Time evolution of the population distribution in charge exchange collisions

Kento Shimada*[1], Naoki Numadate*, Yoshiyuki Uchikura*, Takuto Akutsu*, Ling Liu†, Jianguo Wang†, and Hajime Tanuma*[2]

* Department of Physics, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397, Japan,
† Institute of Applied Physics and Computational Mathematics, Beijing 100088, China

Synopsis
We had calculated the population distributions of many electronic excite states as a function of time in collisions of bare, hydrogen-like and helium-like C, N and O ions with neutral targets, H, He, and H_2. Using the population distribution, we had calculated theoretical emission spectra in the collision system. Comparing of the theoretical spectra with the observation, we have estimated the detection efficiency of the spectrometer and discuss the singlet-triplet ratio in charge exchange collisions of hydrogen-like ions.

Both the soft X-ray emission from the comets and the X-ray background signals observed with the X-ray satellite observatories have been understood as the transitions of the highly charged ions in the solar wind which underwent charge-exchange collisions with neutral gases around the comets in the heliosphere [1, 2, 3]. For the quantitatively analyses of future observed X-ray spectra with high resolution micro-calorimeters, the accurate charge exchange cross sections and emission cross sections are required by astrophysicists.

We have measured electron capture cross sections and emission cross sections in collisions of highly charged ions produced with 14.25 GHz electron cyclotron resonance ion source with neutral gas targets. In the emission cross section measurements, we have used a collision cell of 50 mm long and only the emission from the center of the cell has been observed with a window-less silicon drift detector for soft X-ray and a grazing incident spectrometer for extreme ultra-violet (EUV) region. In the experiments, we kept the target gas pressure low enough to avoid double collisions in the cell. However, the contribution of the intermediate lifetime states produced upstream of the observation center must be investigated. Furthermore, detection efficiency of EUV spectrometer which strongly depends on the wavelength must be estimated to obtain emission cross sections.

In this study, we have calculated the time dependence of population for many electronic excited states of incident ions in a collision cell filled by target gas with very low density to keep single collision conditions. For this calculation, we have used the single electron capture cross sections by the AOCC (Atomic Orbital Close Coupling) method [4] and Einstein's A-coefficients stored in the CHIANTI atomic database [5]. Using the cross sections and the transition rates, we have assumed the following simultaneous rate equations:

$$\frac{\mathrm{d}[\mathrm{X}^{(q-1)+}(\mathscr{S})]}{\mathrm{d}t} = \sigma_{\mathscr{S}}\, v[\mathrm{X}^{q+}][\mathrm{Y}] + \sum_{\mathscr{S}'}\left\{A_{\mathscr{S}',\mathscr{S}}[\mathrm{X}^{(q-1)+}(\mathscr{S}')]\right\} - \left\{\sum_{\mathscr{S}''}A_{\mathscr{S},\mathscr{S}''}\right\}[\mathrm{X}^{(q-1)+}(\mathscr{S})],$$

where $[\mathrm{X}^{(q-1)+}(\mathscr{S})]$ means the population of the $\mathscr{S}$ state of the incident ion after the electron capture, [Y] is the density of the target gas, v is the collision velocity, $A_{i,j}$ is the optically transition rate from i to j, and $\sigma_{\mathscr{S}}$ means state-selective capture cross section to the $\mathscr{S}$ state. In the AOCC calculation, it is difficult to distinguish the fine-structure with different total angular moment J. Therefore, we assumed the statistical weight ratios of $2J+1$ for each capture cross section. After the calculation of the population evolution of the incident highly charged ions, we have also calculated the emission spectra.

We had calculated the population evolution and the emission spectra in collisions of bare, hydrogen-like, and helium-like C, N, and O ions with H, He, and H_2 target gasses. And, by comparing of the observed emission spectrum with the theoretical spectrum, we could estimate the detection efficiency of the EUV spectrometer if the theoretical capture cross sections are appropriate. However, singlet-triplet ratio in collisions of hydrogen-like ions are not sure at present. In this study, we will discuss the singlet-triplet ratio in the capture cross sections.

[1] E-mail: shimada-kento1@ed.tmu.ac.jp
[2] E-mail: tanuma-hajime@tmu.ac.jp

References

[1] S. L. Snowden *et al.* 1994 *Astrophys. J.* **424** 714-728
[2] C. M. Lisse *et al.* 1996 *Science* **274** 205-209
[3] T. E. Cravens, 2002, *Science,* **296(5570)** 1042-1045
[4] L. Liu, *private communication*
[5] P. R. Young *et al.* 2016 *J. Phys. B* **49(7)** 074009