§5. Multi-electron Capture Processes in Highly Charged Ion – Alkali-earth Metal Atom Collisions

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In general, when highly charged ions (HCIs) collide with neutral species, HCIs dominantly strip off some electrons from them. This multi-electron capture process is one of the cooling mechanisms in plasma. And using this process, we can carry out the plasma diagnosis of thermonuclear plasma called the charge exchange spectroscopy(CXS). A lot of experiments concerning the collision of HCI with atoms and molecules have been conducted for these reasons. The previous NICE-experiment group has chosen Iodine as a projectile highly charged ion, I^{q+}, and have already measured total absolute electron capture cross sections of the collisions of,

$$I^{q+}(1.5qkeV) + A \rightarrow I^{(q-j)+} + A^{j+},$$

as a study of multi-electron capture processes. Where A is the target species, and j is the number of transferred electrons. As a result, we have proposed the following scaling law[1)] for rare gas atoms (Ne, Ar, Kr and Xe) and simple molecules (H_2, N_2, CO, CO_2 and CH_4).

$$\sigma_{total} = 2.6\times10^3\, q/IP^2 \qquad (\text{Å}^2). \qquad (1)$$

Where σ_{total} is the total electron capture cross section, and IP is the first ionization energy (eV) of target species. Almost all the experimental data are reproduced well by this scaling law within errors of 20%. From the recent experiments of HCI-alkali atom, rubidium(Rb) , cesium(Cs), and sodium(Na) collisions, it was found that the coefficient of eq.(1) for alkali atoms is different from that of rare gas ones[2)]. That is probably due to the difference of the electron configuration of the target. Alkali atoms do not have a closed shell but have one electron in outer s-orbital, and its first ionization energy is much lower than rare gas atoms.

In this work, we attempted the measurement of the total electron capture cross section of the Xe^{q+} + Li collision as a first step of the experiments of alkali-earth metal collisions. The goal for this study is the measurement of the total absolute electron capture cross sections for HCI-alkali earth atom collisions.

The simplified schematic of experimental setup is shown in Fig.1. The HCI was produced by the electron beam ion source(cryo-NICE) that is electron beam ion source (EBIS), and led to the collision region after the charge selection with the analyzing magnet. A lithium(Li) atoms were generated through a thermal oven, and target density was estimated by a surface ionizer. The oven was newly made to use the alkali earthy metal with a high melting point as a target species this time. The Xe^{q+} ions collide with the Li atoms in the target cell, and some electrons of Li are captured by Xe^{q+}. Both the Xe^{q+} and $Xe^{(q-j)+}$ were led toward the four meshed electrodes situated at the front of micro-channel plate(MCP) after the collisions. The retarding voltage Vr was applied to the second and third meshes which were connected together. Using this Vr, we can analyze the charge of ions finally detected with MCP.

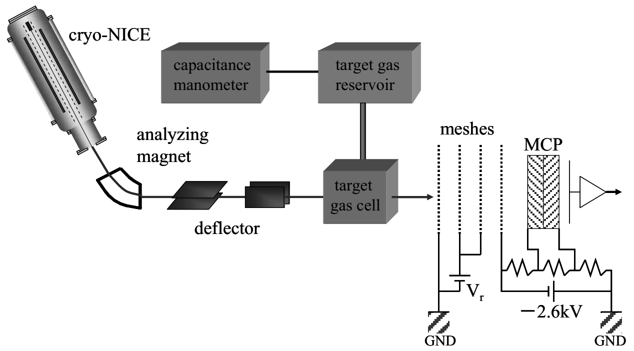

Fig. 1. Illustration of the experimental apparatus

Figure 2 shows the relative total electron capture cross sections of the Xe^{q+} + Li collisions as a function of the electric charge q. It is clear that the total electron capture cross section is proportional to q. We tried calculating the absolute values of total electron capture cross sections. The estimated cross sections take the values from 3×10^3 to 4×10^3 (Å^2), which satisfies the scaling law. Therefore, it is expected that the scaling law is still valid for the Li target though we don't determine the absolute values in this experiment because the experimental error is large.

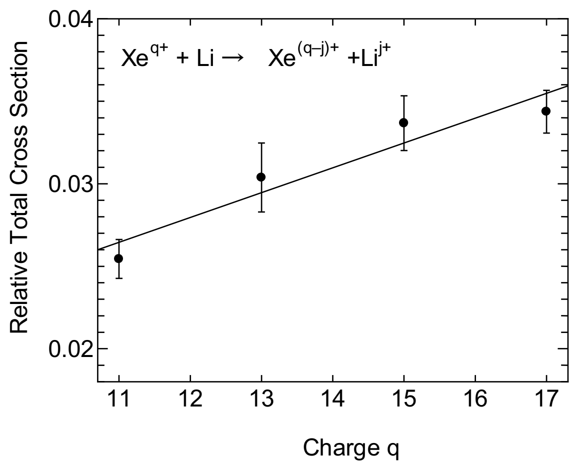

Fig. 2. Relative total multi-electron capture cross sections of Xe^{q+} + Li collisions

The experiments for the alkali earth metal targets have just started. In order to explain the multi-electron capture processes, we will measure the absolute for all alkali and alkali earth metals.

1) M.Kimura, et.al., J. Phys. B **28**(1995)L643.
2) H.A.Sakaue, et.al., J. Plasma Fusion Res. **7**(2006)195.