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Gauge independence of pion masses in a magnetic field within the Nambu–Jona-Lasinio model

We investigate the properties of neutral and charged pions in a constant background magnetic field mainly at zero temperature within the Nambu–Jona-Lasinio model. In the previous calculations of the charged pion masses in a constant magnetic field, the Ritus method is employed to involve complete Schwinger phases in a fixed gauge within the momentum-space random phase approximation˜[Phys. Lett. B **782**, 155-161 (2018)]. However, gauge invariance of the charged pion masses has not yet been examined. In this work, by adopting the linear response theory based on the imaginary-time path integral formalism, we derive the correlation functions for pions in the coordinate space, where the corresponding Schwinger phases show up automatically. At sufficiently large imaginary time
τ, the meson correlation function approaches an exponential form $\sim \exp(-E_{\mathrm{G}}\tau)$, where E_{G} is the ground-state energy of the one-meson state and is hence determined as the meson mass. Within this imaginary-time method, we show that the mass of the charged pions is gauge independent, i.e., independent of the choice of the vector potential for the constant background magnetic field. We also show that the previously used momentum-space random phase approximation, which simply discarded the Schwinger phases and determined the meson mass as the pole at zero momentum, is actually equivalent to the imaginary-time method used in this work.

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