resources 11](#_Additional_Resources_1)

Here you will find additional labs, simulations, lessons, and project ideas that you can use with your students alongside this article.

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# Anticipation Guide

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

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

As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Scientists waited until astronauts had walked on the moon to begin planning Mars missions.
 |
|  |  | 1. Most of the oxygen produced on Mars will be needed for rocket launches.
 |
|  |  | 1. Combustion reactions produce light and heat.
 |
|  |  | 1. Mars’ atmosphere is mostly methane.
 |
|  |  | 1. The first robot landed on Mars in 1996.
 |
|  |  | 1. NASA plans to produce oxygen on Mars so that humans can return to Earth.
 |
|  |  | 1. The rover Perseverance will take an instrument to Mars to test the technology to produce oxygen on Mars.
 |
|  |  | 1. Solar power is very reliable on Mars.
 |
|  |  | 1. A nuclear fission reactor has been proposed to produce energy on Mars.
 |
|  |  | 1. The oxygen generator would accompany astronauts to Mars.
 |

# Student ReadingComprehension Questions

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

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

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

**Student Reading Comprehension Questions, cont.**

1. Why can’t NASA just send extra oxygen with the astronauts so there will be enough oxygen for the combustion needed in the return launch from Mars?
2. MOXIE is an instrument designed to take the carbon dioxide from the Mars atmosphere and chemically isolate some of its oxygen atoms in order to generate oxygen gas (O2) that is required for a combustion reaction.
	1. Using the description of the process from the article, write chemical equations to show the two basic steps, including adding or removing electrons, that generate oxygen gas from carbon dioxide. These two steps, when added, should be equivalent to the electrolysis equation shown. (You do not need to include the cathode, anode, or conductor material, but should recognize that without these the process could not occur.)
	2. For the overall electrolysis process, draw a particle diagram to show 10 molecules of carbon dioxide as a “before” picture and the appropriate product particles as an “after” picture.
3. MOXIE is being used in this mission as a proof-of-concept, rather than to functionally generate massive amounts of oxygen. If this test device can generate 6.00 grams of O2 in an hour, then what is the daily consumption of carbon dioxide in grams?
4. An instrument that makes use of a nuclear reaction is also being explored for use on Mars. Write a balanced nuclear equation to represent the reaction modeled in the Powering Mars sidebar.

**Questions for Further Learning**

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

1. Sketch a picture of the electrochemical cell used in the MOXIE instrument.
	1. On the sketch, identify the following:
		1. Where oxidation occurs, along with the oxidation half-reaction.
		2. Where reduction occurs, along with the reduction half-reaction.
		3. The species that gets oxidized.
		4. The species that gets reduced.
		5. The direction of electron flow between the anode and cathode.
	2. Is this a galvanic cell or an electrolytic cell? Justify your answer with information from the article.
2. The standard reduction potentials for experimental technologies are not as well-known as those for simple aqueous solutions. For this exercise, you will use the more well-known aqueous potentials for the half-reactions involved in the MOXIE process, as shown below. In aqueous solution, oxide ions exist as hydroxide ions. All hydrogen species below are a result of water being the solvent.

CO2 + 2e- + 2H+ ⇋ CO + H2O -0.104 V

O2 + 2H2O + 4e- ⇋ 4OH- +0.400 V

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

# Graphic Organizer

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

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

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

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

# Answers to Reading Comprehension Questions & Graphic Organizer Rubric

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

*Oxygen gas, O2*

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

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

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

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

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

*2 C8H18 + 25 O2 🡪 16 O2 + 18 H2O*

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

$$600 galC\_{8}H\_{18} ×\frac{2.6 kg}{1 gal}×\frac{1000 g}{1 kg}×\frac{1molC\_{8}H\_{18}}{114.232g}×\frac{12.5molO\_{2}}{1molC\_{8}H\_{18}}×\frac{31.998gO\_{2}}{1mol}×\frac{1kg}{1000g}=5462kg=5500 kgO\_{2}$$

