

Although concern about global atmospheric warming has intensified in recent decades, research into the greenhouse effect actually began in the 19th century. Fourier compared the influence of the atmosphere on temperature to the heating of a glass-covered bowl with an interior coated with black cork (1). He and other scientists such as Tyndall (2) and Langley (3) appreciated that without heat-absorbing gases in the atmosphere, the temperature on the ground would be considerably lower, making life as we know it impossible. However, in 1896 the Swedish scientist Svante Arrhenius was the first to make a quantitative link between changes in CO₂ concentration and climate (4). The centenary of the publication of his paper was celebrated at a recent workshop at the Royal Swedish Academy of Sciences (5).

Although he had a wide range of interests, Arrhenius is best known for his work on electrolytic dissociation, for which he received the Nobel prize in Chemistry in 1903, and on the theory of reaction kinetics. In his work on the effect of CO₂ on global climate (4), Arrhenius made clever use of data provided by Langley (6), who had measured the emission spectrum of the moon for different lunar heights and seasons. This data allowed the calculation of the absorption coefficients of CO₂ and H₂O and of the total heat absorbed in the atmosphere of the Earth for a variety of CO₂ concentrations, as well as the corresponding temperature change.

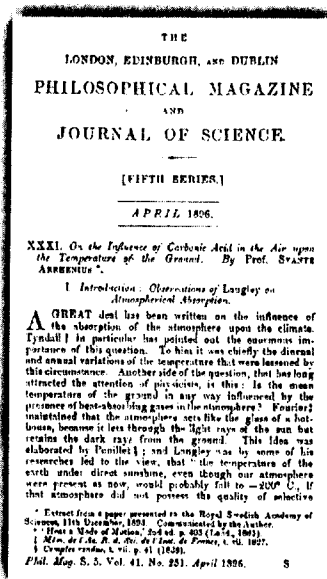
After an estimated 10,000 to 100,000 calculations by hand (7), Arrhenius predicted a temperature rise of 5° to 6°C for a doubling of CO₂, not too different from recent estimates of 1.5° to 4.5°C (8). Arrhenius primarily ascribed changes in CO₂ levels to changes in volcanic activity and concluded that they could be the cause of glacial cycles on a geological time scale. In a lecture in 1896 (9), he estimated that a doubling of CO₂ as a result of fossil fuel burning would take 3000 years. At the time, he was rather in favor of the resulting slow warming, which in his view would result in better living conditions and higher crop yields.

Arrhenius's work, and that of his contemporaries, showed remarkable insight into many factors influencing climate, such as aerosols, ice fields, clouds, and the oceans as a sink for CO₂. In

the 1930s, human forcing of climate through fossil fuel emissions began to be considered as a cause of significant temperature increases in the short term (10). Today, sophisticated atmospheric models (general circulation models) incorporate a growing number of factors (11). Compared to the real climate, these models are still crude: typical parameters are a time step of 1 hour, a spatial grid size of 250 km, and up to 20 vertical levels (12). Reliable long-term observational data of climate system variables and detailed physical understanding of feedback mechanisms associated with, for example, clouds, oceans, and vegetation are often lacking. However, there is general agreement among many different studies about the detection of change and its attribution to natural or human-induced influences.

Last year, the Intergovernmental Panel on Climate Change (IPCC) concluded that "the balance of evidence suggests that there is a discernible human influence on climate" (13). Despite uncertainties in climate predictions and a highly political climate, perhaps it is reassuring that 100 years of research

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Hot paper. Title page of Arrhenius's paper in *Philosophical Magazine*.

have affirmed Arrhenius's initial considerations.

References and Notes

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11. See, for example, J. T. Houghton et al., Eds., *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios* (Cambridge Univ. Press, Cambridge, 1995).
12. Exact values differ widely for different models.
13. *IPCC Second Assessment Report 1995*, in *IPCC Working Group I 1995 Summary for Policymakers* (Cambridge Univ. Press, Cambridge, April 1996). Available at <http://www.unep.ch/ipcc/ipcc95.html>