Characterization of charge-exchange collisions between ultracold ^{6}Li atoms and ^{40}Ca$^+$ ions

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Synopsis We experimentally investigate the charge-exchange cross section between Ultracold ^{6}Li atoms and ^{40}Ca$^+$ ions. We systematically scan the atom-ion collision energy to study the energy dependence of the cross sections. The obtained energy dependence is consistent with the Langevin collision model in the temperature range of milliKelvin to Kelvin. We further investigate the internal-state dependence of the charge-exchange cross sections, which varies over three orders depending on the state of the ions. We compare our experimental results with the calculation results for deeper understanding of ultracold atom-ion inelastic collisions.

Laser cooled ions immerced in a cold atomic gas, so called atom-ion hybrid system, can be a new ideal platform to study ultracold chemistry. Since internal and external degrees of freedom of the atoms and ions can be controlled precisely on a single quantum level using lasers, this system is suitable for the systematic investigation of chemical reactions.

In this presentation, the charge-exchange collision, that is an elementary step of chamical raction, is systematically investigated about energy and internal-state dependence of its cross section in a cold ^{6}Li-^{40}Ca$^+$ mixture.

In order to measure energy dependence, deliberately excited micromotion of ions are utilized to control the ion kinetic energy. The shape of fluoresence spectra of ion in rf trap deforms, that is well known as micromotion-modulated fluorescence spectra[2]. And we estimate the kinetic energy of ion by that spectral shape and control collision energy from miliKelvin to Kelvin.

In this experiment, frequency of charge exchange collision is observed by the loss of the Ca$^+$ from ion trap during mixing with atomic gas. We identified the loss of Ca$^+$ ions are caused by charge-exchange process using mass spectroscopy. The figure shows the measured charge-exchange cross section as a function of collision energy. During mixing Li atoms and Ca$^+$ ions, both cooling and repumping laser for ions are irradiated, and Ca$^+$ ions are in the mixing state of $S_{1/2}$, $P_{1/2}$ and $D_{3/2}$. From this result, we find out energy dependence of charge-cexchange collision obey the Langevin model, shown with the solid line in the figure. The charge-exchange collision happens when the distance between an atom and an ion is small. Therefore charge-exchange collision is part of the Langevin collision and its cross section smaller than Langevin's one.

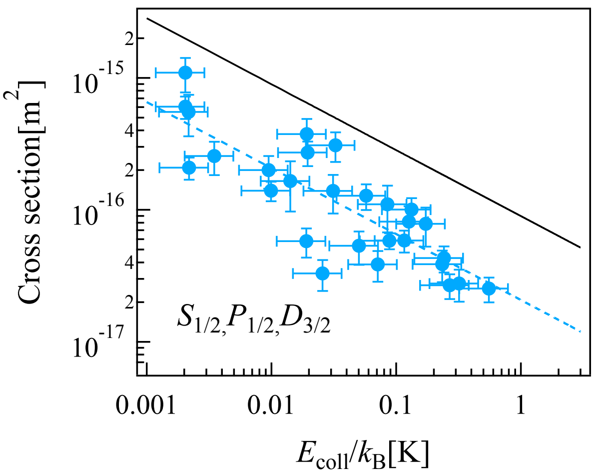

Figure 1. Charge-exchange collision cross section vs collision energy for the mixture of the $S_{1/2}$, $P_{1/2}$ and $D_{3/2}$ state.

We also study the internal state dependence of the charge-exchange cross section. The ions prepared in the $S_{1/2}$, $D_{3/2}$ and $D_{5/2}$ states by optically pumping just before transporting the atoms to make a mixture. We observed that the charge-exchange collision cross section changes by several orders depending on wich internal state ions are prepared. While ions in the ground state $S_{1/2}$ has low reactivity, ions in the excited states show quite high reactivity.

Calculations of LiCa$^+$ potential energy curve is performed to compare with the experinatal result. Then, we identify the route of the charge-exchange collision and reveal high reactivity in D state caused by mixing between incoming and outgoing state.

References

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