Decuplet Baryon Magnetic Moments in Strange Matter

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Introduction

The study of decuplet baryon properties has been an important area of research since their discovery in heavy ion collision experiments. It is quite difficult to calculate static properties such as magnetic moment and charge radius of decuplet baryons because of their short life time and occurrence in high baryonic density regime. Due to this reason, only the magnetic moments of Ω^- [1] and Δ^{2+} [2] have been measured experimentally. On the theoretical side, the vacuum magnetic moments of decuplet baryons have been widely studied using different models. However, the calculations of decuplet baryon magnetic moments in the presence of baryonic matter have not been done in the available literature. The calculation of in-medium magnetic moments can help in determination of other properties of decuplet baryons such as electromagnetic form factors and charge radii and also to understand their behavior in external magnetic field. In the present work, we use chiral SU(3) quark mean field model [3] to determine the medium modified masses of constituent quarks and decuplet baryons in the strange baryonic matter at zero temperature. We use these medium modified masses to determine in-medium magnetic moments of constituent quarks alongwith the calculation of medium modified spin polarizations due to valence quarks and quark sea. These medium modified values of magnetic moments and spin polarizations will further be used to calculate the magnetic moment of decuplet baryons in strange matter.

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Chiral SU(3) Quark Mean Field Model

The total effective Lagrangian density in chiral SU(3) quark mean field model is written as

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{q0} + \mathcal{L}_{qm} + \mathcal{L}_{\Sigma\Sigma} + \mathcal{L}_{VV} + \mathcal{L}_{\chi SB} + \mathcal{L}_{\Delta m} + \mathcal{L}_{c}. \tag{1}$$

The details of above Lagrangian densities can be found in [3, 4]. The effective quark mass m_q^* is derived from scalar meson fields and given as

$$m_q^* = -g_\sigma^q \sigma - g_\zeta^q \zeta + m_{q0}, \tag{2}$$

where m_{q0} ($m_{u0} = m_{d0} = 0$ and $m_{s0} = 29$ MeV) is introduced to reproduce exact vacuum masses of constituent quarks. The analytical expression for effective energy of quark e_q^* is written as

$$e_q^* = m_q^* + \frac{3\sqrt{k_c}}{\sqrt{2(e_q^* + m_q^*)}}, \tag{3}$$

where the constant $k_c = 100$ MeV.fm^{-2} [4]. The effective mass and energy of j^{th} decuplet baryon can be calculated using effective quark energies through the relations

$$M_j^* = \sqrt{E_j^{*2} - < p_{j\,\mathrm{cm}}^{*2} >}, \tag{4}$$

where

$$E_j^* = \sum_q n_{qj} e_q^* + E_{j\,\mathrm{spin}}, \tag{5}$$

where $E_{j\,\mathrm{spin}}$ represents the correction to baryon energy coming from spin-spin interaction between constituent quarks. The details of $E_{j\,\mathrm{spin}}$ and other parameters appearing in eqns. (2,4,5) can be found in [4]. Following the chiral quark model approach [5], the magnetic moment of baryons, including the contributions from valence quarks, quark sea and orbital angular momentum of quark sea in terms

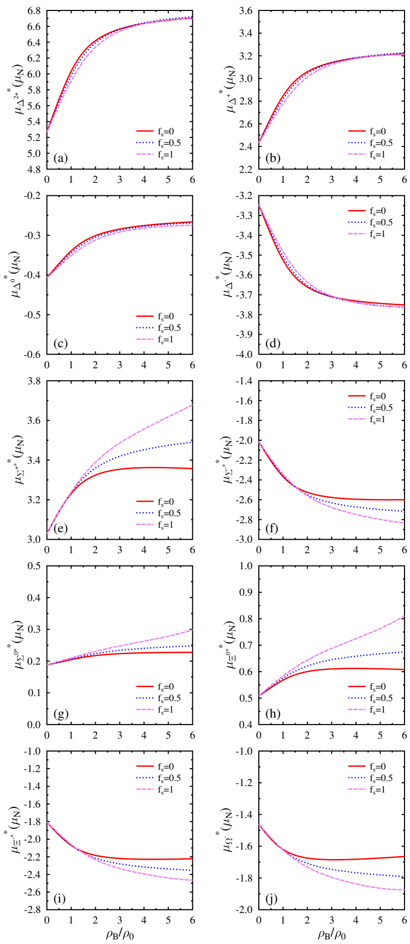

FIG. 1: Decuplet baryon magnetic moments versus baryonic density (in units of nuclear saturation density ρ_0) for strangeness fractions f_s = $0, 0.5$ and 1.

of respective spin polariations can be written as

$$\mu\left(B\right)_{\text{total}} = \sum_{q=u,d,s}\left(\Delta q_{\text{val}}\mu_q^* + \Delta q_{\text{sea}}\mu_q^* + \Delta q_{\text{orbital}}\mu_q^*\right), \quad (6)$$

where Δq_{val}, Δq_{sea} and $\Delta q_{\text{orbital}}$ are the spin polarisations due to valence quarks, quark sea and orbital angular momentum of quark sea, respectively. In eq. (6), μ_q^* represents the constituent quark magnetic moment and for u, d and s quarks these are given by

$$\mu_d^* = -\left(1 - \frac{\Delta M}{M_B^*}\right), \quad \mu_s^* = -\frac{m_u^*}{m_s^*}\left(1 - \frac{\Delta M}{M_B^*}\right), \quad \mu_u^* = -2\mu_d^*, \quad (7)$$

respectively. Above relations incorporate the property of quark confinement and relativistic correction to quark magnetic moments [6].

Results

The total effective magnetic moment of decuplet baryons as a function of density and for different values of strangeness fraction (f_s) are presented in fig. (1). We find that

1) For given strangeness fraction, in the low baryonic density regime, the magnetic moment of non-strange decuplet baryons show a large increase in their magnitudes as a function of baryonic density of the medium as compared to the strange decuplet baryons.

2) For baryonic densities upto nuclear saturation density, the magnitude of magnetic moment of strange decuplet baryons are not effected by the rise of strangeness content of the medium. However, for more higher densities, these baryons show a large increase in the magnitudes of their magnetic moments. The magnetic moments of non-strange baryons show a small decrease in their magnitudes with the rise of strangeness fraction for densities upto $3\rho_0$ and become almost unaffected for more higher values of baryonic densities.

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