Dynamical Stoner instability

Magnetism plays a prominent role in both everyday life and scientific world. Spanning wide, from electric motors and tape recorders to normal helium-3 liquids and quark matter within the crust of neutron stars, it holds a position of one of the most mysterious phenomena. Itinerant ferromagnets, such as iron or nickel, have their electrons' spins aligned to form a magnetic state, but not in a localized fashion as in the optical lattice. Rather, they are extended, similarly to electrons responsible for conduction.

In the times of classical physics, ferromagnetism lacked satisfactory explanation and remained an unsolved mystery. Not until the advent of early quantum mechanics was it successfully described in terms of spins, exchange interaction and Pauli repulsion between indistinguishable particles. It was a victory, however a bit Phyrric – physicists were unable to apply their models to real materials in a quantitative way. From one side, their oversimplified approaches missed vital features relevant for more complicated systems, and from the other – methods to solve problems involving highly correlated settings were yet to be developed.

Fortunately, these early models have become a very suitable tool to study clean systems brought to existence by the experimental realization of ultracold quantum gases. In such setups electrons are replaced by very dilute fermionic gas in which freely moving atoms interact only via head-on collisions. When this repulsive interaction becomes strong enough, particles of opposite spin start to occupy different positions in space, manifesting a ferromagnetic order.

Such a phenomenon, called an itinerant or Stoner instability has not only been predicted theoretically, but also has recently been realized experimentally. Despite some controversy over existence of such a ferromagnetic phase transition, these experiments constitute a playground to investigate more complicated systems, from real-life magnets to high-temperature superconductors.

In recent years, our group has secured a strong position among the avant-garde of the theoretical research in this field. With our proposal, we intend to match the pace of experimental groups and create a project, the results of which would push forward our comprehension of the topic. The topic, which is not satisfactorily understood and is absolutely fundamental from the perspective of future potential technological applications.

We plan to study a few ideas that are closely related and seem to be important to research of the Stoner instability. All of them are natural and logical extensions to the results that we have obtained so far. Our project involves investigation of the following problems.

(i) **Existence of a low-dimensional ferromagnetic phase transition in a repulsive spin-mixture of Fermi gases**

Recent experiments and theoretical works have almost undoubtedly confirmed the occurrence of ferromagnetic transition in three-dimensional Fermi gas in which atoms interact by short-range repulsion. It is however not clear if such a transition happens in the system that is characterized by a reduced dimensionality. Some studies suggest that para- to ferro-magnetic phase transition does not occur, while other works suggest exactly the opposite.

(ii) **3D-to-2D crossover in a Fermi gas in the context of ferromagnetic instability**

While it is not clear whether the sharp ferromagnetic transition occurs in two-dimensional geometry, it is certain that there is some continuous transition in gas behavior during the crossover from three- to two-dimensional system. We plan to check whether the transition actually happens across the crossover and to find some characteristic point for which it vanishes, if it indeed does.

(iii) **Small-amplitude oscillations of a Fermi gas in a ferromagnetic phase**

Finding natural frequencies is a standard procedure while studying any system. Our framework allows us to go beyond previous results – we can study small-amplitude oscillations in a ferromagnetic phase, as in contrast to all the research that was done in a paramagnetic one.

(iv) **Stoner instability in the mixture of atoms of non-equal masses**

As the experiments with different types of atoms are being under construction, we plan to study ferromagnetic signatures for systems with non-equal masses.

(v) **Stoner instability at a finite temperature**

Non-zero temperature is inherent to every experiment and as such, it ought not to be neglected. With the introduction of thermal effects, our results could experience some quantitative corrections that are relevant in experimental settings.