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

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

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

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

1. **MOXIE is an instrument designed to take the carbon dioxide from the Mars atmosphere and chemically isolate some of its oxygen atoms in order to generate oxygen gas, O2, that is required for a combustion reaction.**
	1. **Using the description of the process from the article, write chemical equations to show the two basic steps, including adding or removing electrons, that generate oxygen gas from carbon dioxide. These two steps, when added, should be equivalent to the electrolysis equation shown. (You do not need to include the cathode, anode or conductor material, but should recognize that without these the process could not occur.)**

*CO2 + 2e- 🡪 CO + O2-*

*2O2- 🡪 4e- + O2*

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

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

|  |  |
| --- | --- |
| ***BEFORE*** | ***AFTER*** |
|  |  |
| *10 CO2* | *10 CO + 5 O2* |

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

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

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

$$+\rightarrow ++3$$

**Questions for Further Learning**

1. **Sketch a picture of the electrochemical cell used in the MOXIE instrument.**



* 1. **On the sketch, identify the following:**
		1. **Where oxidation occurs, along with the oxidation half-reaction.**
		2. **Where reduction occurs, along with the reduction half-reaction.**
		3. **The species that gets oxidized.**
		4. **The species that gets reduced.**
		5. **The direction of electron flow between the anode and cathode.**
	2. **Is this a galvanic cell or an electrolytic cell? Justify your answer with information from the article.**

*Electrolytic cell – The article says that CO2 is drawn into an electrolysis stack, meaning electricity is used to break up the molecule. It also says that it requires some electricity, but consumes less power than a toaster oven. This means it is nonspontaneous and requires energy input for the reaction to occur, making it an electrolytic cell.*

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

 Eo (V)

CO2 + 2e- + 2H+ ⇋ CO + H2O -0.104 V

O2 + 2H2O + 4e- ⇋ 4OH- +0.400 V

1. **What is the value of the standard cell potential for the electrolysis reaction shown in the article? Show your work.**

*One method is shown here, but there are many correct methods for this calculation.*

*CO2 + 2e- + 2H+ ⇋ CO + H2O Eo = -0.104 V*

*4OH- ⇋ O2 + 2H2O + 4e- Eo = -0.400 V*

***Eocell = -0.504 V***

1. **How can the standard cell potential help to justify that this reaction requires an input of energy to proceed?**

*Since the standard cell potential is negative, this means it is nonspontaneous in the designated direction, meaning it requires a steady input of energy to react.*

**Graphic Organizer Rubric**

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

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

# Additional Resources

**Labs and demos**

**How Much Energy is in Your Snack Food?:** An introduction to calorimetry. In this lab, students will find the amount of heat energy stored in foods and compare heat calories with food calories. <https://teachchemistry.org/classroom-resources/how-much-energy-is-in-your-snack-food>

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

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

**Simulations**

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

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

**Lessons and lesson plans**

**Scaffolding Stoichiometry for Struggling Students:** Recorded webinar

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

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

**Thermochemistry Lesson Idea**

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

**AP Chemistry Redox Lesson Idea**

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

**Projects and extension activities**

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

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

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

# Chemistry Concepts, Standards, and Teaching Strategies

**Connections to Chemistry Concepts**

The following chemistry concepts are highlighted in this article:

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

**Correlations to Next Generation Science Standards**

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

**HS-ETS1-3**

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

**Disciplinary Core Ideas:**

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

**Crosscutting Concepts:**

* Energy and Matter
* Structure and Function

**Science and Engineering Practices:**

* Developing and using models
* Planning and carrying out investigations

**Nature of Science:**

* Scientific investigations use a variety of methods.

**Correlations to Common Core State Standards**

See how *ChemMatters* correlates to the[**Common Core State Standards**](https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html)  at www.acs.org/chemmatters.

**Teaching Strategies**

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

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