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

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The results of semi-classical calculations of rate coefficients of (n-n') -mixing processes in collisions of Rydberg atoms He* (n) with He(1s^2) atoms are presented. These processes have been modelled by the mechanism of the resonant energy exchange within the electron component of He* (n)+He collision system. The calculations of the rate coefficients, based on this model, were performed for the series of principal quantum numbers, n and n', and atomic, Ta, and electronic, Te, temperatures. It was shown that these processes can be of significant influence on the populations of Rydberg atoms in non-equilibrium weakly ionized helium plasmas (ionization degree ≤ 10^{-4}), and therefore have to be included in appropriate models of such plasmas.

1. Introduction

As it is known, the rate of ionization-recombination processes in weakly ionized gaseous plasmas essentially depends on the rate of excitation-deexcitation processes in the lower part of block of Rydberg atom states where usually there is the minimum of the excited states atom population distribution function. So, for hydrogen plasmas of solar photosphere and lower chromosphere, with the temperature 4500K ≤ T ≤ 6000K, the mentioned minimum corresponds to the principal quantum number 4 ≤ n ≤ 6 in accordance with the standard models of solar atmosphere [1, 2]. Similar situation there is in the case of helium plasmas of some DB white dwarfs photospheres in layers with temperatures 10000K ≤ T ≤ 15000K, as it follows from the corresponding standard models [3]. In the same region of n there is the minimum of the excited states atom population distribution function in the case of laboratorial plasma of helium non-equilibrium arc, where the electron temperature is several times larger then the atom temperature [4]. From all mentioned it follows an importance of knowledge of the excitation and deexcitation collision processes rate coefficients from the region 3 ≤ n ≤ 12. Here, we keep in mind, as first, the electron-Rydberg atom processes

$$A^*(n) + e_k \rightarrow A^*(n' = n + p) + e_{k'}, \qquad (1)$$

$$A^*(n) + e_k \rightarrow A^*(n' = n - p) + e_{k'}, \qquad (2)$$

and the corresponding atom-Rydberg-atom processes

$$A^*(n) + A \rightarrow \begin{cases} A^*(n' = n + p) + A, \\ A + A^*(n' = n + p), \end{cases} \qquad (3)$$

$$A^*(n) + A \rightarrow \begin{cases} A^*(n' = n - p) + A, \\ A + A^*(n' = n - p), \end{cases} \qquad (4)$$

where the excited atomic states with the principal quantum number n and n ± p belong to Rydberg's block, e_k and $e_{k'}$ denotes a free electron in the initial and final states, and p ≥1. Since all models of collisional-radiative recombination gave the main role to the electron-atom processes (1) and (2), many papers were devoted to these processes until now. Among them we will mention only the paper in [7] where the resonant mechanism of non-elastic processes in atom-Rydberg atom symmetric collisions was introduced into consideration. Just this mechanism was successfully used for treatment of chemi-ionisation and chemi-recombination processes with alkali metal atoms (see for example [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18]) and with hydrogen and helium atoms (see for example [19, 20, 21, 22, 23, 24, 25]). In these papers it was shown that at the relations between the block of Rydberg states and free electron continuum the chemi-ionisation and chemi-recombination processes dominate very often in comparison with the corresponding electron-atom and electron-ion ionisation and recombination processes in weakly ionised hydrogen and helium plasmas. Keeping in mind this fact, in [26] the same resonant mechanism was investigated in the case of the processes (3) and (4) with A=H in the region 4 ≤ n ≤ 10 for several atom and electron temperatures (Ta and Te). It was shown that in all considered cases the efficiency of the processes (3) and (4) is comparable or even larger then the efficiency of the processes (1) and (2). It was confirmed in the case of plasma of solar photosphere in [24]. All above mentioned suggested to continue these investigations applying the resonant mechanism to the other most important case, i.e. to the case of the processes (3) and (4) with A=He.

