Science News

EDUCATOR GUIDE

GERALD EICHSTADT/MSSS/SWRI/JPL-CALTECH/NASA

May 8, 2021 & May 22, 2021

Physics Helps Alien Rain Stay in Shape

SOCIETY FOR SCIENCE

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About this Guide

In this Guide, based on the online *Science News* article "How the laws of physics constrain the size of alien raindrops," students will learn about a new model that scientists can use to better understand precipitation on other planets. Then, students will compare the physical and chemical properties of rain on Earth with rain on a planet of their choice. They will use that information to create a short weather forecast for the planet.

This Guide includes:

Article-based Comprehension Q&A — Students will answer questions about the online *Science News* article "How the laws of physics constrain the size of alien raindrops," which explores a new model for rain on planets across the Milky Way. A version of the story, "Physics helps alien rain stay in shape," appears in the May 8, 2021 & May 22, 2021 issue of *Science News*. Related standards include NGSS-DCI: HS-PS1; HS-PS1; HS-ESS1.

> **Student Comprehension Worksheet —** These questions are formatted so it's easy to print them out as a worksheet.

Cross-curricular Discussion Q&A — Students will compare and contrast rain on Earth with rain on other planets and practice drawing molecular structures of various rain substances to examine their physical and chemical properties. They will use that information, along with the planetary conditions needed to form rain, to create a short weather forecast for one planet. Related standards include NGSS-DCI: HS-PS1; HS-PS1; HS-ESS1.

> **Student Discussion Worksheet —** These questions are formatted so it's easy to print them out as a worksheet.

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Article-based Comprehension, Q&A

Directions for teachers: Ask students to read the online *Science News* article "How the laws of physics constrain the size of alien raindrops," which explores a new model for rain on planets across the Milky Way, and answer the following questions. A version of the story, "Physics helps alien rain stay in shape," appears in the May 8, 2021 & May 22, 2021 issue of *Science News*.

1. What is the first generalized model of alien rain?

The model is a set of equations for what happens to a falling raindrop after it has left a cloud. The equations can be applied to any planet.

2. What does the model suggest about the shape of raindrops across the Milky Way?

All liquid raindrops have a similar shape and behave similarly, regardless of what the liquid is made of or what planet the rain falls on.

3. Why is this model important, according to astronomer Tristan Guillot?

It will help scientists understand what happens in the atmospheres of other worlds.

4. What role does rain play in planets' atmospheres?

Raindrops help transport chemical elements and energy.

5. What types of rain did scientists consider when making the model? What celestial objects is the rain found on?

Researchers considered water rain on Earth, ancient Mars and exoplanet K2 18b, methane rain on Saturn's moon Titan, ammonia "mushballs" on Jupiter and iron rain on exoplanet WASP 76b.

6. What does the model indicate about raindrops' size? How does a planet's gravity affect raindrop size?

Raindrops' radii fall within a narrow range, from a tenth of a millimeter to a few millimeters. Planets with higher gravity tend to produce smaller raindrops and planets with weaker gravity tend to produce larger raindrops.

7. What happens to small and large raindrops that fall beyond the size range determined by the model?

Larger raindrops break apart into smaller droplets, and smaller raindrops quickly evaporate.

8. Why do the different raindrops behave similarly, according to planetary scientist Kaitlyn Loftus?

All of the raindrops behave similarly because they are governed by the same physical equations.

9. What do the researchers want to use the model to study next?

The scientists would like to study solid precipitation such as hail.

10. What goal does this model bring scientists a step closer to achieving?

To develop an understanding of how planets and atmospheres work that isn't solely influenced by our knowledge of how Earth works.

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Student Comprehension Worksheet

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7. What happens to small and large raindrops that fall beyond the size range determined by the model?

8. Why do the different raindrops behave similarly, according to planetary scientist Kaitlyn Loftus?

9. What do the researchers want to use the model to study next?

10. What goal does this model bring scientists a step closer to achieving?

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Cross-curricular Discussion, Q&A

Directions for teachers:
Before this discussion, students should read the online *Science News* article "How the laws of physics constrain the size of alien raindrops." A version of the story, "Physics helps alien rain stay in shape," appears in the May 8, 2021 & May 22, 2021 issue of *Science News*.

With a partner, students will answer the first set of questions comparing and contrasting rain on the planets and moon mentioned in the *Science News* article with rain on Earth. Pairs should work together to build or draw the structures of the different molecules that compose rain droplets, using outside resources as needed. Based on the structures and their knowledge about bond polarity, pairs will determine the intermolecular attraction forces between molecules in a raindrop. They should use that information to discuss conditions that might allow rain to form on other planets and create a brief weather forecast for a planet of their choice that they can present to the class.

