

**Teacher’s Guide**

**The Earth’s Chemical Fingerprint**

***April 2024***

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

[***Reading Comprehension Questions***](#_3znysh7) ***3***

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***](#_fbh2674qb7v5) ***6***

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***](#_djipzn7z1r1b) ***7***

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

[***Additional Resources***](#_8qbtv1wio6jt) ***11***

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

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

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

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. In our solar system, only Earth has water vapor in the atmosphere. |
|  |  | 2. Scientists agree about where Earth’s water came from. |
|  |  | 3. Planets close to the sun do not have solid compounds containing hydrogen such as methane and ammonia. |
|  |  | 4. Deuterium’s mass is almost twice that of hydrogen. |
|  |  | 5. Earth, the sun, and comets have similar deuterium-to-hydrogen ratios. |
|  |  | 6. Asteroids far from the sun contain carbon and water ice. |
|  |  | 7. Any hydrogen atom can react with oxygen to form water. |
|  |  | 8. Earth’s crust has more water than Earth’s mantle. |
|  |  | 9. Solar radiation may have blasted away any water on the early Earth. |
|  |  | 10. Scientists look for water because water is required for life. |

# Student Reading Comprehension Questions

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

1. Why don't planets that are closer to the sun contain solid H2O, NH3 or CH4?
2. Using details from the graphic, titled “Birth of a Solar System”, explain the role of gravity in the formation of our earth from a protoplanetary disk.
3. When a set of atoms are classified as isotopes, it means that they are all fundamentally the same element. Use the graphic, titled “Hydrogen’s Isotopes”, to answer the following questions:
   1. Which feature of the three isotopes shown allows us to call them all “hydrogen”?
   2. Chemical symbols can be written to differentiate different isotopes from each other. The type of chemical symbol used in this case is called the “isotope notation” or “isotope symbol”. List the isotope name for each of the isotope symbols below.

|  |  |  |
| --- | --- | --- |
| **Symbol** | **Isotope name** | **Common name** |
|  | Hydrogen-1 |  |
|  | Hydrogen-2 |  |
|  | Hydrogen-3 |  |

* 1. What do the “1”, “2”, and “3” in the isotope name represent?
  2. Circle each of the following symbols that, together, would represent a set of isotopes for the fictional element, X.

1. When scientists need a way of comparing things, they often choose a reference value to which all others can be compared. This reference value, the Vienna Standard Mean Ocean Water (VSMOW) is the standard mean isotopic ratio of deuterium (D) to protium (H) in the Earth’s oceans and was found to be 1.56x10-4. Because this represents a ratio of amounts, it is a unitless number. One source lists the average relative abundance of hydrogen-1 (H) and hydrogen-2 (D) as shown below:

|  |  |
| --- | --- |
| **Isotope** | **Relative Abundance** |
|  | 0.999851 |
|  | 0.000149 |

1. According to this data, is there a higher ratio of deuterium in the oceans or in the rest of the earth? Use a calculation to defend your answer.
2. How is a meteorite different from an asteroid?
3. The “frost line” for our solar system is the radial distance from the sun beyond which it is possible for a particular substance to exist in the solid form. The presence of snow and icebergs on our planet shows that we are currently farther out from the sun than the water frost line in our solar system. Piani’s group, however, proposes that our earth was created from the material that was inside (closer to the sun than) the water frost line when the planets were being formed. This conclusion is partially described below. Add the **reasoning** that connects the evidence to the claim. Your reasoning should clearly *identify any relevant knowledge* and *use science principles* to explain why the claim makes sense based on the evidence.

**Claim**: It is likely that the earth formed from the material inside the frostline

**Evidence**: The chemical fingerprints, like D/H ratios, on enstatite chondrites are very similar to those on earth.

**Reasoning**: ?

1. Why does Sean Raymond believe that Earth’s water came from several different places?
2. Why can studying meteorites help scientists to understand origins of the earth?
3. Studying the origins of the earth is a very large and very complex undertaking. Why are scientists interested in pursuing this knowledge?

**Student Reading Comprehension Questions, cont.**

**Questions for Further Learning**

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

1. There is a quote in the article from Laurette Piani that says, “We use the meteorites as an archive for the solar system.” Write a paragraph that explains the meaning of this quote, using details from the article.
2. The article ends with a quote from Sean Raymond, “Life requires water, so we want to know where the water came from, simply put.” Conduct some research to identify some areas in which this knowledge could be useful.

# Graphic Organizer

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

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

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

# Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Why don't planets that are closer to the sun contain solid H2O, NH3 or CH4?  
   The temperatures are too hot for these to exist in anything other than their gaseous forms.
2. Using details from the graphic, titled “Birth of a Solar System”, explain the role of gravity in the formation of our earth from a protoplanetary disk.  
   Students should highlight the following:  
   - The matter from the protoplanetary disk condensed in several phases into the bodies of our solar system  
   - Gravitational attraction and the subsequent collisions of matter is what made it clump together into planets  
   - Distance from the sun affected how different atoms condensed
3. When a set of atoms are classified as isotopes, it means that they are all fundamentally the same element. Use the graphic, titled “Hydrogen’s Isotopes”, to answer the following questions:
   1. Which feature of the three isotopes shown allows us to call them all “hydrogen”?  
      They each have 1 proton.
   2. Chemical symbols can be written to differentiate different isotopes from each other. The type of chemical symbol used in this case is called the “isotope notation” or “isotope symbol”. List the isotope name for each of the isotope symbols below.

|  |  |  |
| --- | --- | --- |
| **Symbol** | **Isotope name** | **Common name** |
|  | Hydrogen-1 | Protium |
|  | Hydrogen-2 | Deuterium |
|  | Hydrogen-3 | Tritium |

* 1. What do the “1”, “2”, and “3” in the isotope name represent?  
     The mass #, which is the total # of protons + neutrons in the nucleus.
  2. Circle each of the following symbols that, together, would represent a set of isotopes for the fictional element, X.

