Grey-molasses optical-tweezer loading:
Controlling collisions for scaling atom-array assembly

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Introduction

- Optical tweezer technology can be used to isolate and control individual atoms/molecules => engineer quantum systems from bottom-up
- Applications in QInfo, simulations, metrology
- Essential to scale up => need high loading rates

Light-assisted collisions for sub-Poissonian loading


Red-detuned Polarization Gradient Cooling

Doppler shift used for optical molasses

Additional damping due to magnetic field

This paper

- Λ-enhanced grey molasses loading on the D1 line of Rb$^{87}$
- Cooling laser is blue-detuned of a type-II ($F_0 \leq F$) transition and in a Λ configuration with a coherent repump laser
RPGC vs. ΛGM

**RPGC:** 64(1)% at [-14 MHz, 1.1(1) mK]

**ΛGM:** 89(1)% at [45 MHz, 0.55(5) mK]
Monte-Carlo of Collision Dynamics

Assumptions:

1. ΛGM loads at least a few atoms per traps.
2. Re-thermalizes remaining atoms after collision.
3. Sample: Poisson with $\bar{N}_{atom} = 5$, temperature $T$
4. Two atoms collide at spacing < 100 nm.
5. Collision ejects 0 or 1 or 2 atoms determined by pre-collision energy and energy gain $\hbar [\Delta_{AGM} - \delta_{trap}]$

6. RPGC imaging consistent with loading. Until $N \leq 1$:
   a. $N_{atom} = N_{atom} - 2$, probability = 0.65
   b. $N_{atom} = N_{atom} - 1$, probability = 0.35
Three physical regimes

- **$E \ll 2U$**
  - No atom loss
  - 65%
- **$E \sim 2U$**
  - Single-atom and 2-body losses
  - 75%
- **$E \gg 2U$**
  - 2-body loss
  - 50%
- **Maximal**
  - **$E < 2U$**
    - Only single-atom loss

$10 \times 10$ array: ~80%
Impact on array assembly

Rearrangement algorithm:
1. Image atom locations
2. Find 6x6 sub-array
3. Remove excess atoms
4. Contract array in one move

Low efficiency: 0.1%
Atom loss at 17% when rf off.
Summary

- Loading in shallow tweezers can be enhanced by controlling the process of photoassociation to molecular states.
- $1 \text{ mK}, 100 \text{ traps, 50 atoms} \Rightarrow 0.27 \text{ mK, 370 traps, 300 atoms } \Rightarrow \times 6$ increase
- Can reduce number of rearrangement moves
  - 300 atoms at $P = 50\% \Rightarrow 900$ moves, but at $P = 80\% \Rightarrow 320$ moves

requires 320 moves. As a result, the probability to retain all 300 atoms in the rearrangement protocol increases roughly from 0.1\% to 10\% when going from $P = 50\%$ to $P = 80\%$, assuming a 420 second atom lifetime [35], 1 ms per move, and a 99.3\% move fidelity [10].