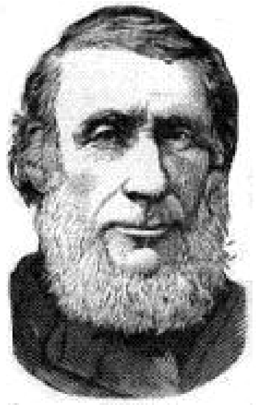


John Tyndall's Research on Trace Gases and Climate

The solar heat possesses. . . the power of crossing an atmosphere; but, when the heat is absorbed by the planet, it is so changed in quality that the rays emanating from the planet cannot get with the same freedom back into space. Thus the atmosphere admits of the entrance of the solar heat, but checks its exit; and the result is a tendency to accumulate heat at the surface of the planet. —Tyndall

In the second half of the nineteenth century John Tyndall (1820-1893) conducted experiments at the Royal Institution on the radiative properties of various gases, demonstrating that "perfectly colorless and invisible gases and vapours" were able to absorb and emit radiant heat. He identified the importance of atmospheric trace constituents as efficient absorbers of long wave radiation and as important factors in climatic control. Specifically, he established beyond a doubt that the radiative properties of water vapour and carbon dioxide were of importance in explaining meteorological phenomena such as the formation of dew, the energy of the solar spectrum, and possibly the variation of climates over geological time.

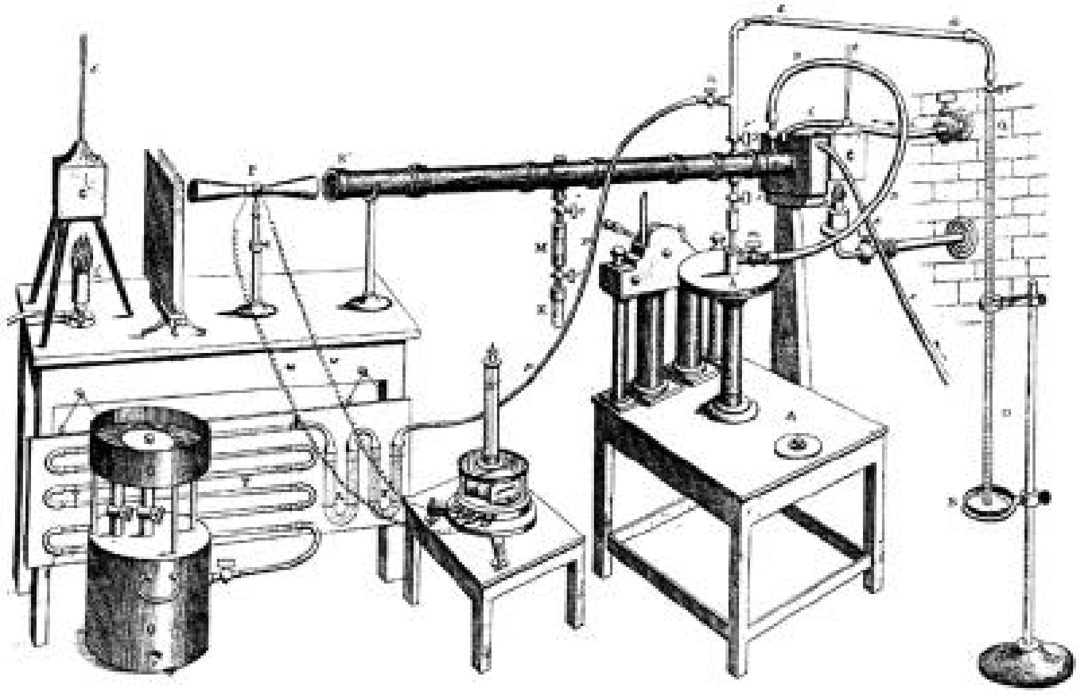
In January 1859, Tyndall turned his attention to radiant heat and the absorption of radiation by gases and vapours, which he saw as "a perfectly unexplored field of inquiry," in order to bring molecules "under the dominion of experiment." He experimented on the radiative properties of various gasses, including aqueous vapor, carbonic acid, ozone, and hydrocarbons. By May of that year he was able to exclaim in his journal, "Experimented all day; the subject is completely in my hands!"

