Lesson Plan
Eunice Foote and the Greenhouse Gas Effect

An illustration of Eunice Newton Foote collecting observations for her groundbreaking atmospheric research.

Illustration by Carlyn Iverson

Grade Level(s): 9-12	**Subject(s): Physics, History, Earth Science**

Supplements: Physics Topic

In-Class Time: 75-90 minutes	**Prep Time: 15-20 minutes**

Materials

- A/V Equipment Optional
- Internet Access Optional
- Copy of Opening Discussion Prompts (found in Supplemental Materials)
- Copies of Foote vs Tyndall (found in Supplemental Materials, Optional)
- Copies of Foote vs Tyndall Discussion Questions (found in Supplemental Materials, Optional)
- Lab Instructions (found in Supplemental Materials)
    - identical, large, clear, plastic bottles with screw-on caps (1L water bottles will work)
        - One will measure common air, one with water-saturated air, one with carbon dioxide

- 3 thermometers to fit inside the bottles (analog, digital, digital recording will work)
  - If a digital recording probe is used, you will need to drill a hole in the cap for the wire. The holes can later be sealed with clay, hot glue, or another sealant.
- Clock or watch that displays seconds and minutes
- Hair dryer (optional)
- 150 mL vinegar
- 250 mL baking soda
- An extra bottle or beaker to prepare carbon dioxide
- 3 sponges or sponge pieces of equal dimensions to be placed in the bottle
- 3 identical light sources or direct sunlight

Objective

In this lesson, students will learn about Eunice Newton Foote's 1856 discovery of the Greenhouse Effect of carbon dioxide. Students will recreate her experiment in the lab to learn about the Greenhouse Effect. (To cover the same material without conducting the lab, see the teaching guide "Eunice Foote: Climate Scientist.") Students will then learn about the constraints experienced by an American, female scientist in the 1800s and how the Greenhouse Effect contributes to global warming and climate change.

Introduction

Eunice Newton Foote (1819-1888) was a scientist, inventor, and women's rights activist who first discovered carbon dioxide's ability to retain heat and concluded that an increase in the presence of carbon dioxide in the atmosphere would cause global warming. Today, we call this the greenhouse effect and though Foote discovered it in 1856, she did not receive credit for her discovery until 2011.

Very little is known about Eunice Foote's early life. Her father was Isaac Newton Jr. of Bloomfield, New York, her mother unknown.[1] She attended Troy Female Seminary, an all-girls school and took classes at a nearby men's science college, now known as Rochester Polytechnic Institute. Though she never received any specific physics education, she was trained in general science which no doubt aided her future scientific endeavors. In 1841, she married Elisha Foote a mathematician, inventor, and judge.[2] They were both women's rights activists and attended the 1848 Seneca Falls convention, credited for sparking the women's rights movement. Together they had two daughters, Mary Newton Henderson and Augusta Newton Arnold.[3]

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[1] Reed, Elizabeth W. *American Women in Science Before the Civil War*. Minneapolis, 1992.
[2] Joseph D. Ortiz and Ronald Jackson. "Understanding Eunice Foote's 1856 Experiments: Heat Absorption by Atmospheric Gases." *Notes and Records: The Royal Society Journal for the History of Science* (26 August 2020), 1-18. https://doi.org/10.1098/rsnr.2020.0031.
[3] Reed, *American Women in Science Before the Civil War*.

As a scientist, Eunice Foote was groundbreaking. Though she published just two papers, she was one of the first female scientists published in the United States.[4] Her first paper, "Circumstances Affecting the Heat of the Sun's Rays," was published in 1856 and covered her experiment to test how different atmospheric conditions such as air density, humidity, and gases respond to heat from the sun. Her discovery in this paper, that carbon dioxide absorbs and retains heat significantly more than the other conditions is what we know today as the greenhouse effect.[5] Her second paper, "On a New Source of Electrical Excitation," was published in 1858 and addressed how varying moisture content effects the static electricity in the air.[6] In addition to conducting scientific research, Foote was also an inventor and held the patent for a shoe filling.[7]

