Publ. Astron. Obs. Belgrade No. 102 (2022), 277 - 280 *Contributed Paper*

THE CHEMI-RECOMBINATION PROCESSES IN ALKALI-METAL ASTROPHYSICAL AND LOW-TEMPERATURE LABORATORY PLASMAS: RATE COEFFICIENTS

V. A. SREĆKOVIĆ[1], L. M. IGNJATOVIĆ[2], V. VUJČIĆ[2] and M.S. DIMITRIJEVIĆ[2,3]

[1]*Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*
E-mail vlada@ipb.ac.rs

[2]*Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia*
E-mail mdimitrijevic@aob.rs

[3]*Observatoire de Paris, PSL Université, CNRS, Sorbonne Université, F-92195 Meudon, France*

Abstract. In this contribution, some collisional processes i.e. chemi-recombination processes in alkali-metal low-temperature plasmas are investigated. The spectral rate coefficients which involve alkali metals, as well as corresponding data on species, are calculated as a function of quantum numbers and temperatures. The presented results can be of interest for laboratory plasmas as well as for the research of chemistry of different stellar objects with various astrophysical plasmas.

1. INTRODUCTION

Collisional processes which include atoms and molecules in geo-cosmical plasmas constantly attract the attention of scientists (see e.g. Sreckovic et al. 2020; Klyucharev et al. 2007; Ignjatovic et al. 2020). Among these processes, those which produce highly excited Rydberg atoms are of particular interest (Gnedin et al. 2009; Mihajlov et al. 2011; Sreckovic et al. 2018a). Primarily this can be attributed to a group of chemi-recombination (CR) processes (Mihajlov et al. 2003, Sreckovic et al. 2018b). In a series of papers of Mihajlov and coworkers' CR processes involving hydrogen and helium have been studied from the point of view of their effect on the optical (spectral line shapes) and kinetic properties of weakly ionized laboratory and astrophysical plasmas. This contribution is a continuation of this research.

Here we will consider the following chemi-recombination processes,

$$A_2^+ + e \Rightarrow A^*(n) + A \qquad (1a)$$
$$A + A^+ + e \Rightarrow A^*(n) + A \qquad (1b)$$

where A and A^+ are alkali (Li or Na) atoms and ions in their ground states, and A_2^+ is molecular-ion in the ground electronic state.

The importance of chemi-recombination (eqs. (1a)– (1b)) and chemi-ionization processes in a geo-cosmic plasma, is determined by comparing corresponding fluxes. This is performed under the standard assumption that in photosphere plasmas $Te = Ta = T$, where Te and Ta are the electron and atom temperatures and T is their common value. Under this assumption, the deviation from LTE in a given plasma is manifested through the departure of the excited atom state populations from Boltzman's distribution. Therefore, it is necessary to take into account all processes which can influence the excited atom state populations, particularly ionization/recombination processes.

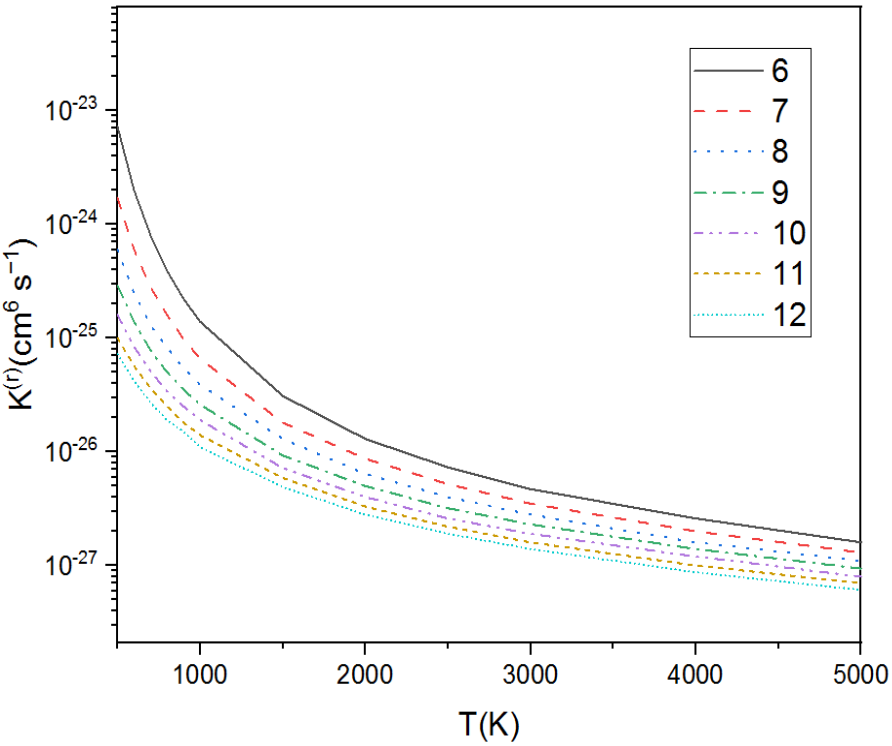

Figure 1: Total chemi-recombination rate coefficients for processes (1) for the case A=Li, with 500 K < T < 5000 K and for principal quantum numbers 6 < n < 12.

