Ultracold interactions of alkali-metal and alkaline-earth-metal ions with spin-polarized metastable helium atoms

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Synopsis Ion-atom mixtures with the large ion-to-atom mass ratio are promising systems to reach the quantum regime of ion-atom collisions in experiments using hybrid traps. We investigated cold interactions and collisions of alkali-metal and alkaline-earth-metal ions immersed into an ultracold gas of spin-polarized metastable helium atoms. We calculated potential energy curves for spin-stretched molecular electronic states and evaluated channels of possible chemical transformation. When it was possible, we predicted scattering lengths and analyzed magnetically tunable Feshbach resonances.

The Bose-Einstein condensates of metastable $^4He^*$ [1,2] and Fermi gases of $^3He^*$ [3] were created. The metastable helium possesses high internal energy and can ionize most of neutral atoms in a process known as Penning ionization. However this process can be controlled in ultra-low temperature regime, as was demonstrated for a mixture of neutral ^{87}Rb and $^4He^*$ [4].

In this work, we investigated cold interactions and collisions of He^* with the following ions: Li^+, Na+, K^+, Rb^+, Be^+, Mg^+, Ca^+, Sr^+. In the first step, we computed potential energy curves (example in Fig. 1). We limited our studies to the electronic states of the highest possible multiplicity. We can split studied here ions into two groups, depending on the shape of interaction potential. Lighter ions (Li^+, Na+, Be^+, Mg^+) exhibit shallow potential energy curve (well depths not larger than 1500 cm^{-1}) and exhibit minima at significant interatomic distance (larger than 11 bohr). Remaining ions (K^+, Rb^+, Ca^+, Sr^+) interact stronger with He^*, their potentials are characterized by well depths in the range of 6000-8000 cm^{-1} and equilibrium distances in the range of 7.5-7.9 bohr.

The closer inspection of possible chemical reaction channels showed that after a collision between lighter ions and He^* the charge transfer process leading to He^+ (^2S) and neutral metal atom is energetically possible even assuming spin polarization of the system. Alkaline-earth-metal ions are subject to the Penning ionization. This is not the case for alkaline-metal, however, in case of Rb^+, the core-electron excitation is energetically possible. Obviously, all systems studied here can be subject to spin relaxation.

In order to evaluate the rate constants of charge transfer collisions, we studied transition dipole moments between relevant electronic states. We also proposed and analyzed prospects for using magnetically tunable Feshbach resonances to control charge transfer and Penning ionization processes. When it was possible, we predicted scattering lengths.

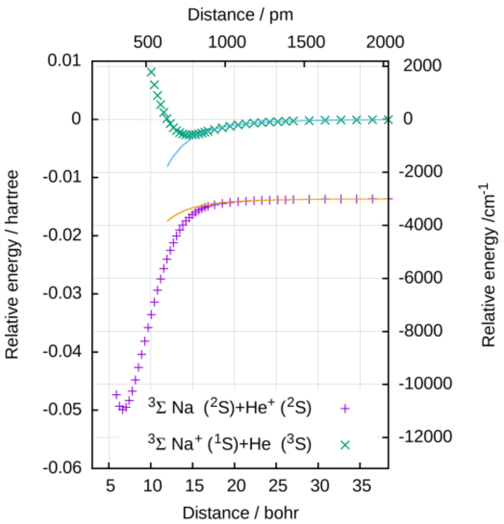

Figure 1. Potential energy curves for $^3\Sigma$ states of $HeNa^+$. The points come from *ab initio* computations. The solid lines present asymptotic behavior of interaction.

References

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