Nonzero temperatures dynamics of a repulsive two-component Fermi gas

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The long-standing picture of itinerant ferromagnetism posed by Stoner in his pioneering work is now being tested experimentally. As he predicted, free (i.e., not localized) electrons become ferromagnetic when a short-range screened Coulomb repulsion between opposite spin particles gets strong enough to overcome the Fermi pressure. To verify Stoner's original idea one needs a system free of all these beyond-short-range repulsion effects, which are typical for solids. Cold fermionic atoms seem to be the solution. In the recent experiment [G. Valtolina et al., Nat. Phys. 13, 704 (2017)] the Stoner idea was tested experimentally. In my thesis I try to describe the results of this experiment using two approaches. Namely I use atomic orbital approach and develop a new version of temperature dependent hydrodynamic approach.

In the first model I apply the atomic-orbital method combined with a Monte Carlo technique based sampling to probe finite temperatures. I analyze the spin-dipole oscillations of a two-component fermionic mixture, demonstrating that the ferromagnetic phase shows up at a stronger repulsion between components while the temperature rises. Numerical calculations were done for 24+24 atoms. Even though the number of atoms is small, results agree quantitatively with experiment [G. Valtolina et al., Nat. Phys. 13, 704 (2017)]. The results were published in "Nonzero-temperature dynamics of a repulsive two-component Fermi gas" PHYSICAL REVIEW A 101, 013618 (2020).

In the second model I investigate the finite-temperature dynamics of a two-component fermionic mixture by using a density-functional-like description. This model is able to handle large numbers of atoms comparable to the experiment. To derive the equations of motion I start by introducing the semiclassical distribution function for fermions. Then I evoke the Kohn and Sham way of treating a nonzero temperature case within the density-functional methods and replace the local kinetic energy expression by the one corresponding to free energy. This way I obtain non-linear Schrodinger equations of motions for pseudo wavefunctions. Some parts of results were obtained by switching to the quantum hydrodynamic description of the system. To do so I apply the inverse Madelung transformation, and follow the Dirac prescription to get the desired equations. I analyze the spin-dipole oscillations of a two-component fermionic mixture, and the radial oscillations of weakly interacting repulsive Fermi gases. Numerical calculations were done for 1000+1000 atoms and 50000 + 50000 atoms (like in experiment) for spin-dipole oscillations, demonstrating that the ferromagnetic phase shows up at a stronger repulsion between components while the temperature rises. I obtain a good agreement with experimental data [G. Valtolina et al., Nat. Phys. 13, 704 (2017)]. In case of radial oscillations of weakly interacting repulsive Fermi gases, numerical calculations were done for 56+56 atoms and 1000 + 1000 atoms. I compare results with the outcome of the Hartree-Fock orbital calculations done for a system with a small number of fermions at zero temperature. Radial oscillation frequency decrease while the temperature rises. The results were published in “Dynamics of large samples of repulsive Fermi gases at nonzero temperatures” PHYSICAL REVIEW A 105, 023315 (2022).