Magnetic moment of Σ^+ hyperon in isospin asymmetric magnetized strange matter

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Introduction

Hadronic matter under extreme conditions provides a unique environment to investigate the non-perturbative aspects of QCD. Among its observables, baryon magnetic moments are particularly significant as they encode quark dynamics, spin polarizations, and sea quark contributions, thereby linking microscopic interactions with macroscopic properties of dense matter. Extensive studies using quark models [1], QCD sum rules [2], chiral perturbation theory, and lattice QCD have explored baryonic magnetic moment in vacuum and symmetric matter [3], at zero magnetic field. The aim of present work is to explore the impact of strong magnetic field on the magnetic moment of Σ^+ hyperons, considering finite isospin asymmetry and strangeness fraction.

In this context, this study employs the chiral constituent quark model extended to SU(4) to calculate the magnetic moments whereas the in-medium modification are incorporated using the chiral SU(3) quark mean field model (CQMF).

Methodology

In the CQMF model the effective Lagrangian consists of the kinetic energy term for quarks, the quark mean interaction term, the self interaction term for scalar and vector mesons, as well as an explicit chiral symmetry breaking term. In the CQMF model interactions among quarks are mediated through the exchange of scalar field (σ, ζ, δ) and vector field (ω, ρ, ϕ).

Effective quark mass of u,d,s quarks arise from scalar couplings and its expressed as,

$$m_q^* = m_q - g_\sigma^q \, \sigma - g_\zeta^q \, \zeta - g_\delta^q I_{3q} \, \delta, \quad (1)$$

where m_q is the vacuum quark mass and g_σ^q, g_ζ^q, g_δ^q are coupling constants and I_{3q} is the third component of isospin.

In the chiral constituent quark model, the total magnet moment of baryon is expressed as,

$$\mu_B^* = \mu_B^{*\text{val}} + \mu_B^{*\text{sea}} + \mu_B^{*\text{orbit}}, \quad (2)$$

$$\mu_B^{*\text{val}} = \sum_{q=u,d,s} \Delta q^{\text{val}} \, \mu_q^*, \quad (3)$$

$$\mu_B^{*\text{sea}} = \sum_{q=u,d,s} \Delta q^{\text{sea}} \, \mu_q^*, \quad (4)$$

$$\mu_d^* = -\left(1 - \frac{\Delta M}{M_B^*}\right), \qquad \mu_u^* = -2\mu_d^*, \quad (5)$$

$$\mu_s^* = \left(\frac{m_u^*}{m_s^*}\right) \mu_d^*, \qquad \mu_c^* = -\left(\frac{2m_u^*}{m_c}\right) \mu_d^*, \quad (6)$$

where $\Delta M = M_{vac} - M_B^*$. Here, M_{vac} is vacuum mass of baryon and M_B^* is effective baryon mass. The third term in Eq.(2) considers the contribution of orbital angular momentum associated with quark sea [4, 5]. Here, Δq^{val} and Δq^{sea} denotes spin polarization due to valence and sea quarks, respectively. Here, Eq.(5) and Eq.(6) represent the effective magnetic moments of u,d,s,c quark and m_u^*, m_s^* represents the effective masses of up and strange quark respectively and the

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strange quark mass, $m_c = 1270$ MeV. The impact of finite magnetic field is incorporated in the calculations through scalar and vector densities of baryons [6].

Results and Discussion

In Fig 1 and Fig 2 we illustrate the variation of total magnetic moment of Σ^+ hyperon (in units of μ_N) as a function of magnetic field i.e. eB/m_π^2 ($m_\pi = 139$ MeV).

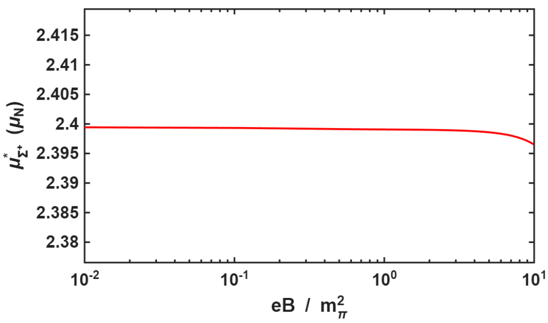

FIG. 1: Variation of the total magnetic moment, $\mu^*_{\Sigma^+}$ (in units of μ_N), with respect to the magnetic field strength eB/m_π^2, in vacuum at T = 100 MeV ($\rho_B = 0\ fm^{-3}$, $\eta = 0, fs = 0$).

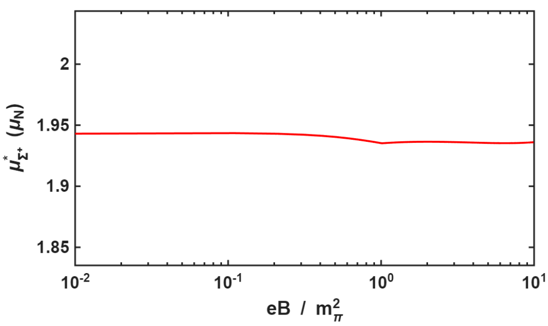

FIG. 2: The total magnetic moment, $\mu^*_{\Sigma^+}$ (in units of μ_N), as a function of eB/m_π^2, at finite density, in asymmetric strange matter at T = 100 MeV ($\rho_B = 0.16\ fm^{-3}$, $\eta = 0.3, fs = 0.3$).

The results are shown for a finite temperature of T = 100 MeV with isospin asymmetry parameter, $\eta = 0$ and 0.3 and the strangeness factor, $fs = 0$ and 0.3 respectively.

In Fig 1, negligible variation is seen in the total magnetic moment of Σ^+ hyperon at $\rho = 0$, that is at vacuum. The valence quark contribution is highest compared to quark sea and orbital angular momentum. Since, the change in magnetic moment comes from the effective quark mass (m_q^*) and the scalar fields affect the m_q^*. In this case, the variation is negligible, resulting minute change in the total magnetic moment of the Σ^+ hyperon.

In Fig 2, we present the results of the total magnetic moment of Σ^+ hyperon at finite density in asymmetric strange matter, where the value of $\mu^*_{\Sigma^+}$ is noticeably lower compared to the vacuum value. The change in the $\mu^*_{\Sigma^+}$ with respect to eB/m_π^2 is negligible as a result of mild change in the values of m_q^* due to very small variation in the scalar fields. The present calculations of in-medium magnetic moments of hyperons can be used as input to calculate their polarization in heavy-ion collisions [7, 8].

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