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Effective Masses of Pentaquark Θ^+ in Nuclear Matter*

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Abstract The properties of baryons in nuclear matter are analysed in the relativistic mean-field theory(RMF). It is found that the scalar field σ meson affects the properties of baryon at high density. A density dependent scalar coupling g_σ^{N} is determined according to the idea of quark-meson coupling model and extended to RMF. It is shown that g_σ^{N} affects the property of nuclear matter weakly at low density, but strongly at high density. The relation between the scalar density ρ_{S} and the nuclear density ρ and the effective mass of the pentaquark Θ^+ are studied with the density dependent coupling constant. The density dependent scalar coupling obviously affects the effective masses of baryons in nuclear matter, especially at high density.

Key words pentaquark Θ^+, density dependent coupling, effective mass

1 Introduction

The relativistic mean field formalism(RMF) has widely and successfully been used in describing the properties of nuclear matter and finite nuclei[1]. One of the important aspects in RMF is how to determine the effective interactions of meson-baryon couplings. In recent years, a number of models such as NL-Z, NL3, NL-SH[2] have been developed. However, these models have their own limits in predicting the properties of nuclear matter or finite nuclei and the constant coupling may not be practical at high density.

Since a positive charged extremely narrow pentaquark state $\Theta^+(\mathrm{uudd\bar{s}})$ with the mass of 1.54GeV and $J^P = \frac{1}{2}^+$ was predicted in 1977[3], searching such a state has been a hot topic of investigation in hadron physics. After 2003, several experimental groups announced[4—12] that the evidence of the existence of Θ^+ was found. For example, the LEPS Collaboration[4] at Spring-8 in Japan reported the observation of the $S=+1$ baryon resonance at $1.54\pm 0.01\mathrm{GeV}/c^2$ with a width smaller than $25\mathrm{MeV}/c^2$ and a Gaussian significance of 4.6σ in the reaction of $\gamma\mathrm{n}\rightarrow\mathrm{K^+K^-n}$. This resonance can be interpreted an exotic pentaquark state ($\mathrm{uudd\bar{s}}$) which will decay into a $\mathrm{K^+}$ meson and a neutron. Also, the DIANA Collaboration at ITEP[5] recently announced their finding of a narrow peak at $1.539\pm0.002\mathrm{GeV}/c^2$ with a statistical significance of 4.4σ in the reaction of $\mathrm{K^+n}\rightarrow\mathrm{K^0p}$. The CLAS Collaboration studied the reaction of $\gamma\mathrm{d}\rightarrow\mathrm{pK^-K^+n}$[6], and found the evidence of Θ^+ decaying to $\mathrm{nK^+}$ with a mass of about $1.54\mathrm{GeV}/c^2$ and a statistical significance of $(5.2\pm0.6)\sigma$. In 2004, the COSY-TOF Collaboration[12] reported about their recent results with the strangeness production in the reaction of $\mathrm{PP}\rightarrow\mathrm{KYN}(\mathrm{Y}=\Lambda,\Sigma)$, in which K and N might form a hypothetical pentaquark state Θ^+. But,