Among his most striking discoveries were the vast differences in the abilities of "perfectly colorless and invisible gases and vapours" to absorb and transmit radiant heat. The "elementary gases," oxygen, nitrogen, and hydrogen, were almost transparent to radiant heat, while more complex molecules, even in very small quantities, absorb much more strongly than the atmosphere itself.

As an accomplished lecturer and writer, Tyndall employed numerous metaphors to describe his experiments with radiant heat. His desire was to apply to gases and vapors "a coercion far more powerful than any to which they had previously been subjected." He wanted to "question the vapour itself as to its absorbent power and to receive from it an answer which did not admit of doubt." The answer he received was that water vapour, among the constituents of the atmosphere, was the strongest absorber of radiant heat and was the most important gas controlling the Earth's surface temperature:

"The aqueous vapour constitutes a local dam, by which the temperature at the earth's surface is deepened; the dam, however, finally overflows, and we give to space all that we receive from the sun." He painted a vivid verbal picture of an England devoid of the blanketing effect of water vapour and devastated by frost.

"Aqueous vapour is a blanket more necessary to the vegetable life of England than clothing is to man. Remove for a single summer-night the aqueous vapour from the air which overspreads this country, and you would assuredly destroy every plant capable of being destroyed by a freezing temperature. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost."



Tyndall's experimental apparatus, the first ratio spectrophotometer, consisted of a long tube that he filled with various gases. The ends of the tube were capped with slabs of rock salt crystal, a substance known to be highly transparent to heat radiation. A standard Leslie cube emitted radiation that traversed the tube and interacted with the gas before entering one cone of a differential thermopile. Radiation from a second Leslie cube passed through a screen and entered the other cone. The common apex of the two cones, containing the differential thermopile junction, was connected in series to a galvanometer that measured small voltage differences. The intensity of the two sources of radiation entering the two cones could be compared by measuring the deflection of the galvanometer, which is proportional to the temperature difference across the thermopile. Different gases in the tube would cause varying amounts of deflection of the galvanometer needle. If the intensity of the reference source of radiation was known, the intensity of the other source (and thus the absorptive power of the gas in the tube) could be calculated.

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Tyndall linked his laboratory results to experiments in the free air. He pointed out that dew and hoarfrost were caused by a loss of heat through radiative cooling and that the “ultra-red rays” were missing from the solar spectrum because of the “enormous absorption of the solar rays by the aqueous vapour of the air.” One of his experiments led him to consider London as a “heat island.” From these and other results, Tyndall correctly pointed out that the role of water vapour “must form one of the chief foundation-stones of the science of meteorology.”

Concerning climate, Tyndall thought that changes in the amount of any of the radiatively active constituents of the atmosphere—water vapour, carbon dioxide, ozone, or hydrocarbons—could have produced “*all the mutations of climate which the researches of geologists reveal* . . . they constitute true causes, the *extent* alone of the operation remaining doubtful.” He gave credit to his predecessors Saussure, Fourier, and Pouillet, among others, for the intuition that “the rays from the sun and fixed stars could reach the earth through the atmosphere more easily than the rays emanating from the earth could get back into space.” The experimental verification of this phenomenon, however, belonged to Tyndall.

John Tyndall's carefully executed laboratory experiments clearly demonstrated that trace atmospheric constituents were active absorbers of heat radiation, at least in the near infrared. His meteorological and climatological speculations kept alive what was called the “hot-house theory,” and suggested to Svante Arrhenius, T.C. Chamberlin and others that the Earth's heat budget may be controlled by changes in the trace constituents of the atmosphere.

James Rodger Fleming, *Historical Perspectives on Climate Change* (New York and Oxford: Oxford University Press, 1998).
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