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This Lady Scientist Defined the Greenhouse Effect But Didn't Get the Credit, Because Sexism

Eunice Foote's career highlights the subtle forms of discrimination that have kept women on the sidelines of science

Ahead of her time: Foote first identified the greenhouse effect, now a seminal concept in climate science. (Blend Images / Alamy)

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The morning of August 23, 1856, saw hundreds of men of science, inventors and curious persons gathered in Albany, New York, for the Eighth Annual Meeting of the American Association for the Advancement of Science, the largest attended to date. The

annual meetings of the AAAS brought together scientists from around the United States to share groundbreaking new discoveries, discuss advancements in their fields and explore new areas of investigation. Yet this particular meeting failed to deliver any papers of quality—with one notable exception.

That exception was a paper entitled "Circumstances affecting the heat of the sun's rays," by Eunice Foote. In two brisk pages, Foote's paper anticipated the revolution in climate science by experimentally demonstrating the effects of the sun on certain gases and theorizing how those gases would interact with Earth's atmosphere for the first time. In a column of the September 1856 issue of *Scientific American* titled "Scientific Ladies," Foote is praised for supporting her opinions with "practical experiments." The writers noted: "this we are happy to say has been done by a lady."

Foote's paper demonstrated the interactions of the sun's rays on different gases through a series of experiments using an air pump, four thermometers, and two glass cylinders. First, Foote placed two thermometers in each cylinder and, using the air pump, removed the air from one cylinder and condensed it in the other. Allowing both cylinders to reach the same temperature, she then placed the cylinders with their thermometers in the sun to measure temperature variance once heated and under various states of moisture. She repeated this process with hydrogen, common air and CO2, all heated after being exposed to the sun.

Looking back on Earth's history, Foote explains that "an atmosphere of that gas would give to our earth a high temperature ... at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted." Of the gases tested, she concluded that carbonic acid trapped the most heat, having a final temperature of 125 °F. Foote was years ahead of her time. What she described and theorized was the gradual warming of the Earth's atmosphere—what today we call the greenhouse effect.

Three years later, the well-known Irish physicist John Tyndall published similar results demonstrating the greenhouse effects of certain gases, including carbonic acid. Controversial though well recognized at the time, Tyndall theorized that Northern Europe was once covered in ice but gradually melted over time due to atmospheric changes. This laid the groundwork for how atmospheric variations over time in addition carbon dioxide emissions could have profound effects on global climate. Presently, Tyndall's work is widely accepted as the foundation of modern climate science, while Foote's remains in obscurity.

Why?

It goes without saying that the 19th century was not an easy era to be a woman and scientifically curious. With limited opportunities in higher education for women and the gate-keeping of scientific institutions like AAAS, which was all-male until 1850, science was largely a male-dominated field. Even the Smithsonian Institution, one of America's premier scientific research institutions, was built on the clause "for the increase and diffusion of knowledge *among men*" (emphasis added). Born in 1819, this is the landscape that Foote found herself navigating.

Although nothing is known about Foote's early education, it is clear from her experiments that she must have received some form of higher education in science. Her appearance, along with her husband Elisha Foote, at the 1856 AAAS meeting is the first recorded account of her activity in science.

Unlike many other scientific societies, the AAAS did allow amateurs and women to become members. Astronomer Maria Mitchell became the first elected female member in 1850, and later Almira Phelps and Foote, though without election from its standing members. But despite the society's seemingly open door policy, there were hierarchies within the society itself. Historian Margaret Rossiter, author of the comprehensive three volume series *Women Scientists in America*, notes that the AAAS created distinctions between male and female members by reserving the title of "professional" or "fellow" almost exclusively for men, whereas women were regarded as mere members.

These gender disparities were highlighted during the August 23 meeting, where Foote was not permitted to read her own paper. Instead, her work was presented by Professor Joseph Henry of the Smithsonian Institution. (Foote's husband, by contrast, was able to read his paper, also on gases.)

At the meeting, Henry appended Foote's paper with his own added preface: "Science was of no country and of no sex. The sphere of woman embraces not only the beautiful and the useful, but the true." The introduction, intended to praise Foote, more than anything highlights her difference as a woman in a sea of men, indicating that her presence among them was indeed unusual and needed justification. Even *Scientific American*'s praise of Foote's paper was included in a column two pages after the AAAS meeting report. Though both Henry and *Scientific American* seemed to see Foote as an equal in scientific endeavors, she was still kept separate from the fold.

Adding insult to injury, Foote's paper was left out of the society's annual *Proceedings*, a published record of the papers presented at the annual meetings. In *The Establishment of Science in America*, historian Sally Gregory Kohlstedt gives some indication of why this might be.

In the 1850s, Alexander Dallas Bache, a leading force for the AAAS, promoted open membership. But Bache also enforced strict and critical reviews of all papers published in the *Proceedings* in order to cultivate a specific image and voice for American science; even if a local committee of the association approved papers for publication, the standing committee of the AAAS, on which Bache served, could reject them. Just by glancing at the member list and published papers, it is clear that image and that voice were predominantly male.

The only copy of Foote's paper published in its entirety is found in *The American Journal of Science and Arts*, and without this outside publication, only Henry's read version would remain. Compared to other papers published from this meeting, Foote's—a demonstration of rigorous experimentation and sound reasoning—should arguably have been included in the 1856 collection.

I spoke with Raymond Sorenson, an independent researcher and co-editor for *Oil-Industry History*, who was the first to publish a paper on Foote in 2011. A collector of scientific manuals, Sorenson found Foote's paper as read by Joseph Henry in David A. Wells's *Annual of Scientific Discovery*. (Wells is the only known source to include Joseph Henry's impromptu introduction, most likely retrieved through stenographer records of meetings.)

Sorenson says that Foote's biographical information is difficult to find and piece together, but he has found her correspondence archived at the Library of Congress and has traced some of her familial connections. The more Sorenson researched Foote, the more he realized he has a book project on his hands. Yet before writing tha book, Sorenson decided to go ahead and publish his 2011 article because, as he says, "Eunice Foote deserves credit for being the first to recognize that certain atmospheric gases, such as carbon dioxide would absorb solar radiation and generate heat…[three] years before Tyndall's research that is conventionally credited with this discovery."

It now appears that Foote was the first to demonstrate the greenhouse effects of certain gases and also the first to theorize about their interaction with the Earth's atmosphere over an extended period of time. Her explanation of the greenhouse effect—which would help scientists understand the underlying mechanisms behind global warming in the 20th century—predated Tyndall's by three years.

For a woman like Eunice Foote—who was also active in the women's rights movement—it could not have been easy to be relegated to the audience of her own discovery. *The Road to Seneca Falls* by Judith Wellman shows that Foote signed the 1848 Seneca Falls Convention Declaration of Sentiments, and was appointed alongside Elizabeth Cady Stanton herself to prepare the Convention proceedings for later publication. As with many women scientists forgotten by history, Foote's story highlights the more subtle forms of discrimination that have kept women on the sidelines of science.

Foote's work with greenhouse gases does not supersede that of Tyndall, whose body of work overall has been more integral to current climate science. Yet, by including Foote's 1856 work in the history of climate science, we are reminded that the effort to understand the Earth's atmosphere and human interactions with it has been an ongoing endeavor over a century in the making. And one of the first steps toward that understanding, it turns out, was taken by a lady.