Interactions of η-meson in asymmetric nuclear matter

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ABSTRACT

The interactions between η-meson and nucleons are studied by the unification of chiral SU(3) model and chiral perturbation theory. The η meson-nucleon interactions for the next to leading order terms are derived by expanding the ηN interaction Lagrangian within the chiral perturbation theory. Using the chiral SU(3) model, we calculate the in-medium scalar density of protons, ρ_s^p and neutrons ρ_s^n for different values of temperature, T, isospin asymmetry, I, and nucleonic density, ρ_N. Within chiral SU(3) model the in-medium properties of nucleons are evaluated in terms of scalar-isoscalar fields σ, and ζ and the scalar-isovector field δ. Further, by clubbing the ηN equation of motion with the scalar density, the in-medium mass and optical potential of η meson are derived. We solve the equation of motion for sigma term, $\Sigma_{\eta N}$=280±130 MeV and scattering length, $a^{\eta N}$=1.025 fm for different values of asymmetry of the medium. We find an attractive mass-shift of the η meson in nuclear medium and magnitude of shift increase with increase in density. Finite isospin asymmetry of the medium causes less drop in the in-medium mass of η mesons. The negative mass-shift indicates the possibility of the formation of η-mesic nuclei.

INTRODUCTION

The study of baryon-meson interactions is a very interesting topic of research in strong interaction physics both theoretically and experimentally [1]. The interactions of kaon/pion/quarkonia with baryons have been much studied in the literature [2, 3] but η-baryons interactions still need more attentions. The ηN interactions were studied by Haider and Liu and it was anticipated that eta-nucleon interactions are attractive and there is a possibility of formation of eta-mesic nuclei [3]. Since then the bound states of η-nucleons has been one of the interesting research topics in the hadron physics [1, 4]. In ref. [1], for a correct description of the η-nuclear interactions, the off-shell terms *i.e.* next-to-leading order terms were added in the Lagrangian using heavy baryon chiral perturbation theory [4] and in-medium masses of η mesons were evaluated. The scalar and vector densities appearing in the equation of motion of η mesons were calculated using relativistic mean-field model at zero temperature. In the present work, we follow the work of [1] for the interaction of eta meson with nucleons. However, the values of scalar and vector density of nucleons are evaluated using chiral SU(3) model for finite temperature and isospin asymmetry of the medium [5]. Within chiral SU(3) model, coupled equations of motion for the scalar fields σ and ζ, the scalar-isovector field δ, the scalar dilaton field χ and the vector fields ω and ρ are solved to obtain their in-medium values. The scalar fields σ, ζ and δ are used to calculate the scalar densities of nucleons.

METHODOLOGY

In chiral perturbation theory the Lagrangian density of the meson-baryon interactions up to second order can be written as [1]

$$\mathcal{L}_{\eta N} = \frac{1}{2}\partial^\mu\eta\partial_\mu\eta - \frac{1}{2}\left(m_\eta^2 - \frac{\Sigma_{\eta N}}{f_\pi^2}\bar{\Psi}\Psi\right)\eta^2 + \frac{1}{2}\frac{\kappa}{f_\pi^2}\bar{\Psi}\Psi\partial^\mu\eta\partial_\mu\eta. \quad (1)$$

The second term in the above equation is called the sigma correction term and we consider the value of $\Sigma_{\eta N}$, parameter as $\Sigma_{\eta N}$=280 ±130 MeV [1]. The last term in the Eq.(1) is known as kappa term and the parameter κ is evaluated from the ηN scattering length using the following expression

$$\kappa = 4\pi f_\pi^2\left(\frac{1}{m_\eta^2} + \frac{1}{m_\eta m_N}\right)a^{\eta N} - \frac{\Sigma_{\eta N}}{m_\eta^2}, \quad (2)$$

where m_η (547 MeV) and m_N (939 MeV) are the vacuum mass of η-meson and nucleon, respectively [1]. In the present work, for η meson-nucleon scattering length, we consider $a^{\eta N}$ *i.e.* 1.02 fm [1]. Under the mean field approach, the Fourier transform of the equation of motion gives

$$-\omega^2 + \vec{k}^2 + m_\eta^2 - \frac{\Sigma_{\eta N}}{2f_\pi^2}\left(\rho_p^s + \rho_n^s\right) + \frac{\kappa}{2f_\pi^2}\rho_N^s\left(-\omega^2 + \vec{k}^2\right) = 0, \quad (3)$$

which is solved to obtain the energy of η meson in the nuclear matter. In above, $\langle\bar{\Psi}\Psi\rangle \equiv \left(\rho_p^s + \rho_n^s\right)$ represents the net scalar density of the nucleons, ρ_N^s, calculated in the chiral SU(3) model. The vector and scalar densities of nucleons at finite temperature are defined as

$$\rho_i^v = \gamma_i\int\frac{d^3k}{(2\pi)^3}\left(\frac{1}{1+\exp\left[\beta(E_i^*(k)-\mu_i^*)\right]} - \frac{1}{1+\exp\left[\beta(E_i^*(k)+\mu_i^*)\right]}\right), \quad (4)$$

and

$$\rho_i^s = \gamma_i\int\frac{d^3k}{(2\pi)^3}\frac{m_i^*}{E_i^*(k)}\left(\frac{1}{1+\exp\left[\beta(E_i^*(k)-\mu_i^*)\right]} + \frac{1}{1+\exp\left[\beta(E_i^*(k)+\mu_i^*)\right]}\right), \quad (5)$$

respectively. Also, μ_i^* and $E_i^* = \sqrt{m_i^{*2}+k^2}$ define the chemical potential and single particle energy of the nucleons, respectively. Here, $m_i^* = -g_{\sigma i}\sigma - g_{\zeta i}\zeta - g_{\delta i}\delta$ define the in-medium mass of nucleons. The impact of asymmetry on the vector density is incorporated by the formula, $I = -\frac{\sum_i \tau_{3i}\rho_i^v}{2\rho_N}$ [2, 5].

