Variational Theory and Parquet Diagrams for Nuclear Systems: A Comprehensive Study of Neutron Matter

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The most difficult aspect of the nuclear many-body problem is the form of the microscopic nucleon-nucleon interaction which depends at least on the spin, isospin, and relative orientation and angular momentum of the interacting particles. To deal with this problem we have combined ideas of the Jastrow-Feenberg variational method and the local parquet-diagram theory. We find demonstrate that non-parquet diagrams contribute significant corrections to the Bethe-Goldstone equation.

The relationship of these two methods, specifically the "optimized (Fermi)-hypernetted chain" ((F)HNC-EL) approximation and the parquet-diagram summation, has been clarified in much detail for simple systems like electrons or the helium liquids. Realistic nucleon-nucleon interactions pose, however, problems for variational methods because the simple correlation functions used for electrons and quantum fluids are inadequate. Correlation functions that have the same structure as the interactions lead to so-called "commutator diagrams" that have, so far, been mostly ignored. We have shown in the past that these corrections can be very important if the two-body interactions are very different in different spin- or isospin channels. In the language of diagrammatic perturbation theory, "commutator diagrams" can be identified with non-parquet diagrams. These amount, in their simplest version, to corrections to the Bethe-Goldstone equation that cause a coupling of spin-singlet and spin-triplet states though the exchange of spin-fluctuations. We include these diagrams in a way that is suggested by the Jastrow-Feenberg approach and show that the corrections from non-parquet contributions are, at short distances, larger than all other many-body effects.

Calculations are carried out for neutron matter interacting via the so-called v_8 version of four popular interactions. We determine the structure and effective interactions and apply the method to the calculation of the energetics, structure and dynamic properties of neutron matter such as the single-particle self-energy and the dynamic response functions as well as BCS pairing in both singlet and triplet states. We find that many-body correlations lead to a strong reduction of the spin-orbit interaction, and, therefore, to an almost complete suppression of the $^3P_2$ and $^3P_2$-$^3F_2$ gaps. We also find pairing in $^3P_0$ states; the strength of the pairing gap depends sensitively on the potential model employed.