In-medium properties of light mesons in the magnetized nuclear matter

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Introduction

The in-medium masses of the light vector, isovector, ρ ($J^{PC} = 1^{--}$), and the axial-vector state, A_1 ($J^{PC} = 1^{++}$), are studied in a magnetized nuclear medium, using the QCD sum rule approach. The masses are calculated in terms of the light quark and scalar gluon condensates, obtained from the chiral effective model. Effects of magnetic field on the masses are accounted for both the Fermi and Dirac sea of nucleons in a magnetized nuclear matter. Mass modifications of the light mesons in an external magnetic field, have impact on their in-medium hadronic decay widths, and hence may affect the light mesons yield in the peripheral, ultra-relativistic, heavy-ion collision experiments, where estimated magnetic field is very large [1].

In-medium masses

The in-medium masses of ρ and A_1 mesons are computed within the QCD sum rule framework. The masses are determined using the light quark condensate (up to four-quark condensate), the scalar gluon condensate, and some parameters of the QCD Lagrangian [for e.g., the current quark masses (m_u, m_d) and the coupling constant (α_s)]. The in-medium condensates are obtained in terms of the scalar fields (isoscalar, non-strange, σ, strange, ζ; isovector, δ and the dilaton field, χ), within the chiral $SU(3)$ model, which is based on the non-linear realization of chiral $SU(3)_L \times SU(3)_R$ symmetry [2]. A logarithmic potential in χ breaks the scale-invariance of QCD, and hence simulates the gluon condensates, within the chiral model. In-medium effects of the baryon density (ρ_B) and isospin asymmetry (η), are incorporated through the nucleons number and scalar densities ($\rho_i, \rho_i^s; i = p, n$), into the scalar fields of the chiral model. An external magnetic field is contributed through the modified $\rho_i, \rho_i^s; i = p, n$, due to the Landau energy levels of protons and the anomalous magnetic moments of the nucleons, in the Fermi sea. The scalar densities ($\rho^s_{n,p}$) also include the contributions from the magnetized Dirac sea of nucleons. The coupled equations of motion of the scalar fields, as derived from the chiral effective Lagrangian, in the mean-field approximation, are solved by incorporating the medium effects via ρ_i, ρ_i^s ($i = p, n$) [4]. Scalar fields, within the chiral model, are proportional to the chiral condensates, i.e., $\sigma \sim (\langle \bar{u}u \rangle + \langle \bar{d}d \rangle)$, $\zeta \sim \langle \bar{s}s \rangle$, $\delta \sim (\langle \bar{u}u \rangle - \langle \bar{d}d \rangle)$, etc. [3]. There is observed to be an enhancement of scalar fields with magnetic field, due to the effects of magnetized Dirac sea [4]. This effect is called magnetic catalysis (MC). The masses are studied, incorporating the effects of magnetic catalysis, in terms of the scalar fields, at $\rho_B = 0$ and ρ_0. The anomalous magnetic moments are considered, for both the Fermi and Dirac sea of nucleons.

The Borel transform, followed by the finite energy sum rules (FESRs), are applied in the mass calculations of ρ and A_1 mesons, in terms of the chiral condensates calculated in the chiral model. Operators up to dimension-6, are considered in the Wilson's operator product expansion (OPE) of the current correlation function [$\Pi(q^2)$], at the large space-like region, ($Q^2 = -q^2$) >> 1 GeV^2 [5]. The c-numbered coefficients ($c^i; i = 0, 1, 2, 3$) in the OPE, contain the QCD non-perturbative effects, via the quark and gluon condensates. The $c^i s$ for the different current quark-billinears of ρ and A_1 mesons are used [3, 4]. On the phenomenological side, the $Im\Pi(s)$ is parametrized by the

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hadronic resonance and a perturbative continuum part. For the axial-vector current, it contains an additional pole of π meson [4]

$$Im\Pi(s)_A^{phen.} \propto F_A\delta(s-m_A^2)+c_0\Theta(s-s_0^A)+ f_\pi^2\delta(s-m_\pi^2) \quad (1)$$