At zero momentum, the expression for in-medium mass, m_η^*, of η mesons is given as

$$m_\eta^* = \sqrt{\left(m_\eta^2 - \frac{\Sigma_{\eta N}}{2f_\pi^2}\rho_N^s\right)\Big/\left(1 + \frac{\kappa}{2f_\pi^2}\rho_N^s\right)}. \quad (6)$$

DISCUSSION

- The in-medium mass of η-meson decrease with the increase in nuclear density.
- The effective mass decrease less in the asymmetric medium and for non-zero temperature.
- The effective mass decreases more with an increase in the $\Sigma_{\eta N}$ parameter.

Table 1: In-medium mass $m_\eta*$ of η-meson

	ρ_N=ρ_0				ρ_N=4ρ_0			
	T=0 MeV		T=100 MeV		T=0 MeV		T=100 MeV	
$\Sigma_{\eta N}(MeV)$	η=0	η=0.5	η=0	η=0.5	η=0	η=0.5	η=0	η=0.5
150	431	433	445	445	325	335	338	343
280	429	431	437	438	316	327	331	336
410	426	429	441	442	305	317	321	326

CONCLUSIONS

✓ The effect of nuclear density is substantial on the in-medium mass of η-meson whereas the asymmetry and temperature effects are less.

✓ We find an attractive mass-shift which predicts the possibility of eta-mesic nuclei formation.

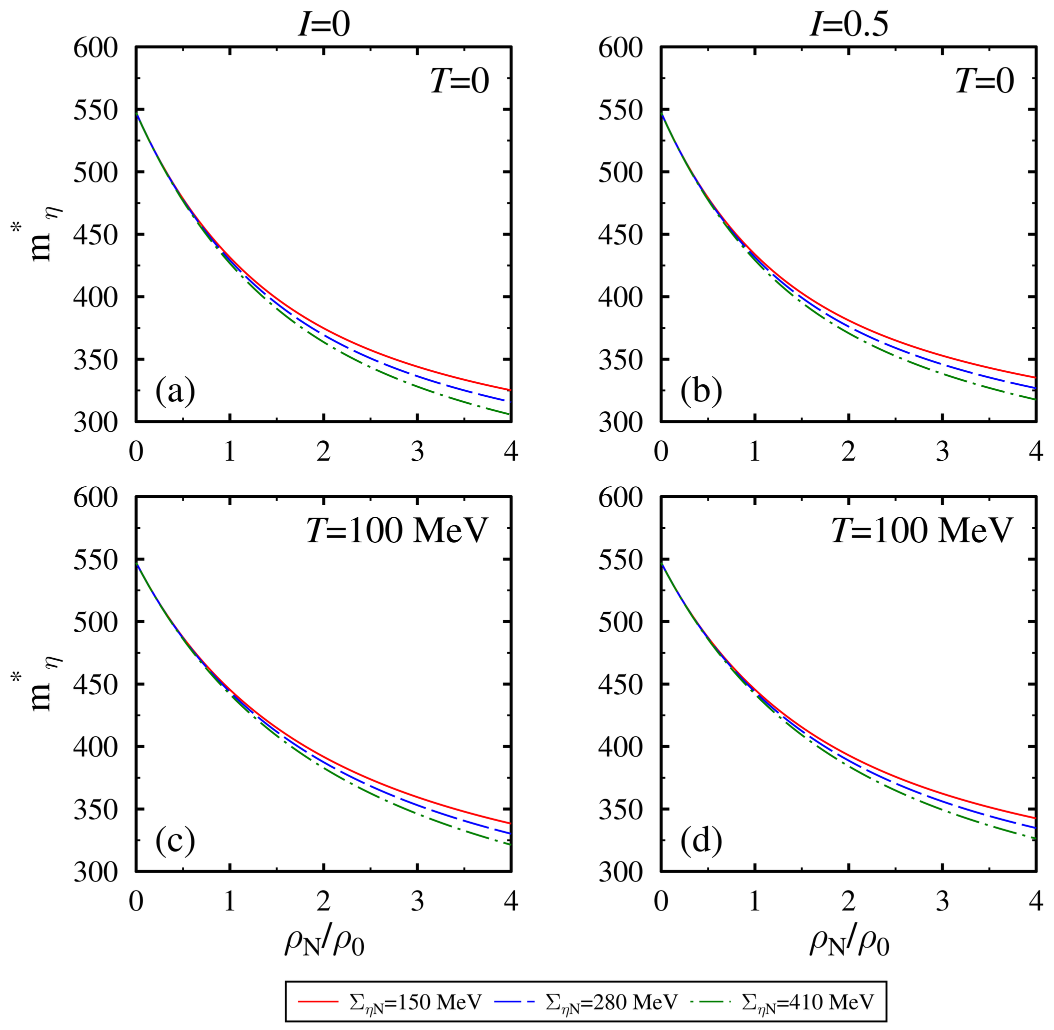

Figure 1: In-medium mass of η-meson

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