1. When scientists need a way of comparing things, they often choose a reference value to which all others can be compared. This reference value, the Vienna Standard Mean Ocean Water (VSMOW) is the standard mean isotopic ratio of deuterium (D) to protium (H) in the Earth’s oceans and was found to be 1.56x10-4. Because this represents a ratio of amounts, it is a unitless number. One source lists the average relative abundance of hydrogen-1 (H) and hydrogen-2 (D) as shown below:

|  |  |
| --- | --- |
| **Isotope** | **Relative Abundance** |
|  | 0.999851 |
|  | 0.000149 |

1. According to this data, is there a higher ratio of deuterium in the oceans or in the rest of the earth? Use a calculation to defend your answer.  
   D/H = 0.000149/0.999851 = 0.000149 = 1.49 x 10-4   
   Since this ratio is lower than the standard ocean ratio noted above, there is a lower ratio of deuterium in the rest of the earth than in the ocean.
2. How is a meteorite different from an asteroid?  
   An asteroid is a large rocky body orbiting the sun. A meteorite is a smaller piece of an asteroid that has entered and survived the earth’s atmosphere with enough intact matter to reach Earth’s surface.
3. The “frost line” for our solar system is the radial distance from the sun beyond which it is possible for a particular substance to exist in the solid form. The presence of snow and icebergs on our planet shows that we are currently farther out from the sun than the water frost line in our solar system. Piani’s group, however, proposes that our earth was created from the material that was inside (closer to the sun than) the water frost line when the planets were being formed. This conclusion is partially described below. Add the **reasoning** that connects the evidence to the claim. Your reasoning should clearly *identify any relevant knowledge* and *use science principles* to explain why the claim makes sense based on the evidence.

**Claim**: It is likely that the earth formed from the material inside the frostline

**Evidence**: The chemical fingerprints, like D/H ratios, on enstatite chondrites are very similar to those on earth.

**Reasoning**: ?  
Reasoning should include:

* All matter to form planets and asteroids originated from the same protoplanetary disk
* You’d expect a set of matter to behave similarly in similar conditions
* Since the D/H ratios are so different in different places, it is logical to consider that masses of similar D/H ratio (and other chemical fingerprints) may have formed in the same part of the creation of the solar system

1. Why does Sean Raymond believe that Earth’s water came from several different places?  
   Because the D/H ratios in Earth’s water and land are very different from each other and from other solar system components.
2. Why can studying meteorites help scientists to understand origins of the earth?  
   Asteroids were formed in the same process as were the planets. Since asteroids are essentially untouched, when small parts of them break off to become meteorites and land on earth, we can study the chemical composition of the meteorites to learn how matter organized itself a long, long time ago.
3. Studying the origins of the earth is a very large and very complex undertaking. Why are scientists interested in pursuing this knowledge?  
   Many possible answers – It can help in the overall search for other places that can support life; it can help scientists identify good/bad conditions for forming or trapping water, and find possible solutions to the problem of water scarcity on earth and on a future possible home planet.

**Graphic Organizer Rubric**

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

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

# 

# Additional Resources and Teaching Strategies

**Additional Resources**

* **Labs and demos**
  + Hands-on Modeling Isotopes: AACT Sweet Model of the Atom<https://teachchemistry.org/classroom-resources/sweet-model-of-the-atom>
* **Simulations**
  + PhET simulation: Isotopes and Atomic Mass<https://phet.colorado.edu/en/simulations/isotopes-and-atomic-mass>
  + PhET simulation: Build an Atom<https://phet.colorado.edu/en/simulations/build-an-atom>
* **Lessons and lesson plans**
  + Video: AACT What are Isotopes?<https://teachchemistry.org/classroom-resources/what-are-isotopes-video-questions>
  + Calculating Average Atomic Mass: AACT Candy Isotopes and Atomic Mass<https://teachchemistry.org/classroom-resources/candy-isotopes-and-atomic-mass>
  + Set of Lessons on isotopes, radioactivity, and half-life: AACT Radiocarbon Dating and Willard Libby<https://teachchemistry.org/classroom-resources/radiocarbon-dating-and-willard-libby>
* **Projects and extension activities**
  + Series of lessons on teaching Earth Chemistry: AACT Teaching Earth Chemistry<https://teachchemistry.org/periodical/issues/september-2019/teaching-earth-chemistry-1>
  + Researching resources needed to sustain life: AACT Working for NASA<https://teachchemistry.org/classroom-resources/working-for-nasa>
  + AACT Earth Month Resources:<https://teachchemistry.org/news/earth-month-resources>

**Teaching Strategies**

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

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

# Chemistry Concepts and Standards

**Connections to Chemistry Concepts**

The following chemistry concepts are highlighted in this article:

* States of matter
* Isotopes

**Correlations to Next Generation Science Standards**

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

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

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

**Disciplinary Core Ideas:**

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

**Crosscutting Concepts:**

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

**Science and Engineering Practices:**

* Obtaining, evaluating, and communicating information

**Nature of Science:**

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

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