Population imbalanced atomic Fermi gas ferromagnetism

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INTRODUCTION

1. OVERALL AIM

Having observed the BEC-BCS crossover in ultracold atomic gases it is natural to search for a strongly correlated ferromagnetic phase. This phase contrasts to solid state systems as ultracold atoms present the additional constraint that the magnetic moment along the quantisation axis is fixed.

SPECIFIC AIMS OF THIS PROJECT

- Search for ferromagnetism in ultracold atomic gases
- Allow for an arbitrary population imbalance between spin species
- Consider the experimentally realisable trapped system

2. STONER FERROMAGNETISM

As the repulsive interaction g between opposite spin atoms is increased it becomes energetically favourable for the atom spins to align, with the penalty of increased kinetic energy due to a larger Fermi surface with density of states v. The ferromagnetic phase transition occurs at the Stoner criterion $gv \geq 1$, see Fig. 1.

The ferromagnetic transition is experimentally found to be second order in most solid state materials such as Fe and Co, and this is backed up by mean-field theory. Here we go beyond mean-field and consider corrections due to fluctuations in all three spin channels and also the density channel. This gives an analytical expansion for the energy in terms of interaction strength.

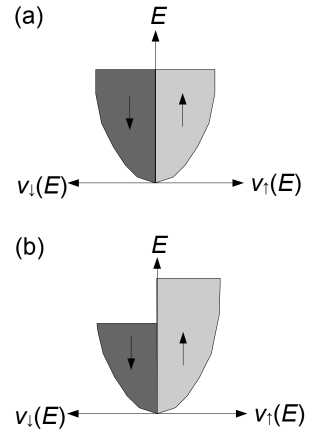
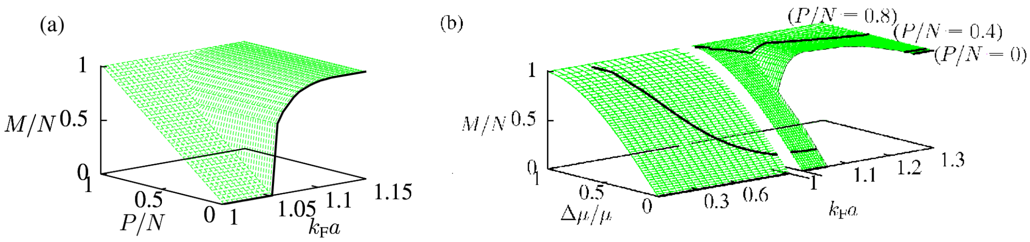


Fig. 1. (a) shows two equal Fermi surfaces (unmagnetised). (b) shows magnetisation due to a Stoner instability.

FREE SYSTEM

Fig. 2. (a) shows the magnetisation M with population imbalance P and interaction strength $k_F a$ with fixed species populations. (b) shows M at fixed species chemical potentials $\mu_{\uparrow\downarrow}=\mu\pm\Delta\mu$.



3. FREE SYSTEM

In the canonical regime Fig. 2(a) there is a first order transition into the ferromagnetic state at $k_F a \approx 1.05$, agreeing with Ref. [1].

The effects of population imbalance can be observed in the canonical regime. At $k_F a < 1.05$ population imbalance sets the minimum magnetisation, whereas at $k_F a > 1.05$ the first order ferromagnetic transition can exceed the population imbalance so the magnetisation has an in-plane component.

TRAPPED SYSTEM

4. HARMONIC POTENTIAL

The trap is treated with the local density approximation with an effective chemical potential $\mu(\mathbf{R})=\mu_0-V(\mathbf{R})$. The profiles shown in Fig. 3 correspond to the three trajectories highlighted in Fig. 2(b).

***P/N*=0:** With no population imbalance the first order transition means in-plane magnetisation jumps to saturation.

***P/N*=0.4:** Small population imbalance means magnetisation is maximal at small radii where $k_F a$ is large, and also at large radii where $k_F a$ is small but the chemical potential of the minority spin species is negative. The magnetisation has a characteristic minimum at intermediate radii.

***P/N*=0.8:** With large population imbalance magnetisation is saturated at all radii.

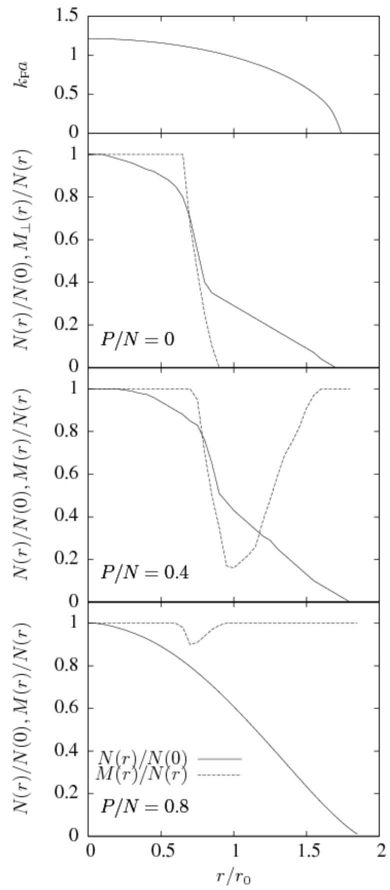


Fig. 3. Radial density profiles in three identical harmonic traps each with different population imbalance. Solid lines show the radial density, the dashed line shows the local population imbalance. The plot labels correspond to the trajectories that are highlighted in Fig. 2(b).

CONCLUSIONS

- Using a formalism that takes into account a correction due to the fluctuations beyond the mean-field solution, an analytical expansion for the energy in terms of interaction strength was found.
- A first order paramagnetic-ferromagnetic transition was seen
- Fixed populations mean that magnetisation forms in-plane, if the population imbalance is large then following the ferromagnetic transition a chemical potential shift might still be required.

REFERENCES

[1] R.A. Duine and A.H. MacDonald. Itinerant ferromagnetism in an ultracold atom Fermi gas. PRL **95**, 230403, 2005.

[2] G.J. Conduit and B.D. Simons. PRA **79**, 053606, 2009.

ACKNOWLEDGEMENTS

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