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Magnetic catalysis effect kills neutral pion superfluidity and vacuum superconductivity in strong magnetic field

Summary

In the chiral effective Nambu–Jona-Lasinio (NJL) model with two- and three-flavor quarks, we demonstrate that the naively expected neutral pion (π^0) superfluidity (NPSF) and vacuum superconductivity (VSC) in constant magnetic field $\mathbf{B} = B\hat{z}$ are both disfavored, due to the well-known magnetic catalysis effect (MCE) to chiral symmetry breaking. Based on the simple two-flavor NJL model, we illuminate in the lowest Landau level approximation the similar origins of π^0 and $\bar{\rho}_1^+$ (ρ^+ meson with spin $S_z = 1$) mass reductions with B and thus of NPSF and VSC tendencies. With the full Landau levels, the two-flavor NJL model is found to be invalid to study the magnetic field effect to $\bar{\rho}_1^+$ meson with physical vacuum mass 775 MeV. Then, restricted to ρ meson mass below two-quark threshold in vacuum, that is $m_\rho^v < 2m_q^v$, it is found that π^0 mass decreases and then increases with B slowly, and $\bar{\rho}_1^+$ mass vanishing point is delayed to larger B compared to the point particle result. In the more realistic three-flavor NJL model, all the quark masses split in strong magnetic field as a combinatorial result of their different current masses and electric charges. By choosing a vacuum mass closer to the physical one, $\bar{\rho}_1^+$ meson mass is found to be consistent with the LQCD results semi-quantitatively in smaller B region but increase in larger B region. These features are mainly outcomes of the interplay between the $S_z - B$ coupling effect and splitting MCE to the composite u and d quarks, which definitely disfavors VSC when the latter dominates. Furthermore, mesonic flavor mixing is modified by B among the neutral pseudoscalars: π^0, η_0 and η_8, which is very important to suppress the mass enhancement of the effective mass eigenstates at large B.

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