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CHEMI-IONIZATION/RECOMBINATION ATOMIC PROCESSES IN THE AGNs BROAD-LINE REGION

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Abstract. The chemi-ionization and chemi-recombination processes in atom - Rydberg atom collisions, are considered as factors of influence on the atom excited-state populations and ionization level in clouds in Broad Line Region (BLR) of active galactic nuclei (AGN). The presented results are related to the moderately ionized layers of dense parts of the BLR clouds. The preliminary analyses show that the considered chemi-ionization/recombination processes should have a very significant influence on the optical properties of some regions in AGN.

1. INTRODUCTION

Elementary processes in plasma phenomena traditionally attract astrophysicist's attention (see e.g. Barklem 2007). For diagnostic methods needed in order to estimate physical conditions in the broad line region (BLR) in active galactic nuclei (AGN) the study of the influence of various atomic and molecular processes may be of interest (Netzer 1990). Consequently, it is of interest to investigate the influence of chemi-ionization/recombination processes in similar conditions that probably hold in some parts of BLR clouds in AGN.

When an electron is excited into a high lying Rydberg state, with large principal quantum number, even inelastic thermal collisions can be sufficiently energetic to lead to ionization reactions (see Mihajlov et al. (2011, 2012)). These types of reactions can be classified as chemi-ionization reactions (associative ionization and non-associative ionization).

$$H^*(n) + H \Rightarrow e + H_2^+ \qquad (1)$$

$$H^*(n) + H \Rightarrow e + H^+ + H \qquad (2)$$

and the corresponding inverse recombination processes:

$$H_2^+ + e \Rightarrow H^*(n) + H \qquad (3)$$

$$H^+ + H + e \Rightarrow H^*(n) + H \qquad (4)$$

where H and H^+ are atoms and atomic ions in their ground states, $H^*(n)$ is atom in a highly excited (Rydberg) state with the principal quantum number n ≥ 2.

Using these partial rate coefficients, we will determine the total ones, namely,

$$K_{ci}^{(ab)}(n,T) = K_{ci}^{(a)}(n,T) + K_{ci}^{(b)}(n,T). \qquad (5)$$

which characterizes the efficiency of the considered chemi-ionization and chemi-recombination processes together (for details see paper of Mihajlov et al. (2015)). These rate coefficients enable inclusion of these excited-state reactions in modeling AGNs. Using rate coefficients, we can obtain the total chemi-ionization and chemi-recombination fluxes caused by the processes (1) and (2) i.e.,

$$I_{ci}(n,T) = K_{ci}(n,T) \cdot N_n N_1 \text{ and } I_{cr}(n,T) = K_{cr}(n,T) \cdot N_1 N_i N_e . \quad (6)$$

Using these expressions, we can calculate quantities Fi;ea($n;T$) = Ici($n;T$)/ Ii;ea($n;T$) which characterize the relative efficiency of partial chemi-ionization processes (1) and (2) together and the impact electron-atom ionization Ii;ea as one of most important concurrent process in the considered plasma, Mihajlov et al. (2011).

2. RESULTS AND DISCUSSION

The values of the calculated total chemi-ionization and recombination rate coefficients $K_{ci}(n;T)$ and $K_{cr}(n;T)$ are illustrated by Fig. 1. The results cover the regions of quantum numbers and temperatures which are relevant for considered cases. This enabled the correct inclusion of these processes in the modeling of AGNs since in the existing literature processes (1) and (2) are poorly defined and described.

In order to enable the better and more adequate use of data, we have derived for the rate coefficients a simple and accurate fitting formula based on a least-square method, which is logarithmic and represented by a second-degree polynomial:

$$\log(K_{ci}(T)) = a_1 + a_2 \log(T) + a_3(\log(T))^2 \quad (7)$$

The fits are valid over the temperature range of 4000 K $\leq T \leq$ 20000 K and *n* up to 20. Also, it is possible that the fit is applicable outside this area, but with caution. In the Tab. 1 are presented the fits for $2 \leq n \leq 14$.

The preliminary analyses of the behavior of the quantities $F_{i;ea}(n;T)$ as functions of temperature were done. It follows that the efficiency of the considered chemi-ionization processes in comparison with the electron-atom impact ionization increases with increasing temperature and could be important for *n* up to 10. We need to continue research in the direction of higher values of *n* and region of higher temperatures.

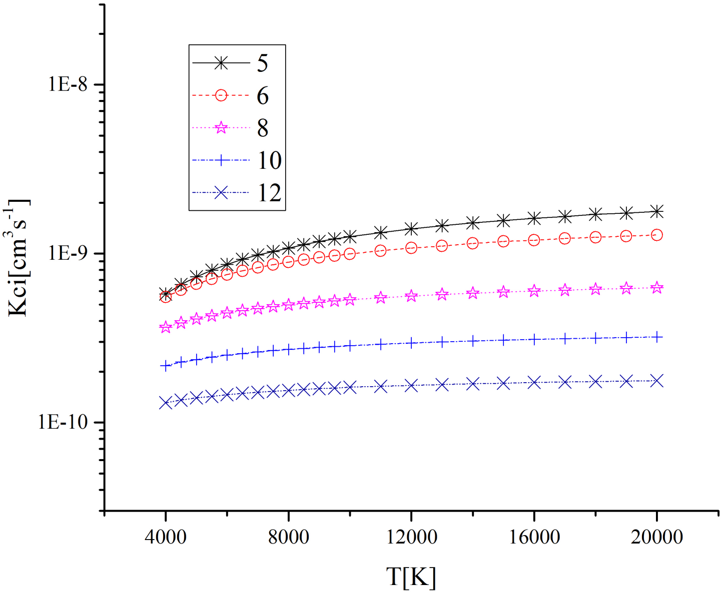

Figure 1: Values of collisional ionisation rate coefficients Kci[cm3/s] (2.1) as a function of n and T.

3. CONCLUSIONS

The obtained results about chemi ionization/ recombiontion processes could be used for determination of limiting high densities in clouds in AGN BLR and NRL regions and for the improvement of modelling of dense moderately ionized layers in them. Of course, the presented values of the corresponding rate coefficients are also very useful for the modelling and analysis of similar layers in the photospheres of Sun and solar like stars.

Table 1: The fits Eq.(7) of the rate coefficient Eq.(5). A portion is shown here for guidance regarding its form.

n	a1	a2	a3
2	-56.410500	19.716100	-2.0390600
3	7.0794400	-8.930940	1.2185400
4	12.4053000	-11.40770	1.5155100
5	-19.6284000	4.7246900	-0.5105980
6	-17.1562000	3.5990500	-0.3900280
7	-15.6337000	2.8749300	-0.3124150
8	-14.5801000	2.3479700	-0.2552700
9	-13.8527000	1.9646600	-0.2135550
10	-13.3764000	1.6961900	-0.1845360
11	-13.0238000	1.4848800	-0.1616660
12	-12.6763000	1.2725000	-0.1378230
13	-12.5340000	1.1620000	-0.1261860
14	-12.4537000	1.0833400	-0.1182720

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