2. Results and discussion

Here, the method developed in [26] was modified to the helium case of the processes (3) and (4). The potential curves of the states $X^2\Sigma_u^+$ and $A^2\Sigma_g^+$ of the molecular ion He_2^+, as well as the values of the corresponding dipole matrix element, which are necessary for determination of the processes (3) and (4) rate coefficients, are taken from [28, 29]. The part results of calculations of the rate coefficients $K_{n,n+p}(T_a)$ for the excitation processes (3), in the regions $4 \le n \le 10$, $1 \le p \le 4$ and $5000K \le T_a \le 20000K$, are presented in Table 1. The rate coefficients $K_{n,n-p}(T_a)$ for the de-excitation processes (4) can be obtained by means of the thermo dynamical balance principle. Similarly to [26], the relative efficiency of atom-atom processes (3) and (4) and electron-atom processes (1) and (2) will be characterized by the parameter $F_{n,n+p} \equiv F_{n,n+p}(T_a, T_e)$ given by relation

$$F_{n,n+p} = \frac{K_{n,n+p}(T_a)}{\alpha_{n,n+p}(T_e)} \cdot \eta, \qquad \eta = \frac{N_{He}}{N_e}, \tag{5}$$

where N_{He} and N_e are helium atom and free electron densities and $\alpha_{n,n+p}(T_e)$- the rate coefficient for the electron-atom excitation processes (1). The values of $\alpha_{n,n+p}(T_e)$ are obtained on the base of data from [27, 6, 5]. The values of $F_{n,n+p}$ are presented in Figs. 1 and 2 for T_a=5000K and T_e=5000K and 20000K, respectively.

These figures show that the efficiency of the atom-atom processes (3) and (4) with A=He, for n=3, 4, 5 and 6, although the region of internuclear distance relevant to them is smaller then the corresponding region in hydrogen case, is significantly larger or at least comparable with the efficiency of electron-atom processes (1) and (2). However, keeping in mind some results from previous paper [24], one can expect that the influence of the considered atom-atom processes will be noticeable in the whole block of Rydberg states of helium atom relevant for the considered weakly ionized plasmas.

Table 1 The values of the rate coefficient $K_{n,n+p}(T_a)$ for the excitation processes (3).

		T[*1000 K]				
n	p	5.0	6.0	10.0	14.0	20.0
4	1	1.143	1.243	1.462	1.562	1.638
	2	0.244	0.283	0.374	0.419	0.455
	3	0.095	0.114	0.161	0.186	0.206
	4	0.048	0.058	0.087	0.102	0.114
5	1	0.728	0.760	0.824	0.852	0.873
	2	0.191	0.207	0.239	0.254	0.265
	3	0.083	0.092	0.111	0.119	0.126
	4	0.045	0.050	0.062	0.068	0.072
6	1	0.448	0.459	0.481	0.490	0.497
	2	0.132	0.138	0.151	0.156	0.160
	3	0.062	0.065	0.073	0.076	0.079
	4	0.035	0.037	0.042	0.045	0.046
8	1	0.184	0.186	0.189	0.191	0.192
	2	0.061	0.062	0.065	0.066	0.066
	3	0.031	0.032	0.033	0.034	0.034
	4	0.018	0.019	0.020	0.021	0.021
10	1	0.086	0.086	0.087	0.088	0.088
	2	0.031	0.031	0.031	0.032	0.032
	3	0.016	0.016	0.017	0.017	0.017
	4	0.010	0.010	0.010	0.010	0.011

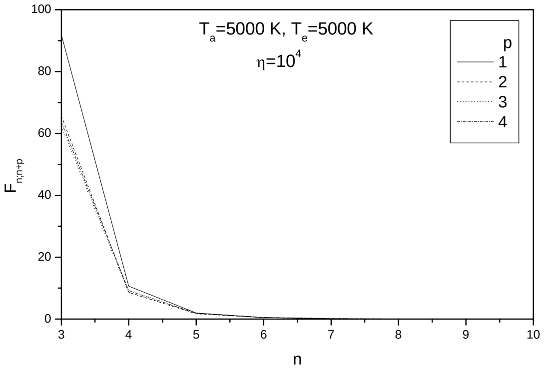

Fig. 1 The behaviour of the parameter $F_{n,n+p}$ for T_a=5000K and T_e=5000K.

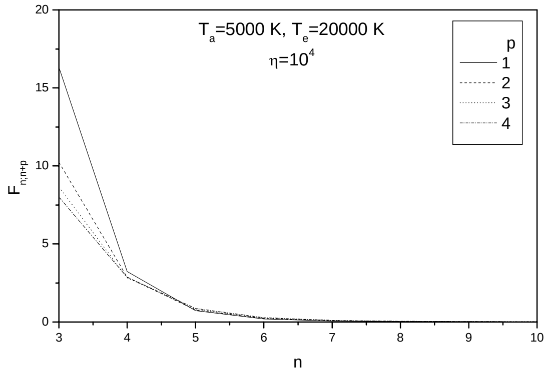

Fig. 2 The same as in Fig. 1, but for T_a=20000 K

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