# Formation of Kaonic Atoms and Kaonic Nuclei in In-Flight ($K^-$,p) Reactions

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In this study, we investigate the structure and formation of kaonic atoms and kaonic nuclei. We use two different kaon-nucleus optical potentials which are obtained from the chiral unitary model and a phenomenological fit of existing kaonic atom data. We theoretically study the structure of kaonic atoms and kaonic nuclei using these potentials and determined the differences between the obtained level schemes of the kaonic nuclear states.

We also study the formation cross sections of deeply bound kaonic atoms and kaonic nuclei which cannot be observed with standard X-ray spectroscopy. All the atomic states are theoretically predicted to be quasi-stable. We investigate the $(K^-, p)$ reaction theoretically and evaluate the cross section of $^{40}$Ca$(K^-, p)$ reaction in detail [1].

We also systematically study the formation cross sections of kaonic nuclear states in $(K^-, p)$ reactions for various targets. In order to take into account the phase space suppression effects of the decay widths, we introduce a phase space factor to obtain the $(K^-, p)$ spectra. We found in our theoretically studies that in the $(K^-, p)$ reactions, a certain bumpy structure due to the kaonic nucleus formation can be seen only for the case of a deep ($\sim$ 200 MeV) phenomenological kaon nucleus potential (Fig.1). Due to the phase space suppression, the decay widths of kaonic states become so narrow that we can see certain bumpy structure in the reaction spectrum, which could be seen in experiments. For the case of the chiral unitary potential, the binding energies are too small to reduce the decay widths and to see the bumpy structure in the spectra of the $(K^-, p)$ reactions.

In order to obtain more decisive results theoretically, we apply Green function methods for the states with large widths and consider energy dependence of the optical potential properly [2]. The detailed discussions are given in Ref. [2].

Furthermore, we should consider the changes and/or deformations of the nucleus due to the existence of the kaon inside and solve the problem in a self-consistent manner for kaonic nucleus states. However, we believe that the present theoretical efforts to evaluate the absolute cross sections for the kaonic bound state formation are relevant for determining a suitable method to observe them and helpful for developing the physics of kaon-nuclear bound systems and kaon behavior in nuclear medium. Further investigations both theoretically and experimentally are needed to understand the kaon behavior in nuclear medium more precisely.

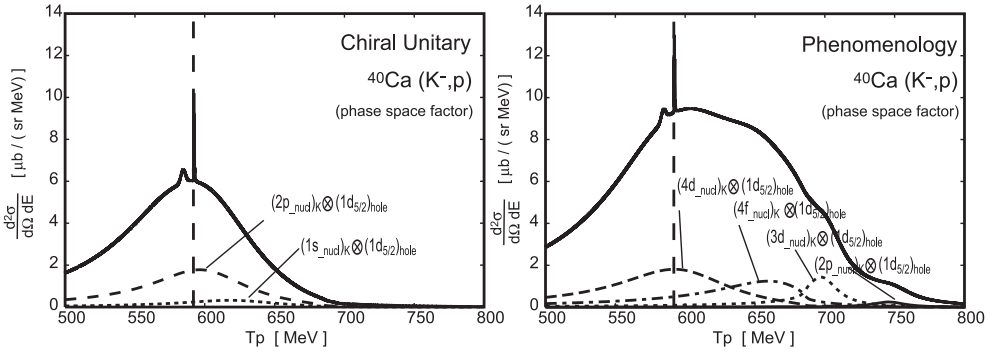


Figure 1: Kaonic nucleus formation cross sections in $^{40}$Ca$(K^-, p)$ reactions are plotted as functions of emitted proton energies at $\theta_{\rm p}^{\rm Lab} = 0$ [degree] and $\rm T_K = 600$ MeV for (left) chiral unitary model and (right) phenomenological K-nucleus optical potential cases. Detailed discussions are given in Ref. [1].

## References

[1] J. Yamagata, H. Nagahiro, Y. Okumura and S. Hirenzaki, Prog.Theor.Phys.114, 301-316 (2005); Erratum-ibid.114, 905, (2005).

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