Ferromagnetism of a repulsive Fermi gas

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Repulsive Fermi gases

Stoner (‘33): Perturbation theory & short-range repulsion: kinetic vs interaction energy

\[ \sim \frac{4\pi \hbar^2 a}{m} \delta(r) \]
Why ultracold gases?

Fermi system with short repulsive interaction

- No lattice
- No impurities (disorder)

Problem: Short-ranged repulsive interactions only if a bound state exists

- Geometry
- Dimensionality (3D-2D-1D-0D)
- Temperature (T/TF)
- Population imbalance
Control of the interactions

C. Chin et al., Rev. Mod. Phys. 82, 1225 (2010)

Zeeman levels

Fano-Feshbach resonance

Experimental tuning of the interactions
N(●) and N(●) fixed separately (no spin-exchange)

Spontaneous magnetization → domains of unequal ● & ● densities

Short-ranged repulsive interactions only if a bound state exists

Repulsive Fermi gas intrinsically metastable (upper branch)

FM instability always competing with pairing

NJP 13, 055003 (2011); PRA 80, 051605(R) (2009); Ann. Phys. 326, 2544 (2011); PRL 106, 050402 (2011)
Our approach

1. Create a 1-2 Li mixture @300 G ($a_{12} \sim -300a_0$) in a crossed trap

   $v_{x,y} \sim 285 \text{ Hz}$
   $v_z \sim 22 \text{ Hz}$
   $N_{\uparrow,\downarrow} \sim 4 - 8 \times 10^4$
   $E_F \sim 7 - 11 \text{ kHz}$
   $\frac{T}{T_F} \sim 0.05 - 0.7$

2. Adiabatically separate the two spin clouds @ 0.5G ($\mu_1 \sim -\mu_2$) via magnetic gradient

3. Rise up thin optical barrier, and ramp up the Feshbach field to $B_f$
Sudden release of the barrier

Spin-dipole frequency univocally linked to spin susceptibility:

\[ \omega_{SD}^2 = \frac{N_\uparrow + N_\downarrow}{m \int d\mathbf{r} z^2 \chi(n)} \]

Softening of \( v_{SD} \) unveils FM instability!

Small amplitude modulation on top of a slow (exponential) drift
Sudden release of the barrier

After removal of the drift via exp. fit... isolate out-of-phase motion $\Delta d(t)$

Theory by A. Recati for: 100% overlap
25% overlap
Adiabatic release of the barrier

Monitor magnetization dynamics after slow release at varying repulsion:

\[ \Delta M = \frac{M_{\uparrow} - M_{\downarrow}}{2} \]

- At short evolution time, for strong repulsion, complete halt of spin dynamics!
- \( \tau_p \) longer for large \( \kappa_F a \) & low T. Duration explainable by repulsive polaron properties
Adiabatic release of the barrier

Close interconnection between jump of $v_{SD}$ in #1 and $\tau_P > 0$ in #2 !!

Use $\tau_P > 0$ to draw boundary for existence of a (meta)stable FM state
Conclusion and outlooks

Indication of a ferromagnetic instability (at least in a metastable sense) in a repulsive Fermi Gas

- Softening of the spin dipole frequency
- Freezing of the spin dynamics (short time)


Outlooks:
• Study of repulsive and attractive polarons at broad Feshbach resonance (in progress).
• Implementation of disorder in the system.
• Quasi-2D regime.
Thank you

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