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Scrutinizing the pion condensed phase

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When the isospin chemical potential exceeds the pion mass, charged pions condense in the zero- momentum state forming a superfluid. Chiral perturbation theory provides a very powerful tool for studying this phase. However, the formalism that is usually employed in this context does not clarify various aspects of the condensation mechanism and makes the identification of the soft modes problematic. We re-examine the pion condensed phase using different approaches within the chiral perturbation theory framework. As a first step, we perform a low-density expansion of the chiral Lagrangian valid close to the onset of the Bose-Einstein condensation. We obtain an effective theory that can be mapped to a Gross-Pitaevskii Lagrangian in which, remarkably, all the coefficients depend on the isospin chemical potential. The low- density expansion becomes unreliable deep in the pion condensed phase. For this reason, we develop an alternative field expansion deriving a low-energy Lagrangian analog to that of quantum magnets. By integrating out the "radial"fluctuations we obtain a soft Lagrangian in terms of the Nambu-Goldstone bosons arising from the breaking of the pion number symmetry. Finally, we test the robustness of the second-order transition between the normal and the pion condensed phase when next-to-leading-order chiral corrections are included. We determine the range of parameters for turning the second-order phase transition into a first-order one, finding that the currently accepted values of these corrections are unlikely to change the order of the phase transition.

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