Robust Generation of Entanglement and Gate Operations with Trapped Ions Using Adiabatic Approaches

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Dicke state generation with RAP

Symmetric Dicke states:
- Entangled states symmetric with regard to permutation of particles

\[
|D^m_N\rangle = \frac{1}{\sqrt{C_m^N}} \sum_{\pi} P_{\pi} \left( |\uparrow\uparrow\uparrow\cdots\uparrow\rangle + \sum_{m \neq 0} (-1)^{m+n} |m\rangle |\uparrow\cdots\uparrow\downarrow\cdots\downarrow\rangle \right)
\]

- Single photon generation by collective coupling
- Projective measurement on large Dicke state yields different classes of entangled states -use as entanglement resources for QIP

Rapid adiabatic passage (RAP/ARP)

Population transfer using optical pulse with time-dep. envelope/frequency

Advantages:
- Robustness against pulse area (intensity/time) fluctuation
- One step transfer over multi-level ladder

Disadvantages:
- Dynamical phase due to time-dependent pulse envelope leading to uncontrollable global phase

Applications:
- Large (entangled) state preparation

DICKE STATES

Symmetric: \[ |D^m_N\rangle = \frac{1}{\sqrt{C_m^N}} \sum_{\pi} P_{\pi} \left( |\uparrow\uparrow\uparrow\cdots\uparrow\rangle + \sum_{m \neq 0} (-1)^{m+n} |m\rangle |\uparrow\cdots\uparrow\downarrow\cdots\downarrow\rangle \right) \]

Dicke state gen. by RAP


Distributed measurement on both ions

Basis transformation (Wigner-Sh寇 restoration)

Energy

Dicke state generation with square pulse:


Summary
- Rapid adiabatic passage of two ions in sideband transitions
- Individual addressing using AC Stark shifter optical beam
- Entanglement generation by adiabatic passage
- Fidelity: 0.66 ± 0.03
- Effect of AC Stark shift due to time-dependent pulse envelope analyzed

Prospects
- Dicke state generation with more particles/excitations

Robust single-qubit gate with tripod-STIRAP

STIRAP in λ-type three-level system
- Population transfer using a dark state

STIRAP in tripod-type four-level system
- Two dark states
- Geometric phase factors form 2x2 matrix non-commutative(non-Abelian) unitary operations

Gate operations using tripod-STIRAP
- Robust operations
- Insensitive to pulse shapes (peak height, length)

References
- Tripod system
  - Gate operations/hoovemier: QC
  - Applications of non-Abelian holonomy to cold atoms

Encoding to levels in single 40Ca+

Z-rotation gate

X-rotation gate

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Summary
- X-rotation and Z-rotation with two STIRAP on a tripod system
- Demonstrated using single 40Ca+
- Visibility > 0.9

Prospects
- Verifying robustness
- Implement to S-D optical qubit