Total chemi-recombination rate coefficients can be defined as the sum of the partial ones describing both processes (1a) and (1b):

$$K_r^{(tot)} = K_r^{(a)} + K_r^{(b)} \qquad (2)$$

For details see e.g. Mihajlov et al. 2003, 2011. The rate coefficients for the chemi-recombination (CR) processes are calculated for a wide region of temperatures and the principal quantum numbers. The obtained data are needed for modeling and research of cool stars, lithium stars, sodium clouds around Io cometary tails, and primordial gas containing Li atoms and ions (Gnedin et al., 2009), etc.

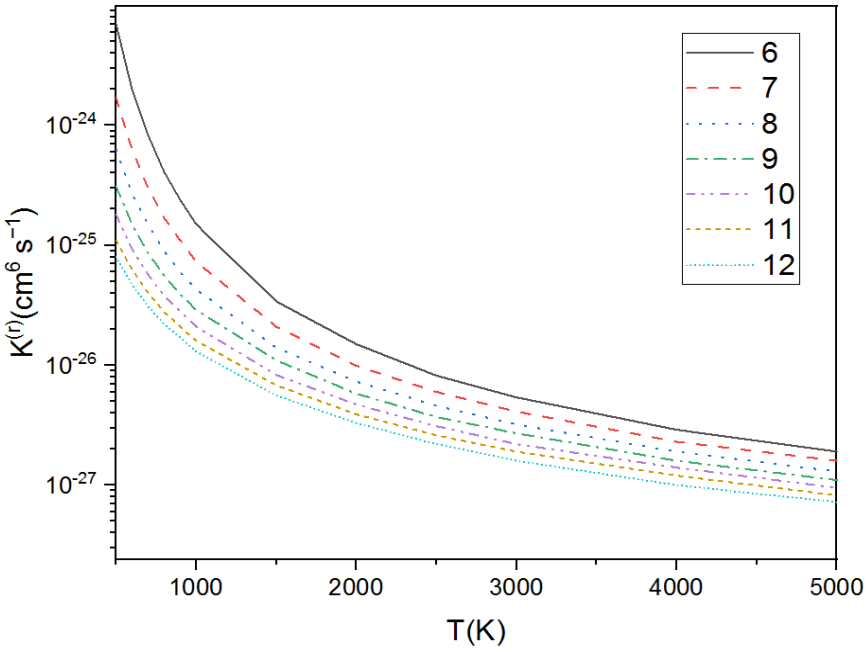

Figure 2: Total chemi-recombination rate coefficients for processes (1) for the case *A*=Na, with 500 K < T < 5000 K and for principal quantum numbers 6 < n < 12.

2. RESULTS AND APPLICATION

We give the total rate coefficients for CR processes for sodium and lithium cases (*A*=Na, Li) for principal quantum numbers $6 \leq n \leq 12$ in a wide region of temperatures $500\ K \leq T \leq 5000\ K$.

The total CR rate coefficients $K_r^{(tot)}(n,T)$ are shown in Figs. 1 and 2 for the cases of Li and Na. The results presented here show the influence of chemi-recombination processes (1) in populating the highly excited atoms in non-equilibrium alkali plasmas in broad ranges of parameters. It can be observed that the total rate coefficient for all cases decreases with increasing temperature and the coefficient decreases with increasing principal quantum numbers.

3. SUMMARY

The results presented here show the influence of chemi-recombination processes (1) in populating the highly excited atoms in non-equilibrium alkali plasmas in broad ranges of parameters. Therefore, these processes have to be included in all collisional radiative models dealing with such plasmas. Generally, the obtained results have potential astrophysical use in the improvement of chemistry and modeling of different layers of weakly ionized geo-cosmical plasmas of the atmospheres of various stars and cosmic objects (Sreckovic et al. 2014; Mihajlov 2011, Sreckovic et al. 2020). The results are also important in theoretical and laboratory spectroscopic plasmas research, industry, and technology application.

Acknowledgments

The authors acknowledge the support from the Institute of Physics, Belgrade, which was made possible by grants from the Ministry of Education, Science and Technological Development of the Republic of Serbia (including contract no 451-03-68/2022-14/200287)

References

Gnedin, Y. N., Mihajlov, A. A., Ignjatovic, L. M., et al.L 2009. *New. Astr. Rev.*, **53**, 259

Ignjatović, L.M.; Srećković, V.; Dimitrijević, M.: 2020, *Contrib. Astron. Obs. Skaln. Pleso*, **50**, 187.

Mihajlov, A. A., Ignjatović, L. M., Dimitrijević, M. S., & Djurić, Z.: 2003, *Astrophys. J., Suppl. Ser.*, **147**(2), 369.

Mihajlov, A. A., Ignjatović, L. M., Srećković, V. A., et al.: 2011, *Astrophys. J., Suppl. Ser.*, **193**(1), 2.

Klyucharev, A. N., Bezuglov, N. N., Matveev, A. A., et al.: 2007, *New. Astr. Rev.*, **51**, 547.

Srećković, V.A.; Mihajlov, A.A.; Ignjatović, L.M.; Dimitrijević, M.S.: 2014, *Adv. Space Res.*, **54**, 1264.

Srećković, V. A., Dimitrijević, M. S., Ignjatović, L. M., et al.: 2018a, *Galaxies*, **6**(3), 72.

Srećković, V. A., Dimitrijević M. S. and Bezuglov N. N.: 2018b, *Atoms* **7**.1, 3.

Srećković, V. A., Ignjatović, L. M., & Dimitrijević, M. S.: 2020, *Molecules*, **26**(1), 151.