Referee report on the PhD thesis entitled „Spin-polarized impurities in ultracold Fermi gas" by Bugra Tüzemen

UNIWERSYTET
JAGIELLOŃSKI
W KRAKOWIE

Instytut

Fizyki Teoretycznej

Zakład Optyki Atomowej

Mr. Tüzemen in his PhD thesis, published by Warsaw University of Technology in a nice compact form, discusses the physics of low lying excitations in the ultracold gas of fermions. He concentrates on a particular situation with spin-imbalanced gas which leads to a possibility of the creation of a ferron – a new proposed quasiparticle. The thesis is presented on 107 pages, consists of 6 chapters. While the first one gives a general historical introduction to ultracold Fermi gases, the second one brings a concise description of the BCS theory of superconductivity. Both these chapters while not containing any original material, set the ground for the rest of the thesis. Third chapter describes numerical tools used by the author to analyze the properties of the ferron. The introduction to density functional theory is rather short, while all ingredients are mentioned, one cannot find even a simple discussion of limitations of that approach. Instead the reader is provided with fragmentary comparisons between Superfluid Local Density Approximation (SLDA) and Quantum Monte Carlo (QMC) results in extensive Fig3.3 which in fact is a detailed table of not explained numbers. The quality of the print as well as the font size makes it hard for the present referee to see any data in this extensive table which is not the original contribution of the thesis but a reprint of data from [68]. The statement that "this comparison shows the high agreement between the methods and validates the accuracy of the (A)SLDA method" should be further developed if Fig3.3 is given, in particular, the quantities printed explained. One could simply write that the accuracy of the (A)SLDA method was extensively tested in [68] without reproducing this table. Otherwise, I find this chapter informative enough to make the studies reported later credible.

As I understand, the original contributions of the author are covered in the remaining three chapters and consider a dynamical creation, an internal structure as well as some dynamical properties of the ferron. The thesis is based on results obtained and published in three papers, two in Physical Review A and one in Acta Physica Polonica B. In the first two articles the order of authors is alphabetic, it is thus hard to isolate the contribution of Mr. Tüzemen, he is the first author of the third paper. Since the papers do not constitute a formal part of the thesis but the thesis is based on them, statements of the coauthors of the original papers on individual contributions are not mandatory.

ul. St. Łojasiewicza 11

PL 30-348 Kraków

tel. +48(12) 664-45-55

e-mail:

jakub.zakrzewski@uj.edu.pl

Chapter 4 considers a dynamical creation of the spin-polarized impurity – dubbed ferron in the thesis and addresses its stability. An exemplary simulation shows the ferron creation and its stability in time. Then different regimes of parameters are used to check the robustness of the process. In particular, it is shown that a sufficiently large box in 3D space is needed for the ferron to survive. It took the referee some time to find out that the unit of length adopted is the coherence length ξ, defined in (2.60) 25 pages earlier; ξ is used in p.52 even without its name "coherence length". The formation of the ferron was tested for different widths and amplitudes of the gaussian perturbing potential as well as switching time of the potential. Here there is a confusion of the notation. In p.50 a switching time t_on appears for a smooth tanh turn-on function. To a surprize of the referee in p.55 another, undefined quantity t_switch appears. It is written p.55 that it "describes the effect of adiabaticity" – I believe the author wanted to say that it "controls the degree of adiabaticity". Same t_switch appears in the caption of Fig.4.7 (p.58). The next page brings, without any warning, another time profile (4.6). For it to make sense, T in denominator of sinus must be equal to T_1, otherwise the function would be discontinuous. Is there any physical reason to change the shape of the ramp between p.50 and p.59?

A further analysis of stability is carried in 1D geometry. Apart from various numerical tests the author provides an in-depth discussion of physical mechanisms of the stability. The rest of the chapter considers dynamical properties of ferrons, e.g., effects due to a creation of the deformed object, application of a moving potential to drag the ferron, and creating collisions of ferrons. That provides convincing examples for the robustness of the spin-polarised impurity studied.

