Space-like magnetic form factors of proton in nuclear medium

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Introduction

The study of the properties of hadrons at finite density and temperature is an active topic of research in the non-perturbative regime of QCD. The internal structure of hadrons which can be studied through the electromagnetic form factors may modify at finite density and/or temperature of the nuclear medium [1].

In the present work, we calculate the magnetic form factors of proton in asymmetric nuclear medium. The form factors of proton are calculated using vector meson dominance model and considering the internal quark structure. The in-medium effects are introduced through the medium modification of the masses of vector mesons as well as the modification in magnetic moment of nucleons. The masses of vector mesons in asymmetric nuclear matter are calculated using QCD sum rules and chiral SU(3) mean field model. For the calculation of medium modified magnetic moments, we use the chiral SU(3) quark mean field model. The finite baryonic density as well as the isospin asymmetry of the medium are found to affect significantly the magnetic form factors of proton.

In-medium electromagnetic form factors

Under the principle of relativistic invariance, the nucleon current is written in terms of Dirac form factor F_1 and Pauli form factor F_2 through the relation

$$J_\mu = F_1(Q^2)\gamma^\mu + \frac{1}{2M_N} F_2\left(Q^2\right) i\sigma^{\mu\nu} q_\nu. \quad (1)$$

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To calculate the electromagnetic form factor of nucleons in the present work, we employ the vector meson dominance model, within which photons couple to nucleons through the vector mesons ω, ρ and ϕ [2]. Coupling of nucleons to the vector mesons leads to the relation of sach form factors G_E and G_M of protons to the isoscalar form factor F^S and isovector form factor F^V, expressed as [2]

$$\begin{aligned} G_{M_p} &= \left(F_1^S + F_1^V\right) + \left(F_2^S + F_2^V\right) , \\ G_{E_p} &= \left(F_1^S + F_1^V\right) - \tau\left(F_2^S + F_2^V\right) , \end{aligned} \quad (2)$$

where

$$\begin{aligned} F_1^S(Q^2) &= \frac{1}{2} g(Q^2)\Big[1 - \beta_\omega - \beta_\varphi + \beta_\omega V_\omega^* + \beta_\varphi V_\varphi^*\Big] , \\ F_1^V(Q^2) &= \frac{1}{2} g(Q^2)\left[1 - \beta_\rho + \beta_\rho V_\rho^*\right] , \\ F_2^S(Q^2) &= \frac{1}{2} g(Q^2)\Big[\left(\mu_p^* + \mu_n^* - 1 - \alpha_\varphi\right) V_\omega^* + \alpha_\varphi V_\varphi^*\Big] , \\ F_2^V(Q^2) &= \frac{1}{2} g(Q^2)\Big[\frac{(\mu_p^* - \mu_n^* - 1 - \alpha_\rho)}{1+\gamma Q^2} + \alpha_\rho V_\rho^*\Big]. \end{aligned} \quad (3)$$

In the above equations, $V_i^* = \frac{m_i^{*2}}{m_i^{*2}+Q^2}$, where i denotes the vector mesons ω, ρ or ϕ. Here, m_i^* is the in-medium mass of vector mesons and is calculated using the QCD sum rules and chiral SU(3) model [3]. In QCD sum rules, the masses of vector mesons are expressed in terms of quark and gluon condensates. The expectation values of quark and gluon condensates are calculated at finite density and isospin asymmetry of the medium using mean field chiral SU(3) model through the scalar fields σ and ζ and the scalar-isovector field δ, and are used as input in QCD sum rules, to obtain the density dependent masses of vector mesons [3]. The Q^2 dependence of the form factors in the present calculations is sensitive to the decay width of ρ mesons. The in-medium decay width Γ_ρ^* of ρ mesons enters in eq. (3) through substitution [2]

$$V_\rho^* \to \frac{m_\rho^{*2} + 8\Gamma_\rho^* m_\pi/\pi}{m_\rho^{*2} + Q^2 + (4m_\pi^2 + Q^2)\,\Gamma_\rho^* \alpha(Q^2)/m_\pi}. \quad (4)$$

The in-medium decay width Γ_ρ^* is calculated using equation

$$\Gamma_\rho^* = \frac{g_{\rho\pi\pi}^2}{48\pi} m_\rho^* \left(1 - \frac{4m_\pi^2}{m_\rho^{*2}}\right)^{3/2} (X - Y). \quad (5)$$

In the above equation, $X = \left(1 + f\left(\frac{m_\rho^*}{2}\right)\right)$ and $Y = f\left(\frac{m_\rho^*}{2}\right)$. Here, $f(z) = exp\left[z/T - 1\right]^{-1}$ $(z = m_\rho^*/2)$ is the Bose-Einstein distribution function. The coupling constant $g_{\rho\pi\pi}$ is fixed to the vacuum value of decay width of ρ meson.

The effective magnetic moment μ_p^* and μ_n^* of protons and neutrons used in the present calculations include the contribution of valence quarks, sea quarks and orbital angular momentum of sea quarks [4], i.e.,

$$\mu_B^* = \mu_{B,\text{val}}^* + \mu_{B,\text{sea}}^* + \mu_{B,\text{orbital}}^*, \quad (6)$$

where $B = (p, n)$. Various other parameters $(\beta_\omega, \beta_\rho, \beta_\varphi, \alpha_\rho, \alpha_\varphi, \gamma)$ appearing in eq. (3) are taken from ref. [2]. In the present paper, we discuss only the magnetic form factor of proton at finite density and isospin asymmetry of the medium.

Result and discussions

In fig. 1, we show the proton magnetic form factor $\frac{G_{M_p}}{\mu_p^* G_D}$ as a function of Q^2 in space-like region, normalized with respect to the dipole form factor $G_D = \left(1 + Q^2/0.71\right)^{-2}$. The results are shown for baryonic density $\rho_B = 0, 0.4\rho_0$ and ρ_0, where $\rho_0 = 0.15$ fm^{-3} is the nuclear saturation density. For finite density, we compare the results at isospin asymmetry $\eta = 0$ and 0.3 $(\eta = \frac{\rho_n - \rho_p}{2\rho_B})$. Increase in the baryonic density of the medium is observed to cause an increase in the value of magnetic form factor of proton. For densities below 0.09 fm^{-3}, magnetic form factor

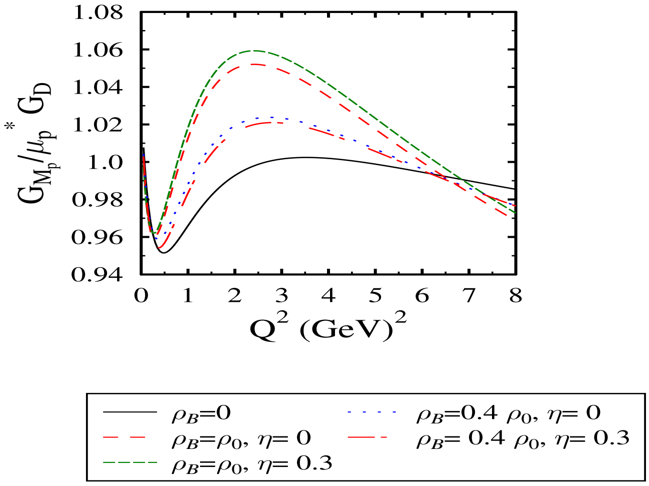

FIG. 1: Magnetic form factor $\frac{G_{M_p}}{\mu_p^* G_D}$ in space-like region

decrease with increase in isospin asymmetry whereas above this density, magnetic form factor increase with increase in the isospin asymmetry.

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