Negative Kaons in Dense Baryonic Matter

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Kaons are considered as a good probe of heavy-ion collision dynamics. Kaonic modes are essentially modified due to strong interactions in heated and dense baryonic matter. Of particular interest is the analysis of the p-wave effects on the K^- spectra in nucleus-nucleus collisions. The kaon-nucleon interaction can lead also to a kaon condensation in interiors of neutron stars. In our investigation we start with the general study of the behavior of kaonic modes, first in the cold baryonic medium of arbitrary isotopic composition including both the s- and p-wave K^--baryon interactions. We construct the K^- polarization operator. In order to describe the kaon-nucleon interaction we use the kaon-nucleon scattering amplitude obtained recently as a solution of the coupled-channel Bethe-Salpeter equation with the interaction kernel derived from the relativistic chiral SU(3) Lagrangian with the large N_c constrains of QCD [1]. We calculate explicitly the pole terms of the K^- polarization operator related to Λp^{-1}, ΣN^{-1}, $\Sigma^* N^{-1}$ excitations with K^- quantum numbers and analyze effects due to the hyperon $H = (\Lambda, \Sigma, \Xi)$ Fermi seas. To describe the baryon properties we use the relativistic mean-field model.

We compare the s-wave regular part of our polarization operator with the simplified form written in terms of the KN Σ-term and the Weinberg-Tamazawa term, which is widely used in the literature. The Σ-term extracted from this comparison ($\Sigma \simeq 150$ MeV) is found to be two-three times smaller compared to that allows for the s-wave K^- condensation in ordinary neutron star matter composed mostly of neutrons. However, we find the essential attractive support from hyperon exchange terms of the p-wave scattering amplitude contributing to the s-wave part of the polarization operator. Inclusion of these terms, which were omitted in previous works, makes a second-order phase transition to the s-wave K^- condensate state possible at densities $\simeq 3\rho_0$ in the given model, when the correlation effects are not included yet.

We evaluate baryon-baryon correlation parameters and correct all the s- and p-wave terms of the polarization operator, accordingly. Inclusion of correlations essentially suppresses the kaon-nucleon attraction. E.g., it shifts the critical point of the second-order phase transition to the s-wave K^- condensate state toward larger densities, $\gtrsim (4 \div 5)\rho_0$. We estimate feed-back effects from quantum fluctuations arguing that their contributions are not too large at the low kaon energies under consideration and zero temperature.

We check the possibility of a second-order phase transition to the p-wave K^- condensate state. We show that, in the vicinity of the critical point of the s-wave K^- condensation, the p-wave part of the polarization operator, induced mainly by Λ-proton holes and Σ^*-nucleon holes and regular terms, is rather large and attractive. It may change the sign of the momentum derivative of the energy at the lowest K^- spectrum branch at origin. If occurred, this would mean that we have p-wave condensate instead of the s-wave one at somewhat smaller density. This statement, although being rather model dependent, holds for a wide range of varying parameters.

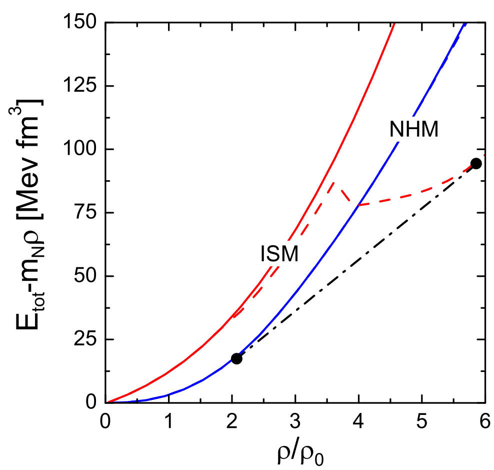

Figure 1: Energy densities of ordinary neutron star matter and isospin symmetrical matter with and without the K^- condensate shown by dashed and solid lines, respectively. The dash-dotted lines represent the double-tangent Maxwell constructions between two phases.

We consider a possibility of a first-order phase transition to a K^- condensate state. We calculate the energies of the baryonic matter with different compositions with and without the inclusion of the K^- condensation. We find that at densities $\gtrsim 3{\div}4\rho_0$ the isospin-symmetrical neutron-proton matter with a K^- condensate becomes more energetically favorable than the standard nucleon-hyperon-lepton matter. The K^- excitations are condensed in the p-wave state at this transition. The hyperon Fermi seas are melting. Hyperons are replaced by nucleons and electrons are replaced by the condensate K^- mesons. With the help of the Maxwell construction we find that the critical density of the beginning of the phase transition is about $2\rho_0$, cf. Figure 1. The final state density is about $(5 \div 6)\rho_0$. Appearance of such a strong first order phase transition may have interesting observable consequences as blowing off a part of the exterior of the neutron star, a strong neutrino pulls, a gravitational wave, a strong pulsar glitch, etc. Calculations of the kaon spectra in the heated dense nuclear matter with given kaon polarization operator are on the way.

References

[1] M.F.M. Lutz, E.E. Kolomeitsev, Nucl. Phys. A **700** (2002) 193.