For the vector meson [3–5],

$$Im\Pi(s)_V^{phen.} \propto F_V\delta(s-m_V^2)+c_0\Theta(s-s_0^V) \quad (2)$$

Where, s_0 denotes the threshold between the low energy resonance part and the high energy perturbative continuum; f_π, m_π are the pion decay constant and mass respectively. F is the resonance strength. The in-medium values of the resonance parameters, i.e., mass (m'), strength (F') and perturbative threshold (s_0'), can be solved from the finite energy sum rules (FESRs). For the axial-vector mesons [4]

$$F_A' = \left(c_0 s_0^{'A} + c_1 - f_\pi^2 - \frac{\rho_B}{4M_N}\right)$$

$$F_A' m_A^{'2} = \left(\frac{c_0(s_0^{'A})^2}{2} - c_2' - f_\pi^2 m_\pi^2\right)$$

$$F_A' m_A^{'4} = \left(\frac{c_0(s_0^{'A})^3}{3} + c_3^{'A} - f_\pi^2 m_\pi^4\right) \quad (3)$$

FESRs for the vector mesons can similarly be obtained [3, 4]. The scattering of the light vector and axial-vector mesons with the nucleons are taken into account, giving rise to a damping term, denoted by $\rho_{sc} = \frac{\rho_B}{4M_N}$ [3–5].

Results and Discussion

The in-medium masses of ρ and A_1 mesons are obtained by solving their respective finite energy sum rules. The coefficients of the scalar four-quark condensates, κ, are fixed from their vacuum FESRs, by using the vacuum masses of $m_\rho^{vac.} = 770$ MeV and $m_{A_1}^{vac.} = 1230$ MeV. The parameters m_u, m_d and α_s are given in ref.[3, 4]. In Fig.1, the in-medium masses of the neutral ρ and A_1 mesons are observed to rise with increasing magnetic field ($|eB|/m_\pi^2$), at $\rho_B = 0,\ \rho_0$; $\eta = 0,\ 0.5$, incorporating the catalysis effect. Masses of the charged mesons ($\rho^\pm, A_1^\pm$) are seen to rise with $|eB|$, due to the catalysis effect, with values nearby to their neutral partners [4]. In comparison to this, there are no appreciable changes in masses, without the effect of magnetic catalysis. As the masses of both ρ and A_1 mesons increase with $|eB|$, in-medium partial decay widths of the possible decay modes of $A_1 \to \rho\pi$ (for e.g., $A_1^0 \to \rho^\pm\pi^\mp$), will decrease with magnetic field due to the effects of magnetized Dirac sea on the masses [4].

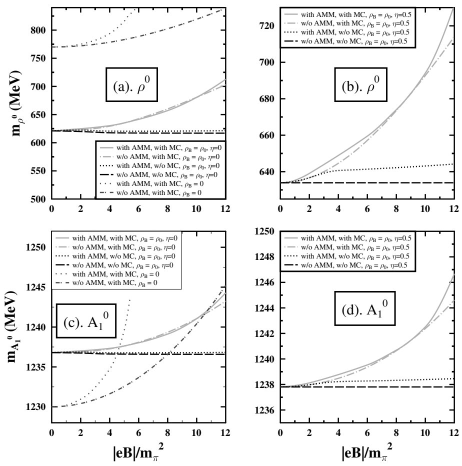

FIG. 1: In-medium masses (in MeV) of ρ^0 and A_1^0 mesons, plotted as a function of magnetic field, $|eB|$ (in units of m_π^2), at $\rho_B = 0,\ \rho_0$ and $\eta = 0,\ 0.5$. The effects of magnetic catalysis (MC) are compared with the case when it is not considered. Comparison are shown on the basis of nucleons anomalous magnetic moments (AMM).

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