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in 2004 and 2005, many negative reports appeared, and some reported positive evidences in favor of the existence of pentaquark baryons have emerged[13—17]. For example, in Ref. [15], the CLAS Collaboration at Jefferson Lab, they re-studied the reaction of $\gamma d \rightarrow pK^-K^+n$ with an integrated luminosity which is more than 30 times larger than that in their earlier measurement[6]. Their new result showed no any evidence for a narrow pentaquark resonance. The upper limit of the production cross section of Θ^+ in the mass range of 1.52—1.56GeV/c^2 in the $\gamma d \rightarrow pK^-\Theta^+$ reaction is 0.3nb. By using tagged-photon beam in the energy range between 0.8 and 3.6GeV[16], the data in the $\gamma d \rightarrow \Lambda nK^+$ reaction was also taken in the Hall-B at the Jefferson Laboratory. The cross section was found to be between about 5—25nb. No any statistically significant structure was observed in the nK^+ invariant-mass distribution. At the same time, the narrow-doubly charged Θ^{++} pentaquark state with strangeness $S=1$ and isospin $I=1$ was also searched in the pK^+ invariant mass spectrum in the reaction of $\gamma p \rightarrow pK^+K^-$ with a photon energy of 1.8—3.8GeV at the Jefferson Laboratory[18]. It was shown that there is no statistically significant evidence of a Θ^{++}. The upper limits of the total and differential cross sections for the reaction of $\gamma p \rightarrow K^-\Theta^{++}$ were obtained in the mass range of 1.5—2.0GeV/c^2. The negative results have higher statistics and are quite convincing, but they may not completely wash away the evidence yet, in other words, the pentaquark is not dead for sure. Guzey[17] analysed the Θ^+ production in the $\gamma + D \rightarrow \Lambda + n + K^+$ reaction and studied the dependence of the reaction differential cross section on the nK^+ invariant mass and on the momentum of the final neutron p_n. He pointed out the importance of the interference between the signal and background. Due to a result of the cancellation between the interference and signal contributions, the Θ^+ signal was almost washed out after integrating over p_n. This is consistent with the CLAS'conclusion that no statistically significant structure has been found in analyzing the data of the $\gamma + D \rightarrow \Lambda + n + K^+$ reaction. For Θ^{++}, Huang[19] presented the STAR's results in nuclear collisions. A peak has been observed in the invariant mass distribution of $pK^+ + \bar{p}K^-$ in 18.6M d+Au collision events at $\sqrt{s_{NN}} = 200$GeV. The peak is centered at the mass of 1528±2±5MeV/c^2 with a statistical significance of 4.2σ. A weak signal with less statistical significance ($\sim 3\sigma$) has also been observed in 5.6M Au+Au collision events at 62.4GeV and no significant signal was observed in 10.7M Au+Au collision events at 200GeV.

Even if the pentaquark Θ^+ really existed in nature, its spin and parity had to be confirmed experimentally. In spite of many theoretical works on Θ^+, the predicted spin and parity for Θ^+ are not agreed with each other. For example, the chiral model advocated the positive parity for Θ^+[3], whereas the lattice QCD and the QCD sum rule claimed that its parity should be negative[20, 21]. Using the density-dependent part of the Θ^+ self-energy, Hyun-Chul Kim[22] et al investigated the medium modifications of the pentaquark Θ^+ in dense matter and took into account different parities of the Θ^+ baryon. In Ref. [23], the self-energy of Θ^+ at finite temperature and density was calculated at one-loop level of pseudovector and pseudoscalar $N\Theta^+K$ couplings with positive and negative Θ^+ parity. The Θ^+ mass shift and width shift in the medium were obtained. With the consideration of the new self-energy pieces relating to the coupling of the Θ^+ resonance to a baryon and two mesons, it was shown that the in-medium renormalization of the two meson cloud of Θ^+ could lead to a sizable attraction which is large enough to produce a bound and narrow Θ^+ state in the nucleus[24]. Whereas, H. Shen and H. Toki[25] assumed that the interactions of quarks and the meson fields such as σ, ω, and ρ mesons in nuclear matter and in nuclei change the properties of bayons in hadronic matter. The effective mass of the exotic baryon Θ^+ was investigated in the framework of RMF[26—28] and the Density Dependent Relativistic Hadron(DDRH)[29] theory.

In this paper, we try to select a density dependent scalar coupling according to the idea of the QMC model. We study the effect of the density dependent coupling $g_\sigma^N(\sigma)$ and the effective mass of Θ^+ with the density dependent coupling constant on the nuclear density ρ in RMF. The density dependent scalar coupling obviously affects both the baryon effective masses and the relation between the scalar density ρ_S and the nuclear density ρ in nuclear matter, especially at high density.