Note: Students will need background knowledge of Lewis Dot Structures and the Valence Shell Electron Pair Repulsion model.

Want to make it a virtual lesson? Post the online *Science News* article to your virtual classroom. Discuss the article and questions with your class on your virtual platform.

Rain: alien or not
1. How would you define rain? What is meant by the phrase "alien rain?"

Rain on Earth is primarily water (H_2O) that condenses to form clouds in the atmosphere and then falls to the planet's surface. Alien rain refers to rain on other planets. That rain may form through a similar condensation process, but is not necessarily made of water.

2. Based on the first generalized physical model of alien rain covered in the *Science News* article, how do droplet shape and size vary across planets? How does the rain's chemical makeup affect these attributes?

According to the model, falling droplets of a liquid tend to take on the same shape regardless of what the liquid is made of or what planet the droplets fall on. The model predicts that raindrops fall within a fairly narrow size range that varies by less than a millimeter. Worlds with higher gravity produce slightly smaller drops.

3. In the table below, compare and contrast the makeup, shape and maximum size of raindrops on Earth with raindrops on another planet mentioned in the *Science News* article. Consult outside resources as needed, and be sure to cite your sources. Use the last column to explain why you think each similarity or difference occurs.

The sample answer below compares Earth rain with Jovian rain.

Rain attributes	Earth	Planet: *Jupiter*	Explain
Makeup	*Primarily water*	*Ammonia and water*	*Since the atmospheric composition and condition of some other planets are drastically different than Earth's, atoms or molecules other than* H_2O *may be present in high atmospheric concentrations, and under the relatively extreme conditions of another planet may be able to condense into clouds and eventually fall toward the planet's center as a liquid.*
Shape	*Oblate spheroid (like the top of a hamburger bun)*	*Oblate spheroid (like the top of a hamburger bun)*	*The physical laws of fluid mechanics and thermodynamics allow rain on any planet to take on a similar shape.*
Maximum size	*About 11 millimeters*	*About 7 millimeters*	*Jupiter's gravity is significantly higher than Earth's gravity. The model predicts that worlds with higher gravity produce slightly smaller drops. This may be due to the fact that the external forces acting on falling liquid drop may be more compressive or that higher gravity environments tend to produce droplets composed of fewer atoms or molecules.*

Sources:
K. Loftus and R. D. Wordsworth. The physics of falling raindrops in diverse planetary atmospheres. JGR Planets, Volume 126, Issue 4, April 2021. doi:10.1029/2020JE006653.
American Geophysical Union. A comparison of alien raindrops. Eurekalert. Published 2021.
NASA. 'Shallow lightning' and 'Mushballs' reveal ammonia to NASA's Juno scientists. Published August 5, 2020.

4. What affects the evaporation rate of a raindrop? Which do you think would evaporate faster: Earth raindrops or raindrops falling on the planet you chose?

Student answers will vary, but students should note that the evaporation rate depends on the droplet's surface area. Students may mention that droplets with larger surface areas could perhaps initially evaporate faster than droplets with smaller surface areas.

Chemical breakdown
Answer the following questions with your partner to explore the molecular composition of rain on different planets compared to rain on Earth. This information will help you predict conditions that might exist on the planet you chose.

1. Make a list of the planets and moons mentioned in the *Science News* article that have rain. State what the rain is made of for each celestial object, whether the substance is an atom or a molecule and give its chemical formula. If the substance is a molecule, state how many atoms of each element are within one molecule of it and what types of bonds exist between the atoms.

Earth, ancient Mars and exoplanet K2 18b rain water. Water is a molecule composed of 2 hydrogen atoms and one oxygen atom. Its chemical formula is H_2O.

Titan: Rains methane. Methane is a molecule composed of 4 hydrogen atoms covalently bonded to one carbon atom. The chemical formula is CH_4.

Exoplanet WASP 78b: Rains iron. Iron is an element, and has the elemental symbol of Fe.

Jupiter: Rains "mushballs" of ammonia and water. Ammonia is molecule composed of three hydrogens covalently bonded to a nitrogen atom. Its chemical formula is NH_3 *Water is a molecule composed of 2 hydrogen atoms and one oxygen atom. Its chemical formula is* H_2O.

2. Using your knowledge of Lewis Dot Structures and the Valence Shell Electron Pair Repulsion model (VSEPR), explore the shape of each molecule in the table below. Make sure to include bond angles and the common name for the molecule's shape in your VSEPR model. Finally, state whether you would expect the molecule to be polar or nonpolar and why. Note that iron is not a molecule, rather it is a metal atom.

