Masses of Δ baryons in isospin asymmetric non-strange hot resonance matter

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Introduction

The study of modification in the baryon properties within the dense medium is a significant area of research in strong interaction physics [1]. In the current work, we investigate the in-medium mass modifications of Δ baryons in isospin asymmetric non-strange resonance matter comprising of p, n, Δ^{++}, Δ^{+}, Δ^{0}, and Δ^{-} baryons at finite temperature using the chiral hadronic SU(3) model. The role of isospin-dependent medium effects is particularly significant for gaining insights into the structure of neutron stars, as the core of neutron stars is highly isospin asymmetric, and also for forthcoming asymmetric HIC experiments at the GSI FAIR [2].

Chiral SU(3) hadronic mean field model

The chiral SU(3) model depends on the non-linear realization of chiral symmetry and broken scale invariance [3]. We use this model to compute the medium-modified scalar, vector fields, and also the masses of Δ baryons. The effective Lagrangian density of this model is given by

$$\mathcal{L} = \mathcal{L}_{\rm kin} + \sum_{M=P,X,V,A} \mathcal{L}_{BM} + \mathcal{L}_0 + \mathcal{L}_{\rm vec} + \mathcal{L}_{\rm SB}. \tag{1}$$

In Eq. (1), $\mathcal{L}_{\rm kin}$ represents the kinetic term, and $\mathcal{L}_{BM}$ gives interaction term of the baryon with spin-0 and spin-1 mesons. $\mathcal{L}_0$ and $\mathcal{L}_{vec}$ describe the scalar and vector mesons self-interaction terms. The last term, $\mathcal{L}_{SB}$, of Eq. (1), stands for the explicit chiral symmetry breaking. To explore the properties of hadrons, we employ the mean-field approximation in which only scalar and vector mesons terms are included in $\mathcal{L}_{BM}$ interaction term.

The effective masses of baryons within this framework can be defined as

$$m_i^* = -\left(g_{\sigma i}\sigma + g_{\zeta i}\zeta + g_{\delta i} I_{3i}\delta\right) + m_{i0}, \tag{2}$$

where i= p, n, Δ^{++}, $\Delta^{\pm,0}$ and I_3 represents the third component of isospin. Also $g_{\sigma i}$, $g_{\zeta i}$, and $g_{\delta i}$ are coupling constants of scalar fields σ, ζ, and δ respectively. The additional mass term m_{i0} is considered to fit the vacuum masses of baryons. For this model, the thermodynamic potential per unit volume, $\frac{\Omega}{V}$ under the mean-field approximation, is provided by the equation,

$$\begin{aligned}\frac{\Omega}{V} &= -\frac{\gamma_i T}{(2\pi)^3}\sum_i \int d^3k \left\{ \ln\left(1 + e^{-\beta[E_i^*(k)-\mu_i^*]}\right) \right. \\ &\quad \left. + \ln\left(1 + e^{-\beta[E_i^*(k)+\mu_i^*]}\right)\right\} \\ &\quad - \mathcal{L}_{\rm vec} - \mathcal{L}_0 - \mathcal{L}_{SB} - V_{\rm vac}. \end{aligned} \tag{3}$$

The above thermodynamic potential is minimized with respect to the mesonic field σ, ζ, δ, χ, ω, and ρ to evaluate the coupled equations of motion. These equations are solved to acquire the in-medium values of these fields and masses of baryons for various values of baryonic density ρ_B, temperature T, and isospin asymmetry parameter $I_a = -\frac{\sum_i I_{3i}\rho_i}{\rho_B}$, where ρ_i is number density of i^{th} baryons.

Results and discussion

In this section, we present the results on the in-medium masses of Δ baryons in isospin symmetric and asymmetric non-strange reso-

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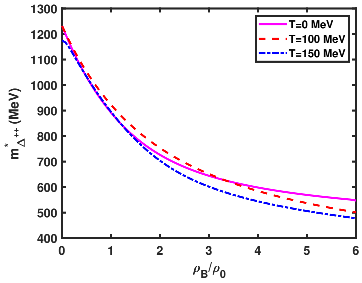

Figure 1: The in-medium masses of Δ^{++} baryons plotted as a function of the baryon density ρ_B/ρ_0 (in units of nuclear saturation density ρ_0), for symmetric ($I_a = 0$) non-strange resonance matter at temperatures, $T = 0$, 100 and 150 MeV.

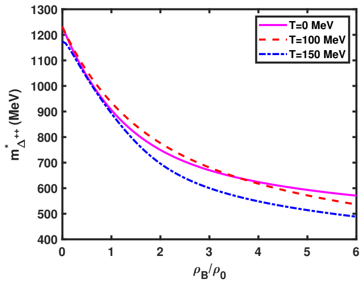

Figure 2: Same as Fig. 1, for $I_a = 0.3$

nance matter. In Fig. (1) and (2), we show dependence of the effective mass of Δ^{++} baryons on the baryon density ρ_B/ρ_0 at temperatures, $T = 0$, 100 and 150 MeV for $I_a = 0$ and 0.3. For given temperature T and isospin asymmetric parameter I_a, the in-medium mass of Δ^{++} baryon decreases with increasing baryonic density. As the ρ_B increases from 0 to ρ_0, there is a large decrease in the value of the $m^*_{\Delta^{++}}$, whereas for densities beyond ρ_0, the rate of drop in its values becomes slow .

	T=0 MeV		T=100 MeV		T=150 MeV	
I_a	ρ_0	$4\rho_0$	ρ_0	$4\rho_0$	ρ_0	$4\rho_0$
0	27.7	51.6	25.0	52.6	27.4	55.8
0.3	26.5	49.3	24.0	50.0	27.5	55.4

Table I: The relative percentage change in $m_{\Delta^{++}}$ from its vacuum value at different fixed values of ρ_B, I_a, and T.

For an isospin symmetric medium $I_a = 0$, the rate of drop in $m^*_{\Delta^{++}}$ becomes less pronounced as the temperature rises from 0 to 100 MeV for baryon densities below $4\rho_0$, while as the baryon density exceeds beyond $4\rho_0$, this rate of drop in its value increases as illustrated in Fig. 1. For same medium at T=150 MeV, $m^*_{\Delta^{++}}$ decreases more significantly compared to $T = 0, 100$ MeV when ρ_B exceeds $1.5\rho_0$. This effect can be explained by partial restoration of chiral symmetry at high temperature.

While shifting from $I_a = 0$ to 0.3, it is observed that there is slightly less drop in the $m^*_{\Delta^{++}}$, as shown in Fig. 2. This is due to the fact that effective masses of baryons are directly dependent on scalar fields σ, ζ, and scalar isovector field δ. These fields affect the in-medium masses of Δ baryons. The presence of baryons within the medium enhance attractive interactions , resulting in a more significant reduction in $m^*_{\Delta^{++}}$ as temperature rise. The relative percentage change in $m^*_{\Delta^{++}}$ from its vacuum value (1232 MeV) are tabulated in Table I at different values of ρ_B, I_a, and T. The in-medium masses of $\Delta^{\pm,0}$ baryons exhibit a similar trend like $m^*_{\Delta^{++}}$ because they belong to the same isospin multiplet.

Acknowledgments

The authors sincerely acknowledge the support for this work from the Ministry of Science and Human Resources (MHRD), Government of India, through an Institute fellowship under the National Institute of Technology Jalandhar. Arvind Kumar sincerely acknowledge Anusandhan National Research Foundation (ANRF), Government of India for funding of the research project under the Science and Engineering Research Board-Core Research Grant (SERB-CRG) scheme (File No. CRG/2023/000557).

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