Renormalization group approach to neutron matter

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The main idea of the renormalization group (RG) approach to Fermi liquids [1] is to "adiabatically" include the in-medium corrections to the effective interaction by solving the RG equations in the relevant channels. In this exploratory calculation [2], we include the particle-hole (ph) channels, which play a special role in Fermi liquid theory. The main effect of scattering in the particle-particle channel, the taming of the short-range repulsion, is taken care of by using $V_{\rm low\ k}$ [3] as the starting point of the RG flow. The low-lying excitations in this channel, which are responsible, e.g., for superfluidity, are not included. These are then treated explicitly when we compute the superfluid gap by employing BCS theory for the fully reducible scattering amplitude.

We derive the one-loop RG equations for the quasiparticle interaction and the scattering amplitude at zero temperature. The evolution of the effective mass is included in the RG flow, as well as a simplified treatment of the renormalization of the quasiparticle strength. As we decimate down to the Fermi surface, by taking the cutoff $\Lambda \to 0$, we obtain not only the forward scattering amplitude for low-lying quasiparticle-quasihole excitations, but also the amplitude for general (non-forward) scattering processes of quasiparticles on the Fermi surface.

The one-loop RG equations in the ph channels are solved at zero temperature. The corresponding diagrams, which renormalize the four-point vertex, are shown in Fig. 1. Here the momenta p_i of the intermediate ph pair lie in a shell $\Lambda - d\Lambda \leq |p_i - k_{\rm F}| \leq \Lambda$. When only one channel is considered, the one-loop RG equation is exact in the sense that it is equivalent to the corresponding scattering equation, and when both the direct and exchange ph channels are included, the scattering amplitude remains antisymmetric under the RG flow. The RG approach includes the induced interaction. We work in the approximation that both ph momentum transfers are small compared to the Fermi momentum. The physical system considered is neutron matter, where complications of the tensor force do not enter in the S-wave.

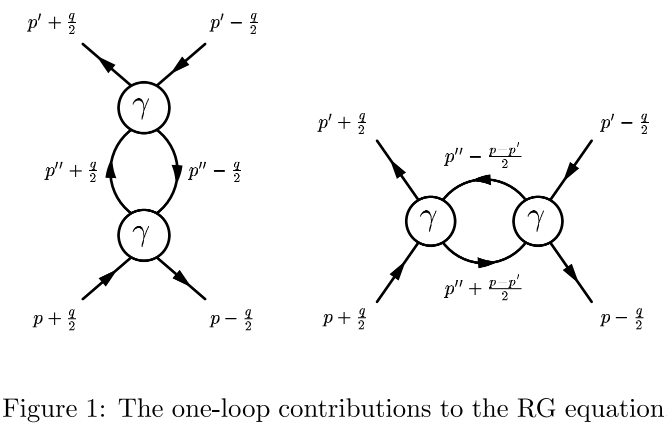

Figure 1: The one-loop contributions to the RG equation. γ denotes the running effective four-point vertex.

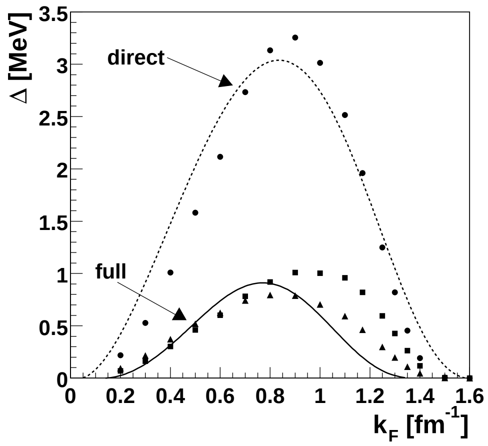

Figure 2: The $^1S_0$ superfluid gap versus the Fermi momentum $k_{\rm F}$. The dots denote the pairing obtained from $V_{\rm low\ k}$ only, whereas the squares and the triangles are computed from the full RG solution using different approximations for the quasiparticle strength [2]. In comparison, the dashed line is obtained by solving the BCS equation with the bare NN interaction [5], while the solid line includes the ph polarization effects [4].

Using the resulting Fermi liquid parameters, we compute the $^1S_0$ superfluid pairing gap in weak coupling BCS theory, Fig. 2. This application probes the angular dependence of the scattering amplitude. We generally find good agreement with the results obtained in the polarization potential model by Wambach *et al.* [4].

The RG method is a promising tool for studying a wide range of nuclear many-body problems. For a similar analysis of symmetric or asymmetric nuclear matter, it is necessary to extend the flow equations to incorporate tensor interactions. Fairly large renormalization effects are expected and spin non-conserving interactions are generated in the medium [6]. In particular, polarization effects on the $^3P_2$–$^3F_2$ pairing of neutrons, where the tensor and spin-orbit forces play a crucial role, may have important effects on neutron star properties.

References

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