

Interacting Relativistic Bosons at Finite Temperatures: Comparison with Lattice QCD

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We study an interacting relativistic system of charged bosons at finite temperature and fixed isospin density within a thermodynamically consistent mean-field approach. Two forms of repulsive self-interaction, ⁴ and ⁶, are considered. The interactions lead to a density-dependent effective mass M of the bosonic quasiparticles and an associated excess-pressure contribution. The thermodynamics is formulated in the Extended Canonical Ensemble, obtained from the grand canonical description by a Legendre transformation from the isospin chemical potential to the conserved isospin density. This formulation is particularly useful in the Bose-condensed phase, where the isospin chemical potential is constrained by the condensation condition, $I = M$, and must be determined self-consistently.

The formalism is applied to a pion-like system at finite isospin density and compared with lattice-QCD results. We discuss the difference between the isospin chemical-potential conventions used for pion and quark degrees of freedom and adopt the convention in which the condensation threshold is $I = m/2$. At $T = 122$ MeV, the pressure, isospin density, energy density, and trace anomaly are compared with lattice data. Both the ⁴ and ⁶ models reproduce the main features of the lattice results, with the ϕ^6 interaction providing a better overall description. The results demonstrate that the Extended Canonical Ensemble provides a consistent framework for describing interacting particle-antiparticle systems across the transition from the thermal to the Bose-condensed phase.

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