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The influence of $(n-n')$-mixing processes in $He^*(n)+He(1s^2)$ collisions on $He^*(n)$ atoms' populations in weakly ionized helium plasmas

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Abstract

The results of semi-classical calculations of rate coefficients of $(n-n')$-mixing processes due to collisions of Rydberg atoms $He^*(n)$ with $He(1s^2)$ atoms are presented. It is assumed that these processes are caused by the resonant energy exchange within the electron component of $He^*(n)+He$ collision system. The method is realized through the numerical simulation of the $(n-n')$-mixing processes, and is applied for calculations of the corresponding rate coefficients. The calculations are performed for the principal quantum numbers n, n' in ranges $4 \leqslant n < n' \leqslant 10$, and the atom and electron temperatures, T_a, T_e, in domains $5000\,K \leqslant T_a \leqslant T_e \leqslant 20\,000\,K$. It is shown that the $(n-n')$-mixing processes can significantly influence the populations of Rydberg atoms in non-equilibrium weakly ionized helium plasmas with ionization degree $\sim 10^{-4}$. Therefore, these processes have to be included in the appropriate models of such plasmas.

Keywords: Atomic and molecular collisions; Rydberg states

1. Introduction

Several existing models of collisional-radiative recombination [1–9] showed that in the weakly ionized plasmas, with ionization degree $\sim 10^{-4}$, the electron transfer from the lowest atomic states to the continuum and in the opposite direction is dominantly caused by the cascade mechanism. These processes of excitation/de-excitation are very important for populations in the lower part of the Rydberg's block of states. The reason for this is the distribution function of the excited atom states' populations in weakly ionized plasmas, which shows a distinct minimum ("bottleneck") in the lower part of Rydberg's block of states. For example, paper [10] compared LTE (local thermodynamical equilibrium) and non-LTE distribution functions, corresponding to different layers of the solar photosphere [5,6]. It was found that both functions had distinct minimum in the domain of principal quantum numbers $n = 5-6$. Such behavior is illustrated in Fig. 1, showing LTE distribution functions for hydrogen plasmas at the temperatures $T = 5000$ and 6000 K.

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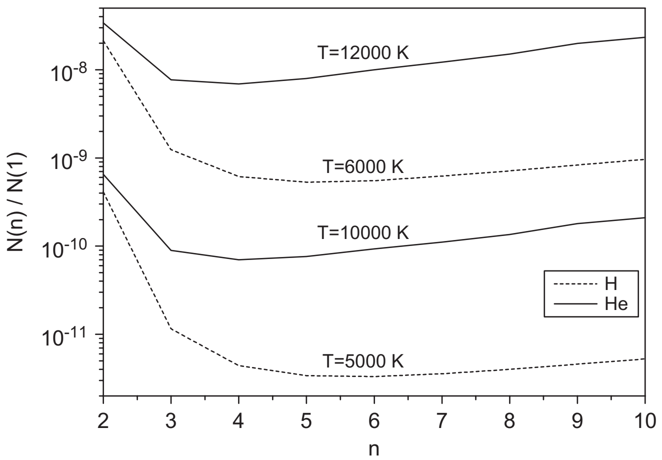

Fig. 1. The distribution function of excited atom population.

Similar behavior of the distribution functions for excited atomic states in the case of weakly ionized helium plasmas, for the temperatures $T = 10\,000$ and $12\,000\,\mathrm{K}$ typical for photospheres of some helium rich white dwarfs [11], is illustrated in the same figure. The experimental data for weakly ionized plasma of non-equilibrium helium arc [12], show that the distribution function has a similar shape, even in the case when the electron temperature is 4 times higher than atomic temperature. It can be concluded that the kinetics of weakly ionized hydrogen and helium plasmas strongly depends on excitation and deexcitation processes in the region $4 \lesssim n \lesssim 10$, where the "bottleneck" of distribution function occurs.

The models of collisional-radiative recombination, used to estimate the influence of non-elastic processes which populate the lower part of Rydberg's block of states, included the radiation processes and the excitation/de-excitation processes caused by electron–atom collisions. The latter was assumed to be dominant for plasmas with the ionization degree $\sim 10^{-4}$. However, the distribution of excited atom states' populations experimentally obtained in [12], showed a significant influence of $(n - n')$-mixing processes in $\mathrm{He}^*(n) + \mathrm{He}(1s^2)$ collisions. It was found that the distribution function was similar to Boltzmann with the temperature about $11\,000\,\mathrm{K}$, close to the mid-value between $T_a \cong 4500\,\mathrm{K}$ and $T_e \cong 18\,000\,\mathrm{K}$. Consequently, the mechanism of the resonant energy exchange within the electron component of the atom-Rydberg atom collision systems (*resonant mechanism*) has been introduced in [13] to explain such a behavior. In cited paper and in [14,15] the resonant mechanism was tested only for $(n - n')$-mixing processes in $\mathrm{H}^*(n) + \mathrm{H}(1s)$ collisions, and the results obtained had only a qualitative character.

The resonant mechanism has been successfully applied to chemi-ionization processes in alkali Rydberg's atoms collisions with their parents' ground state [16], and further for alkali atoms' collisions [17–26]. In the case of hydrogen and helium atoms, the resonant mechanism was used to analyze the chemi-ionization and their inverse chemi-recombination processes [27–33]. It was shown that in weakly ionized hydrogen and helium plasmas the chemi-ionization/recombination processes caused by the resonant mechanism can be dominant in populating the Rydberg's states. This mechanism was also investigated in the case of $(n - n')$-mixing processes in $\mathrm{H}^*(n) + \mathrm{H}$ collisions populating the states within the Rydberg's block [10] (see also [14,15]). In [10] the corresponding rate coefficients were determined as functions of n and T_a. It was shown that in hydrogen plasma with the ionization degree $\sim 10^{-4}$, and $4 \leqslant n \leqslant 10$, the efficiency of these processes is comparable or even higher than the concurrent excitation/de-excitation processes caused by electron–atom collisions. This was confirmed later for weakly ionized hydrogen plasma of solar photosphere in [34].

The efficiency of the resonant mechanism for chemi-ionization/recombination processes in weakly ionized hydrogen and helium plasmas [29,30] suggested that one should expect similar situation in the case of $(n - n')$-mixing processes. The semi-classical method based on this mechanism, developed in [10], was used in this