Baryon Magnetic Moments in Nuclear Matter at Finite Temperature and Density

Harpreet Singh,* Arvind Kumar, and Harleen Dahiya
Department of Physics, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar - 144011, Punjab, India.

Introduction

The study of the properties of baryons at finite temperature and density is important for understanding the experimental observables produced in different experimental facilities, for example, at RHIC, LHC and future CBM at FAIR, GSI etc. The experiments performed by European Muon Collaboration (EMC) show that the electromagnetic properties of nucleons in the medium are different as compared to free space [?]. The contribution in magnetic moments due to strange quark in nucleons plays an important role beside those from non-strange quarks. Therefore, one must consider $SU(3)$ symmetry based models for the study of baryon magnetic moments. In the present work, we investigate the modification of magnetic moment of baryons at finite density and temperature of nuclear matter. Magnetic moments are very useful to study baryon structures and have been extensively studied in free space [?].

In Medium Baryon Magnetic Moments

To study medium modification of magnetic moment of baryons, we have used Chiral $SU(3)$ Quark Mean Field (QMF) model. Finite nuclei properties have been studied by using this approach and reasonably good results have been obtained [?]. Within QMF model the effective masses of quarks and baryons can be expressed in terms of scalar fields σ and ζ. The coupled equations of motion, for scalar fields σ and ζ, are obtained from Lagrangian density [?] and are solved at finite density and temperature of nuclear medium. Using these constituent quark masses, we can calculate effective masses of baryons. We use the obtained effective masses to find magnetic moments of baryons due to valence quarks and quark sea effects from the equation,

$$\mu(B)_{\rm total} = \mu(B)_{\rm val} + \mu(B)_{\rm sea}, \quad (1)$$

where, the valence and the sea contributions, in terms of quark spin polarizations, can be expressed as

$$\mu(B)_{\rm val} = \sum_{q=u,d,s} \Delta q_{\rm val} \mu_q, \quad (2)$$

and

$$\mu(B)_{\rm sea} = \sum_{q=u,d,s} \Delta q_{\rm sea} \mu_q, \quad (3)$$

respectively. In above equations, $\mu_q = \frac{e_q}{2M_q}$ ($q = u, d, s$) is the quark magnetic moment, e_q and M_q are the electric charge and the mass for the quark q, respectively. Quark spin polarizations can be defined as, $\Delta q = q_+ - q_- + \bar{q}_+ - \bar{q}_-$, where, $q_\pm$ and $\bar{q}_\pm$ can be calculated from the spin structure of a baryon.

Results and Summary

For the calculation of scalar meson fields, we have used the parameter set from Ref. [?]. For including the valence quark and quark sea effects in magnetic moments, we use the parameters given in Ref. [?]. In the low density region, the σ meson field varies rapidly with the increase in baryonic density, however,

*Electronic address: harpreetmscdav@gmail.com

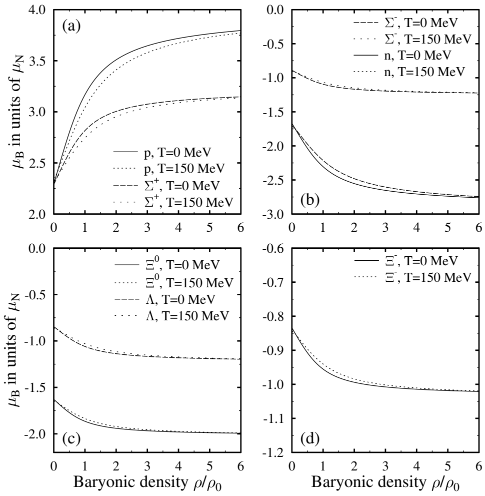

FIG. 1: Magnetic moment (in units of nuclear magneton, μ_N) of baryons (at T=0 MeV and T=150 MeV) versus baryonic density (in units of nuclear saturation density ρ_o).

for densities more than saturation density, the variation is very slow. This is due to constraints of saturation of nuclear matter. The ζ meson field varies very slowly with density because there is no coupling between the ζ meson and non-strange quarks (u,d). In Fig. 1, we show the variation of magnetic moment of nucleons (hyperons) with density, at T=0 MeV (T=150 MeV). We see the sequence, at T=0 MeV, $\mu_p^*/\mu_p = 1.38$, $\mu_n^*/\mu_n = 1.38$, $\mu_\Sigma^*/\mu_\Sigma = 1.3$, $\mu_\Lambda^*/\mu_\Lambda = 1.25$, $\mu_\Xi^*/\mu_\Xi = 1.14$, at nuclear saturation density, where, $\mu_p, \mu_n, \mu_\Sigma, \mu_\Lambda, \mu_\Xi$ ('*'denotes in medium) are the magnetic moments of baryons in the free space. They have values, $\mu_p = 2.293, \mu_n = -1.669, \mu_{\Sigma^+} = 2.288, \mu_{\Sigma^-} = 0.889, \mu_\Lambda = -0.8449, \mu_{\Xi^0} = -1.628, \mu_{\Xi^-} = -0.834$ (all values in units of nuclear magneton μ_N), obtained in this model. At T=150 MeV, the ratios of μ_B^*/μ_B shift to 1.32, 1.32, 1.19, 1.22, 1.127, respectively. From the above listed values, we observe that, at finite density and temperature of the medium, the nucleons are effected more as compared to hyperons. The probable cause behind this behavior is the dependence of magnetic moments on the effective baryonic masses considered in model here, which in turn depend on effective quark masses.

We find that, with the rise of temperature, the variation of magnetic moment with baryonic density is less. These results are further justified by the work of Ref. [**?**], in which the similar calculations have been done using MIT bag model and quark meson coupling model. However, the QMF model used in the present work for the calculation of magnetic moment of baryons is more improved, in respect of basic properties of QCD, as compared to MIT bag model and QMC model.

Acknowledgments

A. Kumar gratefully acknowledge the Department of Science and Technology (Government of India) for financial help under project (SR/FTP/PS-209/2012).

[1] J.J. Aubert *et al.*, Phys. Lett. B **123**, 275 (1983).
[2] H. Dahiya, M. Gupta, Phys. Rev. D **64**, 014013 (2001).
[3] W. Ping, *et al.* Commun. Theor. Phys. **36**, 71 (2001).
[4] C.Y.Ryu. *et al.* J.Phys. G **37**, 105002 (2010).