


# CLIMATE CHANGE

Critical Concepts in the Environment

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**Volume I**

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# ON THE INFLUENCE OF CARBONIC ACID IN THE AIR UPON THE TEMPERATURE OF THE GROUND

*Svante Arrhenius*<sup>1</sup>

Source: *Philosophical Magazine and Journal of Science*, 5th Series 41(251) (1896): 237-276.

## I Introduction: observations of *Langley* on atmospherical absorption

A great deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall<sup>2</sup> in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier<sup>3</sup> maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet<sup>4</sup>; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to  $-200^{\circ}$  C., if that atmosphere did not possess the quality of selective absorption".<sup>5</sup> This view, which was founded on too wide a use of Newton's law of cooling, must be abandoned, as Langley himself in a later memoir showed that the full moon, which certainly does not possess any sensible heat-absorbing atmosphere, has a "mean effective temperature" of about  $45^{\circ}$  C.<sup>6</sup>

The air retains heat (light or dark) in two different ways. On the one hand, the heat suffers a selective diffusion on its passage through the air; on the other hand, some of the atmospheric gases absorb considerable quantities of heat. These two actions are very different. The selective diffusion is extraordinarily great for the ultra-violet rays, and diminishes continuously with increasing

wave-length of the light, so that it is insensible for the rays that form the chief part of the radiation from a body of the mean temperature of the earth.<sup>7</sup>

The selective absorption of the atmosphere is, according to the researches of Tyndall, Lecher and Pernter, Röntgen, Heine, Langley, Ångström, Paschen, and others.<sup>8</sup> of a wholly different kind. It is not exerted by the chief mass of the air, but in a high degree by aqueous vapour and carbonic acid, which are present in the air in small quantities. Further, this absorption is not continuous over the whole spectrum, but nearly insensible in the light part of it, and chiefly limited to the long-waved part, where it manifests itself in very well-defined absorption-bands, which fall off rapidly on both sides.<sup>9</sup> The influence of this absorption is comparatively small on the heat from the sun, but must be of great importance in the transmission of rays from the earth. Tyndall held the opinion that the water-vapour has the greatest influence, whilst other authors, for instance Lecher and Pernter, are inclined to think that the carbonic acid plays the more important part. The researches of Paschen show that these gases are both very effective, so that probably sometimes the one, sometimes the other, may have the greater effect according to the circumstances.

In order to get an idea of how strongly the radiation of the earth (or any other body of the temperature  $+15^{\circ}$  C.) is absorbed by quantities of water-vapour or carbonic acid in the proportions in which these gases are present in our atmosphere, one should, strictly speaking, arrange experiments on the absorption of heat from a body at  $15^{\circ}$  by means of appropriate quantities of both gases. But such experiments have not been made as yet, and, as they would require very expensive apparatus beyond that at my disposal, I have not been in a position to execute them. Fortunately there are other researches by Langley in his work on 'The Temperature of the Moon,' with the aid of which it seems not impossible to determine the absorption of heat by aqueous vapour and by carbonic acid in precisely the conditions which occur in our atmosphere. He has measured the radiation of the full moon (if the moon was not full, the necessary correction relative to this point was applied) at different heights and seasons of the year. This radiation was moreover dispersed in a spectrum, so that in his memoir we find the figures for the radiant heat from the moon for 21 different groups of rays, which are defined by the angle of deviation with a rocksalt prism having a refracting angle of 60 degrees. The groups lie between the angles  $40^{\circ}$  and  $35^{\circ}$ , and each group is separated from its neighbours by an interval of 15 minutes. Now the temperature of the moon is nearly the same as that of the earth, and the moon-rays have, as they arrive at the measuring-instruments, passed through layers of carbonic acid and of aqueous vapour of different thickness according to the height of the moon and the humidity of the air. If, then, these observations were wholly comparable with one another, three of them would suffice for calculating the absorption coefficient relatively to aqueous vapour and carbonic acid for any one of the 21 different groups of rays. But, as an

inspection of the 24 different series of observations will readily show, this is not the case. The intensity of radiation for any group of rays should always diminish with increasing quantity of aqueous vapour or carbonic acid traversed. Now the quantity of carbonic acid is proportional to the path of the ray through the atmosphere, that is, to the quantity called "Air-mass" in Langley's figures. As unit for the carbonic acid we therefore take air-mass = 1, *i.e.* the quantity of carbonic acid that is traversed in the air by a vertical ray. The quantity of aqueous vapour traversed is proportional partly to the "air-mass," partly to the humidity, expressed in grammes of water per cubic metre. As unit for the aqueous vapour I have taken the quantity of aqueous vapour that is traversed by a vertical ray, if the air contains 10 grammes per cubic metre at the earth's surface<sup>10</sup>. If we tabulate the 24 series of observations published by Langley in the work cited with respect to the quantities of carbonic acid and aqueous vapour, we immediately detect that his figures run very irregularly, so that very many exceptions are found to the rule that the transmitted heat should continuously decrease when both these quantities increase. And it seems as if periodic alternations with the time of observation occurred in his series. On what circumstance these alterations with the time depend one can only make vague conjectures: probably the clearness of the sky may have altered within a long period of observation, although this could not be detected by the eye. In order to eliminate this irregular variation, I have divided the observations into four groups, for which the mean quantities of carbonic acid (K) and of water-vapour (W) were 1.21 and 0.36, 2.21 and 0.86, 1.33 and 1.18, and 2.22 and 2.34 respectively. With the help of the mean values of the heat-radiation for every group of rays in these four groups of observations, I have roughly calculated the absorption coefficients ( $x$  and  $y$ ) for both gases, and by means of these reduced the value for each observation to the value that it would have possessed if K and W had been 1.5 and 0.88 respectively. The 21 values for the different rays were then summed up, so that I obtained the total heat-radiation for every series of observations, reduced to  $K = 1.5$  and  $W = 0.88$ . If the materials of observation were very regular, the figures for this total radiation should not differ very much from one another. In fact, one sees that observations that are made at nearly the same time give also nearly equal values, but if the observations were made at very different times, the values differ also generally very much. For the following periods I have found the corresponding mean values of the total radiation:—

Period.	Mean value.	Reduction factor.
1885. Feb. 21–June 24	4850	1.3
1885. July 29–1886. Feb. 16.	6344	1.00
1886. Sept. 13–Sept. 18	2748	2.31
1886. Oct. 11–Nov. 8	5535	1.15
1887. Jan. 8–Feb. 9	3725	1.70

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