Topic number: 11.

DISSOCIATION OF CO_2: APPLICATION TO ATMOSPHERIC MARTIAN ENTRIES

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The atmospheric entry of a spacecraft or a probe constitutes the more critical step of the flight as illustrated by the dramatic crash of Columbia in 2003. During this phase, the incident flow reaching the fuselage is indeed hypersonic ($v \approx 10$ km.s^{-1}) and the compressible nature of the incident gas leads to the formation of a shock layer where the flow undergoes an important increase of the temperature. Excited and ionised species are subsequently produced by the chemistry induced: finally, the wall interacts with a high enthalpy flow whose convective heat exchange reinforced by radiation can damage the spacecraft or the probe. The amount of species and their inner excitation degree is the key point of the interaction between the plasma and the wall: the clear identification of the underlying chemistry is therefore crucial.

We have already contributed to works related to air chemistry [1] and we are henceforth interested by CO_2 in relation with Martian entries planned by the space agencies in the frame of the future project of human flight. The Martian atmosphere is mainly composed by carbon dioxide molecules whose chemistry is largely less known than for air even if some models have been elaborated so far. The most popular one is due to Park [2] and is in part based on assumptions concerning the rate coefficient k_D for CO_2 dissociation. Figure 1 illustrates the temperature depending rate coefficient due to Park and other authors. It is interesting to note that large discrepancies exist between 5000 and 7000 K (10^{-20} m^{3}s^{-1} $< k_D <$ 10^{-19} m^{3}s^{-1}) and at higher temperature. These peculiarities are the main reasons of the present study: this work has been performed in the purpose of determining the CO_2 dissociation rate coefficient particularly at high temperature.

CO_2 is a molecule with three modes of vibration: a symmetric ($h\nu_1$) and an asymmetric ($h\nu_3$) non degenerate stretching modes and a doubly degenerate bending mode ($h\nu_2$). In the conditions of the shock layer formed during the entry phase, the ionisation degree remains low. The dissociation of CO_2 molecules is consequently the result of collisions with other heavy particles, mainly carbon dioxide but also CO and O resulting from the dissociation. In the present situation, the dissociation is therefore caused by the stepwise vibrational excitation.

In a first approximation, CO_2 molecules are assumed to behave like a harmonic oscillator. In addition, the energy diagram is assumed totally independent from the Fermi resonance ($h\nu_1 = 0.172$ eV $\approx 2\times h\nu_2$). The VT (vibration-translation) and VV (vibration-vibration) elementary processes are taken into account by using rate coefficients between the first excited vibrational levels experimentally obtained and extrapolated at high temperature and up to the dissociation limit with the help of the SSH equations [3]. The influence of the Fermi resonance is accounted for when considering the VV processes. CO_2 molecules are assumed dissociated when the vibrational excitation exceeds the dissociation limit ($h\nu_d = 5.52$ eV).

Figure 2 illustrates the time dependent evolution of numerous population densities resulting from our model.

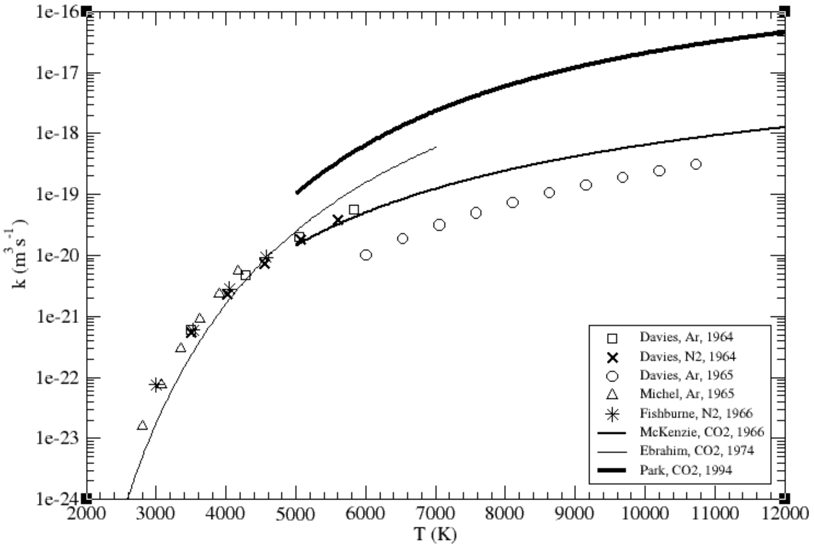

Fig. 1: CO_2 dissociation rate coefficients for different collision partners.

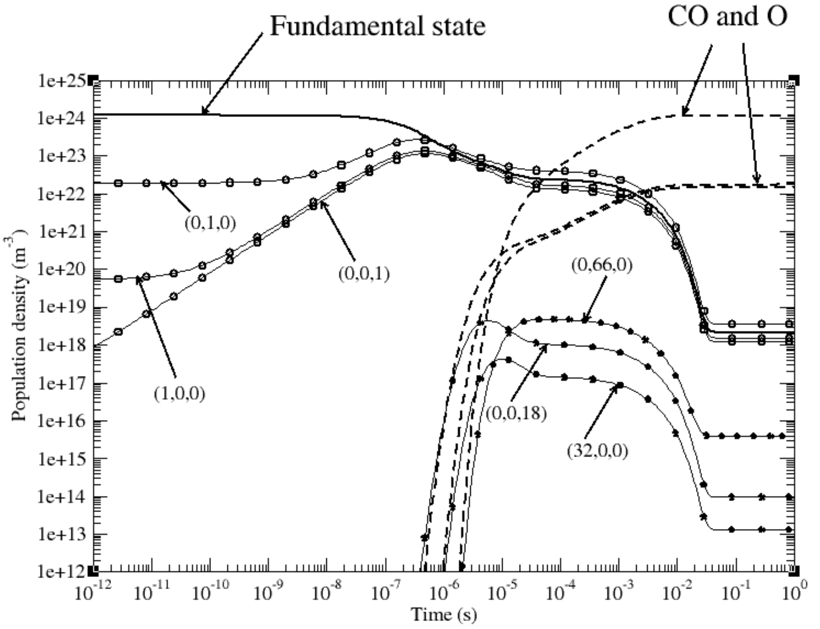

Fig. 2: CO_2 vibrational excitation dynamics resulting from our model for $p = 10^5$ Pa and T = 6000 K.

It is interesting to note the behavior of the population densities in the vicinity of $t \approx 1$ ms where a strong correlation occurs. A global rate coefficient can be deduced from this correlation [4]. During this conference, we will present the details of the approach developed in this work as well as the resulting CO_2 dissociation global rate coefficient.

References

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