Lambda-Sigma Mixing Induced by Condensed Pions in Dense Matter

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It has been expected that there appear various hadron phases in dense nuclear matter, such as pion condensation, K condensation, admixture of hyperons and so on. These phases provide us of more excitements in studying nuclear matter under low-temperature high-density extreme conditions. In many of preceding works, each of these phases has been considered separately. Towards an unified understanding of dense matter, we investigate the coexisting phase of hyperon admixture and pion condensation, which have different mechanisms in energy gain.

In hyperonic matter, condensed pions would mix Λ with Σ baryons coherently through the $\Lambda\Sigma\pi$ coupling. Recently, this coherent $\Lambda\Sigma$ coupling has been applied to solve the long standing problem – consistent understanding of Λ - separation energy of three-, four-, and five-body hypernuclei .[1] If this coherent coupling is induced by OPEP, it would be equivalent to the pion condensation through the p-wave $\Lambda\Sigma\pi$ coupling.

We have included the $S = 0, -1$ octet and decouplet baryons into the traditional treatment of pion condensation.[2] In addition to the p-wave $BB\pi$ couplings, we have included the short range repulsion in the form of the Landau-Migdal interaction with a universal parameter $g' = 0.6$. The FD ratio parameter for hyperons is selected to be $F/(F + D) = 0.35$.

The left panel of Fig. 1 shows the energy per baryon under charged pion condensation in dense neutral matter. First, we consider those cases without decouplet resonance contributions. At low densities, the energy is lower without hyperons because of the mass difference of nucleons and hyperons. However, at higher densities, hyperon mixed matter becomes more favorable due to the large nucleon Fermi energy and $\Lambda\Sigma\pi$ coupling, and hyperon admixture in the pion condensed phase would emerge. Next, we include the effects of decouplet baryon resonances with $S = 0, -1$, $\Delta(1232)$ and $\Sigma^*(1385)$. The coupling constants of $BB^*\pi$ and $B^*B^*\pi$ are estimated by using the SU(6) quark model. The octet-decouplet couplings in the $S = 0$ and -1 baryons are given as $f_{N\Delta\pi}/f_{NN\pi} = \sqrt{72}/5$, $f_{\Lambda\Sigma^*\pi}/f_{NN\pi} = \sqrt{36}/5$, and $f_{\Sigma\Sigma^*\pi}/f_{NN\pi} = \sqrt{12}/5$, respectively. In spite of large mass differences of octet and decouplet baryons, the effects of resonance baryons are very large due to these large $BB^*\pi$ couplings. Especially, since the coupling of $N\Delta\pi$ is very large, it generates large energy gain. Although there is also a large energy gain in hyperon mixed matter from $\Lambda\Sigma^*\pi$ coupling, it is smaller than that from $N\Delta\pi$ coupling and hyperons cannot appear even at very high densities.

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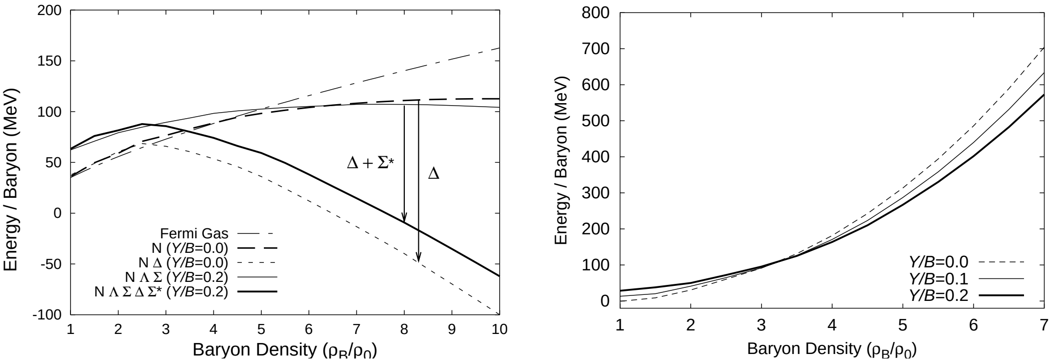

Fig. 1. Left panel : Energy per baryon under charged pion condensation. Only the $BB\pi$ and Landau-Migdal interaction are included in the figure. Right panel : Energy per baryon under charged pion condensation with uniform mean field simulating that from σ and ω mesons in neutral matter. The contributions from the uniform mean field effects are added simply to the results in the left panel, and quark counting rule is considered.

The above observations suggest that hyperons would not emerge in the pion condensed $N\varDelta$ state at high densities. However, it should be noted that hyperons are considered to feel less repulsive (uniform and spin-independent) potentials at higher densities, which makes hyperons to admix at $\rho_B = (2-4)\,\rho_0$ in RMF$^{3)}$ and G-matrix$^{4)}$ models. The mechanism of this less repulsion may be understood as follows: In RMF, the main part of the repulsive potential comes from ω mesons, which couples to u and d quarks in the baryon. Based on this simple picture, we have assumed that hyperons feel the spin-independent uniform mean field, which is 2/3 times of that for nucleons, $U_Y = 2/3U_N$. The right panel of Fig. 1 shows energy per baryon which includes the effects from this uniform mean field, simulating those from σ and ω mesons. For nucleon mean field, we have used the Skyrme type parametrization, $U_N = \alpha\,(\rho/\rho_0) + \beta\,(\rho/\rho_0)^\gamma$, and a hard EOS is chosen here. Nuclear matter is favorable at low densities due to the mass difference and stronger attraction, but hyperonic matter is favorable at high densities because of the smaller repulsion.

In summary, we have investigated the coexistence of hyperon admixture and pion condensation. We have found that pion condensation favors non-strange baryons rather than hyperons, because the couplings are stronger for non-strange baryons. However, it is still a delicate problem whether hyperon admixture and pion condensed phase coexist or not. We have shown that it would be possible when we consider the smaller repulsion for hyperons in dense matter. For a more reliable description, contributions of ρ mesons, form factors, and the mean field coming from other mesons such as ϕ have to be taken care of.

References

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