

# Chiral and $U(1)_A$ symmetries in background magnetic fields from lattice QCD

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Understanding how external magnetic fields affect chiral and singlet  $U(1)_A$  symmetry breaking is an important question in QCD under extreme conditions. In a pure magnetic background, the unequal electric charges of the light quarks explicitly reduce the non-singlet flavor symmetry, making it necessary to identify the appropriate neutral mesonic partner channels. We clarify the neutral-sector symmetry structure and identify  $\chi_{\pi^0} - \chi_\sigma$  as the chiral-partner splitting associated with the surviving neutral non-singlet axial symmetry, and  $\chi_{\pi^0} - \chi_{\delta^0}$  as the singlet  $U(1)_A$  partner splitting.

Using fixed-scale  $(2+1)$ -flavor HISQ ensembles with  $m_\pi \simeq 220$  MeV at vanishing magnetic field, we study these observables over a broad range of temperatures and magnetic fields. At low temperatures, both splittings increase with  $eB$ . At intermediate temperatures, both splittings decrease with increasing  $eB$  once the field is sufficiently strong. The decrease of the singlet  $U(1)_A$  partner splitting sets in at larger  $eB$  and is milder than in the chiral channel. These results provide fixed-scale lattice-QCD evidence for distinct magnetic responses of the neutral chiral and singlet  $U(1)_A$  partner susceptibility splittings.

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