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論文 / 著書情報
Article / Book Information

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種別(和文)	論文要旨
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Dynamical symmetry breaking of QCD's chiral symmetry is the mechanism responsible for the bulk of all hadron mass in the universe. One of the order parameters of chiral symmetry breaking is the chiral quark condensate. Theoretical model-independent calculations have shown that the absolute value of this quark condensate is reduced in nuclear matter. This might be an indication of (at least partial) restoration of the chiral symmetry compared to the unbroken phase in the vacuum. The linear-order density dependence of this symmetry breaking process is well known. If we knew higher orders of this density dependence, we might be able to extrapolate to even higher densities. This could for instance lead to a better understanding of neutron stars.

The goal of this work is to investigate the density dependence of the chiral quark condensate as well as certain pion properties in isospin-asymmetric nuclear matter using in-medium chiral perturbation theory up to the next-to-leading order of the density expansion. The isospin asymmetry of the nuclear matter ground state is realized via different proton and neutron densities, expressed via the ratio $r = \rho_n / \rho_p$. Hence a ratio of $r = 1.5$ corresponds to a neutron-to-proton ratio commonly found in heavy nuclei and $r \approx 10$ represents the situation in neutron stars.

For our calculations, we use an SU(2) in-medium chiral perturbation theory, initially formulated by Oller and further developed by Meißner, Oller and Wirzba. The partition function is defined in terms of the ground state, which we assume to be described by Fermi seas of non-interacting protons and neutrons. These states can be written as excitations of the vacuum, where we include all momenta up to the Fermi momentum, which depends on the nucleon density. Since this approach allows us to calculate general Green's functions, we can apply it to both the quark condensate as well as the pion properties. Our expansion scheme allows us to consider diagrams with one or two in-medium nucleon propagators and pion-nucleon interactions up to second order in the chiral counting. In total, we restrict our calculations to the order of the Fermi momentum to the fifth power. Higher contributions, i.e. proportional to the square of the nucleon density can be considered by including nucleon-nucleon correlation effects.

In order to compute the density dependence of the chiral quark condensate in nuclear matter, we investigate the two-point pseudoscalar correlation function by means of the chiral Ward identity. We find that at normal nuclear density, the absolute value of the quark condensate is reduced by around 35% compared to its vacuum value. This is in good agreement with earlier model-independent calculations. Although the effect of isospin-asymmetric nuclear matter is small, it is non-zero and leads to slight changes for large asymmetry of protons and neutrons. At fixed density, the reduction of the quark condensate is unchanged under the inversion of the neutron-to-proton ratio, i.e. a certain ratio r and the inverse ratio 1/r lead to the same result.

By extending this method using the chiral Ward identity to an SU(3) Lagrangian, we can also investigate the density dependence of the difference of the up- and down quark condensates in nuclear matter. The density dependence of this difference is smaller than for the sum of up- and down quark condensates, but the effect of isospin-asymmetric nuclear matter is more pronounced. Depending on whether the nuclear matter ground state exhibits more protons or more neutrons, the sign of this difference changes. Furthermore, we also present results of the density dependence of the strange quark condensate, although this result is largely dependent on the choice of the SU(3) low-energy constants.

For the in-medium pion properties, we first calculate the in-medium pion self-energy, which lets us compute the in-medium pion mass and wave function renormalization. The isospin asymmetry in the nuclear matter leads to a splitting of the pion triplet quantities, since the self-energy now has three independent components corresponding to the three states in the pion triplet. It is interesting that under the inversion of the neutron-to-proton ratio, the neutral pion's properties are unchanged, whereas the charged pions' properties are exchanged. We find that for normal nuclear density and a neutron-to-proton ratio of $r = 1.5$, the negative pion's mass is increased by around 10%. This agrees with an extrapolation of experimental data of the pion-nucleon optical potential, obtained from pionic atoms. Furthermore, we also investigate the in-medium pion decay constant via a different set of Feynman diagrams. We find that the negative pion's decay constant is reduced by around 10% at normal nuclear density and a neutron-to-proton ratio of $r = 1.5$. Our results for the pion properties are in good agreement with experimental findings.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。
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