Quantum Magnetism with $^7$Li

Niklas Jepsen, Ivana Dimitrova, Jesse Amato-Grill, Michael Messer, Graciana Puentes, David Weld, David Pritchard, Wolfgang Ketterle

MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics
Department of Physics, Massachusetts Institute of Technology, Cambridge

Introduction

The Need 4 Speed

- Two-component Bose-Hubbard Hamiltonian
  \[ H = - \sum_{\langle i,j \rangle, \sigma=\uparrow,\downarrow} (t_{ij} a_i^{\dagger} a_j + h.c.) + \frac{1}{2} \sum_{i=1}^{N} \Delta n_i (n_i - 1) + \sum_{i} U_i n_i \]
  Super-exchange dominated spin-interactions \[ J = \frac{t^2}{U} \]

- Light mass of Li-7
  \[ E_B = \frac{\hbar^2 k_B}{2m} \]
  \[ t \approx E_B \frac{4}{\sqrt{(V_0/E_B)^{1/4} - \sqrt{1 + k}}} \]
- Green optical lattice
  \[ U = \phi \sqrt{\frac{\gamma}{2}} (V_0/E_B)^{1/4} \]
- Feshbach resonance

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

Possible Experiments

- Spin transport by super-exchange interactions

<table>
<thead>
<tr>
<th>Spin Dynamics</th>
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<tbody>
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<td>(d) Prepare a 50-50 spin mixture</td>
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<td>(e) Separate spins by magnetic field gradient</td>
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<td>(f) Apply optical lattice</td>
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<td>(g) Allow spins to mix by decreasing magnetic field gradient</td>
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Quantum Simulation

- Realization of 2-component Spin Hamiltonians
- Anisotropic Heisenberg Model (XXZ model)
  \[ H = \sum_{\langle i,j \rangle, \sigma=\uparrow,\downarrow} \left[ J_{ij \sigma} a_i^{\dagger} a_j + h.c. \right] + \sum_{i} B_i n_i \]
  \[ J_{ij \sigma} = \frac{\hbar}{2U_i} \]
- Magnetic phase diagram

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 \( \lambda \) 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

<table>
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<tr>
<th>Design</th>
<th>Realization</th>
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<tbody>
<tr>
<td>(a) Light mass of Li-7</td>
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<td>(b) Green optical lattice</td>
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<td>(c) Feshbach resonance</td>
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Funding Acknowledgements

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