2 Relativistic mean-field formalism in nuclear matter

In the RMF theory, the effective Lagrangian density for baryons can be written as[1, 30]

$$\begin{aligned}\mathscr{L} = &\sum_B(\bar{\Psi}_B(\mathrm{i}\gamma^\mu\partial_\mu - M_B)\Psi_B - g_\sigma^B\bar{\Psi}_B\sigma\Psi_B - \\ &g_\omega^B\bar{\Psi}_B\gamma^\mu\omega_\mu\Psi_B - g_\rho^B\bar{\Psi}_B\gamma^\mu\rho_\mu^a\tau^a\Psi_B) + \\ &\frac{1}{2}\partial^\mu\sigma\partial_\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 - \\ &\frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_\omega^2\omega^\mu\omega_\mu - \\ &\frac{1}{4}R^{a\mu\nu}R^a_{\mu\nu} + \frac{1}{2}m_\rho^2\rho^{a\mu}\rho^a_\mu - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \\ &e\bar{\Psi}_B\gamma^\mu A^\mu\frac{1}{2}(1-\tau_3)\Psi_B,\end{aligned} \tag{1}$$

with

$$\begin{aligned}\Omega^{\mu\nu} &= \partial^\mu\omega^\nu - \partial^\nu\omega^\mu, \\ R^{a\mu\nu} &= \partial^\mu\rho^{a\nu} - \partial^\nu\rho^{a\mu}, \\ F^{\mu\nu} &= \partial^\mu A^\nu - \partial^\nu A^\mu.\end{aligned} \tag{2}$$

where B represents the nucleon or the pentaquark Θ^+. The meson fields are denoted by σ, ω_μ and ρ_μ, and corresponding masses of the mesons are m_σ, m_ω and m_ρ, respectively. g_σ^B , g_ω^B, g_ρ^B are the σ-baryon, ω-baryon and ρ-baryon coupling constants, respectively. The isospin Pauli matrix is written as τ^a with τ^3 being the third component.

Using the mean-field approximation, replacing the meson fields by their mean values, and neglecting the Coulomb field, we immediately have the equation of motion for baryons:

$$(\mathrm{i}\gamma_\mu\partial^\mu - M_B - g_\sigma^B\sigma_0 - g_\sigma^B\gamma^0\omega_0 - g_\rho^B\gamma^0\tau^3\rho_{03})\Psi_B = 0, \tag{3}$$

where σ_0 and ω_0 are the mean-field values of the scalar and vector mesons, respectively.

For nucleon, the effective mass is defined by

$$M_N^* = M_N - g_\sigma^N\sigma_0 \ . \tag{4}$$

Now, we look for the effective mass expression of Θ^+. By using the MIT bag model in Ref. [31,32], the coupling constants σ-S (the strange baryons) are obtained as

$$g_\sigma^S = n_q g_\sigma^q S_S(\sigma = 0), \tag{5}$$

where

$$S_S(r) = \frac{\Omega_0/2 + m_q^* R_S(\Omega_0 - 1)}{\Omega_0(\Omega_0 - 1) + m_q^* R_S/2} \ , \tag{6}$$

$$g_\sigma^S = \frac{n_q}{n} g_\sigma S_S(\sigma = 0)/S(\sigma = 0) = \frac{n_q}{n} g_\sigma \Gamma_{S/B} \ , \tag{7}$$

$$g_\sigma = \frac{n_q}{3} g_\sigma^N, \quad g_\omega = \frac{n_q}{3} g_\omega^N, \quad g_\rho = g_\rho^N, \tag{8}$$

with R_S being the bag radius for the strange baryon. g_σ^N, g_ω^N, g_ρ^N are the coupling constants for nucleon. For exotic baryon Θ^+, we assume isospin $I=0$, $\tau^a=0$ and $n_q=4$, which means that Θ^+ does not couple to the ρ meson. Thus, the relation of coupling constants can be written as[30]

$$g_\sigma^\Theta = \frac{4}{3} g_\sigma^N \Gamma_{\Theta/B}, \quad g_\omega^\Theta = \frac{4}{3} g_\omega^N \ , \tag{9}$$

and the effective mass of Θ^+ can be expressed as

$$M_{\Theta^+}^* = M_\Theta^+ - \frac{4}{3}\Gamma_{\Theta/B} g_\sigma^N \sigma_0 \ . \tag{10}$$

