New experimental protocols to probe the Stoner transition in a Fermi gas

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Stoner instability with repulsive interactions

\[ \hat{H} = \sum_{k, \sigma} \epsilon_k c_{k \sigma}^\dagger c_{k \sigma} + g \sum_{k, k', q} c_{k \uparrow}^\dagger c_{k' \downarrow}^\dagger c_{k' \downarrow}\quad c_{k \uparrow} + q \quad c_{k' \uparrow} \quad c_{k' \uparrow} + q \quad c_{k \uparrow} \]

- Mean-field energy

\[ E = \sum_{k, \sigma} \epsilon_k n_{\sigma} (\epsilon_k) + g \quad N_{\uparrow} \quad N_{\downarrow} \]

Not magnetised

Partialy magnetised
Atomic gases: a new forum for ferromagnetism

- A gas of atoms simulates electrons in a solid

\[ |F = 1/2, m_F = 1/2 \rangle \quad \text{Up spin electron} \]

\[ |F = 1/2, m_F = -1/2 \rangle \quad \text{Down spin electron} \]

- Key experimental advantages:
  - Magnetic field controls interaction strength
  - Contact interaction
  - Clean system
Ketterle experiment

Jo et al., Science 325, 1521 (2009)
GJC & Simons, PRL 103, 200403 (2009)

Non-interacting

Strongly repulsive

Cloud radius

Kinetic energy

Loss rate
Two-body loss

Pekker et al, PRL 106, 050402 (2011)
Alternative strategy: spin spiral

(a) Fully polarized state

(b) Magnetic field gradient forms spin spiral

(c) Interactions cant the spiral
Spin spiral collective modes

- Exponentially growing collective modes if $k < Q$ [GJC & Altman, PRA 82, 043603 (2010)]

$$\Omega = \pm \left( \frac{1}{2} - \frac{2^{2/3} 3}{5k_F a} \right) k \sqrt{Q^2 - k^2}$$

![Graph showing critical slowing with $k_F a$ parameter]
Mass imbalance ferromagnetism

\[ \hat{H} = \sum_{k} \frac{k^2}{2m_{\uparrow}} c_{k\uparrow}^\dagger c_{k\uparrow} + \sum_{k} \frac{k^2}{2m_{\downarrow}} c_{k\downarrow}^\dagger c_{k\downarrow} + g \sum_{kk'q} c_{k\uparrow}^\dagger c_{k'^\uparrow}^\dagger c_{k'^\downarrow} c_{k\downarrow} \]

- Magnetic moment formed along quantization axis

Keyserlingk & GJC, PRA 83, 053625 (2011)
Behavior in a trap

- At zero interaction strength atoms spread all over trap, at high interaction strength light atoms forced to outside.
Reduced many-body losses

\[ \frac{m_{\uparrow}}{m_{\downarrow}} = 20/3 \]
Summary

• Ketterle's experiment is consistent with the formation of a ferromagnetic ground state

• Competing many-body instabilities provide alternative explanation

• Circumvent loss by studying the evolution of a spin spiral or mass imbalance

• Answer long-standing questions about solid state ferromagnetism and motivate new research arenas