Quantum Magnetism with ^{7}Li

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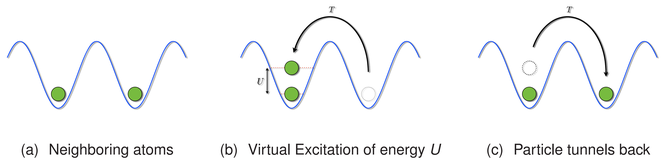
Introduction

The Need 4 Speed

Two-component Bose-Hubbard Hamiltonian

$$H = -\sum_{\langle ij\rangle,\sigma=\uparrow,\downarrow}\left(t_\sigma a^\dagger_{i\sigma}a_{j\sigma} + h.c.\right) + \frac{1}{2}\sum_{i,\sigma=\uparrow,\downarrow} U_\sigma n_{i\sigma}(n_{i\sigma}-1) + U_{\uparrow\downarrow}\sum_i n_{i\uparrow}n_{i\downarrow}$$

Super-exchange dominated spin-interactions $J = t^2/U$



(a) Neighboring atoms (b) Virtual Excitation of energy U (c) Particle tunnels back

are enabled by

(1) Light mass of Li-7 $\quad E_R = \frac{\hbar^2 k^2}{2m}$ $\quad t \approx E_R \cdot \frac{4}{\sqrt{\pi}}(V_0/E_R)^{3/4} e^{-\sqrt{V_0/E_R}}$

(2) Green optical lattice

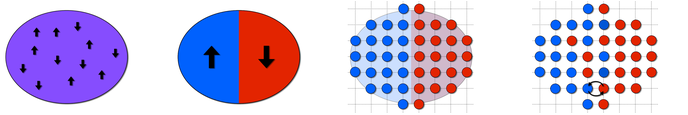
(3) Feshbach resonance $\quad U \approx a \cdot \sqrt{\frac{8}{\pi}} k (V_0/E_R)^{3/4} E_R$

$\Rightarrow$ Higher critical temperature for magnetic ordering ($k_B T_c \sim t^2/U$)
$\Rightarrow$ Faster spin dynamics within experimentally relevant timescales

Possible Experiments

Spin Dynamics

- Spin transport by super-exchange interactions



(d) Prepare a 50-50 spin mixture (e) Separate spins by magnetic field gradient (f) Apply optical lattice (g) Allow spins to mix (by decreasing magnetic field gradient)

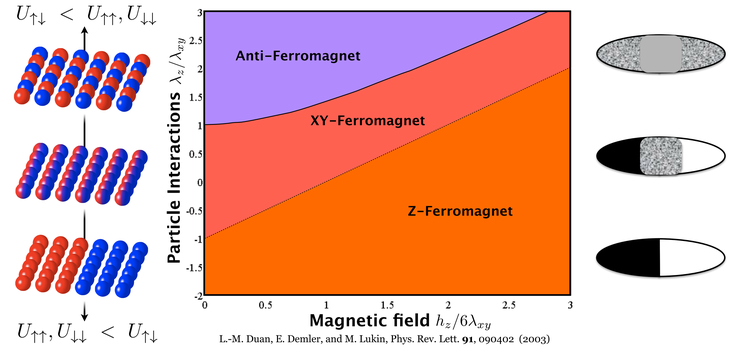
Quantum Simulation

- Realization of 2-component Spin Hamiltonians
- Anisotropic Heisenberg Model (XXZ model)

$$H = \sum_{<i,j>}[\lambda_z s_i^z s_j^z - \lambda_{xy}(s_i^x s_j^x + s_i^y s_j^y)] - B_z \sum_i s_i^z$$

$$\lambda_z = \frac{t_\uparrow^2 + t_\downarrow^2}{2U_{\uparrow\downarrow}} - \frac{t_\uparrow^2}{U_{\uparrow\uparrow}} - \frac{t_\downarrow^2}{U_{\downarrow\downarrow}} \qquad \lambda_{xy} = \frac{t_\uparrow t_\downarrow}{2U_{\uparrow\downarrow}}$$

- Magnetic phase diagram



L.-M. Duan, E. Demler, and M. Lukin, Phys. Rev. Lett. **91**, 090402 (2003)

Experimental Realization

Experimental Model

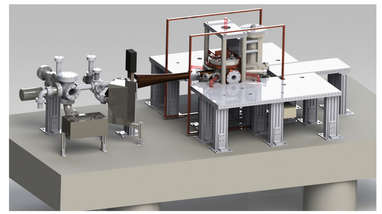
- Two-component Hamiltonian realized by ^{7}Li atoms in two hyperfine states placed in an optical lattice
- Freely tunable experimental parameters:
  - Energy ratio t/U by optical lattice depth
  - On-site interaction energy U by a Feshbach resonance
  - Spin separating potential by a magnetic field gradient
  - Temperature by evaporation time

Experimental Sequence

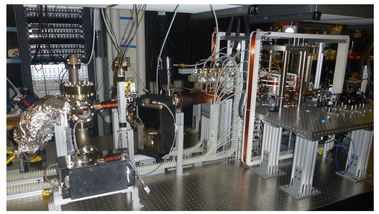
1. Zeeman-slowing and Magneto-optical trapping
2. Evaporative cooling in a plug trap
3. BEC in a dipole trap supported by a Feshbach resonance
4. Green lattice plus dipole trap

Machine Table

Design

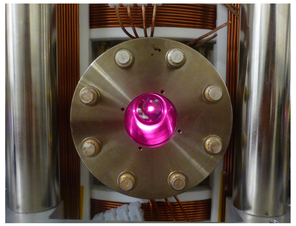


Realization



Performance of the Magneto-optical Trap

- Atom number: $3 \cdot 10^{10}$
- Loading time: $5s$
- Decay constants: $13s$, $75s$
- Temperature: $10mK$
- Velocity: $1ms^{-1}$



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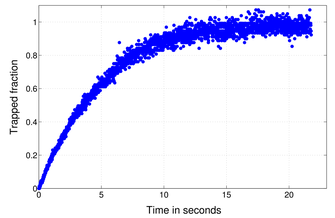
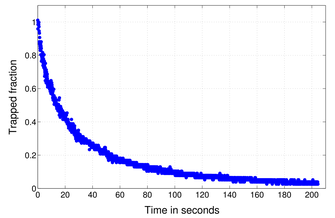


Lifetime



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