For symmetric infinite nuclear matter, the equations for the meson-field values of the scalar and vector mesons are written as

$$m_\sigma^2\sigma_0 + g_2\sigma_0^2 + g_3\sigma_0^3 = \sum_B \frac{\partial M_B^*}{\partial\sigma}\rho_S(B) \ , \tag{11}$$

$$m_\omega^2\omega_0 = \sum_B g_\omega^B \rho_B, \tag{12}$$

$$m_\rho^2 b_0 = \sum_B g_\rho \langle\Psi_B^+\tau^3\Psi_B\rangle, \tag{13}$$

where $\rho_S(B) = \langle\Psi_B^+\Psi_B\rangle$ and $\rho_B = \langle\Psi_B^+\gamma^0\Psi_B\rangle$. The scalar and vector densities in the infinite nuclear matter are

$$\rho_B = \frac{2}{(2\pi)^3}\int_{|k|<k_{F_B}} \mathrm{d}^3k = \frac{2k_{F_B}^3}{3\pi^2}, \tag{14}$$

$$\begin{aligned}\rho_S = &\frac{2}{(2\pi)^3}\int_{|k|<k_{F_B}} \mathrm{d}^3k\frac{M_B^*}{E_B^*} = \\ &\sum_B \frac{M_B^*}{\pi^2}\left[k_{F_B}E_{F_B}^* - M_B^{*2}\ln\frac{k_{F_B}+E_{F_B}^*}{M_B^*}\right],\end{aligned} \tag{15}$$

where

$$E_B^* = (M_B^{*2} + k_F{}^2)^{1/2} \ , \tag{16}$$

$$k_F = \left(\frac{3\pi^2\rho_B}{2}\right)^{1/3}. \tag{17}$$

The density-momentum tensor is defined by

$$T_{\mu\nu}=\sum_i \frac{\partial \mathscr{L}}{\partial(\partial_\mu \Psi_i)}\partial^\nu \Psi_i - g_{\mu\nu}\mathscr{L} \ . \tag{18}$$

The density of energy is given by

$$\begin{aligned}\varepsilon \ = \ \langle T_{00}\rangle &= \frac{1}{2}m_\sigma^2\sigma_0^2+\frac{1}{3}g_2\sigma_0^3+\frac{1}{4}g_3\sigma_0^4+\frac{1}{2}m_\omega^2\omega_0^2+\\ &\sum_{\mathrm{B}}\frac{2}{(2\pi)^3}\int_0^{k_{\mathrm{F}}(\mathrm{B})}\mathrm{d}\boldsymbol{k}(\boldsymbol{k}^2+M_{\mathrm{B}}^{*2})^{1/2}=\\ &\frac{1}{2}m_\sigma^2\sigma_0^2+\frac{1}{3}g_2\sigma_0^3+\frac{1}{4}g_3\sigma_0^4+\frac{1}{2}m_\omega^2\omega_0^2+\\ &\frac{2}{(2\pi)^3}\int_0^{k_{\mathrm{F_N}}}\mathrm{d}\boldsymbol{k}(\boldsymbol{k}^2+M_{\mathrm{N}}^{*2})^{1/2}+\\ &\frac{2}{(2\pi)^3}\int_0^{k_{\mathrm{F}_{\Theta^+}}}\mathrm{d}\boldsymbol{k}(\boldsymbol{k}^2+M_{\Theta^+}^{*\,2})^{\frac{1}{2}} \ .\end{aligned} \tag{19}$$

In our calculation, we select this method follow the fact that if assuming that only one exotic baryon exists in the symmetric infinite nuclear matter so that the effect of the single exotic baryon on the mean field value can be neglected[33].

3 Density dependent coupling in RMF

In the framework of RMF, nucleons are assumed as structureless particles, but quark degrees of freedom may appear in the high density matter. Thus, it is necessary to consider the effect of the quark structure of nucleon, which has intensively been studied in the quark-meson coupling (QMC) model[32]. In the QMC model, quarks in non-overlapping nucleon bags couple directly to scalar σ and the vector ω mesons. The nucleon behaves essentially as a point-like particle with an effective mass M_{N}^*, which only depends on the position through the σ field, moving in the vector potential generated by the ω meson. The difference between the RMF and QMC models only appears at the scalar coupling g_σ^{N}, namely, the scalar coupling g_σ^{N} of the RMF model is extended from that of the QMC model.