Molecule	**Chemical formula**	**Lewis Dot structure**	**VSEPR model**	**Polarity**
Methane	CH_4	*Four solid lines connecting each H to the central C.*	*Tetrahedral, with bond angels of 109.5°.*	*Based on the nonpolar bonds and the symmetrical tetrahedral shape, we would assume this molecule is nonpolar.*
Ammonia	NH_3	*Three solid lines connecting each H to the central N, and one lone*	*Trigonal pyramidal, with bond angles of 107°.*	*Based on the highly polar bonds and non-symmetrical*

		pair of electrons (two dots) on the central N.		*shape, you would expect the molecule to be polar.*
Water	*H_2O*	*Two solid lines connecting each H to the central O, and two lone pairs of electrons (four dots) on the central O.*	*Tetrahedral bent, with bond angles of 104.5°.*	*Based on the polar bonds and bent shape, you would expect the molecule to be polar.*

3. Draw the general shape of a rain drop. Then draw a zoomed in view of the atoms or molecules within each type of raindrop. Indicate the forces of attraction between the atoms or molecules within the liquid raindrops.

The raindrops should be shaped like the top of a hamburger bun. Zoomed in to the molecular level for each type of rain, students should show discrete molecules or atoms of the substance randomly moving around each other. The attractive forces between the molecules for each type of rain are:

Methane: London dispersion forces, the weakest attraction force.

Ammonia: Dipole-dipole interaction forces with strong hydrogen bonding effects from the bonds between nitrogen and hydrogen. Students' diagrams should show attraction between the partially negative N in one molecule to the partially positive H in another molecule.

Water: Dipole-dipole interaction forces with strong hydrogen bonding effects from the bonds between hydrogen and oxygen. Students' diagrams should show attraction between the partially negative O in one molecule to the partially positive H in another molecule.

Iron: We would expect it to bond metallically to other atoms, which means that delocalized electrons will be shared across its lattice structure. Students' diagram could show individual iron atoms among a sea of delocalized electrons.

Make it rain

Discuss the following questions with your partner, then create a short weather forecast about a planet other than Earth that you will present to your class. Be sure to include high and low temperatures, and whether you expect there to be a chance of rain.

1. Could the various types of alien rain mentioned in the *Science News* article exist as rain on Earth? Explain why or why not. (Hint: Consider each type of rain's intermolecular forces of attraction and the typical conditions on Earth.)

Student answers will vary, but they should focus their answers on the relative difference in intermolecular forces of the substances. The weak forces between methane molecules would not allow it to condense to a liquid in Earth's atmosphere. The strong metallic bonding between atoms in iron would not allow it to liquefy on Earth, etc.

2. Based on the intermolecular attraction forces in an alien raindrop, predict a few conditions that might exist on your chosen planet that would allow rain to form. Examples of conditions include high and low temperatures, air pressure, weather patterns, wind speed and direction, and humidity. Use those conditions to create a short weather forecast. Note that you may need to look up additional information, like the boiling point, or full phase diagram of a substance.

Student answers will vary but should include at least a high and low temperature that is in the range of the boiling point of the alien rain substance. Students should also note an air pressure that would allow the substance to exist as a gas in the atmosphere, then condense to a liquid. Encourage students to have fun creating their forecast.

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Student Discussion Worksheet

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Rain: alien or not

1. How would you define rain? What is meant by the phrase "alien rain?"

2. Based on the first generalized physical model of alien rain covered in the *Science News* article, how do droplet shape and size vary across planets? How does the rain's chemical makeup affect these attributes?

3. In the table below, compare and contrast the makeup, shape and maximum size of raindrops on Earth with raindrops on another planet mentioned in the *Science News* article. Consult outside resources as needed, and be sure to cite your sources. Use the last column to explain why you think each similarity or difference occurs.

Rain attributes	**Earth**	**Planet:**	**Explain**
Makeup			
Shape			
Maximum size			

Sources:

4. What affects the evaporation rate of a raindrop? Which do you think would evaporate faster: Earth raindrops or raindrops falling on the planet you chose?

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2. Using your knowledge of Lewis Dot Structures and the Valence Shell Electron Pair Repulsion model (VSEPR), explore the shape of each molecule in the table below. Make sure to include bond angles and the common name for the molecule's shape in your VSEPR model. Finally, state whether you would expect the molecule to be polar or nonpolar and why. Note that iron is not a molecule, rather it is a metal atom.

Molecule	**Chemical formula**	**Lewis Dot structure**	**VSEPR model**	**Polarity**
Methane				
Ammonia				
Water				

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2. Based on the intermolecular attraction forces in an alien raindrop, predict a few conditions that might exist on your chosen planet that would allow rain to form. Examples of conditions include high and low temperatures, air pressure, weather patterns, wind speed and direction, and humidity. Use those conditions to create a short weather forecast. Note that you may need to look up additional information, like the boiling point, or full phase diagram of a substance.

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