Coexistence of antikaons and hyperons in nuclei and in neutron stars

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Multi-strangeness systems in hadronic matter have been providing unique aspects in strangeness nuclear physics. Searching for deeply bound kaonic nuclei and multi kaonic clusters may reveal kaon-nucleon (K-N) interaction and kaon dynamics in nuclear medium\cite{1}. Stimulated by these studies, we have investigated multi-antikaonic nuclei (MKN), where several $K^-$ mesons are bound in the nucleus\cite{2}. Studies of double $\Lambda$ hypernuclei and $\Xi$ hypernuclei as well as single $\Lambda$ and $\Sigma$ hypernuclei, have also been unveiling hyperon(Y)-N, Y-Y interactions\cite{3}. In these studies, kaons and hyperons have been considered separately. We consider a possible coexistence of $K^-$ mesons and hyperons in nuclei and clarify interplay between them in multi-strangeness nuclei.

We base our framework on the relativistic mean-field theory (RMF) for baryon-baryon interaction, coupled with the effective chiral Lagrangian which incorporates $\bar{K}$-baryon and nonlinear $\bar{K}\bar{K}$ interactions. The $K^-$ mesons are initially put into the target nucleus with mass number $A$ and atomic number $Z$. The number of the $K^-$ mesons is denoted as $j_{S}$. Part of the strangeness $j_{S}$ is supposed to be transferred to that of hyperons through $K^-N\rightarrow Y$. On the assumption of spherical symmetry, the ground state is obtained from minimization of the thermodynamic potential under the conditions of baryon number $A$, electric charge $Z$, and strangeness $j_{S}$ conservations.

In the Figure, the density profiles of baryons are shown for the ground state of the multi-strangeness nuclei in the case of initial target nucleus $^{15}$O and $|S|=2$ (solid lines) and 10 (dashed lines). The $K^-$ optical potential depth $U_K$ is taken to be $|U_K| \lesssim 180$ MeV. The ground state is given by multi-hypernuclei without bound $K^-$ mesons with central density $\rho_c \sim \rho_0$ ($=0.153$ fm, the standard nuclear density). This is because all the strangeness initially carried by $K^-$ mesons is absorbed by the nucleons and is taken over by the hyperons ($\Lambda$) through $K^-N\rightarrow Y$. Therefore the MKN without hyperon-mixing [2] should be considered as the higher energy state. We also consider kaon condensation in hyperonic matter which may be realized in neutron stars [4] within the same interaction model elucidated here.

References
\begin{itemize}
\item [{1}] Y. Akaishi and T. Yamazaki, Phys. Rev. C 65 044005 (2002);
\item [{4}] T. Muto, Phys. Rev. C 77, 015810 (2008), and references therein.
\end{itemize}