THE GREENHOUSE EFFECT OF THE CO$_2$
IN THE ATMOSPHERE

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The CO$_2$ is a polar molecule, having a strong absorption band in the region 450--870 cm$^{-1}$. This is just the maximum intensity region for a black body radiation of $T = 288$ K, corresponding to the average surface temperature of the Earth. The consequence of the atmospheric CO$_2$ is a greenhouse effect, which is in the focus of recent interest. Taking the intensity and line width values for 2500 spectral lines of CO$_2$ into account, the atmospheric absorption has been calculated for different CO$_2$ concentrations. At higher concentrations the line shape has a considerable influence. The past and future climatic consequences are also discussed in some detail.

Introduction

The role of the CO$_2$ content in influencing the surface temperature of our home planet is a subject of recent discussions. Several estimations have been made in the last decades [1]. It has been agreed that a future doubling of the present 330 ppm atmospheric concentration of CO$_2$ may be expected due to the fast combustion of fossil fuels and to deforestation of tropical continents. According to the pioneering studies of MÖLLER [2] and others, this may result in an overall temperature increase of a few degrees. This has been considered by several authors to be alarming: it may cause a disappearance of the polar ice cap (i.e. a catastrophic rise of the sea level) and a shift of precipitation already in the coming century [3, 4]. The thermodynamics and evolution of the atmosphere and ocean is really worth understanding. It has been emphasized in an earlier note [5], that the past history of the atmosphere may serve as a testing ground for any predictive theory.

Biologists assume the existence of a reducing atmosphere in the era of the formation of oceans on the Earth. Geophysicists, on the other hand, deduce the composition of this early atmosphere from the present composition of volcanic gases (consisting mainly of CO$_2$ and H$_2$O). This is certainly a relevant question from the point of view of the origins of life, which appeared practically simultaneously with the formation of oceans, about 3.8 billion years ago [6]. There is a majority consensus, however, that for a considerable part of terrestrial history (between $-3.5$ billion and $-0.75$ billion years)
the main component of the atmosphere was CO$_2$. This was transformed into O$_2$ by spreading vegetation and into CaCO$_3$ by sea life and anorganic chemistry. The long CO$_2$ era on Earth resembled the present state of Mars and Venus. The calculated weight of terrestrial CO$_2$, bound now mainly in CaCO$_3$ and in organic compounds has been estimated to be about 100 atm [7], comparable to the present Venusian atmosphere. The planet Venus shows, however, a surface temperature of 500°C. By making a simple estimation of the greenhouse effect Rasool and De Bergh [8] concluded that the atmospheric CO$_2$ had never exceeded one tenth atm on Earth; the present material of the terrestrial atmosphere might be a consequence of recent outgasing from the crust.

On our home planet life has existed without interruptions in the past 3.8 billion years [6, 9]. This fact contains a very valuable message about this planet: the temperature of the world ocean did not exceed the boiling point of H$_2$O (100°C) or the melting point of DNA (80°C) in the last 3.5 billion years. The mean chemical composition of the atmosphere changed drastically from polar CO$_2$ to apolar O$_2$, N$_2$ compounds in the last 0.75 billion years. In order to understand the thermal stability on the surface of the Earth, in spite of these recent drastic changes, one has to study the atmospheric absorption of a thick CO$_2$ atmosphere (this will be made in the next chapter), then one has to combine the calculated greenhouse effect with other long scale phenomena influencing the temperature (this will be made in the closing chapter). The theoretical conclusions can be compared with the temperature history of Earth, deciphered by geophysical methods.

The atmospheric absorption of the 15μ CO$_2$ band

The intensity of the terrestrial radiation at a certain wave number in the infrared region of the emission spectrum can be given [10] as follows:

$$J_\nu = \varepsilon_\nu B_\nu(T_s) \tau_{\nu,s} + \int_{P_s}^{1} B_\nu(T(p)) d\tau_\nu(T, p, u).$$

(1)

Here $B_\nu(T)$ is the Planck radiation, $\varepsilon_\nu$ is the emissivity of the surface, $p$ is the pressure, $u$ is the optical mass of the absorbing gas, $\tau_\nu$ is the transmissivity, $\nu$ is the wave number usually in cm$^{-1}$. The subscript “S” refers to surface values. On the right side of this equation the first term gives the radiation of the surface and the second term gives that of the atmosphere. Utilizing the fact that the mixing ratio of the CO$_2$ in the atmosphere along a vertical path of ray is constant, the transmission function takes this form:

$$\tau_{\nu,s} = \exp \left[ - \varepsilon \int_0^{P_s} K_\nu(p, T) dp \right],$$

(2)