論文内容の要旨

論文題目: Unitary Fermi gas in the ϵ expansion

(和訳: ϵ展開を用いたユニタリー・フェルミ気体の研究)

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We construct systematic expansions around four and two spatial dimensions for a Fermi gas near the unitarity limit. Near four spatial dimensions such a Fermi gas can be understood as a weakly-interacting system of fermionic and bosonic degrees of freedom. To the leading and next-to-leading orders in the expansion over $\epsilon = 4 - d$, with d being the dimensionality of space, we calculate the thermodynamic functions and the fermion quasiparticle spectrum as functions of the binding energy of the two-body state. We also show that the unitary Fermi gas near two spatial dimensions reduces to a weakly-interacting Fermi gas and calculate the thermodynamic functions and the fermion quasiparticle spectrum in the expansion over $\bar{\epsilon} = d - 2$.

Then the phase structure of the polarized Fermi gas with equal and unequal masses in the unitary regime is studied using the ϵ expansion. We find that at unitarity in the equal mass limit, there is a first-order phase transition from the unpolarized superfluid state to a fully polarized normal state. On the BEC side of the unitarity point, in a certain range of the two-body binding energy and the mass difference, we find a gapless superfluid phase and a superfluid phase with spatially varying condensate. These phases occupy a region in the phase diagram between the gapped superfluid phase and the polarized normal phase.

Thermodynamics of the unitary Fermi gas at finite temperature is also investigated from the perspective of the expansion over ϵ. We show that the thermodynamics is dominated by bosonic excitations in the low temperature region $T \ll T_{\mathrm{c}}$. Analytic formulas for the thermodynamic functions as functions of the temperature are derived to the lowest order in ϵ in this region. In the high temperature region where $T \sim T_{\mathrm{c}}$, bosonic and fermionic quasiparticles are excited and we determine the critical temperature T_{c} and the thermodynamic functions around T_{c} to the leading and next-to-leading orders in ϵ and $\bar{\epsilon}$.

Finally we discuss the matching of the two systematic expansions around four and two spatial dimensions in order to extract physical observables at $d = 3$. We find good agreement of the results with those from recent Monte Carlo simulations.