In the QMC model, the nucleon effective mass is obtained by

$$M_{\mathrm{N}}^*(\sigma(\boldsymbol{r}))=M_{\mathrm{N}}-g_\sigma(\sigma(\boldsymbol{r}))\sigma(\boldsymbol{r}). \tag{20}$$

Then the derivative of M_{N}^* is given by[33]

$$\frac{\partial M_{\mathrm{N}}^*}{\partial \sigma}=-3g_\sigma^{\mathrm{q}}\int_{\mathrm{bag}}\mathrm{d}\boldsymbol{r}\bar{\Psi}_{\mathrm{q}}\Psi_{\mathrm{q}}=-3g_\sigma^{\mathrm{q}}S(\sigma), \tag{21}$$

where g_σ^{q} is the coupling constant between quark and σ meson. $C(\sigma)$ is denoted by

$$C(\sigma)=S(\sigma)/S(0), \tag{22}$$

The σ-N coupling constant at $\sigma=0$ is denoted by g_σ, and the relationship between g_σ and g_σ^{q} is given by

$$g_\sigma=3g_\sigma^{\mathrm{q}}S(0) \ , \tag{23}$$

Using Eqs. (20), (21), (22) and (23), we obtain

$$\frac{\partial M_{\mathrm{N}}^*}{\partial \sigma}=-g_\sigma|_{\sigma=0}C(\sigma)=-\frac{\partial}{\partial \sigma}(g_\sigma(\sigma)\sigma) \ . \tag{24}$$

In Refs. [32,33], the scalar density ratio $C(\sigma)$ decreases linearly (to a very good approximation) with increasing $g_\sigma|_{\sigma=0}\sigma$. It can be written as:

$$C(\sigma_0)=1-a_{\mathrm{N}}(g_\sigma|_{\sigma=0}\sigma_0). \tag{25}$$

with $a_{\mathrm{N}}=8.8\times10^{-4}\mathrm{MeV}^{-1}$. σ_0 satisfies[32]

$$m_\sigma^2\sigma_0=g_\sigma|_{\sigma=0}C(\sigma_0)\rho_{\mathrm{S}}. \tag{26}$$

According to Eqs. (24) and (25), it is easy to obtain

$$M_{\mathrm{N}}^*=M_{\mathrm{N}}-g_\sigma^{\mathrm{N}}|_{\sigma=0}\left(1-\frac{a_{\mathrm{N}}}{2}g_\sigma^{\mathrm{N}}|_{\sigma=0}\sigma_0\right)\sigma_0. \tag{27}$$

On the other hand,

$$M_{\mathrm{N}}^*=M_{\mathrm{N}}-g_\sigma^{\mathrm{N}}(\sigma_0)\sigma_0. \tag{28}$$

Consequently, we get the scalar coupling g_σ^{N}

$$g_\sigma^{\mathrm{N}}(\sigma_0)=g_\sigma^{\mathrm{N}}|_{\sigma=0}\left(1-\frac{a_{\mathrm{N}}}{2}g_\sigma^{\mathrm{N}}|_{\sigma=0}\sigma_0\right). \tag{29}$$

In order to extend Eq. (29) in the QMC model to the RMF model, the effect of Θ^+ in Eq. (11) is neglected. If the effect of the internal structure of nucleon, which has been considered in the QMC model, is considered in the RMF model, it is reasonable to believe that the σ_0-dependent scalar coupling g_σ^{N} in RMF is similar to Eq. (29) in QMC. In RMF, the effective mass is $M_{\mathrm{N}}^*\approx0.6M_{\mathrm{N}}$ at normal nuclear density. It should not be changed at normal nuclear density, although we introduce the density dependent coupling $g_\sigma^{\mathrm{N}}(\sigma_0)$. To ensure this condition, $g_\sigma^{\mathrm{N}}=g_\sigma^{\mathrm{N}}(\sigma_0|_{\rho_0})$ is required only. So, it can be rewritten as

$$g_\sigma^{\mathrm{N}}=g_\sigma^{\mathrm{N}}|'_{\sigma=0}\left(1-\frac{a'_{\mathrm{N}}}{2}g_\sigma^{\mathrm{N}}|_{\sigma=0}\sigma_0\right). \tag{30}$$