Foote's atmospheric experiments were likely motivated by an interest in the geologic past. At the time, scientists were confused why areas of higher elevation contained evidence of plants and animals found in warmer environments and speculated of a warmer past.[8] To explore what changes to the atmosphere could foster a warmer environment, Foote recreated different atmospheric conditions in glass jars and exposed them to the sun. She filled jars with common air, pumping in more air or removing some to compare different densities, adding moisture to others, or even different gases like carbon dioxide. She measured the difference in temperature of the jars in sunlight and a control jar of each gas left in the shade. Based on her observations, she concluded that higher pressure air, damp air, and some gases are more affected by the sun's rays than common air, the most dramatic effect from carbon dioxide.[9] Though Foote did not account for *how* the gases cause climate change, understood now to be the invisible infrared wavelengths of light that radiate off Earth's surface in the form of heat, she was the first to recognize the gas's ability to absorb heat its implications.[10]

Criticism for her work lies in the limitations of its scope. She measured the heating of different atmospheric conditions without attempting to speculate the causes for heating.[11] Though her conclusions were indisputably accurate, the precise mechanism she believed to cause heating, direct sunlight, is not the cause of the greenhouse effect. Instead, it is the heat radiating off the Earth's surface as invisible infrared radiation that gets trapped by greenhouse gases and causes the Earth's temperature to rise. Though Foote likely was not measuring the effect of infrared bands on carbon dioxide, she did recognize the gas's potential for absorbing heat.[12]

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[4] Ortiz and Jackson, "Understanding Eunice Foote's 1856 Experiments," 1-18.

[5] Eunice N. Foote, "On the Heat in the Sun's Rays," *The American Journal of Science and Arts* 22 (November 1856): 377–82.

[6] Eunice N. Foote, "On a New Source of Electrical Excitation," *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 15, no. 99 (1858): 239–40. https://doi.org/10.1080/14786445808642471.

[7] Eunice N. Foote, Filling for the soles of boots and shoes, US Patent Office US28265A (Saratoga Springs, NY, 1860).

[8] Ortiz and Jackson, "Understanding Eunice Foote's 1856 Experiments," 1-18.

[9] Foote, "On the Heat in the Sun's Rays," 377–82.

[10] Ortiz and Jackson, "Understanding Eunice Foote's 1856 Experiments," 1-18.

[11] Foote, "On the Heat in the Sun's Rays," 377–82.

[12] Ortiz and Jackson, "Understanding Eunice Foote's 1856 Experiments," 1-18.

Despite wider recognition than many female U.S. scientists before her, her work received little attention compared to her male counterparts. Comparing the reception of her work to her husband's is a case study in the unequal treatment she received. Both of their research was presented at the 10th American Association of the Advancement of Sciences (AAAS) meeting in 1856. Like most researchers, Elisha Foote presented his own findings, while Eunice's paper was presented by Joseph Henry, then Secretary of the Smithsonian institution. That year, Elisha but not Eunice Foote was voted as a member of AAAS.[13] Henry's coverage and remarks on Eunice Foote's work was published by the *American Journal of Science and Arts* and covered by *Scientific American* in an article about skilled female scientists,[14] but it received little coverage outside of that. It is likely that few at the time understood the wider implications of her discovery, but it is also likely that the minimal coverage and subpar treatment was due to Eunice Foote's gender. In 1859, just three years after Foote's findings were published, the Irish scientist John Tyndall arrived at the same conclusion that variations in atmospheric gases absorb radiation differently and contribute to climate change. He was probably unaware of Foote's work and was credited with the discovery of the greenhouse effect for a century and a half. In 2011, geophysicist Raymond Sorenson rediscovered her work and brought her research back into the public eye.[15]

Instructions/Activities

Engage: 5-10 Minutes

Teachers will introduce topic by discussing the weather. The teacher will get students thinking about how they experience weather and theorize about heat.	
What is the teacher doing? Leading a discussion with the class to kept them thinking about weather and atmospheric heating.	**What are the students doing?** Discussing the questions.

