Unified description of the equation of state and transport properties of the Fermi hard-sphere system.

Report

The formalism based on correlated basis functions and the cluster expansion technique have been recently employed to derive an effective interaction from a realistic nucleon-nucleon interaction. We are investigating the accuracy of the CBF effective interaction approach studying a variety of properties of the fermion hard-sphere system.

It is long known that the hard-sphere model provides an accurate description of several properties of dilute Fermi systems. Algebraic expressions of the ground state energy, the single-particle energy, the effective mass and the momentum distribution can be written as power series in the parameter $(k_F a)$, where k_F is the Fermi momentum and a is the hard-core radius. We use the results obtained from these expansions in the low density limit and from other many body techniques as benchmarks to assess the accuracy of the effective interaction approach, thus providing the basis for its generalisation to neutron matter.

We are developing this work in collaboration with Prof. Artur Polls of the Departament d'Estructura i Constituents del Matèria, Universitat de Barcelona. The aim of this STSM was to discuss the results currently obtained in the derivation of the effective interaction for the Fermi hard-sphere fluid and in the calculation of the properties of the system, as well as doing the groundwork for future applications of this formalism.

We worked at the draft of a paper describing the perturbative calculation of the self-energy at the second order in the CBF effective interaction and the properties of the hard-sphere system resulting from this calculation, namely the single particle energy spectrum, parametrized in terms of the effective mass, and the momentum distribution. The resulting paper, where we present a systematic comparison between our results and those known in literature, is currently under revision.

In this paper we show that, as far as the momentum distribution is concerned, we can establish a correspondence between the hard-sphere system and isospin symmetric nuclear matter at equilibrium density. Motivated by this result, we tied to use the hard spheres to reproduce also the Helium-3 momentum distribution obtained by Monte Carlo calculations. In this case we are not able to reproduce both the discontinuity at the Fermi surface and the depletion. If we choose to reproduce the discontinuity, in fact, we obtain a depletion much smaller than the one obtained in Monte Carlo calculations, thus meaning that Helium-3 probably requires three body correlations to be well described because of its high density.

The other point we analysed was the universal behaviour of the energy of hard and soft spheres. We took into account soft-sphere potentials having the same scattering length of the hard case in order to investigate if the ground state energy and the properties of the system depend on the shape of the potential. We found the height of the potential for a given radius imposing the condition that the scattering length must be the same of the hard-sphere potential, we computed the correlation function and employed the CBF *effective interaction* approach to compute the ground state energy, as well as momentum distribution and effective mass.

It turns out that the dependence of the energy on the shape of the potential becomes relevant when the density increases, with the less soft potential closer to the hard-sphere one. As regards correlation functions differences are obviously more relevant for all the densities, since the radial distribution functions are different form zero inside the range of the potential while in the hard-sphere case it is identically zero inside the core. We observe that the value of the correlation function at the origin is higher and the increase, as a function of the radial coordinate, is steeper for the softest potential, while radial functions are more repulsive for less soft cases.

For the momentum distribution and effective mass, instead, differences are more wide also at low densities and the dependence on the potentials seems to be much more relevant. We are currently studying this behaviour and this will one of the topic for future collaborations.

For the future, we also plan to employ the CBF *effective interaction* approach to obtain the spectral functions and the density response and exploit its flexibility, allowing for a consistent calculation of the *effective* mass and the *in medium* scattering cross section, to calculate the transport coefficients, e.g. the shear viscosity and thermal conductivity, within the framework of the Landau-Abrikosov-Khalatnikov formalism.

On October 2nd 2014 I had a seminar at the Departament d'Estructura i Constituents de la Matèria of the University of Barcelona, on the "Effective interaction approach to the Fermi hard-sphere system" where I presented our results.

Finally, one of the three weeks of the mission has been devoted to the school "The many faces of compact stars" (September 22-26) organized in Barcelona by NewCompStar, Consejo Superior de Investigaciones Científicas and Institut d'Estudis Espacials de Catalunya.

The mission has been executed from September 18th to October 10th 2014, the shift of one week from the dates proposed in the application was due to academic tasks succeeded after the approval of the mission.