The present analysis is valid when the "axial-vector" bosons (mesons with $J^P = 1^+$ and baryons with $J^P = 1^-$) are heavy. When the "axial-vector" bosons are light, we need to include these states. This can be done in the framework of the generalized HLS [10, 19]. Using this formalism, we may investigate the phase structure in the range of μ_B wider than that studied in the present analysis. We hope to obtain a clue to understand the real-life QCD with three colors at finite baryon density through these analyses.

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Appendix A: QCD Lagrangian with external source fields

In this appendix, we give the QCD Lagrangian with the external source fields.

We start with the ordinary QCD Lagrangian with N_f massless quarks:

$$\mathcal{L}^0_{\mathrm{QCD}} = -\frac{1}{2}\mathrm{tr}[G^{\nu\rho}G_{\nu\rho}] + \bar{\psi}\gamma^\nu D_\nu \psi, \tag{A.1}$$

where

$$\begin{aligned} D_\nu \psi &= (\partial_\nu - i g_s G_\nu)\psi, \\ G_{\nu\rho} &= \partial_\nu G_\rho - \partial_\rho G_\nu - i g_s [G_\nu \, , \, G_\rho], \end{aligned} \tag{A.2}$$

with G_ν and g_s being the gluon field matrix and the gauge coupling constant. Note that the gluon field matrix is expressed as $G_\nu = G^a_\nu \frac{\tau_a}{2}$ where τ_a is the Pauli matrix of $SU(2)_{\mathrm{color}}$ defined as

$$\tau_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \tau_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \tau_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}. \tag{A.3}$$