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Strongly correlated systems of several ultra-cold fermions of different masses

The thesis contains the results of an analysis of systems of several ultra-cold fermions of different masses. The studies were motivated by the state-of-the-art experiments on a few quantum bodies, and on the mixtures of fermions of different masses.

The first chapter introduces the topic of ultra-cold atoms. The history of trapping and cooling is described and the broader context is shown. The recent developments in both theoretical and experimental field are discussed.

In chapter two the model of a two-component mixture of fermions is introduced. This specific form of the model is motivated by experiments in the field of a few-body physics. Next, some numerical techniques are described, in particular, the method of exact diagonalization of the Hamiltonian of the system. This method is the main tool used in the thesis.

The third chapter is devoted to general properties of a few interacting bodies. The full many-body energetic spectrum of the fermionic mixture is discussed both in the center-of-mass frame and in the laboratory frame. With an example of a two-body correlation function, it is shown that this function may contain information important from the point of view of ultra-cold gases experiments.

The fourth chapter deals with the phenomenon of the separation of the density profile of one of the components. Such effect is predicted in the mixture of two types of fermions trapped in an external potential: a case of a harmonic trap, as well as a box trap, is analyzed. The separation is seen only when the two repelling components have different masses and generally is not observed in the same-mass systems. Not only the ground state of the system is studied, but also a mixed state. This allows one to comment on a possibility to observe the phenomenon in a real experiment.

The fifth chapter contains a description of the effect of the change of the character of density profile separation when an external potential is adiabatically changed from the box-trap shape to the harmonic oscillator. An unusual transition between different types of spatial separation is described with the help of methods used in the theory of phase transitions.

The sixth chapter is devoted to analyzing the particular case of a system of four particles (two particles of one type and two of another type). The precision of a variational method (so-called interpolatory ansatz) is compared with the results provided by the exact diagonalization technique.

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