Next, we will determine $g_\sigma^{\mathrm{N}}|'_{\sigma=0}$ and a'_{N} in RMF. As an approximation, for both models we assume that with the same value of scalar field σ, the change ratio from $g_\sigma^{\rm N}|_{\sigma=0}$ to $g_\sigma^{\rm N}$ in both the RMF and QMC models should be the same, namely, $\frac{a_{\rm N}}{2}g_\sigma^{\rm N}|_{\sigma=0}\sigma_0$ takes the same value in both the RMF and QMC models. According to Eq. (4), the effective masses of nucleon in the QMC model and in the RMF model at normal density are about $0.8M_{\rm N}$ and $0.6M_{\rm N}$, respectively. As an approximation, assuming $g_\sigma^{\rm N}|_{\sigma=0}\approx g_\sigma^{\rm N}$, we obtain $a'_N \simeq 4.4\times10^{-4}{\rm MeV}^{-1}$ in RMF. Combining Eq. (4) and Eq. (30) at normal density, we can determine the coupling constant $g_\sigma^{\rm N}|_{\sigma=0}$ according to the relation. The obtained $g_\sigma^{\rm N}|_{\sigma=0}$ with various parameter sets given in Ref. [2] and the corresponding data are written in Table 1.

Table 1. The model parameter sets with the density dependent coupling.

model	$M_{\rm N}$	m_σ	$g_\sigma^{\rm N}$	g_2	g_3	$g_\sigma^{\rm N}\|'_{\sigma=0}$
NL-SH	939.0MeV	526.059	10.444	6.9099	−15.8337	11.48
NLB	939.0MeV	510.000	9.6959	2.02714	1.6667	10.665
NLD	939.0MeV	476.700	8.26559	3.7997	8.3333	9.082
NL2	938.0MeV	504.890	9.11122	2.3040	13.7844	10.014

4 Results and discussions

In Eq. (30), we see that the coupling $g_\sigma^{\rm N}(\sigma_0)$ is a function of σ, and consequently is a function of nuclear density ρ according to Eqs. (11) and (15). The coupling $g_\sigma^{\rm N}(\sigma_0)$ as a function of the nuclear density ρ is plotted in Fig. 1. The dotted, solid and dot-dashed curves represent the results with the parameter sets NL2, NLD and NLB, respectively. From Fig. 1, we can see that the density dependent coupling $g_\sigma^{\rm N}(\sigma_0)$ is smaller (larger) than the constant coupling $g_\sigma^{\rm N}$ when the nuclear density ρ is larger (smaller) than normal nuclear density ρ_0.

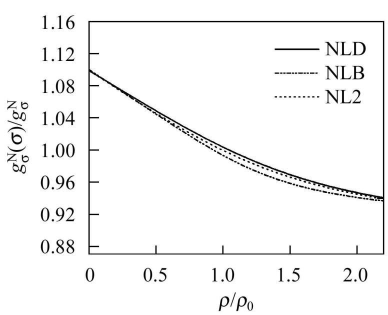

Fig. 1. The density dependent scalar coupling as a function baryon density for different parameter set.

If the constant coupling $g_\sigma^{\rm N}$ is replaced by the density dependent coupling $g_\sigma^{\rm N}(\sigma_0)$ in Eq. (30), a new relation between the scalar density $\rho_{\rm S}$ and the nuclear density ρ can be obtained. The scalar density $\rho_{\rm S}$ as a function of the nuclear density ρ is shown in Fig. 2. In Fig. 2, the dotted and solid curves represent the results with the parameter sets NL2 and NLD, respectively, and the dashed curve denotes the result in the constant coupling case. It is shown that there is no difference among these curves in the region of $\rho<\rho_0$, whereas a visible difference appears in the region of $\rho>\rho_0$, especially in the $\rho>2\rho_0$ region. With the same parameter set and the nuclear density ρ, the scalar density $\rho_{\rm S}$ with $g_\sigma^{\rm N}(\sigma_0)$ is larger than that with the constant coupling.