The study of the internal structure of the ferron is the object of chapter 5. Ferron is presented as composed of Andreev states, here the analysis, for simplicity, is carried out in 2D. The quantum analysis is supplemented by a semiclassical picture. In the caption of Fig.5.1 the description of left and right panels should be reversed. The analysis given yields a simple, analytic estimates of energies of Andreev states. The 2D static analysis enforces the existence of ferron by a step-like behavior of the pairing field. This approach is justified by the time dependent results of the previous chapter. Analysis of the ferron size shows the agreement between the numerical solution of BdG equations and simple analytic based on Andreev approximation. Finally, increasing the temperature the author observes that thermal excitations destroy the ferron for a sufficiently large T.

In the final chapter the dynamics of the ferron is further studied following the concept of fermion pushed by the moving potential. It is shown numerically

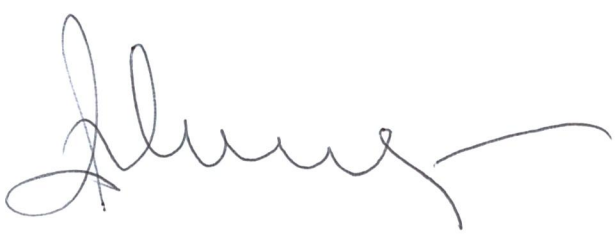
that increasing velocity of the drag, leads to a ferron deformation and eventually destroys it at velocities related to the ferron size. The static calculations allow the author to study this effect by introducing superflow into BdG equations. A further analysis includes estimates of the effective mass of the ferron possible in the presence of the superflow. Its dependence on the ferron size in different pairing regimes is shown in Fig. 6.7 in caption of which we find, surprisingly, the repetition of the definition of Cooper pair size ξ.

The conclusion of the thesis brings interesting speculations on the connection between ferron and FFLO phase, the former being postulated to be a FFLO droplet. Thus, possibly, it is via the ferron creation that one might finally confirm the existence of the celebrated FFLO phase.

Coming to the notion of the ``droplet''. Droplets have also different meaning in cold atom physics for e.g. strong dipolar interactions or in mixtures as discussed in the seminal paper of Dima Petrov in 2015 or colleagues from Institute of Physics PAS later. Are those the similar droplets? What are the physical differences between these objects?

The described thesis reads well. There are occasional, quite frequent language slips, some examples are attached to this report in the form of Appendix. Also, the indents after each formula (created by leaving the empty line in TeX after equations) are not necessary. The weak point of the thesis is an introductory section describing the experimental techniques with cold atoms. Some sentences are not precise, e.g., "The atoms absorb the laser beam, and as a result of the radiation, the atoms slow down." Or quite incorrect: "As a result of the Doppler effect, the atoms moving in the same direction as the laser have a reduced rate of absorption." This does not affect the main results of the thesis, of course.

To summarize, the thesis of Mr. Bugra Tüzemen presents interesting, new results (being based on three published articles) reporting novel spin-polarized impurities in ultracold fermi gases. It fulfils all the requirement necessary for PhD thesis in physics. I give a positive recommendation for a continuation of the procedure towards awarding Mr. Bugra Tüzemen the degree of Doctor in Physics.



Appendix

Corrections needed (exemplary list)

p.8 "During the study of this thesis" → "during the writing" (or "while this thesis was being completed")

p.8 below "are reported" → "have been reported"

p.35 "yields to" either "yields" or "leads to"

p.36, bottom "as the following" → "as follows"

p.37 after (3.11) "arguments" ... "is not limited" should be "are not limited"

such functional → such a functional

p.39 "it is introduced such a scheme" → "such a scheme is introduced"

p.42 "results to" → "results in"

p.44 "needs rather large lattices" → "requires..."

p.50 "excites phonons .... that interacts" should be interact

p.53 in caption "Two snapshots. ... is presented".

p.55 "The final switching parameter is the swithing on/off rates..." instead of rates should be time.

p.59 f(t) does not describe the "switching rates" but the time dependence of the perturbing potential

p.59 "Such form" should be "such a form". There should always be an article between "such" and the following word in singular.