

**Teacher’s Guide:**

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

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

*October/November 2018*

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



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# 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 designed to help students prepare to read the article, and then locate and analyze information from the article.

* **Anticipation Guide (p. 5):** 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** consider the following 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. 6):** 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. 7):** 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: Tools and Resources 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, if needed.***

* + 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.

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**Tools and Resources**

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# 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. |

# Teaching Strategies and Tools

## Standards

* Links to **Common Core Standards for Reading**:
  + **ELA-Literacy.RST.9-10.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  + **ELA-Literacy.RST.9-10.5**: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, 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.

## Vocabulary

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

Structural Formulas

Amino acids

Chemical Reactions

Equilibrium

Reaction Rates

Oxidation & Reduction

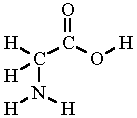
Electrochemistry

* 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>)