Explore: 50-60 Minutes

The teacher will briefly introduce the students to Eunice Newton Foote and lead the students in conducting the lab and completing the Post-Lab Questions. Instructions for the lab and Post-Lab Questions are found in the Lab Instructions located in Supplemental Materials.	
The teacher will briefly introduce Eunice Newton Foote, focusing on the time she was active. Points to mention: • She was born 1819 and published her work in 1856 • Foote attended Troy Female Seminary, but at the time it was uncommon for women to have education • Few women were recognized as scientists in the United States	The students are listening to the introduction to Eunice Newton Foote.

[13] Ibid.
[14] "Scientific Ladies--Experiments with Condensed Gases," *Scientific American* 12, no. 1 (13 September 1856): 5.
[15] Raymond P. Sorenson "Eunice Foote's Pioneering Research on CO_2 And Climate Warming," *Search and Discovery*, no. #70092 (31 January 2011).

• She discovered the greenhouse effect by conducting a similar experiment to what the class will do but did not receive credit for the discovery. Instead, John Tyndall, who discovered the same thing three years after her, did and was known as one of the founders of climate science. The teacher will then lead the lab which recreates Foote's experiment. The teacher will also distribute the Lab worksheet. The teacher will follow the instructions in the Lab Instructions document for setting up the experiment. Materials should be assembled as much as possible before class time.	The students are receiving the Lab worksheet. The students are working in three groups to set up and conduct the experiment. They are recording data and plotting their findings. After completing the lab, they will plot their data and answer the Post-Lab Questions.

Explain: 5-10 Minutes

The teacher will lead students in a class-wide exchange, in which the answers Post-Lab Questions are provided and deliberated.	
What is the teacher doing? Lead the class in examining the correct answers to the Post-Lab Questions. If desired, collect student answers to the Post-Lab Questions for evaluation.	**What are the students doing?** Review answers to the Post-Lab Questions as a class. If instructed, submit answers to the Post-Lab Questions to the teacher for evaluation.

Elaborate: 15-20 Minutes

This lesson could be elaborated either through learning more about the history of Eunice Foote or through learning more about the greenhouse effect. If a greater emphasis on history is desired, the students will read and discuss the Foote vs Tyndall paper found in *Supplemental Materials* to gain more understanding for the context that Tyndall received credit for Foote's discovery. The teacher will then lead a discussion by following the Discussion Questions, also found in *Supplemental Materials*. If a greater emphasis on the greenhouse effect is desired, the teacher could show the videos on the Greenhouse Effect and Climate Change listed in the "Required/Recommended Reading and Resources" and lead discussion. The teacher will also return to the opening questions about weather.	
What is the teacher doing? Provide students copies Foote vs Tyndall. OR, show videos on the greenhouse gas effect. Lead students in a discussion based on the provided discussion questions.	**What are the students doing?** Receive the copy of Foote vs Tyndall and read thoroughly. OR, watch the videos on the greenhouse gas effect. Participate in class discussion regarding Foote vs Tyndall and/or the greenhouse gas effect.

Evaluate:

The main opportunity for evaluation is in the lab. The teacher can evaluate the data table, graph, and post-lab questions produced by the students.

Required/Recommended Reading and Resources

Video

- MinuteEarth. "How Do Greenhouse Gases Actually Work?" YouTube video, 3:08 minutes. Posted May 2015. https://www.youtube.com/watch?v=sTvqIijqvTg
- Climate Reality. "CLIMATE 101 with BILL NYE" YouTube video, 4:33 minutes. Posted September 2011. https://www.youtube.com/watch?v=3v-w8Cyfoq8

Readings

- "Foote vs Tyndall." June 2021.

Discussion Questions

Suggested Opening Questions:

1. What is weather?
2. Describe the weather outside today?
3. What is everyone's favorite weather?
4. Have you noticed that the heat is worse when it is humid outside too?
5. Why might areas of higher elevation, such as mountains, be colder than areas of low elevation?
6. Why do you think summer nights remain warm, even though the sun goes down?

