Magnetic Moments of Σ_b^+ Baryon in Nuclear Medium

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1. Introduction

Studying the magnetic moments of light and heavy baryons is important for probing quark dynamics and testing quantum chromodynamics (QCD) models [1]. In present work, the medium modifications of magnetic moment of Σ_b^+ baryon(valence contribution) in nuclear matter has been studied as a function of density. The in-medium effects have been introduced through chiral $SU(3)$ quark mean-field model, where quarks are considered as the basic degrees of freedom for the valence contribution toward μ_{total}, which has been calculated using the chiral constituent quark model(χCQM).

2. Methodology

In the chiral quark model (χQM), constituent quarks are confined within baryons by a confining potential. With the inclusion of the confining potential χ_c, the Dirac equation for the quark field ψ_{qi} can be expressed as [2]

$$[-i\alpha.\nabla + \chi_c(r) + \beta m_q^*]\psi_{qi} = e_q^*\psi_{qi}.$$

where $\chi_c = \frac{1}{4}k_c r^2(1+\gamma^0)$, with $k_c = 98$ MeV fm^{-2}. Also m_q^* and e_q^* denote effective constituent quark mass, and effective energy of the quarks defined through relations

$$m_q^* = -g_\sigma^q\sigma - g_\zeta^q\zeta + m_{q0}$$
$$e_q^* = e_q - g_\omega^q\omega. \quad (1)$$

The effective mass of the i^{th} baryon is calculated from its effective energy E_i^* and the in-medium spurious center-of-mass momentum $p_{i\,cm}^*$ through the relation [4]

$$M_i^* = \sqrt{E_i^{*2} - < p_{i\,cm}^{*2} >}. \quad (2)$$

where $E_i^* = \sum_q n_q e_q^* + E_{ispin}$

The term $E_{i_{spin}}$ is the correction to the baryon energy, accounting for the spin-spin interaction, and is adjusted to match the observed baryon masses in free space. The spurious center-of-mass momentum, $p_{i_{cm}}^*$ is expressed in term of m_q^* and e_q^* through relation

$$< p^{*2}_{i\,cm} > = \frac{(11e_q^* + m_q^*)}{6(3e_q^* + m_q^*)}(e_q^{*2} - m_q^{*2}).$$

The values of m_q^* and e_q^* are obtained by minimizing the thermodynamic potential Ω with respect to meson fields mentioned above. The thermodynamic potential is defined as

$$\Omega = -\frac{T}{(2\pi)^3}\sum_i \gamma_i \int_0^\infty d^3k \left[\ln\left(1 + e^{-\frac{E_i^*(k)-\nu_i^*}{T}}\right) + \ln\left(1 + e^{-\frac{E_i^*(k)+\nu_i^*}{T}}\right)\right] - \mathcal{L}_M - \mathcal{V}_{\rm vac}. \quad (3)$$

here ν_i^* is effective chemical potential, $\mathcal{V}_{vac}$ is the vacuum energy correction term and $\mathcal{L}_M$ denotes self-interactions of vector and scalar fields. The effective magnetic moment of a given baryon is expressed as [3]

$$\mu^*_{B,total} = \mu^*_{B,val} + \mu^*_{B,sea} + \mu^*_{B,orbit}. \quad (4)$$

The most dominant component $\mu^*_{B,val}$ is expressed as

$$\mu^*_{B,val} = \sum_{q=u,d,c,s,b} \Delta q_{\rm val}\mu_q^*. \quad (5)$$

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The effects of quark confinement and relativistic corrections are accounted through the inclusion of mass adjusted effective magnetic moments of the quarks through relations

$$\mu_d^* = -\left(1 - \frac{\Delta M}{M_i^*}\right), \quad (6)$$

$$\mu_b^* = -\frac{m_u^*}{m_b^*}\left(1 - \frac{\Delta M}{M_i^*}\right), \quad (7)$$

$$\mu_u^* = -2\mu_d^*. \quad (8)$$

Here, M_i^* is the effective mass of the baryon. The value of Δq_{val} is calculated using χCQM. The spin structure of a spin $\frac{1}{2}^+$ baryon is given as

$$B \equiv \langle B|\hat{N}|B\rangle = \cos^2\phi\langle 120,{}^2 20_M|\hat{N}|120,{}^2 20_M\rangle_B + \sin^2\phi\langle 168,{}^2 20_M|\hat{N}|168,{}^2 20_M\rangle_B \quad (9)$$

where $\hat{N}$ is number operator. On solving quark polarization relation we found $\Delta u = \left(\frac{4}{3}cos^2\phi + \frac{2}{3}sin^2\phi\right)$ and $\Delta b = \left(-\frac{1}{3}cos^2\phi + \frac{1}{3}sin^2\phi\right)$ for Σ_b^+ baryon.

3. Results

In fig. 1 the effective mass of Σ_b^+ baryon as a function of ρ_b is shown and found to decrease with density. At baryon density $\rho_b = 0, \rho_0$ and $3\rho_0$ the values of effective masses ($M^*_{\Sigma_b^+}$) are observed to be 5811, 5671.556 and 5554.980 MeV respectively. The variation in mass of baryon with density also has an impact on magnetic moment as well, as evident from eqs (6)-(8). The valence contribution of $\mu(\Sigma_b^+)$ is found to be increase with density as shown in fig. 2

Values of magnetic moment of Σ_b^+ baryon are found to be 2.5248, 2.5816 and 2.6303 at $\rho_b = 0, \rho_0$ and $3\rho_0$ respectively in the unit of μ_N.

The results obtained in this study has been compared with various theoretical models like quark– meson coupling (QMC) model [5],light cone QCD sum rules [1],quark mean field model [2]. Our model shows good agreement with the results presented in these paper except QMC model .

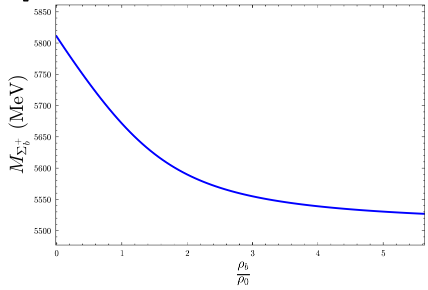

FIG. 1: Effective mass of Σ_b^+ as a function of ρ_b (in units of nuclear saturation density ρ_0)

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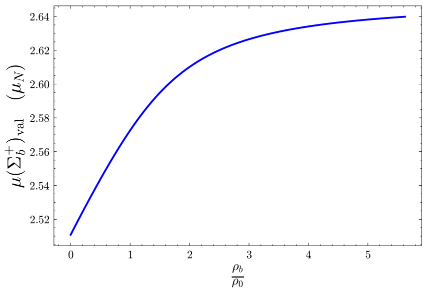

FIG. 2: Valence contribution towards magnetic moment of Σ_b^+ baryon as function of ρ_b (in units of nuclear saturation density ρ_0)

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