Interplay of kaons and hyperons in multi-strangeness systems in relativistic mean-field theory

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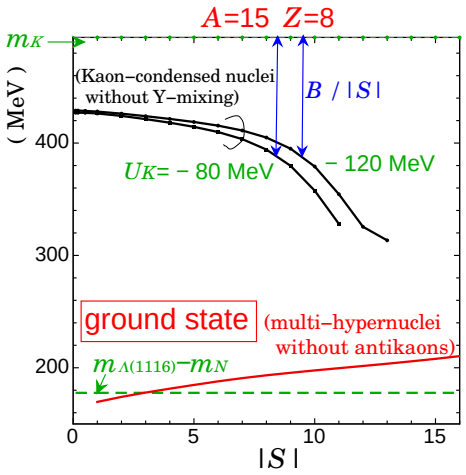
Studies of kaonic nuclei and hypernuclei at J-PARC have been providing us with new aspects on kaon (K)-nucleon (N),hyperon (Y)-N, and Y-Y interactions in nuclear medium. Multi-strangeness systems such as kaon condensation and hyperon-mixed matter in neutron stars have also been considered from viewpoints of nuclear and astrophysics[1]. In this paper, we consider a possible coexistence of bound states of K^- mesons and hyperons in nuclei. We also consider kaon condensation in hyperon-mixed matter [$(Y+K)$ phase], which may be realized in neutron stars, within the same interaction model and discuss interplay of kaons and hyperons in multi-strangeness systems in a unified way for both nuclei and neutron stars.

We base our framework on the relativistic mean-field theory for baryon (B)-B interaction, coupled with the effective chiral Lagrangian incorporating K-B and nonlinear K-K interactions[2]. We further introduce second-order effects, a pole contribution from the Λ (1405) and the range terms for baryons as phenomenologically realistic effects. The range parameters are determined to reproduce the s-wave KN scattering lengths.



In the Figure, the energy difference per unit of the input strangeness number $|S|$ from the reference nucleus $^{15}_{8}$O with $|S|$=0, $[E(A,Z,|S|) - E(A,Z,0)]/|S|$, is shown as a function of $|S|$ for the multi-strangeness nuclei. The K^- optical potential depth U_K is taken to be $|U_K| \lesssim$120 MeV. It is shown that the ground state is given by multi-hypernuclei with central density $\rho_c \sim \rho_0$ (=0.153 fm^{-3}, the standard nuclear density) without bound K^- mesons for the relevant values of $|S|$. The multi-antikaonic nuclei without hyperon-mixing have a binding energy, $B/|S| \gtrsim$ 80 MeV, but always lie as a higher energy state than the multi-hypernuclei.

We have also obtained onset density and the equation of state (EOS) of $(Y+K)$ phase in neutron stars. It is shown that the coexistence of kaon condensation and hyperons leads to significant softening of the EOS at high densities, which should be reconciled with recent observations of massive neutron stars which are as large as two solar mass. We discuss stiffening effects on the EOS of the $(Y+K)$ phase at high baryon density such as anti-symmetrization effects for baryons beyond the Hartree approximation through introduction of tensor coupling of vector mesons. It may also be important to incorporate the effects of many-body forces between baryons such as universal three-body forces beyond the mean-field approximation[3].

[1] T. Muto, Phys. Rev. **C 77**, 015810 (2008) and references therein.

[2] T. Muto, T. Maruyama, T. Tatsumi, Phys. Rev. **C 79**, 035207 (2009); *ibid*, JPS Conf. Proc. **1**, 013081 (2014).

[3] S. Nishizaki, Y. Yamamoto, T. Takatsuka, Prog. Theor. Phys. **108**, 703 (2002).