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Quantifying the Greenhouse Effect

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The Irish physicist John Tyndall discovered the atmospheric warming capacities of water vapor, methane and carbon dioxide in 1859. Tyndall realized that the amounts of these gases were small compared with oxygen and nitrogen—the main elements of earth's lower atmosphere—but he also guessed that they most probably influenced the overall temperature of the earth at its surface.

Tyndall also guessed, correctly it now seems, that ancient climatic oscillations from warm period to ice age and back were at least partially the result of changes in the amounts of these gases in the atmosphere over time.

This left a question he could not answer: Just how much of an increase in, say, C02 would lead to how much of an increase in temperature? Tyndall's work thus fell short of one of the key elements of science according to the famous historian of science Joseph Needham—the application of mathematics to nature.

This task was taken up in 1894 by the Swedish chemist Svante Arrhenius (1859-1927). Arrhenius was a child prodigy in math. His Ph.D dissertation was sufficiently beyond the ability of his faculty readers that they gave it a low mark in 1884, but some of its main arguments won him the third Nobel Prize given in chemistry in 1903. Arrhenius worked for the Nobel Institute for several years after helping to found it in 1900.

In chemistry, Arrhenius is known for the Arrhenius equation. Scientists had long known that chemical reactions occur faster at higher temperatures. Chinese scientists had worked with the effects of heat for centuries and that research lay at the basis of their discovery of gunpowder a bit before the ninth century.

Arrhenius, however, figured out how to quantify the effects of increases in temperature on "activation energy." His equation brought about a remarkable new understanding: chemical reaction rates increased exponentially with increases in temperature. Much of modern industry is based on this knowledge.

On Christmas Eve 1894 Arrhenius began working 14 hours per day on an attempt to calculate the mathematical relationship between the level of CO2 in the atmosphere and the temperature of the earth at its surface. In December 1895 he announced his results to the Swedish Academy of Sciences: if CO2 levels were to increase 2.5 to 3 times their [then] value, earth's temperature in the arctic would increase by about 9 to 11 degrees Celsius (16.2 to 19.8 degrees F). This became known as the "hot house theory."

Extrapolating his findings upwards and downwards, Arrhenius was able to account for then known ice ages and the warming periods between them. He was also able to estimate that the average earth surface temperature would be about 20 degrees Fahrenheit without the hot house warming gases instead of the current 57.2 degrees (14 degrees Celsius).

But what would cause an increase or decrease in any of these gases in the atmosphere?

Here Arrhenius made another major contribution by noticing that the smoke rising from industrial factories, railroads and power stations was increasing the levels of C02 in the atmosphere. Along with this important observation, Arrhenius gave a flawed estimate of the rates of change; he thought the oceans would absorb the industrial CO2 for hundreds of years and that earth's climate would become only very gradually warmer. It would take the observations and insights of an American scientist in the 1960s to alert the world to the real speed and quantity of CO2 in the atmosphere. His name was

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Charles Keeling and his discovery is called the Keeling Curve. Look for a report on it in a future Signs of Sustainability article.

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