Foote vs Tyndall Questions:

1. What is the Greenhouse Effect? What gas did Foote and Tyndall discover causes it?
2. How did Foote's experiment differ from Tyndall's?
3. What factors lead Tyndall to receive credit as the discoverer of the Greenhouse Gas effect?
4. Why is it important that Foote receive credit?

Post-Lab Questions:

1. Describe the plots of temperature over time for each gas.
    a. Which gas warmed most quickly? Was the increase in temperature (slope) constant or did it change?
    b. Which gas had the greatest change in temperature?
    c. How did the cooling of the gases compare to the warming? Which gas retained heat the longest?
2. Compare the gases to the composition of the atmosphere.
3. If you increased CO_2 in the atmosphere, what would happen to the Earth?
    a. How is this related to the greenhouse effect?

AIP American Institute of Physics

Further Reading and Additional Resources

- Foote, Eunice N. "On the Heat in the Sun's Rays." *The American Journal of Science and Arts* 22 (November 1856): 377–82.
- "Scientific Ladies--Experiments with Condensed Gases." *Scientific American* 12, no. 1 (September 13, 1856): 5.
- Joseph D. Ortiz, and Ronald Jackson. "Understanding Eunice Foote's 1856 Experiments: Heat Absorption by Atmospheric Gases." *Notes and Records: The Royal Society Journal for the History of Science* (26 August 2020), 1-18. https://doi.org/10.1098/rsnr.2020.0031.
- Sorenson, Raymond P. "Eunice Foote's Pioneering Research On CO2 And Climate Warming." *Search and Discovery*, no. #70092 (January 31, 2011). https://www.searchanddiscovery.com/pdfz/documents/2011/70092sorenson/ndx_sorenson.pdf.html.
- Jackson, Ronald. "Eunice Foote, John Tyndall and a Question of Priority." *The Royal Institution* 74, no. 1 (February 13, 2019): 105–18. https://doi.org/10.1098/rsnr.2018.0066.

Extensions

History Research Activity

For history projects, see the teaching guide "Eunice Foote: Scientist and Suffragette."

Related AIP Teacher's Guides on the History of the Physical Sciences:

Eunice Foote: Climate Scientist
Eunice Foote: Scientist and Suffragette
Scientific Writing in the Chemical and Earth Sciences
Tuskegee Weathermen

Common Core Standards

For more information on Common Core Standards, visit http://www.corestandards.org/.

Speaking & Listening	
CCSS.ELA-LITERACY.SL.9-10.1	Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9-10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
CCSS.ELA-LITERACY.SL.11-12.1	Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 11-12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
History/Social Studies	
CCSS.ELA-LITERACY.RH.9-10.1	Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

CCSS.ELA-LITERACY.RH.9-10.2	Determine the central ideas or information of a primary or secondary source; provide an accurate summary of how key events or ideas develop over the course of the text.
CCSS.ELA-LITERACY.RH.11-12.1	Cite specific textual evidence to support analysis of primary and secondary sources, connecting insights gained from specific details to an understanding of the text as a whole.
CCSS.ELA-LITERACY.RH.11-12.2	Determine the central ideas or information of a primary or secondary source; provide an accurate summary that makes clear the relationships among the key details and ideas.
Science and Technical Subjects	
CCSS.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.
CCSS.ELA-LITERACY.RST.9-10.2	Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
CCSS.ELA-LITERACY.RST.9-10.3	Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
CCSS.ELA-LITERACY.RST.9-10.9	Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.
CCSS.ELA-LITERACY.RST.11-12.2	Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
CCSS.ELA-LITERACY.RST.11-12.3	Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
CCSS.ELA-LITERACY.RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
CCSS.ELA-LITERACY.RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Next Generation Science Standards

For more information on the Next Generation Science Standards, visit http://www.nextgenscience.org/.

Earth's Systems	
HS-ESS2-4 Earth's Systems	Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. Grade: High School (9-12)

Earth and Human Activity	
[HS-ESS3-5 Earth and Human Activity]	Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems. Grade: High School (9-12)