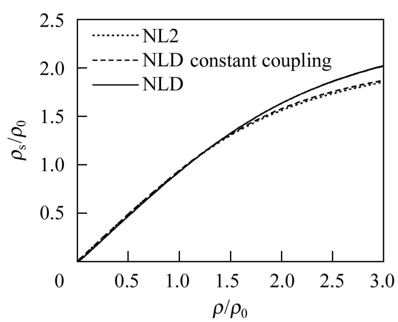

Fig. 2. The scalar density as a function of the baryon density for constant scalar coupling and density dependent scalar coupling.

To study how the density dependent coupling $g_\sigma^{\rm N}(\sigma_0)$ affects baryon effective masses, we replace the constant coupling $g_\sigma^{\rm N}$ in Eq. (10), where $\Gamma_{\Theta/{\rm B}}=1.0$, by the density dependent coupling constant $g_\sigma^{\rm N}(\sigma_0)$. The resultant effective masses of Θ^+ is a function of the nuclear density ρ with $g_\sigma^{\rm N}(\sigma_0)$. This relation is shown in Fig. 3. In this figure, for simplicity, we only demonstrate the result (dashed curve) by using the NL-SH parameter set as an example in the constant coupling case, and show the results calculated with the NL2, NL-SH and NLD sets by the dotted, solid and dot-dashed curves, respectively. From Fig. 3, we can see the effective masses of Θ^+ decrease with the increasing nuclear density ρ for all parameter sets.

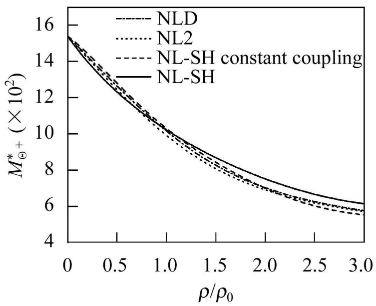

Fig. 3. The ratios of effective masses of Θ^+ in nuclear medium to those of in free space for constant scalar coupling and density dependent scalar coupling.

We compare the effective mass obtained by adopting the density dependent coupling constant $g^{\mathrm{N}}_{\sigma}(\sigma_0)$ with that by using the constant coupling in the NL-SH set case. It is shown that the effective mass of Θ^+ with the density dependent coupling constant is smaller than that with the constant coupling constant in the low density region of $\rho < \rho_0$, but is larger than that with the constant coupling constant in the region of $\rho > \rho_0$, especially in the $\rho > 2\rho_0$ region. It indicates that the interaction between the scalar meson and the baryon is obviously weakened by the density dependent coupling constant $g^{\mathrm{N}}_{\sigma}(\sigma_0)$ in the high density region.

5 Summary and conclusion

In summary, by using the density dependent coupling constant g^{N}_{σ} in the QMC model, we investigate the relations between the scalar density ρ_{S} and the nuclear density ρ and the dependence of effective masses of Θ^+ on the nuclear density ρ. The results show that it is necessary to consider the effect of the density dependent scalar coupling g^{N}_{σ} on the properties of baryon in nuclear matter, especially at high density. We must point out that this is only an attempt to introduce the density dependent scalar coupling constant g^{N}_{σ} in RMF. Our further studies are in progress.

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核物质中五夸克重子态 Θ^+ 的有效质量*

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摘要 在相对论平均场框架下, 根据夸克介子耦合模型思想引入密度相关的标量耦合系数 g_σ^{N}, 计算了密度相关耦合系数下, 核物质标量密度、五夸克重子态 Θ^+ 有效质量随核物质密度的变化情况, 并与不变耦合系数下情况相比较. 发现在低密度区域, 密度相关的耦合系数对其影响很小, 但在高密区域影响明显. 表明, 在密度相关的耦合系数影响下, 标量介子与重子的相互作用在高密度区域被削弱.

关键词 五夸克重子态 Θ^+ 密度相关耦合系数 有效质量

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