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Temperature and pressure dependence of D_3^+ recombination with electrons in afterglow plasma

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Ions H_3^+, D_3^+ and their isotopomers are present in many hydrogen and deuterium containing plasmas. They were detected in planetary atmospheres and interstellar clouds [1]. Study of recombination of these ions is important for the understanding of ion chemistry in various types of plasma, including astrophysically relevant plasmas. The interaction of electrons with simplest triatomic molecular ions such as H_3^+ and D_3^+ is of fundamental importance also for theoretical physics. A theory of binary recombination of these ions was formulated only very recently by inclusion of Jahn-Teller non-Born-Oppenheimer coupling [2].

In the presented study, we used the cryogenic version of the Flowing Afterglow with Langmuir Probe apparatus (Cryo-FALP) to measure the recombination rate coefficients of D_3^+ with electrons in helium buffered plasma. To obtain the recombination rate coefficients, we measured electron density decays in helium with small admixture of Ar and D_2 [3,4]. The overall effective recombination (deionization) rate coefficient (α_{eff}) was measured over a broad range of pressures (from ~200 up to ~2000 Pa) at temperatures ranging from 77 up to 300 K [3,5]. Particular attention was paid to kinetics of formation of D_3^+ dominated plasma [6].

In our well-defined Cryo-FALP experiment, the effective recombination rate coefficients (α_{eff}) corresponding to a plasma decay were measured explicitly as a function of temperature at fixed helium pressure and also as a function of helium density [He] at fixed temperature (see data plotted in Figure 1a and 1b).

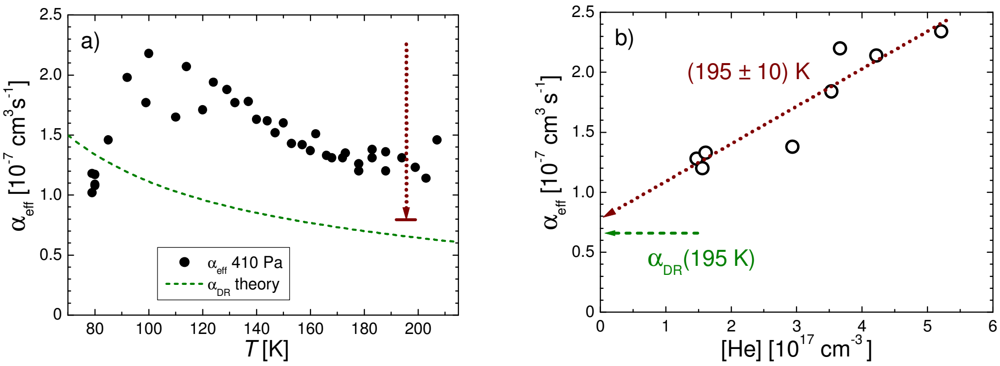

Fig. 1: **a)** The temperature dependence of the effective recombination rate coefficient (α_{eff}) of D_3^+ ions at 410 Pa of He. The partial density of deuterium at 77 K was 3×10^{12} cm^{-3}. Also indicated is the theoretical dependence of rate coefficient of binary dissociative recombination (α_{DR}) [7]. The arrow indicates the projection of measured pressure dependence at 195 K towards low He density. **b)** The dependency of α_{eff} on Helium density at 195 K. Indicated is the calculated value of rate coefficient for binary dissociative recombination (α_{DR}) at 195 K [7].

A linear dependence of measured α_{eff} on [He] clearly indicates that the recombination of D_3^+ has a binary and a ternary channel. With [He] decreasing towards zero α_{eff} is approaching a value corresponding to the binary process. From the linear dependence, we can obtain rate coefficients of binary and ternary channels. A similar process was also observed in a previous work focused on H_3^+ recombination [8].

We expect that the ternary recombination proceeds in two rate determining steps. At first, the ion and an electron collide and form a long-living complex at resonance $D_3^*(np)$. Theoretical calculations show that at low electron energies, certain $D_3^*(np)$ may live up to 100 ps. At sufficiently high pressure $D_3^*(np)$ can collide with He atom and $D_3^*(nl)$ with different angular momentum is formed in *l*-changing collision. This stabilized neutral complex can't autoionize easily. The theory of the ternary recombination of H_3^+ ions was described in detail in our recent papers [8,9]. We assume that the measured sharp decrease of α_{eff} with decreasing temperature can be connected with number of available resonant states $D_3^*(np)$ at the actual temperature.

Further measurements are in progress to characterize the observed ternary process. Theoretical prediction of $D_3^*(np)$ lifetimes support the proposed model of the ternary recombination of D_3^+ ions with electrons in plasma.

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